



(51) International Patent Classification:

C07K 16/28 (2006.01) A61K 39/00 (2006.01)

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(21) International Application Number:

PCT/EP2018/068855

Declarations under Rule 4.17:

— of inventorship (Rule 4.17(iv))

(22) International Filing Date:

11 July 2018 (11.07.2018)

Published:

— with international search report (Art. 21(3))
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1711208.7 12 July 2017 (12.07.2017) GB

(71) Applicant: **IONTAS LIMITED** [GB/GB]; 82B High Street, Sawston Cambridgeshire CB22 3HJ (GB).

(72) Inventors: **KARATT VELLATT, Aneesh**; 82B High Street, Sawston Cambridgeshire CB22 3HJ (GB). **MC-CAFFERTY, John**; 82B High Street, Sawston Cambridgeshire CB22 3HJ (GB). **SURADE, Sachin Badri-nath**; 82B High Street, Sawston Cambridgeshire CB22 3HJ (GB). **LUETKENS, Tim**; 1163 E 200 S., Salt Lake City, UT 84101 (US). **MASTERS, Edward William**; 82B High Street, Sawston Cambridgeshire CB22 3HJ (GB). **DYSON, Michael Richard**; 82B High Street, Sawston Cambridgeshire CB22 3HJ (GB). **BELL, Damian Colin**; 82B High Street, Sawston Cambridgeshire CB22 3HJ (GB).

(74) Agent: **SUTCLIFFE, Nicholas** et al.; Mewburn Ellis LLP, City Tower, 40 Basinghall Street, London Greater London EC2V 5DE (GB).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

(54) Title: SODIUM CHANNEL INHIBITORS

(57) Abstract: Binding members for sodium channel Nav1.7 and their use in medicine including for treatment of pain or epilepsy. Binding members comprise a fusion protein containing a Nav1.7-binding peptide, e.g., venom toxin peptide or knottin ("donor diversity scaffold domain") inserted within an antibody variable domain ("recipient diversity scaffold domain"), and a partner domain (e.g., antibody variable domain), optionally wherein the partner domain enhances specificity of binding to Nav1.7 over other sodium channels.

Sodium Channel Inhibitors

Field

5 This invention relates to binding members with altered diversity scaffold domains, the production of libraries of such binding members and the selection and screening of binding members from such libraries. The invention also relates binding members that inhibit ion channels, especially sodium or calcium channels, and their use in therapy.

Background

Nav1.7 is one of nine members of the Nav1.x family of voltage-gated sodium channels (VGSCs). Nav1.7 ion channels are found in membranes of neurons of peripheral nervous system and open (or gate) in response to membrane depolarisation. This channel opening allows the influx of sodium ions across the membrane and into cells, generating and propagating depolarising action potentials along neurons. In this role of peripheral neuronal action potential generation and propagation, Nav1.7 has been found to be a critical protein in pain signalling¹²⁶. A number of inherited diseases arising from mutant ion channels (channelopathies) have been identified for Nav1.7: both gain-of-function genetic mutations which cause pain hypersensitivity (e.g., inherited erythromelalgia, IEM, and paroxysmal extreme pain disorder, PEPD¹²⁷⁻¹²⁹) and loss-of-function mutations which cause loss of pain sensation (e.g. congenital insensitivity to pain, CIP¹³⁰⁻¹³¹). Further, genetically modified animals where the SCN9A gene (and hence Nav1.7 protein) is knocked-out have shown that Nav1.7 is critical in signalling for acute, inflammatory and/or neuropathic forms of pain¹³². Further details of the Nav1.x VGSC family are shown in Table 30 herein (tables are annexed at the end of the present description).

A number of clinical applications and disease treatments have used compounds that target Nav1.7, blocking the influx of sodium ions into neurons and reducing action potential generation and propagation¹³⁷⁻¹³⁹. Local anaesthetics such as lidocaine and tetracaine have been in use for decades in surgery and dental treatments. Other examples include the treatment of cardiac arrhythmias with propafenone and epilepsy medications such as lamotrigine, phenytoin and carbamazepine. For reviews on the use of Nav1.7 inhibiting compounds to treat several pain states (e.g. acute, chronic, inflammatory and neuropathic) see

references 126 and 140-142. Further, a number of pharmaceutical drug discovery programmes have targeted Nav1.7, aiming to find new small molecules to treat pain¹⁴³⁻¹⁴⁴.

One challenge in developing small molecules to target Nav1.7 is that it is difficult to engineer selectivity for the target ion channel, as their relatively small binding footprint may be found in other, “off-target” ion channels. Biological molecules such as polypeptides, e.g., antibodies, offer the potential to make more extensive contacts with the target molecule, which would in principle enable greater selectivity to target ion channels such as Nav1.7. In practice, however, generating effective biological binders and inhibitors of VGSCs is difficult, at least in part because the the extracellular peptide regions of these channels are extremely limited.

The molecular structure of Nav1.7, and other members of the VGSC family, is based on a single pore-forming, voltage-sensing α subunit and associated β auxiliary subunits¹³³. The α subunit is formed of four domains (D1-D4); each domain has six α -helical transmembrane spanning segments (S1-S6). The four domains each have the following structure: S1-S4 form the voltage-sensing domain (VSD); S5 and S6 transmembrane segments form the pore and ion selectivity filter; and the N- and C-termini are intracellular. Thus, based on numerous structural studies, including bacterial Nav crystal structures¹³⁴, most of the Nav1.7 protein is buried in lipid membrane or found intracellularly, with only limited externally facing peptide loops linking transmembrane segments. Figure 32 shows the amino acid sequence of a human Nav1.7 alpha subunit and indicates its structural features.

As noted, the membrane-buried structure makes it challenging to generate antibodies to Nav1.7 channels. Indeed, when reports of selective Nav1.7 targeting monoclonal antibodies have been made (e.g., SVMab1¹³⁵), independent, follow-up studies have failed to replicate the reported Nav1.7 inhibitory activity¹³⁶.

In nature, small cysteine rich ion channel blocking peptide knottins are found in a multitude of venomous species across the animal kingdom (e.g., spiders)¹⁴⁵⁻¹⁴⁸. Most Nav1.7 inhibiting toxins from spiders share high sequence homology and target similar sites on Nav1.7 protein to achieve channel blockade. Knottins have been investigated as potential therapeutics e.g., Nav1.7 knottin-based molecules have been developed to potentially treat pain¹⁴⁹⁻¹⁵¹.

However, a drawback to using knottin-based molecules as therapeutics is their short half life in vivo, due to rapid renal clearance¹⁵².

WO2012/064658 and Moore & Cochran¹⁵⁶ described fusion proteins comprising engineered knottins, and the use of knottins as scaffolds for engineering molecular recognition. Fusion proteins were created including knottin peptides, in which a portion of the knottin peptide was replaced with a sequence created for binding to a particular target. Libraries of engineered knottins, and screening of such libraries for binders that recognise targets of interest, were described. Multi-specific fusion proteins, able to bind and/or inhibit two or more targets, were also described. Subsequently, WO2014/063012 described knottin peptides containing non-natural amino acids, and knottin variants engineered to contain integrin-binding loops.

The use of non-antibody scaffolds (including knottins) for generating therapeutic molecules was reviewed by Vasquez-Lombardi et al in 2015¹⁵⁷.

In the antibody field, as is well known, antibody humanisation involves combining animal CDRs with human frameworks. CDR grafting is a well-established method used for antibody humanisation. Antibodies generated by immunisation of an animal are sequenced, CDR loops identified and a hybrid molecule is prepared consisting of a human framework with one or more CDRs derived for the animal antibody¹. In CDR grafting, it is likely that the incoming peptide is required to adopt a particular structure to maintain the original binding specificity and it is often necessary to “fine-tune” the humanisation process by changing addition residues including supporting residues within the framework region.

Non-antibody peptides have also been transplanted into antibody frameworks. Barbas et al (1993) inserted a naturally-occurring integrin binding sequence into the VH CDR3 region of a human antibody² and Frederickson et al (2006)³ cloned a 14-mer peptide which was known to bind to the thrombopoietin (TPO) receptor into the several CDR regions of an anti-tetanus toxoid antibody. 2 amino acids at each end of the peptide were randomized and the resultant library selected by phage display. This same work was described in US 20100041012A1, along with insertion of an 18 amino acid peptide known to bind to the erythropoietin receptor⁴. The original erythropoietin receptor binding peptide sequence contained two cysteines which were removed due to anticipated problems with antibody disulphide bond

formation. In these cases, 2-3 codons were randomised at the junction between the inserted peptide coding region and the recipient framework to select optimal junctional sequences from the resultant phage display libraries. Liu et al inserted a 14-16 amino acid peptide with binding activity to CXCR4 into 2 different CDRs (VH CDR3 and VH CDR2⁵). Kogelberg inserted an α V β 6 17 mer peptide which adopts a hairpin:alpha helix motif, into VH CDR3 of a murine antibody⁶. This peptide contained core RGD_{LxxL} element known to direct binding to α V β 6. This work led on to a library-based approach focussed on VH CDR3, which sought to mimic the hairpin:alpha helix structure⁷ of the original insert. In all these cases, the antibody acted as a carrier for the incoming peptide without contributing to target binding.

Gallo *et al* have inserted peptides into a VH CDR3 using an alternative approach for diversification. Antibody diversification naturally occurs within in B cells and US8012714 describes a method replicating this diversification process within heterologous mammalian cells. In maturing B cells antibody genes are assembled by recombination of separate V, D and J segments through the activities of "recombination activating genes" (RAG1 and RAG2) resulting in deletion of large segments of intervening sequences. In US8012714, RAG1, and RAG2 were introduced into human embryonic kidney cells (HEK293) along with plasmids encompassing recombination substrates to replicate recombination V-D-J joining in non-B cells. This RAG1/2 recombination-based approach utilizes DNA repair and excision mechanisms of mammalian cells and has not been demonstrated in prokaryotic cells.

The same mammalian cell-based in vitro system was used in WO2013134881A1 with the D segment being effectively replaced by DNA which encodes peptide fragments derived from two other binding molecules. Since RAG1/RAG2 driven diversification only occurs in mammalian cells this system cannot be used directly in prokaryotic approaches such as phage display. WO2013134881A1 exemplifies the introduction into the heavy chain CDR3 of the same 14-mer peptide fragments used by Frederickson³ and Bowdish (US20100041012 A1). The TPO receptor binding construct was introduced into the middle of CDR3 and so retained the CDR sequences as well as grafting in additional amino acids to create a total of 12 or more amino acids between the antibody framework and the incoming peptide. WO2013134881A1 also exemplifies antibody fusions with extendin-4 which were generated with combined linker length between the antibody framework and the incoming peptide ranging from 9-14 amino acids.

Saini et al^{8,9} reported the occurrence of ultra-long cysteine-rich CDR3s within the VH domain of bovine antibodies. These ultra-long VH CDRs of 40-67 amino acids which constitute 9% of the bovine antibody response were typically restricted to pairing with a specific V λ 1 light chains. Recently the structure of two such bovine antibodies has been determined through X ray crystallography¹⁰ revealing an unusual stalk structure formed by an ascending and descending β strands which is topped by a “knob” comprising a peptide with multiple disulphide bonds formed from cysteine pairs. This stalk: knob structure is formed by CDR3 of the VH domain but the stalk is supported by interactions with VH CDR1, VH CDR2, as well as all CDRs of the partner V λ 1 chain. Thus the entire CDR diversity of these antibodies is devoted to the presentation of the “knob” structure which itself is presented at a distance of approximately 38 Angstroms from the supporting framework to the first cysteine of the “knob”¹¹. The potential of the other CDRs to interact with the same epitope recognized by the knob is therefore abolished or severely limited.

In subsequent work, “the knob” was replaced by cytokines, such as granulocyte colony stimulating factor¹² and erythropoietin¹³, which were linked to the stalk by a flexible Gly-Gly-Gly-Ser (SEQ ID NO: 1) sequence (Gly4Ser) at the N and C terminal junctions. It was subsequently shown that the rigid β sheet stalk structure could be replaced with a rigid anti-parallel coiled coil structure¹¹. Flexible Gly4Ser and Gly-Gly-Ser-Gly (SEQ ID NO: 2) linkers were again placed at each end of the coiled: coil sequence to “optimize the folding and stability of the resulting antibody”. This construction also allowed the presentation granulocyte colony stimulating factor. Liu et al have taken the same approach of using rigid stalk structures coupled with a flexible peptides at both junctions to fuse leptin and Growth Hormone into VH CDR3 and VH CDR2 and VL CDR3¹⁴. In this example, retained antibody binding was seen as a potential disadvantage and the suggestion was made of using a “null” antibody partner e.g. anti-RSV antibody to avoid contribution of binding of the host antibody.

Peng et al (2015) reports the insertion of two natural agonists (leptin and follicle stimulating hormone) as “guests” into an antibody VH CDR3 in a way which retained agonistic activity¹⁵. A library of fusions was created wherein flexible peptides of 5-15 amino acids were inserted between the domains at each of the N terminal and C terminal ends along with a random 3 amino acids at each end (i.e. total linker lengths of 16-36 amino acids). A library of 10⁷ fusion variants was expressed in HEK293 cells and fusions which retained agonist activity of the “guest” were identified through reporter gene activation in an autocrine-based

screening approach. The beneficial half-life properties of the antibody are extended to the incoming guest.

The approach of Peng et al (2015) was carried out in mammalian cells using an autocrine reporter system wherein cells are grown in semi-solid medium and secreted antibody fusions are retained in the vicinity of the producing cell. Thus, relatively high concentrations of the secreted product accumulated in the immediate vicinity of the cell¹⁶ making it difficult to distinguish clones within a library with altered expression/stability or binding properties. Thus, there is a limitation on stringency within the system described by Peng et al (2015). Furthermore the functional screening approach is also limited to screens for which a relevant receptor/reporter system is available. The proportion of clones which worked was low (despite the benefit of endogenous chaperone-assisted folding within mammalian cells).

Antibodies represent a commonly used binding scaffold. As an alternative, the generation of binding members based on non-antibody scaffolds has been demonstrated^{38, 39}. These engineered proteins are derived from libraries of variants wherein exposed surface residues are diversified upon a core scaffold³⁸⁻⁴⁰.

Betton et al (1997)¹⁷ reports fusing β lactamase into several accommodating permissive sites in maltose binding proteins using 9-10 amino acid linkers (DPGG-insert-YPGDP (SEQ ID NOS: 3, 4) and PDPGG-insert-YPGGP (SEQ ID NOS: 5, 6). Collinet¹⁸ reports inserting β lactamase or dihydrofolate reductase into permissive sites of phosphoglycerate kinase using amino acid residues SGG or GG at the N terminal insertion point and GAG at the C terminal insertion point. Studies of the enzyme β -lactamase, which confers bacterial resistance to ampicillin, have also revealed potential sites into which peptide insertions could be accommodated¹⁹. Vandevenne et al reports the insertion into one of these sites of a chitin binding domain protein of the human macrophage chitotriosidase²⁰, using a construct that introduced 6-7 amino acids each at the N and C termini of the insertion. Crasson et al²¹ have demonstrated functionalization of a nanobody by inserting it into a permissive site of β lactamase joining two helices.

Summary of the Invention

The present invention provides knottins that are fused into polypeptide scaffolds, such as antibody variable domains, to generate binding members for ion channels, particularly

voltage gated ion channels, including sodium channels and calcium channels. It is demonstrated herein that such binding members can inhibit ion flux through such voltage gated ion channels.

5 Voltage gated sodium and calcium channels are closely related in overall structure and function. Details of the present invention are illustrated with reference to human Nav1.7 but it is to be understood that the invention extends to other sodium channels, such as those identified in Table 30 (Nav1.1, Nav1.2, Nav1.3, Nav1.4, Nav1.5, Nav1.6, and Nav1.8 and Nav1.9), and to calcium channels also. Thus, unless the context demands otherwise, reference
10 to a sodium channel such as Nav1.7 herein should be taken as illustrative rather than limiting, and the same disclosure may be applied to a calcium channel or a Nav1.1, Nav1.2, Nav1.3, Nav1.4, Nav1.5, Nav1.6, and Nav1.8 or Nav1.9 sodium channel. Binding members that target these ion channels represent candidate therapeutic molecules for clinical development in treating conditions and disorders that are associated with activity of the ion channel. For
15 sodium channels (e.g., Nav1.7), this includes pain and epilepsy.

Binding members according to the present invention can advantageously combine the ion channel modulatory activity of the knottin with the increased half-life and expanded, engineerable binding surfaces of a larger polypeptide scaffold domain (e.g., antibody variable
20 domain). An extended half-life renders a binding member product more convenient for use as a medicament by reducing or slowing its elimination from the body, thereby increasing efficacy and enabling less frequent dosing. Engineering of a binding member for selective binding to the target ion channel, reducing binding to and/or inhibition of other ion channels, has the advantage of reducing off-target effects and may also increase efficacy as a greater
25 proportion of the binding member will be available for interaction with the intended target ion channel. More generally, the incorporation of an entire binding domain (“donor diversity scaffold domain”) within a second binding domain (“a recipient scaffold domain”) increases the diversity of populations of binding members and allows the selection and isolation of binding members with advantageous properties from these populations. This may be useful in
30 selecting binding members which bind to target sodium or calcium channels, e.g., Nav1.7.

Accordingly, the present invention provides a binding member that binds and inhibits a human sodium or calcium channel, the binding member comprising a fusion protein and optionally a partner domain, wherein the fusion protein comprises a donor diversity scaffold

domain inserted into a recipient diversity scaffold domain wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence.

5

In embodiments described herein, the the donor diversity scaffold domain binds a human voltage-gated sodium channel or a human voltage-gated calcium channel. In various embodiments, the donor diversity scaffold domain is a cysteine rich peptide, examples of which include:

10 Huwentoxin-IV and variants thereof such as Huwentoxin-IV 3M and Huwentoxin-IV 3M Gly,

 ProTx-II,

 Ssm6a and variants thereof such as Ssm6a_GGS,

 ProTx-III and variants thereof such as ProTx-III 2M, ProTx-III Gly, ProTx-III 2M

15 Gly and ProTx-III 2M 2Gly, and

 GpTx-1 and variants thereof such as GpTx-1 4M and GpTx-1 4M Gly.

Other cysteine rich peptides may be generated as variants of any of these sequences. Examples of variant sequences are described herein and others will be apparent to the person skilled in the art based on the present disclosure.

20

In some embodiments of the present invention, the donor diversity scaffold domain is a knottin that binds a human sodium channel, e.g., Nav1.7. Binding may be to the alpha subunit of the channel, optionally domain 2 and/or optionally to the region composed of membrane spanning regions S1 to S4. As an example, the knottin may bind domain 2 of the Nav1.7
25 alpha subunit, optionally binding the voltage sensing domain which is composed of membrane spanning regions S1 to S4 of domain 2. The human sodium channel may be Nav1.7 as encoded by the DNA sequence shown in Figure 31 and/or comprising the alpha subunit sequence shown in Figure 32. Figure 32 indicates the location of the voltage sensing domain, and a preferred knottin-binding site within this domain. Binding members may
30 comprise knottins that bind this knottin binding site.

In other embodiments, the donor diversity scaffold domain is a knottin that binds a human calcium channel, e.g., a Cav alpha subunit.

Inhibition of ion channel activity may be determined by assays as described herein, e.g., patch clamp. Inhibition may be determined with reference to an appropriate negative control molecule (optionally buffer only, or buffer comprising an antibody that does not exhibit binding to the ion channel). A statistically significant inhibition of ion flux in a patch clamp
5 assay, relative to control, may be used as an indication of ion channel inhibition.

A binding member according to the invention may inhibit ion flux through the ion channel by at least 20 %, at least 30 %, at least 40 %, at least 50 %, at least 60 %, at least 70 %, at least 80 %, at least 90 % or at least 95 %, e.g., as determined by a whole cell patch clamp assay in
10 which the binding member is applied at a concentration of about 15 μ M. IC₅₀ values for inhibition of ion flux may be calculated from such assays. Preferably, a binding member of the present invention has an IC₅₀ of less than 100 μ M, less than 50 μ M, less than 40 μ M, less than 30 μ M, less than 20 μ M, less than 10 μ M, less than 5 μ M or less than 1 μ M, preferably < 0.5 μ M, < 0.4 μ M, < 0.3 μ M, < 0.2 μ M or < 0.1 μ M in a whole cell patch clamp assay of
15 ion flux through the channel. Preferably, a binding member of the present invention has an IC₅₀ of less than 10 nM, preferably < 1 nM, < 0.5 nM, < 0.4 nM, < 0.3 nM, < 0.2 nM or < 0.1 nM in a whole cell patch clamp assay of ion flux through the channel. Suitable example assay protocols are detailed elsewhere herein, including in Example 19.

The present invention also provides a fusion protein comprising a donor diversity scaffold domain inserted into a recipient diversity scaffold domain wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence. The donor diversity scaffold domain is a knottin that binds the ion channel. As
20 noted, a knottin may for example bind domain 2 of a human sodium channel Nav1.7 alpha subunit. The knottin may comprise an amino acid sequence of ProTx-III 2M, HwTx-IV 3M, GpTx-1 4M or ProTx-III as shown in Table 31. Variant sequences can also be used. Variants may be derived from a sequence shown in Table 31 or from a native knottin sequence such as ProTx-III, HwTx-IV or GpTx-1. Generation of variants is described elsewhere herein. A
25 variant of a reference donor diversity scaffold domain may comprise an amino acid sequence having at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%, or at least 98% sequence identity to the reference sequence, e.g., wherein the reference sequence is a sequence shown in Table 31. Particular
30

amino acid sequence variants may differ from a sequence in Table 31 by insertion, addition, substitution or deletion of 1 amino acid, 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more than 10 amino acids. The variant may for example have between one and five amino acid alterations in said sequence, alteration being a substitution, insertion or deletion of an amino acid. Variants may be tested to confirm binding to and/or inhibition of the ion channel. Variants may retain cysteine residues for disulphide bridge formation in the knottin. Optionally, a variant comprises the ProTx-III 2M, HwTx-IV 3M, GpTx-1 4M or ProTx-III sequence with one, two or three conservative amino acid substitutions.

A glycine residue may be added at the native C terminus of the knottin. It may be positioned immediately prior to a linker sequence or adjacent to the flanking sequence of the recipient scaffold domain. The glycine may promote activity of the knottin in the context of the fusion protein, as knottins in their native form have been shown to undergo the post translational C-terminal amidation^{149, 154-155}.

Incorporation of donor diversity scaffold domains into recipient diversity scaffold domains, optionally using linkers and/or cyclisation of the donor scaffold sequence, is described in detail elsewhere herein. Preferably, a knottin is fused into a recipient diversity scaffold domain that is all or part of an immunoglobulin, e.g., all or part of an antibody variable domain, to generate a KnotBody as described in detail elsewhere herein. Example VL domains are shown in Table 34, which may be modified by inserting the knottin in place of the underlined sequence indicated. The KnotBody VL domain may be paired with the VH domain shown in Table 34.

The recipient diversity scaffold domain may also bind to the ion channel, optionally to the alpha subunit. It may bind the same or a different domain as the knottin. Optionally, the recipient diversity scaffold domain binds the voltage sensing domain of the ion channel.

A binding member (e.g., KnotBody), may further comprise a partner domain, e.g., a partner VH domain may pair with a VL domain fusion protein, or a partner VL domain may pair with a VH domain fusion protein. A partner domain may contribute to binding to the ion channel, e.g., it may include one or more peptide loops that binds the same or a different domain of the ion channel as the knottin. As noted, a knottin sequence may recognise domain 2 of an ion

channel, e.g., sodium channel, e.g., Nav1.7. A partner domain in a binding member may bind domain 2, or it may bind domain 1, domain 3 or domain 4.

In some embodiments, the binding member may comprise a partner domain that increases the selectivity of the binding member for the human sodium or calcium channel. For example, the donor diversity scaffold domain may bind to the voltage sensing domain of a human calcium or sodium channel, such as Nav1.7, and the partner domain may bind to the extracellular linker sequence connecting the S1-S2 or S3-S4 transmembrane regions of the human calcium or sodium channel. Since these extracellular linker sequences differ between different human calcium and sodium channels, this increases the selectivity of the interaction between the binding member and the human sodium or calcium channel. For example, the partner domain may bind to the S1-S2 or S3-S4 extracellular linker sequence of Nav1.7 and not bind to the S1-S2 or S3-S4 extracellular linker sequence of Nav1.1, Nav1.2, Nav1.3 or Nav1.6.

Optionally a binding member may, in addition to binding the sodium or calcium channel, also bind a second target molecule, optionally via a partner domain. Thus, multispecific (e.g., bispecific) binding members can be provided, which bind for example to molecules that facilitate crossing of the blood brain barrier or blood neuron barrier. This may be desirable in binding members that are intended for therapeutic use to treat neurological conditions such as epilepsy or certain types of pain.

Binding members according to the present invention may be used for treating diseases or conditions associated with or characterised by activity (e.g., hyperactivity) or dysfunction of sodium channels, e.g., Nav1.7, or calcium channels. Binding members may be used for treating pain. Pain may be chronic or acute. Pain may be neuropathic pain, (e.g., peripheral neuropathic pain). Pain may be associated with a genetic disorder or may result from trauma. Pain may be post-operative pain, cancer pain, acute inflammatory pain, or pain hypersensitivity (e.g., erythromelalgia or paroxysmal extreme pain disorder).

Fusion proteins and binding members of the present invention may be used for the production of variants and/or may be isolated by screening libraries.

A method of screening may comprise;

- (i) providing a founder library of binding members,
each binding member in the founder library comprising a fusion protein and
optionally, a partner domain associated with the fusion protein,
wherein the fusion protein comprises a donor diversity scaffold domain inserted
5 within a recipient diversity scaffold domain, optionally wherein the N and C terminals of the
donor diversity scaffold domain are each linked to the recipient diversity scaffold domain
with linkers of 4 amino acids or fewer each,
wherein the donor diversity scaffold domain comprises a donor scaffold and a donor
interaction sequence and the recipient diversity scaffold domain comprises a recipient
10 scaffold and a recipient interaction sequence, and one or more of the donor interaction
sequence, recipient interaction sequence and the linkers are diverse in said founder library,
(ii) screening the founder library for founder binding members which display binding
activity, and
(iii) identifying one or more founder binding members in the founder library which
15 display the binding activity.

In some embodiments, the linkers are diverse in said founder library.

The method may further comprise;

- 20 (iv) introducing diverse amino acid residues at one or more positions in the amino
acid sequence of one or more identified founder binding members to produce a modified
library of binding members,
(v) screening the modified library for modified binding members which display a
binding activity and
25 (vi) identifying one or more modified binding members in the modified library which
display the binding activity.

In some embodiments, diverse amino acid residues may be introduced into the donor
interaction sequence, recipient interaction sequence and/or partner domain of the one or more
30 identified founder binding members.

The method may further comprise;

(vii) associating the fusion protein from the one or more identified binding members or modified binding members with a diverse population of partner binding domains (partner chains) to produce a shuffled library of binding members,

5 (viii) screening the shuffled library for shuffled binding members which display a binding activity,

(ix) identifying one or more shuffled binding members which display the binding activity.

A method of producing a library of binding members may comprise;

10 providing a population of nucleic acids encoding a diverse population of fusion proteins comprising a donor diversity scaffold domain inserted into a recipient diversity scaffold domain, optionally wherein the N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain with linkers of 4 amino acids or fewer at each terminal,

15 wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, and

one or more of the donor interaction sequence, recipient interaction sequence and linkers are diverse in said population,

20 expressing said population of nucleic acids to produce the diverse population, and optionally associating the fusion proteins with a population of partner domains. thereby producing a library of binding members.

A library of binding members may comprise;

25 a diverse population of fusion proteins comprising a donor diversity scaffold domain inserted into a recipient diversity scaffold domain,

wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, optionally wherein the N and C terminals of the donor diversity scaffold domain are each linked to the recipient diversity scaffold domain with linkers of 4 amino acids or fewer,

30 wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, and

one or more of the donor interaction sequence, recipient interaction sequence and linkers are diverse in said population, and

optionally wherein the fusion proteins are associated with binding partners to form heterodimers.

5

A fusion protein may comprise a donor diversity scaffold domain inserted into a recipient diversity scaffold domain

wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, optionally wherein the N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain with linkers of 4 amino acids or fewer.

10

Another aspect of the invention provides a binding member comprising a fusion protein described herein and a partner domain associated with the fusion protein.

15

Other aspects of the invention provide isolated donor diversity scaffold domains, recipient diversity scaffold domains or partner domains from binding members identified and/or isolated as described herein, for example isolated donor diversity scaffold domains engineered as described herein or isolated recipient diversity scaffold domains or partner domains which may be useful in heterologous binding members, for example binding members which do not include the original donor diversity scaffold domain.

20

In some embodiments, the donor diversity scaffold domain is not one disclosed in GB patent application no. GB1600341.0 filed on 8th January 2016. In some embodiments, the donor diversity scaffold domain is not a knottin having a sequence of Huwentoxin-IV, ProTx-II or Ssm6a as disclosed in GB patent application no. GB1600341.0. In some embodiments, the donor diversity scaffold domain is not one disclosed GB patent application no. GB1621070.0 filed on 12 Dec 2016. In some embodiments, the donor diversity scaffold domain is not a knottin having a sequence of Huwentoxin-IV, ProTx-II or Ssm6a as disclosed in GB patent application no. GB1621070.0. In some embodiments, the binding member or fusion protein has an amino acid sequence that is not the amino acid sequence of a binding member or fusion protein disclosed in GB patent application no. GB1600341.0 or in GB1621070.0.

25

30

Brief Description of the Drawings

Figure 1A shows a representation of pIONTAS1, showing the cassette encompassing the lacI promoter, M13 leader sequence scFv antibody gene-gene 3 (not to scale). This cassette is present within the Hind3/EcoR1 cloning sites of pUC119 which has an Ampicillin resistance gene and a colE1 origin and an f1 bacteriophage origin of replication. The VH gene is flanked by an Nco1 and Xho1 restriction site and the VL gene is flanked by Nhe1 and Not 1 restriction sites allowing simple cloning into compatible vectors. Figure 1B shows a representation of the VL domain showing positions of framework regions (FW) and CDR regions. A knottin donor has been inserted at CDR1 position of the VL recipient. Pml1 and Mfe1 sites allow cloning of the knottin donor library. The region from FR2 to the end of FR4 is derived from a repertoire of light chains²⁸. Figure 1C is as described for Figure 1B but with the knottin donor replacing CDR2 of the VL gene using Pst1 and BspE1 sites.

Figure 2 shows the sequence of synthetic single chain Fv genes used in KnotBody construction. The VH of an existing antibody D12 was used within KnotBody constructs. Figure 2A shows restriction sites Nco1 and Xho1 which flank the VH sequence as well as the flexible linker joining VH to VL. This is followed by a sequence encoding the Vlamda1a (IGLV1-36) germline. CDR1 of the VL is shown and is preceded by a Pml1 cloning site. A Ser to Thr mutation was introduced to enable the inclusion of a Pml1 site at the end of framework 1. This site allows cloning of the knottin into the CDR1 position of the VL. At the end of VL framework 2 of the synthetic gene is a Pst1 site allowing cloning of a knottin into the CDR2 position. Figure 2B is as for Figure 2A but showing the V kappa germline sequence IGKV1D-39

Figure 3 shows the insertion of EETI-II donor knottin into VL recipient. Figure 3A shows the sequence of knottin donor EETI-II with cysteine residues emboldened and core sequence involved in trypsin binding ("PRIL") underlined. Figure 3B shows a representation of the insertion of EETI-II donor into CDR1 or CDR2 of the lambda germline gene IGLV1-36. Boundaries are defined according to the international ImMunoGeneTics information system (IMGT)²⁹. Amino acids are represented by IUPAC single letter amino acids code. Figure 3Bi shows the sequence of the V lambda recipient domain at CDR1 before insertion of the knottin. Figures 3Bii and 3Biii show the sequence after insertion of the donor EETI-II donor. (Figure 3Biii is generated by a primer which introduced an extra Gly residue between donor and framework residues compared to 3B ii). Figure 3B iv show the sequence of the V lambda

recipient domain at CDR2 before donor insertion and 3B v shows after insertion of the EETI-II donor. Antibody framework residues are shown underlined and residues from the antibody recipient which are lost are shown in lower case. At the junctions, randomising residues are shown as x with those which replace framework or donor residues shown as x in lower case.

5 Any “additional” residues within the linker between the domains are shown emboldened in upper case (A, Z or X). Z means any amino acid from Val, Ala, Asp or Gly. X represents the amino acids encoded by the codon VNC (encoding 12 amino acids) or VNS encoding 16 amino acids in total. (V=A, C or G and S=C or G). Figures 3C-F show the DNA and amino acid sequence of the construct arising from insertion of the EETI-II knottin donor into
10 respectively C. CDR1 of IGLV1-36, D. CDR1 of IGKV1D-39, E. CDR2 of IGLV1-36 and F. CDR2 of IGKV1D-39. (IGLV1-36 is a V lambda germline gene and IGKV1D-39 is a V kappa germline gene). Restriction sites used in cloning are highlighted and the framework and CDR regions are identified.

15 Figure 4 shows an analysis of polyclonal phage from round-2 selection output. The polyclonal phage (X-axis) from round 2 panning of EETI- II CDR1 library (B) and EETI-II CDR2 library (C) were tested for binding to trypsin. Trypsin binding was not achieved when EETI-II directly fused to the N-terminus of gene-III (A). The Y-axis shows trypsin binding in fluorescent units (FU).

20

Figure 5 shows a monoclonal binding assay of KnotBody clones from round-2 selection output. 94 individual clones from EETI-II CDR1 (A) and EETI-II CDR2 (B) library selection output (round-2) were picked into 96 well culture plates and phage were prepared from each clone. The phage supernatant from each clone was tested for binding to biotinylated trypsin
25 immobilised on neutravidin coated Maxisorp™ plates. Phage binding to trypsin was detected using a mouse anti-M13 antibody followed by europium conjugated anti-mouse antibody. The X-axis shows the clone number and the Y-axis shows trypsin binding in fluorescent units (FU).

30 Figure 6 shows western blot analysis of KnotBody clones and their GlyAla mutants. Phage prepared from 11 (randomly chosen) KnotBodies (referred to as W1-W11) and their GlyAla mutants (referred to as M1-M11) were analysed on a western blot using mouse anti-pIII antibody. Wild type (WT) gene III and KnotBody (KB)-gene III fusion were visualised by an anti-mouse IRDye® 680 (LI-COR, Cat. No. 926-32220) secondary antibody.

Figure 7 shows KnotBody Fab expression cassette in pINT12 vector system. In this plasmid, transcription of light chain cassette encoding the EETI-II VL fusion and CL domain is under the control of EF1-alpha promoter. Transcription of the heavy chain cassette encoding

D1A12 VH fused to IgG1 constant domain 1(CH1) is controlled by the CMV promoter.

Figure 8A shows SDS-PAGE analysis of IgG1 KnotBodies expressed in HEK-293F cells (representative example). KnotBody Fabs purified using CaptureSelect affinity matrix were visualised on a SDS-PAGE gel using Coomassie staining. A major band of approximately 50 kD observed for samples prepared under non-reducing conditions correspond to the complete KnotBody Fab molecule (Lane 2 and 4). The upper band (approximately 27 kD) and the lower band (approximately 23 kD) observed for samples prepared under reducing conditions (Lane 3 and 5) correspond to VH-CH1 fusion and Knottin-VL-CL fusion respectively. Lane 1 is a loaded with Biorad protein ladder (Biorad, 161-0373). Figure 8B shows the chromatographic profile of a KnotBody analysed by size exclusion chromatography using over a Superdex200 PC3.2/30 column (GE Healthcare).

Figure 9 shows the structure of EETI-Antibody VL CDR2 fusion. Crystal structure of KB_A05 (A) at 1.9 Å and crystal structure of KB_A12 (B) at 2.5 Å.

Figure 10A (i) shows previously published structure of EETI-II shown in ribbon mode (PDB code 1H9I). Figure 10A (ii) EETI-II as VL CDR2 fusion. Figure 10A (iii) Superimposition of previously published EETI-II structure and EETI-II as VL CDR2 fusion. Figure 10B shows VH and VL (fused to EETI-II) of Fab KB_A05. VH CDR residues are highlighted in black and VH CDR3 is annotated.

Figure 11 shows an analysis of polyclonal phage outputs from the phage display selection of KnotBody VH shuffled libraries. Heavy chain shuffled KB_A07 and KB_A12 (combined) libraries were selected on 5 different antigens: cMET-Fc (A), GAS6-CD4 (B), FGFR4-CD4 (C), uPA (D) and B-gal (E). The polyclonal phage from the 5 selections were each tested for binding to trypsin, all the antigens used in selection, neutravidin and streptavidin to determine background binding. X-axis shows antigens immobilised on Maxisorp™ plates and the Y-axis shows polyclonal phage binding to the antigen in fluorescent units (FU).

Figure 12 shows representative examples of monoclonal bi-specific KnotBodies (from cMET-Fc and GAS6-CD4 selections) binding to trypsin and cMET-Fc or trypsin and GAS6-CD4. Monoclonal phage binding to the antigens immobilised on Maxisorp™ plates were detected using a mouse anti-M13 antibody followed by europium conjugated anti-mouse antibody. X-axis shows the clone number and the Y-axis shows antigen binding in fluorescent units (FU).

Figure 13 shows phage selection cascade from the ‘heavy chain shuffled’ KnotBody library selected on biotinylated trypsin. The optimum antigen concentrations for round-2 and round-3 were determined empirically by selecting the phage KnotBodies against range of trypsin concentrations and comparing the output numbers with a “no antigen control”.

Figure 14 shows the format of the KnotBody capture assay. KnotBody-scFv-Fcs (B) were captured on Maxisorp™ plates coated with an anti-Fc antibody (A) and the binding biotinylated trypsin (C) to KnotBodies are detected using streptavidin conjugated europium (D).

Figure 15 shows a representative example of the performance of affinity improved clones in KnotBody Fc capture assay. KnotBody-scFv-Fcs were captured on Maxisorp™ plates coated with an anti-Fc antibody and the binding biotinylated trypsin to KnotBodies are detected using streptavidin conjugated europium. The binding signals observed for clones isolated from affinity maturation selections were compared to the parent clones KB_A12 and KB_A07. The X-axis shows clone ID of KnotBodies and the Y-axis shows KnotBody binding to trypsin in fluorescent units.

Figure 16 shows an improvement in trypsin binding after heavy chain shuffling. Off-rate of the clone KB_Tr_F03 selected from the heavy chain shuffled library is compared to the two parent KnotBodies KB_A07 and KB_A12. The X-axis shows off rate analysis in seconds and the Y-axis shows resonance units (RU).

Figure 17 shows a KnotBody expression cassette in pINT3-hg1 vector system. In this plasmid, transcription of light chain cassette encoding the knottin/toxin VL fusion and CL domain is under the control of EF1- α promoter. Transcription of the heavy chain cassette encoding D1A12 VH and IgG1 constant domains (CH1-CH2-CH3) is controlled by the CMV

promoter. PstI and BspEI sites in the light chain gene (recipient) allow the insertion of knottins (donor) into the CDR2 position.

Figure 18 shows SDS-PAGE analysis of IgG1 KnotBodies expressed in HEK-293F cells.

5 KnotBodies purified using Protein-A affinity chromatography were visualised on a reducing SDS-PAGE gel using Coomassie staining. The top bands correspond to the antibody heavy chains (HC) and the bottom bands corresponds the antibody light chain displaying knottins/toxins as CDR2 fusions. Samples 1-4 are KB_A12 antibody recipient fused NaV1.7 blockers (Huwentoxin-IV, ProTx-II, Ssm6a, and Ssm6a_GGS). Samples 5-10 are
10 Kv1.3 blockers (Kalitoxin, Moka-1 and Shk) fused to KB_A07 antibody (5, 6 and 7) or KB_A12 antibody (8, 9 and 10). Samples 11 and 12 are parental KnotBody clones (EETI-II fusions) KB_A07 and KB_A12 respectively.

Figure 19 show specific binding of two adhiiron-antibody fusions to LOX-1 protein. In this
15 assay, binding of phage displaying adhiiron-antibody fusions to LOX1 was detected using a mouse anti-M13 antibody followed by europium conjugated anti-mouse antibody. Parent KnotBodies KB_A07 and KB_A12 (EETI-II fusions) were included as controls. Proteins cMET-FC, GAS6-CD4, FGFR4-CD4, UPA and B-gal were used to examine non-specific binding. All antigens were directly immobilised on Maxisorp™ plates.

20

Figure 20 shows a representation secondary structure overlaid on primary sequence

Fig 20A shows the sequence of 10th type III cell adhesion domain of fibronectin. Secondary structural elements (beta sheets) are underlined. The residues which join the beta sheets on the upper face of the domain are shown lower case. Fig 20B shows the sequence of gp2
25 protein with beta sheets and alpha helical regions labelled. Potential sites for donor insertion or diversification are shown in lower case. N and C terminal residues removed without affecting structure are shown in italics and smaller font.

Figure 21 represents a concentration-response curves showing the concentration dependent
30 inhibition of huKv1.3 channel currents by KnotBodies. Log [M] concentration (x-axis) of toxin fusion KnotBodies KB_A12_Shk (Shk toxin, squares), KB_A07_Shk (Shk toxin, triangles) and KB_A07_KTX (kalitoxin, circles) plotted versus % current remaining (y-axis). From these concentration-response curves the concentration at which 50% current inhibition (IC₅₀; see Table 11 for summary) was determined.

Figure 22 shows the binding comparison of KnotBody linker variants to trypsin. Binding of KnotBody Fabs (X-axis) to biotinylated trypsin immobilised on streptavidin coated Maxisorp™ plates using a mouse anti-CH1 antibody followed by a europium conjugated anti-mouse antibody. Y-axis shows normalised binding signal (%) where the binding of Gly4Ser controls are normalised against that of their respective parent clone (i.e. 100% binding).

Figure 23 shows the monoclonal phage binding of clones selected from the KnotBody loop library to β -galactosidase (A) and cMET (B). Monoclonal phage binding to the antigen immobilised directly on Maxisorp™ plates were detected using a mouse anti-M13 antibody followed by europium conjugated anti-mouse antibody. X-axis shows the clone number and the Y-axis shows antigen binding in fluorescent units (FU).

Figure 24 shows a representative example of the screen for KnotBody binders to rat TFR. Monoclonal phage binding to rat TFR immobilised on Maxisorp™ plates were detected using a mouse anti-M13 antibody followed by europium conjugated anti-mouse antibody. X-axis shows the clone number and the Y-axis shows signal from phage binding to TFR in fluorescent units (FU).

Figure 25 shows the binding comparison of KnotBody KB_A12 and a format consisting of a bovine antibody with a natural “ultra long VH CDR3 (“cow ULVC-Ab”). The cysteine rich knob of the cow ULVC-Ab was replaced by the EETI-II knottin (“EETI-II cow ULVC-Ab”). Genes encoding these constructs were cloned into pSANG4 and phage rescued from either KB_A12 or the EETI-II cow ULVC-Ab fusion constructs (X-axis) and was PEG precipitated. 12.5x (A) and 0.5x (B) phage (relative to the initial culture volume) were tested for binding against biotinylated trypsin immobilised on streptavidin coated Maxisorp™ plates. Phage binding to trypsin was detected using an anti-M13 antibody followed by europium conjugated anti-mouse antibody. Y axis shows the phage binding signal in fluorescent units (FU).

Figure 26 shows a schematic representation of the mammalian display vector pD6. Antibody genes are targeted to the human AAVS locus which is located within a 4428 bp intron between the first and second exons of the gene encoding protein phosphatase 1, regulatory subunit 12C, PPP1R12C. A pair of Tale nucleases directed to this region are used

to cleave the genome at this site. 700-800bp of the sequences on the 5' and 3' site of the cleavage site are incorporated into donor vectors as left and right homology arms (HA) respectively. The pD6 donor vector is used to insert antibody genes formatted as single chain Fv (scFv) fused with the Fc region of human IgG1. The vector also has a CMV promoter driving expression of the scFv-Fc gene and an exon encoding the transmembrane domain from the "Platelet derived growth factor receptor (PDGFR-TM). The transgene region encoding the scFv-Fc antibody fusion is flanked by left and right homology arms (left HA, right HA) representing the sequences which flank the cleavage site in the AAVS locus. The vector also encodes a promoter-less blasticidin gene which becomes activated by in-frame splicing to exon 1 within the AAVS locus.

Figure 27 shows the functional expression of KnotBodies on the cell surface. All cells were stained with PE labelled anti-Fc (FL2 channel) and APC labelled streptavidin/biotinylated trypsin complex (FL4 channel). Following transfection cells were selected in blasticidin and analysed by flow cytometry at 15 days post transfection. Panels show the results for (A) KB_A07 (B) KB_A12 or (C) untransfected HEK293 cells.

Figure 28 shows a representation of the insertion of EETI-II donor knottin into VH CDR1 (A), VH CDR2 (B), VH CDR3 (C), VL CDR1 (D), VL CDR2 (E) and VL CDR3 (F) of the anti-TACE antibody D1A12 scFv (Table 23, Tape, C.J., PNAS USA 108, 5578-5583 (2011)).

In addition, a linker library was created for KB_A07 where the EETI-II donor knottin was inserted into VL CDR2 (G). Boundaries in this example were defined according to the VBASE database (MRC, Cambridge UK) according to criteria defined by Chothia (Chothia et al, J. Mol. Biol. 264, 220-232 (1996)). Amino acids are represented by IUPAC single letter amino acids code. Figure 28Ai shows the sequence of the VH recipient domain at CDR1 before insertion of the knottin. Figure 28Aii shows the sequence after insertion of the donor EETI-II donor. Figure 28Bi shows the sequence of the VH recipient domain at CDR2 before insertion of the knottin. Figure 28Bii shows the sequence after insertion of the donor EETI-II donor. Figure 28Ci shows the sequence of the VH recipient domain at CDR3 before insertion of the knottin. Figure 28Cii shows the sequence after insertion of the donor EETI-II donor. Figure 28Di shows the sequence of the VL recipient domain at CDR1 before insertion of the knottin. Figure 28Dii shows the sequence after insertion of the donor EETI-II donor. Figure 28Ei shows the sequence of the VL recipient domain at CDR2 before insertion of the knottin. Figure 28Eii shows the sequence after insertion of the donor EETI-II donor. Figure 28Fi

shows the sequence of the VL recipient domain at CDR3 before insertion of the knottin. Figure 28Fii shows the sequence after insertion of the donor EETI-II donor. Figure 28Gi shows the sequence of the “wild-type” KB_A07 VL recipient domain at CDR2 before linker randomisation. Figure 28Gii shows the sequence after randomization of the linker residues.

5 At the junctions, randomising residues are shown as X.

Figure 29 shows the insertion of the alternatively framed 5-3 EETI-II knottin donor into VL recipient. Alternatively framed knottins were inserted into CDR1 or CDR2 of a V kappa (IGKV1D-39) or V lambda (IGLV1-36) light chain. Figure 29A shows the nucleic acid and amino acid sequence of the alternatively framed knottin construct EET 5-3 which is used as a donor into CDR1 and CDR2 of the VL recipient. Cysteine residues are emboldened and core sequence involved in trypsin binding (“PRIL”) underlined. Figure 29B shows a representation of the insertion of 5-3 EETI-II donor into CDR1 or CDR2 of the lambda germline gene IGLV1-36. Boundaries are defined according to the international ImMunoGeneTics information system (IMGT)²⁹. Amino acids are represented by IUPAC single letter amino acids code. Figure 29Bi shows the sequence of the V lambda recipient domain at CDR1 before insertion of the knottin. Figures 29Bii and 29Biii show the sequence after insertion of the 5-3 EETI-II donor. (The sequence in figure 29Biii is generated by a primer which introduced an extra Gly residue between donor and framework residues compared to 29B ii). Figure 29B iv show the sequence of the V lambda recipient domain at CDR2 before donor insertion and 29B v shows after insertion of the EETI-II donor. Antibody framework residues are shown underlined and residues from the antibody recipient which are lost are shown in lower case. At the junctions, randomising residues are shown as x with those which replace framework or donor residues shown as x in lower case. Any “additional” residues within the linker between the domains are shown emboldened in upper case (A, Z or X). Z means any amino acid from Val, Ala, Asp, Gly or Glu (encoded by GNS codon). X represents the amino acids encoded by the codon VNC (encoding 12 amino acids) or VNS encoding 16 amino acids in total. (V=A, C or G and S=C or G). Figures 29 C-D show the DNA and amino acid sequence of the construct arising from insertion of the 5-3 EETI-II knottin donor into either CDR1 (C) or CDR2 of IGLV1-36 (D). The same 5-3 EET format was also introduced into CDR1 and CDR2 of IGKV1D-39 which is a V kappa germline gene and the depiction of this is shown in figure 3 using the native (1-5) orientation of EETI-II, but applying the same approach as described in example 16 and depicted in figure 29 for

insertion of the 5-3 EETI-II format. Restriction sites used in cloning are highlighted and the framework and CDR regions are identified.

Figure 30 shows that a KnotBody comprising a Kv1.3 blocking donor domain (Shk) reduces cytokine secretion in T cells. PBMCs were activated with an anti-CD3 antibody and were co-incubated with a KnotBody in which the donor diversity domain is either Shk (KB_A12_Shk) or EET (KB_A12). Free Shk is also used as a positive control. Graphs show the levels of Interferon gamma (IFN γ) (Fig 30A); Granzyme (Fig 30B), Interleukin 7A (IL17A) (Fig 30C), and TNF-alpha (Figure 30D) following T cell activation in PBMCs.

Figure 31 shows a nucleotide sequence encoding the alpha subunit of a human Nav1.7 polypeptide. Genbank accession NM_002977.

Figure 32 (a - e) shows the amino acid sequence of a human Nav1.7 alpha subunit with sequence annotation underneath.

Figure 33 shows sequence alignments of human Nav1.7, human Nav1.1, human Nav1.2, human Nav1.3 and human Nav1.6. A) The top panel shows the sequence alignments of S3-S4 region of domain II (DII) of Nav1.7 to Nav1.1, Nav1.2, Nav1.3 and Nav1.6 (where spider toxins such as HwTX-IV and ProTx-III bind). (B) The lower panel shows sequence alignment of S1-S2 linker region of domain II (DII) of Nav1.7 to Nav1.1, Nav1.2, Nav1.3 and Nav1.6.

Figure 34 shows concentration-response curves showing the concentration dependent inhibition of Nav1.7 channel currents by KnotBodies (a. KB_A07_ProTx-III 2M Gly, b. KB_A12_ProTx-III 2M Gly, c. KB_A12_ProTx-III 2M 2Gly) whilst minimal effect was observed in the KB_A12 isotype antibody control. Log [M] concentration (x-axis) of toxin fusion KnotBodies plotted versus % current remaining (y-axis). From these concentration-response curves the concentration at which 50% current inhibition (IC50; see Table 38 for summary) was determined.

Detailed Description

This invention relates to diverse populations and libraries of binding members that comprise a donor diversity scaffold domain inserted within a recipient diversity scaffold domain, and binding members isolated from such populations and libraries.

5

The present inventors have shown that an entire donor diversity scaffold domain is capable of folding correctly into a stable functional conformation following insertion into a recipient binding domain, with both domains remaining biologically active. The recipient binding domain is found to accommodate the incoming donor domain without its structure being compromised. Furthermore, donor and recipient domains with multiple cysteine residues each form the correct disulphide bond patterns within the fusion protein.

10

Combinations of donor and recipient diversity scaffold domains as described herein are useful in increasing the diversity of the populations and libraries of binding members. For example, antibodies are naturally-evolved diversity scaffolds but most of the diversity is focussed within the CDR3 region and in particular the CDR3 region of the antibody heavy chain. The introduction of a donor diversity scaffold domain into a recipient antibody VH and/or VL domain greatly increases the available diversity of the chimaeric donor/antibody binding member.

15

20

Furthermore, if the donor diversity scaffold domain is predisposed to binding a particular class of target molecule, such as an ion channel, this predisposition may be conferred on the binding member comprising the donor diversity scaffold domain. Thus, the binding member may retain the binding activity of the donor diversity scaffold domain (for example, knottin binding to an ion channel) whilst also displaying the in vivo half-life of the recipient diversity scaffold domain (for example, an antibody).

25

Preferably, the donor and recipient diversity scaffold domains of the chimaeric binding member of the invention are joined directly together or linked by short linkers to limit or constrain flexibility and relative movement between the domains, so that the binding member is relatively rigid. Longer, unstructured linkers are more liable to proteolytic degradation and may also facilitate the formation of incorrect disulphide bonds through increased conformational flexibility. In addition, the conformational flexibility of longer, relatively unstructured peptides compromises the affinity of interaction. In an interaction between 2

30

molecules, such as an antibody and an antigen, conformational entropy is lost upon complex formation. With longer linkers between donor and recipient diversity scaffold domains, there are potentially many more conformations available, making complex formation energetically unfavourable. In contrast, complex formation involving a more structured fusion protein with short or absent linkers will be entropically more favourable, potentially leading to a higher affinity interaction^{30,31,32,33}.

Since conformational flexibility carries a thermodynamic “entropic penalty” for binding interactions, constraining the conformational relationship between the donor and recipient diversity scaffold domains as described herein minimises the entropic penalty of interactions, with a resultant benefit in affinity of the resulting interaction of the binding member.

Given the close proximity of the donor and recipient diversity scaffold domains, amino acids on the surface of both donor and recipient diversity scaffold domains may contribute to the paratope that binds to the target molecule or different target molecules within a complex. This may increase affinity or specificity of the binding member compared to either diversity scaffold domain alone. A partner domain of either the donor or recipient diversity scaffold domain may also contribute to binding of target molecule. Any of the donor, recipient or partner domains may contact closely apposed sites on a target molecule or complex.

A binding member described herein may comprise a fusion protein. The fusion protein is a chimaeric molecule comprising two diversity scaffold domains; a donor diversity scaffold domain and a recipient diversity scaffold domain.

The donor diversity scaffold domain is located within the recipient diversity scaffold domain i.e. the donor diversity scaffold domain is flanked at both its N and C termini by the recipient diversity scaffold domain.

Preferably, both the donor and recipient diversity scaffold domains of the fusion protein contribute to the binding activity of the fusion protein, for example binding to the same or different target molecules.

In other embodiments, one of the donor and recipient diversity scaffold domains of the fusion protein, preferably the donor diversity scaffold domain is responsible for the binding activity of the fusion protein, for example the binding of the target molecule.

- 5 In some preferred embodiments, the fusion protein is suitable for display on the surface of a bacteriophage, for example for selection by phage display. A fusion protein for display may further comprise a phage coat protein, such as pIII, pVI, pVIII, pVII and pIX from Ff phage or the gene 10 capsid protein of T7 phage. The phage coat protein may be located at the N or the C terminal of the fusion protein, preferably at the C terminal of the fusion protein.

10

A diversity scaffold domain is an independently folding structural domain with a stable tertiary structure which is able to present diverse interaction sequences with potential to mediate binding to a target molecule. Diversity scaffold domains include domains represented within paralogous or orthologous groups which have been utilized in evolution for driving interactions of said scaffold with other molecules. Diversity scaffold domains also include natural domains which have been engineered to display diversity as well as entirely synthetic proteins evolved or designed to form a stable self-folding structure.

15

Examples of diversity scaffold domains known in the art include immunoglobulin domains⁴¹, cysteine-rich peptides, such as knottins and venom toxin peptides, affibodies (engineered Z domain of Protein A domain)^{42, 43}, monobodies (i.e. engineered fibronectins)⁴⁴, designed ankyrin repeat proteins (DARPs)⁴⁵, adhirons⁴⁶, anticalins⁴⁷, thioredoxin⁴⁸, single domain antibodies^{49, 50} and T7 phage gene 2 protein (Gp2)⁵¹.

20

- 25 In some preferred embodiments, a diversity scaffold domain may comprise multiple disulphide bridges formed by cysteine residues within the scaffold domain.

Preferred diversity scaffold domains for use as described herein include the VH and VL domains of an antibody. The binding of T cell receptors to their targets is also directed by CDR loops present within variable Ig domains (α and β) with greatest diversity present in CDR3 of the β chain. These have been used *in vitro* to present diverse sequences^{34, 35}. Other Ig domains, such as the constant Ig domains in antibody heavy chains (e.g. CH1, CH2, and CH3) and light chains (C kappa, C lambda) may also be used as diversity scaffolds^{36, 37}.

30

Beyond antibodies and T cell receptors, the Ig domain has acted as a diversity scaffold expanding and evolving on an evolutionary timescale and Ig domains are found in many hundreds of different proteins involved in molecular recognition. Ig domains from such proteins may be used as diversity scaffold domains as described herein,

5

The scaffold of the diversity scaffold domain is the framework which maintains the secondary structural elements which combine to form the stable core structure of the domain. The scaffold comprises multiple contiguous or non-contiguous scaffold residues which form covalent and non-covalent interactions with the side chains or the peptide backbone of other scaffold residues in the domain. Interactions may include hydrogen bonds, disulphide bonds, ionic interactions and hydrophobic interactions. The scaffold residues may form secondary structural elements of the domain, such as α helices, β strands, β sheets, and other structural motifs. Because they contribute to the core structure of the diversity scaffold domain, scaffold residues are conserved and substitution of scaffold residues within the diversity scaffold domain is constrained.

10

15

Examples of scaffolds include the framework regions of an antibody variable domain or the cysteine knot framework of knottins (e.g. the six or more cysteine residues which form the characteristic knot structure) together with the knottin beta sheets and 3_{10} helix motif.

20

The interaction sequence of a diversity scaffold domain is a contiguous or non-contiguous amino acid sequence which is presented by the stable core structure of the scaffold. The interaction sequence may interact with other molecules and mediate the binding activity of the domain, for example binding to a target molecule. In some embodiments, the interaction sequence of a domain may comprise one or more diverse residues, allowing selection of binding members with specific binding activity to be isolated from a library.

25

The residues of the interaction sequence may be entirely non-structural and may not support or contribute to the tertiary structure of the domain. For example, the interaction residues may be located at the loops or turns between secondary structural elements or motifs. Because they do not contribute to the core structure of the diversity scaffold domain, the residues of the interaction sequence are less conserved and substitution of interaction residues within the diversity scaffold domain is less constrained. In some embodiments, the interaction sequence

30

of a diversity scaffold domain may comprise residues in the non-loop faces of the protein^{43,44,52}.

Examples of interaction sequences include the CDRs of an antibody variable domain and the loops joining secondary structural elements of stable, self-folding protein domains e.g. the joining loops of a knottin, such as the PRIL motif of loop 1 of EETI-II. Other examples of interaction sequences within scaffold domains are known in the art^{34-38, 41-48, 51, 53}.

In some embodiments, a domain may contain residues which contribute to both binding and secondary structure. These residues may constitute both scaffold and interaction sequences. This is illustrated with affibodies (the engineered Z domain of protein A domain)^{43, 52} and monobodies (engineered scaffolds based on a fibronectin domain)⁴⁴. Residues which contribute to both secondary structure and binding may be diversified in the binding members described herein. Binding members which retain secondary structure may, for example, be identified in libraries using routine selection techniques. In some embodiments, residues which contribute to both secondary structure and binding may not be diversified.

Diversity scaffold domains may be used as either donor or recipient diversity scaffold domains in the fusion proteins and binding members described herein.

The donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence.

Preferably, donor diversity scaffold domains have N and C termini that are proximal to each other within the native structure of the domain. The distance between the termini of the donor may, for example, be within 20% of the distance between the ends of the insertion site in the recipient diversity scaffold domain, more preferably the same distance. Examples of donor domains with proximal termini include knottins⁵⁴, adhirons⁴⁶ and Gp2 scaffolds⁵¹.

In other embodiments, donor diversity scaffold domains may have N and C termini that are not proximal in the native structure of the domain. Donor diversity scaffold domains with non-proximal N and C termini may be inserted into the recipient diversity scaffold domain as described herein using linkers that are sufficiently long to allow fusion of the termini of the donor domain with the loops of the recipient diversity scaffold domain, such that the linkers

bridge the gap between the termini of donor and recipient domains. Alternatively, the donor diversity scaffold domain may be truncated to create a donor domain where the N and C termini are in proximity, or the recipient diversity scaffold domain may be truncated to create a recipient domain in which the termini of the insertion site are in proximity with the termini of the donor domain. The net result will be a loss of residues arising from the fusion of the donor and recipient structural domains. Linkers or truncations may reduce the distance between the termini of the donor domain to within 20% of the distance between the termini of the insertion site in the recipient scaffold or more preferably the same distance.

10 The donor diversity scaffold domain may consist of at least 15, at least 20, at least 25, at least 30 or at least 40 amino acids. The donor diversity scaffold domain may consist of 400 or fewer, 300 or fewer, 200 or fewer or 100 or fewer amino acids. For example, the donor diversity scaffold domain may consist of from 20 to 400 amino acids.

15 The donor diversity scaffold domain may comprise 2, 4, 6, 8, 10 or more cysteine residues which form disulphide bonds in the scaffold domain (i.e. the domain may contain 1, 2, 3, 4, 5 or more disulphide bonds).

In some embodiments, a donor diversity scaffolds may consist of at least 15 amino acids and contain 4 or more cysteine residues.

Examples of suitable donor diversity scaffold domains include an immunoglobulin, an immunoglobulin domain, a VH domain, a VL domain, an affibody, a cysteine-rich peptide, such as a venom toxin peptide or knottin, a “Designed ankyrin repeat protein” (DARPin), an adhiron, a fibronectin domain, an anticalin, a T7 phage gene 2 protein (Gp2) a monobody, a single domain antibody^{49, 50} or an affibody.

Preferred donor diversity scaffold domains include cysteine-rich peptides, such as ion channel-modulating peptides, venom toxin peptides and knottins.

30

Cysteine-rich peptides comprise a network of disulphide bonds as a core structural element. The structural conformations of cysteine-rich peptides are well-known in the art^{55, 6}.

Ion channel-modulating peptides (both agonistic and antagonistic) comprising multiple disulphide bonds are well-known in the art. Examples include venom toxin peptides from venomous species, such as spiders, snakes, scorpions and venomous snails^{26, 55}.

- 5 The structural conformations and disulphide linkage patterns of venom toxin peptides are also well known in the art. For example, an analysis of venoms of spiders and other animals reveals a multitude of conformations and patterns of disulphide linkage^{55, 65, 66, 67}. For example, spider toxin huwentoxin-II has a disulphide linkage pattern of I-III, II-V, IV-VI⁶⁸ and “Janus-faced atracotoxins” (J-ACTXs) has a disulphide linkage pattern of I-IV, II-VII, 10 III-IV and V-VIII (including an unusual “vicinal” disulphide bond between 2 neighbouring cysteines)⁵⁶, where the pairs of roman numeral refer to the order where each cysteine appears in the sequence and the position of the partner cysteine with which it forms a di-sulphide bond.
- 15 Cysteine-rich peptides may have a “disulphide-directed beta hairpin” (DDH) structure comprising an anti-parallel beta hairpin stabilised by 2 disulphide bonds⁵⁶. The DDH core structure is found in the widely studied “inhibitory cysteine knot” structure (hereafter referred to as cysteine-knot miniproteins or knottins).

- Knottins are small cysteine rich proteins that have an interwoven disulfide-bonded 20 framework, triple-stranded β -sheet fold, and one or more solvent exposed loops. Knottins typically comprise at least 3 disulfide bridges and are characterised by a disulphide knot which is achieved when a disulfide bridge between cysteines III and VI crosses the macrocycle formed by the two other disulfides (disulfides I-IV and II-V) and the interconnecting backbone. These bridges stabilise the common tertiary fold formed of 25 antiparallel β -sheets and in some cases a short 3_{10} helix. (The pairs of Roman numeral refers to the order where each cysteine appears in the sequence and the position of the partner cysteine with which it forms a disulphide bond). Knottins are 20–60 residues long, usually 26-48 residues, and are found in diverse organisms ranging from arthropods, molluscs, and arachnids to plants⁵⁷. Knottins arising from conus snails (conotoxins) in particular have been 30 widely studied^{54,58-60}. Many thousands of other knottins have been identified and their sequences and structures are publically available^{57,61,62} for example from on-line databases (such as the Knottin on-line database⁵⁷, Centre de Biochimie Structural, CNRS, France).

In some embodiments, the overall correct secondary structure of the knottin may be conferred by the correct distribution and spacing of cysteines. In other embodiments one or more additional scaffold residues may be required to confer the correct secondary structure. For example, residues 11-15 and 22-25 of EETI-II direct the folding propensity towards the 11-15 3_{10} -helix region and a 22-25 β -turn region respectively in the absence of any disulphides⁶³.

Knottins display a high degree of sequence flexibility and can accommodate large amounts of non-native sequence. For example, EETI-II can accommodate over 50% non-native sequence (by randomising 2 of the loops)²⁴.

A suitable cysteine-rich peptide for use as a diversity scaffold as described herein may for example comprise the amino acid sequence of Huwentoxin-IV, ProTx-II, ProTx-III, Ssm6a, Kalitoxin, mokatoxin-1, Conotoxin- ω , MCoTI-II, Shk, PcTX1 or mambalgin (as shown in Table 8A; SEQ ID NOS: 7-25) or other sequence set out in the Knottin database or may be a fragment or variant of this sequence which retains the correct fold structure.

A knottin which is a variant of a reference knottin sequence, such as sequence shown in Table 8A (SEQ ID NOS: 7-25) or set out in the Knottin database, may comprise an amino acid sequence having at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%, or at least 98% sequence identity to the reference sequence. Particular amino acid sequence variants may differ from a knottin sequence of Table 8A (SEQ ID NOS: 7-25) by insertion, addition, substitution or deletion of 1 amino acid, 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more than 10 amino acids.

Sequence similarity and identity are commonly defined with reference to the algorithm GAP (Wisconsin Package, Accelrys, San Diego USA). GAP uses the Needleman and Wunsch algorithm to align two complete sequences that maximizes the number of matches and minimizes the number of gaps. Generally, default parameters are used, with a gap creation penalty = 12 and gap extension penalty = 4. Use of GAP may be preferred but other algorithms may be used, e.g. BLAST (which uses the method of Altschul *et al.* (1990) *J. Mol. Biol.* 215: 405-410), FASTA (which uses the method of Pearson and Lipman (1988) *PNAS USA* 85: 2444-2448), or the Smith-Waterman algorithm (Smith and Waterman (1981) *J. Mol. Biol.* 147: 195-197), or the TBLASTN program, of Altschul *et al.* (1990) *supra*, generally

employing default parameters. In particular, the psi-Blast algorithm (Nucl. Acids Res. (1997) 25 3389-3402) may be used.

Sequence comparison may be made over the full-length of the relevant sequence described
5 herein.

One or more residues within a loop of a knottin, for example, one or more residues within
loop 1, 2, 3, 4 or 5 of a knottin may be diversified or randomised. In some embodiments, one
or more within the target binding motif, such as the trypsin binding motif PRIL in loop 1 of
10 EETI-II, or the corresponding residues in a different knottin, may be diversified. For
example, 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more residues may be diversified.

The formation of native disulphide linkage patterns in the donor and recipient diversity
together and the adoption of correct secondary structures within the scaffold domains of a
15 fusion protein is exemplified below.

In other preferred embodiments, the donor diversity scaffold is an adhiron. Adhirons are
peptides of about 80-100 amino acids based on plant-derived phytocystatins⁴⁶. Suitable
adhiron sequences are well-known in the art and described elsewhere herein. A suitable
20 adhiron for use as a diversity scaffold as described herein may for example comprise an
amino acid sequence shown in Table 12 (SEQ ID NOS: 26, 27) or may be a fragment or
variant of this sequence.

An adhiron which is a variant of a reference adhiron sequence, such as sequence shown in
25 Table 12 (SEQ ID NOS: 26 & 27) may comprise an amino acid sequence having at least
20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least
90%, at least 95%, or at least 98% sequence identity to the reference sequence. Particular
amino acid sequence variants may differ from a sequence of Table 12 (SEQ ID NOS: 26 &
27) by insertion, addition, substitution or deletion of 1 amino acid, 2, 3, 4, 5, 6, 7, 8, 9, or 10
30 or more than 10 amino acids.

The methods described herein do not require knowledge of the structure of the donor
diversity scaffold domain. Selection of binding members may be based on binding to the
target molecule (if known) or the correct folding of the recipient domain. The donor diversity

scaffold domain may be provided within a library from which clones with proper folding of the recipient scaffold can be selected or may be inserted into an existing recipient diversity scaffold which accommodates an incoming donor diversity scaffold.

- 5 The failure of one scaffold domain to fold will affect the overall expression and stability of the resultant fusion protein and so it will also be possible to introduce diversification in the absence of structural knowledge and screen for retained expression of a folded scaffold domain. However, where the structure of the donor diversity scaffold domain is known, sites for diversification in the construction of libraries may be guided by this structure.

10

The recipient diversity scaffold domain and the donor diversity scaffold domain are preferably heterologous i.e. they are associated by artificially by recombinant means and are not associated in nature. In some preferred embodiments, the donor and recipient diversity scaffold domains are from different scaffold classes e.g. they are not both immunoglobulins,
15 both cysteine-rich proteins, both knottins or both adhirons.

The recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence.

- 20 In some embodiments, the recipient diversity scaffold domain may lack cysteine residues which form disulphide bonds. For example, the scaffold domain may comprise 0 or 1 cysteine residue. In other embodiments, the recipient diversity scaffold domain may comprise 2, 4, 6, 8, 10 or more cysteine residues which form disulphide bonds in the scaffold domain (i.e. the domain may comprise 1, 2, 3, 4, 5 or more disulphide bonds).

25

Examples of suitable recipient diversity scaffold domains include an immunoglobulin domain, a VH domain, a VL domain, a knottin, a Protein A, cysteine-rich peptide, venom toxin, a Designed ankyrin repeat protein (DARPin), an adhiron, a fibronectin domain, an anticalin and a T7 phage gene 2 protein (Gp2).

30

Selection of the insertion site for the donor diversity scaffold domain and linker sequences may be guided by the structure of the recipient domain, where the structure is known^{64, 53, 23, 75, 39, 43}. For example, a suitable insertion site may be located in a region which joins secondary structural elements of the recipient diversity scaffold domain, such as beta strands

or alpha helices. Suitable regions for the insertion site within the 10th type III cell adhesion domain of fibronectin are shown in Fig 20A (SEQ ID NO: 28) and regions for the insertion site within the T7 Gp2 protein are shown in Fig 20B (SEQ ID NO: 29). The identification of suitable insertion sites is described in more detail in example 10 below. Structural

knowledge may also be used to direct diversification in the construction of libraries.

Preferably, the recipient diversity scaffold domain is all or part of an immunoglobulin, most preferably, all or part of an antibody variable domain. For example, the recipient diversity scaffold domain may be an antibody light chain variable (VL) domain or an antibody heavy chain variable (VH) domain.

The incoming donor diversity scaffold domain separates the recipient diversity scaffold domain into N terminal and C terminal parts at the point of insertion into the recipient. The donor diversity scaffold domain is fused internally within the recipient diversity scaffold domain such that the N terminus and C terminus of the donor diversity scaffold domain are connected either directly or via a linker to the N and C terminal parts respectively of the recipient diversity scaffold domain. In some embodiments, one or more residues at the N and/or C terminals of the donor diversity scaffold domain or the recipient diversity scaffold domain may be removed and/or randomised. The recipient diversity scaffold domain retains its original N and C termini, which are not affected by the insertion of the donor diversity scaffold domain into the internal insertion site.

In some embodiments, the orientation of the incoming donor diversity scaffold domain relative to the recipient diversity scaffold domain may be altered by linking the recipient diversity scaffold domain to different positions within the donor diversity scaffold domain. For example, a rotated donor diversity scaffold domain may be designed by cyclising the donor diversity scaffold domain through linkage of the native N and C terminals and linearizing at a different position in the amino acid sequence to generate artificial N and C terminals. These artificial terminals may be linked to the recipient diversity scaffold domain within the fusion protein. In other words, the native N and C termini of a donor diversity scaffold domain, such as a cysteine-rich peptide, may be joined together directly or via a peptide sequence and artificial N and C termini generated at a different position in the sequence of the donor diversity scaffold domain. In a fusion protein generated using these artificial N and C termini, the donor diversity scaffold domain is rotated relative to the

recipient diversity scaffold domain compared to a fusion protein comprising the donor diversity scaffold domain with native N and C terminals. For example, the order of the loops within the donor diversity scaffold domain may be altered. Examples of EETI-II donor diversity scaffold domains with altered orientation are shown in Table 28 (SEQ ID NOS:

302-307).

Preferably, the donor diversity scaffold domain completely replaces some or all of a loop sequence of the recipient diversity scaffold domain, such that the donor diversity scaffold domain is directly linked to scaffold residues of the recipient diversity scaffold domain. For example, loop sequences joining secondary structural elements in the recipient domain (e.g. a CDR joining 2 β strands of a β sheet framework elements in an antibody variable domain) may be removed in their entirety. In some embodiments, one or more scaffold residues may be removed or replaced from the donor diversity scaffold domain or the recipient diversity scaffold domain to reduce the distance between them while enabling folding of the component parts of the fusion protein.

Preferably, the donor diversity scaffold domain is positioned in the fusion protein close to the interaction sequence of the recipient diversity scaffold domain. For example, donor diversity scaffold may be located less than 20 Angstroms from the recipient donor scaffold, for example 8-13 Angstroms in the case of the knottin insertion exemplified herein; calculated from the end of the preceding framework to the first cysteine of the donor/knot motif. This proximity allows both interaction sequences to interact with the same or closely apposed sites on the target molecule or complex, such that both donor and recipient domains may contribute simultaneously to binding. For example, the fusion protein may lack rigid stalks and flexible linkers to connect the donor diversity scaffold domain to the recipient diversity scaffold domain.

In some preferred embodiments, the recipient diversity scaffold is an antibody variable domain, for example an antibody VH or VL domain.

The scaffold of a VH, VL kappa or VL lambda recipient domain may comprise residues 1-26, 39-55 and 66-104 (IMGT numbering) of the domain. The scaffold may also comprise residues of framework 4 which are encoded by the last 11 residues encoded by the J segments of the heavy chain and by the last 10 residues encoded by the J segments of the kappa and

lambda light chains. The interaction sequence of a VH, VL kappa or VL lambda domain may comprise residues 27 to 38 (CDR1), 56 to 65 (CDR2) and 105 to 117 (CDR3) (IMGT numbering).

- 5 Examples of preferred recipient diversity scaffold domains are shown in Table 1 with inserted donor diversity scaffold domains.

Other preferred recipient scaffolds include antibody constant domains, for example a heavy or light chain CH1, CH2 or CH3 domain.

10

The donor diversity scaffold domain may replace part or more preferably all of a CDR (i.e. CDR1, CDR2 or CDR3) in the recipient antibody variable domain.

- 15 Preferably, the donor diversity scaffold domain replaces all or part of the CDR1 or CDR2 of the antibody variable domain. This allows the more diverse and central CDR3 to contribute to the binding activity, as well as the partner antibody variable domain. Insertion of the donor diversity scaffold domain into CDR1 and CDR2 is exemplified below.

- 20 The interaction sequence of the donor diversity scaffold domain and one or more CDRs of the recipient antibody variable domain or partner domain may interact with the same epitope on the target molecule. For example, the interaction sequence of the donor diversity scaffold domain and the CDR3 of the antibody variable domain and/or partner domain may interact with the same epitope on the target molecule.

- 25 In some preferred embodiments, the recipient diversity scaffold domain is an antibody variable domain, for example a VH or VL domain, and the donor diversity scaffold domain is a knottin or adhiron. Examples of binding members comprising a knottin donor diversity scaffold domain and a VL domain recipient diversity scaffold are shown in Table 1. A binding member comprising an antibody variable domain recipient and a cysteine rich donor domain is termed a “Knotbody” herein.
- 30

In one set of preferred embodiments, the recipient diversity scaffold domain is an antibody VL domain, and the donor diversity scaffold domain is a knottin which replaces the CDR2 of the VL domain. Suitable knottins may bind to an ion channel, such as Kv1.3, and may

include ShK and Kaliotoxin. The recipient antibody VL domain may show no target binding or may bind to the same target molecule as the knottin, an associated protein in complex with the knottin target molecule or a different target molecule to the knottin.

- 5 A suitable binding member may for example comprise a fusion protein having the amino acid sequence of any one of SEQ ID NOS: 31 to 35 (as shown in Table 8B), an amino acid sequence encoded by a nucleotide sequence shown in Table 33 or an amino acid sequence as shown in Table 36, or may be a fragment or variant of such a sequence. The binding member may further comprise a partner domain which associates with the fusion protein. Suitable
10 partner domains include any VH domain, for example the D12 A12 VH domain shown in Table 8B (SEQ ID NO: 30) or Table 34.

- Suitable VH domains may be non-binders, may bind to a different target molecule to the fusion protein or may bind to the same target molecule as the fusion protein, for example to
15 increase the binding affinity or binding specificity of the fusion protein.

- A fusion protein which is a variant of a reference sequence, such as sequence shown in Table 1 (SEQ ID NOS: 84-139) Table 8B (SEQ ID NOS: 31 to 35), Table 29 (SEQ ID NOS: 308-317), Figure 29 (SEQ ID NOS 349 and 351), an amino acid sequence encoded by a
20 nucleotide sequence shown in Table 33 or an amino acid sequence as shown in Table 36, may comprise an amino acid sequence having at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%, or at least 98% sequence identity to the reference sequence. Particular amino acid sequence variants may differ from a fusion protein sequence of Table 1 (SEQ ID NOS: 84-139) Table 8B (SEQ ID
25 NOS: 31 to 35), Table 29 (SEQ ID NOS: 308-317), Figure 29 (SEQ ID NOS 349 and 351), an amino acid sequence encoded by a nucleotide sequence shown in Table 33 or an amino acid sequence as shown in Table 36 by insertion, addition, substitution or deletion of 1 amino acid, 2, 3, 4, 5, 6, 7, 8, 9, or 10 or more than 10 amino acids.

- 30 In other preferred embodiments, the recipient diversity scaffold domain may be an immunoglobulin constant domain, for example an immunoglobulin constant domain from an antibody heavy or light chain, and the donor diversity scaffold domain may be a knottin or adhiron.

Preferably, the distance between the framework residues of the recipient diversity scaffold domain and the donor diversity scaffold domain is minimised to reduce proteolytic lability and/or relative flexibility between the domains. This may be useful in promoting binding affinity. For example, the N and C terminals of the donor diversity scaffold domain may
5 each be linked directly to the recipient diversity scaffold domain without a linker or through linkers of 1, 2, 3 or 4 amino acids. The same or different linker sequences may be used to link the N and C terminals of the donor diversity scaffold domain to the recipient diversity scaffold domain.

10 Examples of suitable linker sequences are shown in Tables 2, 26 and 27.

In some embodiments, it may be preferred that the donor and recipient diversity scaffold domains are joined by a linker other than GGSG (SEQ ID NO: 2), a linker other than GGGG (SEQ ID NO: 32) or a linker that does not comprise GG, such as SGG or GG.

15

Linker length refers to the number of amino acid residues that are gained or lost from the scaffold elements of the donor and recipient domains when fused together. For example, the removal of scaffold residues and the use of an equal number of randomized residues to join the donor and recipient diversity scaffold domains is considered herein to be randomization
20 of the removed framework residues rather than the introduction of additional linker residues.

In some embodiments, 1, 2, 3 or 4 amino acids at the N and/or C terminal of the donor diversity scaffold domain and/or 1, 2, 3 or 4 amino acids on each side of the insertion site in the recipient scaffold may be replaced through mutagenesis and/or randomisation.

25

The fusion protein may be associated with the partner domain through a covalent or non-covalent bond.

The partner domain may be associated with the recipient diversity scaffold domain and/or the
30 donor diversity scaffold domain of the fusion protein. Preferably, the partner domain is associated with the recipient diversity scaffold domain.

In some preferred embodiments, the recipient diversity scaffold domain is an antibody light chain variable (VL) domain and the partner domain is an antibody heavy chain variable (VH)

domain. In other preferred embodiments, the recipient diversity scaffold domain is an antibody heavy chain variable (VH) domain and the partner domain is an antibody light variable (VL) domain.

- 5 In some embodiments, antibody heavy and light chain variable domains of a binding member as described herein may be connected by a flexible linker, for example in a scFv format.

A binding member described herein comprises the fusion protein. The binding member may further comprise a partner domain that is associated with the fusion protein. For example, the
10 binding member may be a heterodimer.

In some embodiments, the binding member may comprise two or more fusion proteins or partner domains. For example, the binding member may be multimeric. In some embodiments, the recipient or donor diversity scaffold domain of the binding member may
15 form a homomultimer, such as a homodimer. The recipient or donor diversity scaffold domain of the binding member may partner with a different form of the same domain, such as a wild-type or mutagenized form of the domain.

As noted, preferred examples of binding members are knotbodies comprising an antibody
20 variable domain recipient domain and a cysteine rich donor domain. The binding member may include a VH-VL domain pair, in which the donor domain is inserted in either the VH or VL as described. Optionally, the VH and VL are joined by a flexible linker, and example formats include scFv or scFv-Fc. Alternatively the VH and VL may be non-covalently paired, such as in a whole immunoglobulin format comprising paired antibody heavy and light
25 chains, e.g., IgG. Where a binding member includes an antibody constant region, this is preferably a human antibody Fc domain such as a human IgG1, IgG2, IgG3 or IgG4.

As is well known in the art, the Fc region of an antibody is largely responsible for mediating cellular effector functions such as complement dependent cytotoxicity (CDC) or antibody
30 dependent cell cytotoxicity (ADCC). In some embodiments of the present invention a binding member comprises a human Fc region that is “effector null”, i.e., does not mediate CDC and/or ADCC. Suitable constant regions may be selected accordingly, optionally including mutations that alter (e.g., reduce) Fc effector function. Thus, for example, a binding member may comprise a human IgG1, IgG2, IgG3, IgG4 Fc region or an effector null variant thereof.

In addition to the fusion protein and optional partner domain, the binding member may further comprise a therapeutic moiety, half-life extension moiety or detectable label. The moiety or label may be covalently or non-covalently linked to the fusion protein or the partner domain.

In some embodiments, a binding member may be displayed on a particle or molecular complex, such as a cell, ribosome or phage, for example for screening and selection. The binding member may further comprise a display moiety, such as phage coat protein, to facilitate display on a particle or molecular complex. The phage coat protein may be fused or covalently linked to the fusion protein or the partner domain.

In some embodiments, a binding member as described herein may display advantageous properties, such as increased affinity, stability, solubility, expression, specificity or *in vivo* half-life relative to the isolated donor and/or recipient diversity scaffold domain.

Other aspects of the invention relate to the generation of libraries of binding members as described herein.

A method of producing a library of binding members may comprise;
providing a population of nucleic acids encoding a diverse population or repertoire of fusion proteins comprising a donor diversity scaffold domain inserted into a recipient diversity scaffold domain, optionally wherein the N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain with linkers of up to 4 amino acids,

wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, and

one, two or all three of the donor interaction sequence, the recipient interaction sequence and the linkers are diverse in said population, and

expressing said population of nucleic acids to produce the diverse population or repertoire, and

optionally associating the fusion proteins with a partner domain or population of partner domains, thereby producing a library of binding members.

The population of nucleic acids may be provided by a method comprising inserting a first population of nucleic acids encoding a donor diversity scaffold domain into a second population of nucleic acids encoding a recipient diversity scaffold domain, optionally
5 wherein the first and second nucleic acids are linked with a third population of nucleic acids encoding linkers of up to 4 amino acids, wherein the one, two or all three of the first, second and third populations of nucleic acids are diverse.

10 The nucleic acids may be contained in vectors, for example expression vectors. Suitable vectors include phage-based⁷⁶ or phagemid-based⁷⁷ phage display vectors.

The nucleic acids may be recombinantly expressed in a cell or in solution using a cell-free *in vitro* translation system such as a ribosome, to generate the library. In some preferred
15 embodiments, the library is expressed in a system in which the function of the binding member enables isolation of its encoding nucleic acid. For example, the binding member may be displayed on a particle or molecular complex to enable selection and/or screening. In some embodiments, the library of binding members may be displayed on beads, cell-free ribosomes, bacteriophage, prokaryotic cells or eukaryotic cells. Alternatively, the encoded
20 binding member may be presented within an emulsion where activity of the binding member causes an identifiable change. Alternatively, the encoded binding member may be expressed within or in proximity of a cell where activity of the binding member causes a phenotypic change or changes in the expression of a reporter gene^{16, 78, 79}.

Eukaryotic cells benefit from chaperone systems to assist the folding of secreted protein
25 domains⁸⁰ and these are absent within bacterial expression systems. The data set out below shows that mammalian chaperone systems are not required for the correct folding of the binding members described herein. In addition, binding members identified using prokaryotic phage display systems are by definition amenable to further engineering within the phage display system to create improved binders. Prokaryotic systems, such as phage display, also
30 facilitate construction of larger libraries and facilitate selection, screening and identification of binding members from such libraries. In contrast binding members identified in eukaryotic systems may not be amenable for further engineering within prokaryotic systems.

Preferably, the nucleic acids are expressed in a prokaryotic cell, such as *E coli*. For example, the nucleic acids may be expressed in a prokaryotic cell to generate a library of binding members that is displayed on the surface of bacteriophage. Suitable prokaryotic phage display systems are well known in the art, and are described for example in Kontermann, R & Dubel, S, *Antibody Engineering*, Springer-Verlag New York, LLC; 2001, ISBN: 3540413545, WO92/01047, US5969108, US5565332, US5733743, US5858657, US5871907, US5872215, US5885793, US5962255, US6140471, US6172197, US6225447, US6291650, US6492160 and US6521404. Phage display systems allow the production of large libraries, for example libraries with 10^8 or more, 10^9 or more, or 10^{10} or more members.

In other embodiments, the cell may be a eukaryotic cell, such as a yeast, insect, plant or mammalian cell.

A library of binding members, for example a library generated by a method described above, may comprise;

a diverse population of fusion proteins comprising a donor diversity scaffold domain inserted into a recipient diversity scaffold domain, optionally wherein the N and C terminals of the donor diversity scaffold domain are each linked to the recipient diversity scaffold domain with linkers of up to 4 amino acids,

wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, and

one, two or all three of the donor interaction sequence, the recipient interaction sequence and the linkers are diverse in said population, and

optionally wherein each fusion protein in the population is associated with a partner domain.

The sequences of one, two or all three of the donor interaction sequence, the recipient interaction sequence and the linkers may be diverse. For example, the binding members in the library may have diverse donor interaction sequences and the same recipient interaction sequence; diverse recipient interaction sequences and the same donor interaction sequence; diverse linker sequences and the same recipient and donor interaction sequences or; diverse recipient and donor interaction sequences.

A diverse sequence as described herein is a sequence which varies between the members of a population i.e. the sequence is different in different members of the population. A diverse sequence may be random i.e. the identity of the amino acid or nucleotide at each position in the diverse sequence may be randomly selected from the complete set of naturally occurring amino acids or nucleotides or a sub-set thereof.

Diversity may be targeted to donor interaction sequence, recipient interaction sequence, linkers or sequences within the partner domain using approaches known to those skilled in the art, such as oligonucleotide-directed mutagenesis^{22, 23}, *Molecular Cloning: a Laboratory Manual*: 3rd edition, Russell et al., 2001, Cold Spring Harbor Laboratory Press, and references therein). For example, where the recipient diversity scaffold domain is an antibody variable domain and the donor diversity scaffold domain has replaced one CDR region, amino acid changes, such as diverse sequences, may be introduced into the other CDRs of the recipient domain or partner chain. Where the donor domain is a knottin, diverse sequences may be introduced into regions linking core scaffold elements such as the cysteine knot. The knottin structure has been shown to be able to accommodate over 50% non-native structure²⁴. The introduction of diversity into the knottin scaffolds, such as EETI-II²⁴, kalitoxin²⁵, ProTx-1²⁶, and TRPA1²⁶ to generate libraries is known in the art.

Diverse sequences may be contiguous or may be distributed within the domain. Suitable methods for introducing diverse sequences into domains are well-described in the art. For example, diversification may be generated using oligonucleotide mixes created using partial or complete randomisation of nucleotides or created using codons mixtures, for example using trinucleotides. Alternatively, a population of diverse oligonucleotides may be synthesised using high throughput gene synthesis methods and combined to create a precisely defined and controlled population of variant domains. Alternatively “doping” techniques in which the original nucleotide predominates with alternative nucleotide(s) present at lower frequency may be used. As an alternative, Example 2 below describes methods for introducing diversity into a domain using diversity from a natural source (an antibody repertoire in this example).

Either donor or recipient domains could be part of a multimeric protein with potential additional diversity being introduced by the partner chain. The entire partner chain can be replaced e.g. by chain shuffling²⁷. Alternatively, diversity could be introduced into regions of

an existing partner chain of the recipient or donor e.g. the VH partner of a VL recipient of the donor. In general the heterodimeric nature of antibodies and the ability to select variants of the partner chain independently of the recipient chain supporting the donor adds to the power of this approach.

5

Preferably, the library is a display library. The binding members in the library may be displayed on the surface of particles, or molecular complexes such as beads, ribosomes, cells or viruses, including replicable genetic packages, such as yeast, bacteria or bacteriophage (e.g. Fd, M13 or T7) particles, viruses, cells, including mammalian cells, or covalent, ribosomal or other *in vitro* display systems. Each particle or molecular complex may comprise nucleic acid that encodes the binding member that is displayed by the particle and optionally also a displayed partner domain if present.

10

In some preferred embodiments, the binding members in the library are displayed on the surface of a bacteriophage. Suitable methods for the generation and screening of phage display libraries are well known in the art. Phage display is described for example in WO92/01047 and US patents US5969108, US5565332, US5733743, US5858657, US5871907, US5872215, US5885793, US5962255, US6140471, US6172197, US6225447, US6291650, US6492160 and US6521404.

20

Libraries as described herein may be screened for binding members which display binding activity, for example binding to a target molecule.

Binding may be measured directly or may be measured indirectly through agonistic or antagonistic effects resulting from binding.

25

Binding to the target molecule may be mediated by one or more of the donor diversity scaffold domain, the recipient diversity scaffold domain and the partner domain of the binding member.

30

The interaction sequences of the donor and recipient diversity scaffold domains of the fusion protein may bind to the target molecule, and more preferably the same epitope of the target molecule. The fusion protein and the partner domain of a binding member may bind to the

same target molecule or different target molecules. For example, the fusion protein may bind to a first target molecule and the partner domain may bind to a second target molecule.

5 A binding member may bind the target molecule with the same affinity of a parent donor or recipient diversity scaffold domain, or with a lower or higher affinity. In some embodiments, a binding member may neutralise a biological activity of the target molecule. In other
embodiments, a binding member may activate a biological activity of the target molecule.

10 Suitable target molecules include biological macromolecules, such as proteins. The target molecule may be a receptor, enzyme, antigen or oligosaccharide. In some preferred embodiments, the target may be an integral membrane protein. In some embodiments, the target may be G protein coupled receptor (GPCR). Target molecules which are difficult to target with antibodies, such as ion transporters, may be particularly suitable.

15 In some preferred embodiments, the target molecule may be an ion transporter, such as an ion pump or ion channel.

Suitable ion channels are well known in the art and include Kir1.1, Kir2.1, Kir6.2, SUR2, Kv1.1, KCNQ1, KCNQ, KCNQ4, TRPP2, TRPA1, TRPC6, CNGA1, BK, Nav1.1, Nav1.5,
20 Nav1.6, Nav2.1, Cav1.2, Cav2.1, glycine receptors, GABA-A, CHRNA4⁸² Other suitable ion channels include voltage-gated potassium channels such as Kv1.3, L-Type voltage-gated calcium channels, Cav2.2, hERG, ASICs and Eag1.

25 A binding member described herein may bind to two or more different target epitopes (i.e. the binding member may be multi-specific). The target epitopes bound by the binding member may be on the same or different target molecules. For example, one or more of the donor diversity scaffold domain, recipient diversity scaffold domain and/or partner domain of a multi-specific binding member may bind to a different target epitope to the other domains.

30 In some embodiments, the binding member may be bi-specific i.e. it may bind to two different epitopes.

A bi-specific binding member may bind to two different target epitopes concurrently. This may be useful in bringing a first and a second epitope into close proximity for example to

cross-link molecules or cells. When the target epitopes are located on different target molecules, the target molecules may be brought into close proximity by concurrent binding to the binding member. When the target molecules are located on different cells, concurrent binding of the target molecules to the binding member may bring the cells into close proximity, for example to promote or enhance the interaction of the cells. For example, a binding member which binds to a tumour specific antigen and a T cell antigen, such as CD3, may be useful in bringing T cells into proximity to tumour cells.

Concurrent binding of different target epitopes by a binding member described herein may also be useful in stabilizing a particular conformation of a target molecule or complex of target molecules.

A binding member may bind to the two different target epitopes sequentially i.e. the binding member may bind to one target epitope and then the other. This may be useful, for example in crossing the blood: brain barrier (BBB¹²⁰) or blood: nerve barrier (BNB¹²¹). For example, a binding member may bind to an epitope on a BBB or BNB receptor. Suitable receptors are well-known in the art and include transferrin (TFR), insulin (IR), leptin (LEP-R), glucose (GLUT1), CD98 (LAT1) and lipoprotein (LRP-1) receptors. Once bound to the BBB or BNB receptor, the binding member may be transcytosed across the BBB or BNB, after which it may then bind independently to an epitope on a second target molecule in the brain or peripheral nervous system, for example an ion channel or protease.

In some preferred embodiment, a binding member may bind to TFR. For example, the binding member may comprise a partner domain that binds to TFR and a fusion protein that binds to a second target molecule in the brain or peripheral nervous system. The recipient scaffold in the fusion protein may be a VL domain and the partner domain may be a VH domain. Suitable VH partner domains for targeting TFR may comprise a sequence shown in Table 20 (SEQ ID NOs: 237-245) or a variant thereof.

Suitable in vitro systems for screening libraries for bi-specific binding members able to cross the BBB or BNB are well known in the art (Nakagawa, S. *et al. Neurochem. Int.* 54, 253–263 (2009); Yosef, N. *et al J. Neuropathol. Exp. Neurol.* 69, 82–97 (2010)) and described in more detail below.

In some preferred embodiments, a first domain on the binding member (e.g. one of the donor diversity scaffold domain, recipient diversity scaffold domain and partner domain) may be directed to a first cell surface target molecule. Binding to this first target molecule may sequester the binding member on the cell surface, thereby facilitating interaction of a second binding domain (e.g. another of the donor diversity scaffold domain, recipient diversity scaffold domain and partner domain) to a second target molecule by increasing the local concentration of the binding member on the cell surface. For example, A bi-specific binding member may consist of a VH partner domain which binds with high affinity to an abundant first target molecule on T cells coupled with a VL-knottin fusion which binds and blocks a second target molecule, such as an ion channel e.g. Kv1.3. A cell-specific binding domain (VH in this example) may be generated, for example, by selecting on recombinant protein representing a candidate target molecule (as described in example 6) or by selecting a library on the cell surface of a target cell to look for a partner domain (VH in this example) which enhances the binding of the second domain. Binding of the first domain to the first target molecule sequesters the binding member on the cell surface and may overcome low affinity, low density or relative inaccessibility of the second binding domain for the second target molecule. This may increase the potency of the second binding domain on cells which express the target recognised by the first binding domain. This approach may also increase the specificity of the binding member, since optimal binding/blocking require both target molecules to be on the same cell. The presence of a first binding molecule has been shown to effect a binding enhancement of a second binding molecule over several orders of magnitude based on affinity and antigen density (Rhoden et al (2016) J Biol. Chem. 291 p11337-11347).

Target molecules for use in selection and screening may be produced using any convenient technique. For example, integral membrane proteins may be produced using bacterial, baculoviral or mammalian expression systems^{86,87}, proteoliposomes⁸⁸, “nanodiscs”⁸⁹ or cell lysates⁹⁰.

In some embodiments described herein, an initial “founder” library of binding members may be used to identify one or more founder binding members which allow simultaneous folding of both donor and recipient diversity scaffold domains. These founder binding members may be selected for retained donor and recipient domains which display the desired binding activity, such as binding to a target molecule. In subsequent steps, the founder binding members may be subjected to further modification and screening to optimise binding activity

and other properties. Alternatively, an initial “founder” library of binding members may include any library that combines a recipient diversity scaffold domain, a donor diversity scaffold domain and, optionally a linker, as described herein, in which diversity is introduced into any of said recipient diversity scaffold domain, a donor diversity scaffold domain or linker sequence.

A method of screening as described herein may comprise;

(i) providing a founder library of binding members as described herein;

wherein one, two or all three the donor interaction sequence, the recipient interaction sequence and the linkers are diverse in said founder library,

(ii) screening the library for binding members which display a binding activity, and

(iii) identifying one or more binding members in the founder library which display the binding activity.

The one or more identified binding members may be recovered from the founder library.

In some preferred embodiments, the linker sequences may be diverse in the library. This may be useful in identifying functional fusions of donor and recipient diversity scaffold domains. Examples of diverse linker sequences are presented herein. In some embodiments, diverse linkers of 1, 2, 3, or 4 amino acids may be introduced at the junctions between the donor diversity scaffold domain and the recipient diversity scaffold domain to allow selection of optimal junctional sequences from the resultant libraries.

Optionally, sequences within the recipient diversity scaffold domain may also be diversified to facilitate the identification of a recipient diversity scaffold domain that supports functional fusion to a donor diversity scaffold domain. In some embodiments, one or more amino acid residues of the donor diversity scaffold domain and/or recipient diversity scaffold domain at one or both junctions between the two domains may be diversified (i.e. one or more residues of a domain directly adjacent one or both junctions with the other domain may be diversified). Examples in which framework residues of donor and recipient scaffolds are diversified are provided below. For example, 1, 2, 3, or 4 residues at the N and C terminal junctions of the donor diversity scaffold domain and/or 1, 2, 3, or 4 residues within the recipient diversity scaffold domain at the junctions with the donor domain may be diversified.

The binding activity may be binding to a target molecule. A method of screening a library may comprise;

- providing a founder library of binding members as described herein,
- contacting the founder library with a target molecule, and
- 5 selecting one or more founder library members which bind to the target molecule.

The one or more identified or selected binding members may be recovered and subjected to further selection and/or screening.

- 10 Multiple rounds of panning may be performed in order to identify binding members which display the binding activity. For example, a population of binding members enriched for the binding activity may be recovered or isolated from the founder library and subjected to one or more further rounds of screening for the binding activity to produce one or more further enriched populations. Founder binding members which display binding activity may be
- 15 identified from the one or more further enriched populations and recovered, isolated and/or further investigated.

- Founder binding members which display the binding activity may be further engineering to improve activity or properties or introduce new activity or properties, for example binding
- 20 properties such as affinity and/or specificity, increased neutralization of the target molecule and/or modulation of a specific activity of the target molecule. Binding members may also be engineered to improve stability, solubility or expression level.

- For example, the identified linker sequence of an identified founder binding member may be
- 25 retained in a modified library with diverse sequences introduced into one or more of the recipient, donor or partner domains depending on the application and desired outcome. In some cases further diversification of the linker may be useful in optimising function of the binding member.

- 30 A method of screening as described herein may further comprise;
 - (iv) introducing diverse amino acid residues at one or more positions in the amino acid sequence of one or more binding members as described herein, for example one or more binding members identified in from a founder library, to produce a modified library of binding members,

(v) screening the modified library for modified binding members which display a binding activity and

(vi) identifying one or more modified binding members in the modified library which display the binding activity.

5

The binding activity may be binding to a target molecule. A method of screening a library may comprise;

providing a modified library of binding members as described above,

contacting the modified library with a target molecule and

10

selecting one or more modified library members which bind to the target molecule.

The one or more identified or selected binding members may be recovered and subjected to further rounds of screening.

15 The diverse amino acids may be introduced by any suitable technique as described elsewhere herein, including random mutagenesis or site directed mutagenesis.

One or more modified binding members may be identified which display increased or improved binding activity, for example increased binding affinity and/or specificity, relative to the one or more founder binding members identified in step (iii).

20

Multiple rounds of panning may be performed in order to identify modified binding members which display the improved binding activity. For example, a population of binding members enriched for the improved binding activity may be recovered or isolated from the library and subjected to one or more further rounds of screening for the binding activity to produce one or more further enriched populations. Modified binding members which display improved binding activity may be identified from the one or more further enriched populations and isolated and/or further investigated.

25

30 Founder or modified binding members may be further subjected to further mutagenesis, for example to generate further modified libraries and select binding members with improved or new activity or properties. Amino acid residues may be mutated at one or more positions in the amino acid sequence of one or more identified binding members from the library and/or modified library. For example, amino acid residues within the donor scaffold, donor

interaction sequence, recipient scaffold, recipient interaction sequence, linker or partner domain of the one or more identified binding members may be mutated.

The mutation may introduce diverse amino acid residues at the one or more positions to produce a library of further modified binding members. Examples of the deletion or replacement of interaction and scaffold residues of recipient and donor and their replacement with randomised residues are shown below.

To generate binding members in which a partner domain, such as a partner VH or VL domain, contributes additional interaction contacts with a target molecule, a library may be generated in which the original partner domain is replaced by a whole repertoire of alternative partner domain to create a “chain-shuffled” library. Binding members with improved activity due to the beneficial contribution of the newly selected partner domain may be identified, recovered and isolated.

A method of screening as described herein may further comprise;

(vii) associating the fusion protein from the one or more identified binding members or modified binding members as described above, with a diverse population of partner domains to produce a shuffled library of binding members,

(viii) screening the shuffled library for shuffled binding members which display a binding activity,

(ix) identifying one or more shuffled binding members which display the binding activity.

One or more shuffled binding members may be identified which display increased binding activity relative to the one or more founder binding members identified in step (iii) and/or modified binding members identified in step (vi).

Multiple rounds of panning or functional screening may be performed in order to identify shuffled binding members which display the increased or improved binding activity. For example, a population of shuffled binding members enriched for the improved binding activity may be isolated from the shuffled library and subjected to one or more further rounds of screening for the binding activity to produce one or more further enriched shuffled populations. Shuffled binding members which display improved binding activity may be

identified from the one or more further enriched populations and isolated and/or further investigated.

5 The founder library, modified library or shuffled library may be screened by determining the binding of the binding members in the library to a target molecule

10 Binding may be determined by any suitable technique. For example, the founder library, modified library or shuffled library may be contacted with the target molecule under binding conditions for a time period sufficient for the target molecule to interact with the library and form a binding reaction complex with a least one member thereof.

15 Binding conditions are those conditions compatible with the known natural binding function of the target molecule. Those compatible conditions are buffer, pH and temperature conditions that maintain the biological activity of the target molecule, thereby maintaining the ability of the molecule to participate in its preselected binding interaction. Typically, those conditions include an aqueous, physiologic solution of pH and ionic strength normally associated with the target molecule of interest.

20 The founder library, modified library or shuffled library may be contacted with the target molecule in the form of a heterogeneous or homogeneous admixture. Thus, the members of the library can be in the solid phase with the target molecule present in the liquid phase. Alternatively, the target molecule can be in the solid phase with the members of the library present in the liquid phase. Still further, both the library members and the target molecule can be in the liquid phase.

25

Suitable methods for determining binding of a binding member to a target molecule are well known in the art and include ELISA, bead-based binding assays (e.g. using streptavidin-coated beads in conjunction with biotinylated target molecules, surface plasmon resonance, flow cytometry, Western blotting, immunocytochemistry, immunoprecipitation, and affinity chromatography. Alternatively, biochemical or cell-based assays, such as an HT-1080 cell migration assay or fluorescence-based or luminescence-based reporter assays may be employed.

30

In some embodiments, binding may be determined by detecting agonism or antagonism (including blocking activity in the case of ion channels and enzymes) resulting from the binding of a binding member to a target molecule, such as a ligand, receptor or ion channel.

For example, the founder library, modified library or shuffled library may be screened by
5 expressing the library in reporter cells and identifying one or more reporter cells with altered gene expression or phenotype. Suitable functional screening techniques for screening recombinant populations of binding members are well-known in the art ^{16,78,79,91}.

Systems suitable for the construction of libraries by cloning repertoires of genes into reporter
10 cells have been reported^{16, 78}. These systems combine expression and reporting within one cell, and typically introduce a population of antibodies selected against a pre-defined target (e.g. using phage or mammalian display).

A population of nucleic acids encoding binding members as described herein may be
15 introduced into reporter cells to produce a library using standard techniques. Clones within the population with a binding member-directed alteration in phenotype (e.g., altered gene expression or survival) may be identified. For this phenotypic-directed selection to work there is a requirement to retain a linkage between the binding member gene present within the expressing cell (genotype) and the consequence of binding member expression (phenotype).

This may be achieved for example by tethering a binding member to the cell surface, as
20 described for antibody display or through the use of semi-solid medium to retain secreted antibodies in the vicinity of producing cells¹⁰⁵. Alternatively, binding members may be retained inside the cell. Binding members retained on the cell surface or in the surrounding medium may interact with an endogenous or exogenous receptor on the cell surface causing
25 activation of the receptor. This in turn may cause a change in expression of a reporter gene or a change in the phenotype of the cell. As an alternative the binding member may block the receptor or ligand to reduce receptor activation. The nucleic acid encoding the binding member which causes the modified cellular behaviour may then be recovered for production or further engineering.

30 As an alternative to this “target-directed” approach, it is possible to introduce into a cell a “naïve” binding member population which has not been pre-selected to a particular target molecule. The cellular reporting system is used to identify members of the population with altered behaviour. Since there is no prior knowledge of the target molecule, this non-targeted

approach has a particular requirement for a large repertoire, since pre-enrichment of the binding member population to the target molecule is not possible.

5 The “functional selection” approach may be used in other applications involving libraries in eukaryotic cells, particularly higher eukaryotes such as mammalian cells. For example, a binding member may be fused to a signalling domain such that binding to target molecule causes activation of the receptor. Suitable signalling domains include cytokine receptor domains, such as thrombopoietin (TPO) receptor, erythropoietin (EPO) receptor, gp130, IL-2 receptor and the EGF receptor. Binding member-receptor chimaeras may be used to drive
10 target molecule dependent gene expression or phenotypic changes in primary or stable reporter cells. This capacity may be used to identify fused binding members in the library which drive a signalling response or binders which inhibit the response¹²³⁻¹²⁵.

Combinations of recipients and linker sequences identified using the methods described
15 herein may be used to present different donor diversity scaffold domains of the same class, for example a cysteine-rich protein with the same number of cysteine residues, or a different class.

The donor diversity scaffold domain may be replaced in the one or more identified binding
20 members from the library, the modified library and/or the shuffled library with a substitute donor diversity scaffold domain.

The donor diversity scaffold domain and the substitute donor diversity scaffold domain may be from the same scaffold class. For example, the donor diversity scaffold domain and the
25 substitute donor diversity scaffold domain may comprise the same scaffold and different interaction sequences. In some embodiments, the donor diversity scaffold domain may be a knottin which binds to a first target molecule and the substitute donor diversity scaffold domain may be a knottin which binds to a second target molecule. A recipient diversity scaffold domain which has been optimised for one knottin donor diversity scaffold domain as
30 described herein may be useful for all knottin donor diversity scaffold domains. For example, a donor knottin domain within the recipient antibody variable domain of a founder binding member may be replaced with a different knottin donor domain, as exemplified below.

The donor diversity scaffold domain and the substitute donor diversity scaffold domain may be from the different scaffold classes. For example, the donor diversity scaffold and the substitute donor diversity scaffold may comprise a different donor scaffold and a different donor interaction sequence. For example, a donor knottin domain within the recipient antibody variable domain of a founder binding member may be replaced with an adhi-
5 donor diversity scaffold domain, as exemplified below.

An additional amino acid sequence may be introduced into the fusion proteins or partner domains of the one or more identified binding members from the library and/or modified
10 library. For example, the donor diversity scaffold domain, for example a knottin donor domain, may be engineered to introduce new binding specificities, for example by rational design, loop grafting and combinatorial library based approaches using in vitro display technologies.

15 The additional amino acid sequence may be a target binding sequence, such as a VEGF-A binding sequence⁹² or a Thrombopoietin (TPO) binding sequence⁵⁴.

In some embodiments, a diverse sequence may be introduced into a binding member as described herein to generate a further library for selection of improved variants. For
20 example, diversity may be introduced into the donor or recipient diversity scaffold domain or the partner domain. Suitable diverse sequences may be introduced by oligonucleotide-directed mutagenesis or random mutagenesis²².

In some embodiments, binding mediated by a first domain selected from the donor diversity scaffold domain, recipient diversity scaffold domain and partner domain within a binding
25 member may be used as a guide domain to direct selection from a library using the method described herein to identify modified or shuffled binding members in which a second domain also contributes to binding.

30 The second domain may interact with the same target molecule as the first guide domain or may interact with a second target molecule that is closely associated with it. For example, binding to the alpha sub-unit of an ion channel, such as a voltage gated sodium or potassium channel (e.g. a Nav or Kv channel) by a knottin donor diversity scaffold domain may be increased or extended by additional contacts from a partner VH domain or recipient VL

domain binding either to the same alpha sub-unit or to an associated sub-unit, such as the beta subunit of an ion channel.

In a second round, the original guide domain may also be modified or replaced. For example, one of the donor diversity scaffold domain, recipient diversity scaffold domain or partner domain of a binding member may act as a first guide domain which binds to the target molecule. Having identified a second domain which contributes to binding the target molecule, a method may comprise modifying or replacing said first guide domain to produce a library of binding members comprising the second domain and a diverse first domain. This results in a final fusion protein which benefitted from the availability of the original guide domain during its development as described herein but does not contain the original guide domain. This may be useful, for example if a final binding member is desired which does not contain the fusion of a donor diversity scaffold domain within a recipient diversity scaffold domain.

For example, if a knottin donor diversity scaffold domain within a binding member was used to isolate a partner antibody variable domain (e.g. a VH domain) in a first round of selection, then this partner antibody variable domain can in turn act as a guide in a second round to select for an alternative complementary variable domain (e.g. a VL domain). This complementary domain may be a recipient diversity scaffold domain with a fused donor diversity scaffold domain or may be a normal (i.e. unfused) antibody variable domain. In some embodiments, the antibody variable domain (e.g. VH domain) identified from the first cycle through use of an ion channel binding donor diversity scaffold domain may bind to an associated sub-unit of the ion channel, such as a beta chain which interacts with different alpha chains. This antibody variable domain could then guide the selection of complementary antibody variable domains or VL-donor diversity scaffold domain fusion proteins towards different alpha chains which associate with the same β chain.

In some embodiments, the first domain may bind to the target molecule with low to moderate affinity. For example, affinity may be less than a K_D 100nM. This allows the improvements in binding due to the contribution of the second domain which may bind to the same protein or a closely associated sub-unit. Alternatively the second domain may bind to a non-

interacting or weakly interacting molecule on the same cell which sequesters the second domain on the target cell facilitating its interaction with target.

In some embodiments, the target molecule may be presented on the surface of a cell in a tagged or untagged form to determine binding⁹³. For example, an integral membrane protein, such as an ion transporter or GPCR, may be expressed with a tag. A library of binding members comprising a partner domain which binds the tag (e.g. an antibody VH or VL domain) and a diverse population of donor diversity scaffold domains presented on a VL or VH recipient domain may be subjected to selection for improved binding to the tagged, cell surface expressed target protein. This may allow the identification of fusion proteins and donor diversity scaffold domains that bind the target protein outside the tag. These fusion proteins and donor diversity scaffold domains may be used in further rounds of screening, for example with diverse partner domains, to identify binding members that bind the untagged target protein.

Various suitable tags are known in the art, including, for example, MRGS(H)₆ (SEQ ID NO: 36), DYKDDDDK (SEQ ID NO: 37) (FLAGTM), T7-, S- (KETAAAKFERQHMDS; SEQ ID NO: 38), poly-Arg (R₅₋₆), poly-His (H₂₋₁₀), poly-Cys (C₄) poly-Phe(F₁₁) poly-Asp(D₅₋₁₆), Strept-tag II (WSHPQFEK; SEQ ID NO: 39), c-myc (EQKLISEEDL; SEQ ID NO: 40), Influenza-HA tag (Murray, P. J. et al (1995) *Anal Biochem* 229, 170-9), Glu-Glu-Phe tag (Stammers, D. K. et al (1991) *FEBS Lett* 283, 298-302), Tag.100 (Qiagen; 12 aa tag derived from mammalian MAP kinase 2), Cruz tag 09TM (MKAEFRRQESDR; (SEQ ID NO: 41), Santa Cruz Biotechnology Inc.) and Cruz tag 22TM (MRDALDRLDRLA; (SEQ ID NO: 42), Santa Cruz Biotechnology Inc.). Known tag sequences are reviewed in Terpe (2003) *Appl. Microbiol. Biotechnol.* 60 523-533.

In some embodiments, a library, modified library and/or shuffled library as described herein may be subjected to selection for binding members in which the donor diversity scaffold domain and/or the recipient diversity scaffold domain adopt their native structure i.e. they are correctly folded into an active conformation.

For example, when the donor diversity scaffold domain binds to a known target molecule, the founder library, modified library and/or shuffled library as described herein may be subjected to selection for binding members bind to the target molecule. Binding members that bind to

the target molecule comprise a donor diversity scaffold domain that is active and correctly folded into its native structure. This may be useful, for example, when the actual structure of the donor diversity scaffold domain is not known.

- 5 As well as affinity based selection for the correct folding of the donor diversity scaffold, selection systems such as phage display may provide additional selectivity for correct folding of the recipient since it has been shown that phage display enriches for fusions with superior structural integrity⁹⁴. When the recipient diversity scaffold domain is an immunoglobulin or a fragment or domain thereof, the library, modified library and/or shuffled library as described
- 10 herein may be subjected to selection for binding members that bind to an immunoglobulin binding molecule⁹⁵. Binding members that bind to the immunoglobulin binding molecule comprise a recipient diversity scaffold domain that is active and correctly folded into its native structure despite the fusion of a donor domain. The stringency of the system could be improved further by subjecting the population of displayed elements (e.g. a phage display
- 15 population) to more disruptive conditions e.g. increased temperature, as has been done previously^{94,96}.

Suitable immunoglobulin binding molecules are well known in the art and include wild type and engineered forms of protein L, protein G and protein A, as well as anti-Ig antibodies and

20 antibody fragments. In some embodiments, the immunoglobulin binding molecule may be contained in an affinity chromatography medium. Suitable affinity chromatography media are well-known in the art and include KappaSelectTM, Lambda SelectTM, IgSelectTM, and GammaBindTM (GE Healthcare).

- 25 One or more binding members identified as described above may be further tested, for example to determine the functional effect of binding to the target molecule. A method may comprise determining the effect of the one or more binding members identified from the library, the modified library and/or the shuffled library on the activity of a target molecule.

- 30 In some embodiments, the target molecule may be an ion channel and the effect of the one or more identified binding members on ion flow through the channel may be determined

Ion flux through a channel may be determined using routine electrophysiological techniques such as patch-clamping. For example, ion flux may be measured using a two electrode

voltage clamp following endogenous or heterologous expression of the ion channel. In some embodiments, ion channel function may be determined using fluorescence based screens. For example, cells expressing an endogenous or heterologous ion channel, for example a voltage-gated calcium channel (Cav), may be loaded with a fluorophore, such as Fura3 or Calcium Green. Activation of the ion channel by K^+ induced depolarisation causes a transient increase in intracellular ion concentration which can be readily measured. Suitable systems for depolarising cell membranes and recording responses are available in the art (e.g. FlexStationTM; Molecular Devices Inc USA). Optimal protocols and techniques for patch clamp assays were recently illustrated by Bell & Dallas¹⁴⁴ and are incorporated herein by reference.

Inhibition of ion flux may be determined by a whole cell patch clamp assay using cells transfected with the ion channel of interest (e.g., human Nav1.7) or its alpha subunit. The assay may use a holding voltage of -100 mV and activating pulses of -10 mV may be applied for 30 ms every 10 s or 30 s. Temperature is typically room temperature, e.g., 18 - 25 degrees C, optionally 20 degrees C. A worked example of a whole cell patch clamp assay is set out in Example 19. Assay steps and/or conditions, including buffer compositions, pH and temperature, may be as described in that example.

Ion flux through a channel may also be determined using a fluorescent protein ion sensor. Suitable fluorescent protein ion sensors are available in the art⁹⁷.

In some embodiments, the effect of the one or more identified binding members on a panel of target molecules may be determined. For example, the effect of the one or more identified binding members on ion flow through a panel of ion channels may be determined. This may be useful for example, in determining or characterising the specificity of the binding member. Alternatively the effect of the one or more identified binding members on protease activity may be determined where the target is a protease. Alternatively the effect of the one or more identified binding members on cellular signalling may be determined where the target is a receptor.

Following identification as described above, one or more identified binding members may be recovered, isolated and/or purified from a library, modified library and/or shuffled library.

In preferred embodiments, each binding member in the library may be displayed on the surface of a particle, such as a bead, ribosome, cell or virus which comprises the nucleic acid encoding the binding member.

- 5 Following selection of binding members which display the binding activity (e.g. bind the target molecule) and are displayed on bacteriophage or other library particles or molecular complexes, nucleic acid may be taken from a bacteriophage or other particle or molecular complex displaying a selected binding member.
- 10 Particles displaying the one or more identified binding members may be isolated and/or purified from the library, the modified library and/or the shuffled library. Nucleic acid encoding the one or more identified binding members may be isolated and/or purified from the particles.
- 15 The isolated nucleic acid encoding the one or more identified binding members may be amplified, cloned and/or sequenced.

Suitable methods of nucleic acid amplification, cloning and/or sequencing are well known in the art (see for example *Protocols in Molecular Biology*, Second Edition, Ausubel et al. eds.

- 20 John Wiley & Sons).

The sequence of the isolated nucleic acid may be used in subsequent production of the binding member or fusion protein.

- 25 The one or more identified binding members or encoding nucleic acid may be synthesised. For example, the one or more binding members may be generated wholly or partly by chemical synthesis. For example, binding members, or individual donor or recipient diversity scaffold domains or fusion proteins and partner domains thereof may be synthesised using liquid or solid-phase synthesis methods; in solution; or by any combination of solid-phase,
- 30 liquid phase and solution chemistry, e.g. by first completing the respective peptide portion and then, if desired and appropriate, after removal of any protecting groups being present, by introduction of the residue X by reaction of the respective carbonic or sulfonic acid or a reactive derivative thereof.

Chemical synthesis of polypeptides is well-known in the art (J.M. Stewart and J.D. Young, Solid Phase Peptide Synthesis, 2nd edition, Pierce Chemical Company, Rockford, Illinois (1984); M. Bodanzsky and A. Bodanzsky, The Practice of Peptide Synthesis, Springer Verlag, New York (1984); J. H. Jones, The Chemical Synthesis of Peptides. Oxford

- 5 University Press, Oxford 1991; in Applied Biosystems 430A User's Manual, ABI Inc., Foster City, California; G. A. Grant, (Ed.) Synthetic Peptides, A User's Guide. W. H. Freeman & Co., New York 1992, E. Atherton and R.C. Sheppard, Solid Phase Peptide Synthesis, A Practical Approach. IRL Press 1989 and in G.B. Fields, (Ed.) Solid-Phase Peptide Synthesis (Methods in Enzymology Vol. 289). Academic Press, New York and London 1997).

10

The one or more identified binding members may be recombinantly expressed from encoding nucleic acid. For example, a nucleic acid encoding a binding member may be expressed in a host cell and the expressed polypeptide isolated and/or purified from the cell culture.

- 15 Nucleic acid sequences and constructs as described above may be comprised within an expression vector. Suitable vectors can be chosen or constructed, containing appropriate regulatory sequences, including promoter sequences, terminator fragments, polyadenylation sequences, enhancer sequences, marker genes and other sequences as appropriate. Preferably, the vector contains appropriate regulatory sequences to drive the expression of the
- 20 nucleic acid in a host cell. Suitable regulatory sequences to drive the expression of heterologous nucleic acid coding sequences in expression systems are well-known in the art and include constitutive promoters, for example viral promoters such as CMV or SV40, and inducible promoters, such as Tet-on controlled promoters. A vector may also comprise sequences, such as origins of replication and selectable markers, which allow for its selection
- 25 and replication and expression in bacterial hosts such as *E. coli* and/or in eukaryotic cells.

- Many known techniques and protocols for expression of recombinant polypeptides in cell culture and their subsequent isolation and purification are known in the art (see for example *Protocols in Molecular Biology*, Second Edition, Ausubel et al. eds. John Wiley & Sons,
- 30 1992; *Recombinant Gene Expression Protocols* Ed RS Tuan (Mar 1997) Humana Press Inc).

Suitable host cells include bacteria, mammalian cells, plant cells, filamentous fungi, yeast and baculovirus systems and transgenic plants and animals. The expression of antibodies and

antibody fragments in prokaryotic cells is well established in the art. A common bacterial host is *E. coli*.

Expression in eukaryotic cells in culture is also available to those skilled in the art as an option for production of a binding member. Mammalian cell lines available in the art for expression of a heterologous polypeptide include Chinese hamster ovary (CHO) cells, HeLa cells, baby hamster kidney cells, NS0 mouse melanoma cells, YB2/0 rat myeloma cells, human embryonic kidney cells (e.g. HEK293 cells), human embryonic retina cells (e.g. PerC6 cells) and many others.

One or more of the identified binding members may be re-formatted. For example, a binding member comprising an immunoglobulin recipient binding domain or immunoglobulin partner domain may be re-formatted as an scFv, Fab, scFv-Fc, Fc, IgA, IgD, IgM, IgG, or half-antibody. A method may comprise isolating nucleic acid encoding the immunoglobulin domain (e.g. a VH or VL domain) from cells of a clone, amplifying the nucleic acid encoding said domain, and inserting the amplified nucleic acid into a vector to provide a vector encoding the antibody molecule. Re-formatting from an scFv format to a Fab and an IgG format is exemplified below.

In some embodiments, the donor diversity scaffold domain from the one or more identified binding members may be isolated. A method described herein may further comprise synthesising or recombinantly expressing an isolated donor diversity scaffold domain from one or more of the identified binding members from the founder library, the modified library and/or the shuffled library.

The isolated donor diversity scaffold domain may be re-formatted. For example, the donor diversity scaffold domain may be inserted into a different recipient diversity scaffold domain in a binding member described herein or may be inserted into different binding member format, such as a N or C terminal fusion

In some embodiments, the isolated donor diversity scaffold domain may be used as an independent binding molecule, free of any recipient domain or fusion partner.

A detectable or functional label or half-life extension moiety may be attached to the one or more identified binding members.

A label can be any molecule that produces or can be induced to produce a signal, including but not limited to fluorescers, radiolabels, enzymes, chemiluminescers or photosensitizers. Thus, binding may be detected and/or measured by detecting fluorescence or luminescence, radioactivity, enzyme activity or light absorbance.

Suitable labels include enzymes, such as alkaline phosphatase, glucose-6-phosphate dehydrogenase ("G6PDH"), alpha-D-galactosidase, glucose oxidase, glucose amylase, carbonic anhydrase, acetylcholinesterase, lysozyme, malate dehydrogenase and peroxidase e.g. horseradish peroxidase; dyes; fluorescent labels or fluorescers, such as fluorescein and its derivatives, fluorochrome, rhodamine compounds and derivatives, GFP (GFP for "Green Fluorescent Protein"), dansyl, umbelliferone, phycoerythrin, phycocyanin, allophycocyanin, o-phthaldehyde, and fluorescamine; fluorophores such as lanthanide cryptates and chelates e.g. Europium etc (Perkin Elmer and Cis Biointernational); chemoluminescent labels or chemiluminescers, such as isoluminol, luminol and the dioxetanes; bio-luminescent labels, such as luciferase and luciferin; sensitizers; coenzymes; enzyme substrates; radiolabels including bromine77, carbon14, cobalt57, fluorine8, gallium67, gallium 68, hydrogen3 (tritium), indium111, indium 113m, iodine123m, iodine125, iodine126, iodine131, iodine133, mercury107, mercury203, phosphorous32, rhenium99m, rhenium101, rhenium105, ruthenium95, ruthenium97, ruthenium103, ruthenium105, scandium47, selenium75, sulphur35, technetium99, technetium99m, tellurium121m, tellurium122m, tellurium125m, thulium165, thulium167, thulium168 and yttrium199; particles, such as latex or carbon particles; metal sol; crystallite; liposomes; cells, etc., which may be further labelled with a dye, catalyst or other detectable group; and molecules such as biotin, digoxigenin or 5-bromodeoxyuridine; toxin moieties, such as for example a toxin moiety selected from a group of Pseudomonas exotoxin (PE or a cytotoxic fragment or mutant thereof), Diphtheria toxin or a cytotoxic fragment or mutant thereof, a botulinum toxin A, B, C, D, E or F, ricin or a cytotoxic fragment thereof e.g. ricin A, abrin or a cytotoxic fragment thereof, saporin or a cytotoxic fragment thereof, pokeweed antiviral toxin or a cytotoxic fragment thereof and bryodin 1 or a cytotoxic fragment thereof.

Suitable enzymes and coenzymes are disclosed in Litman, et al., US4275149, and Boguslaski, et al., US4318980, Suitable fluorescers and chemiluminescers are disclosed in Litman, et al., US4275149. Labels further include chemical moieties, such as biotin that may be detected via binding to a specific cognate detectable moiety, e.g. labelled avidin or streptavidin. Detectable labels may be attached to antibodies of the invention using conventional chemistry known in the art.

Suitable half-life extension moieties include fusions to Fc domains or serum albumin, unstructured peptides such as XTEN⁹⁸ or PAS⁹⁹ polyethylene glycol (PEG),

A method described herein may further comprise formulating the one or more identified binding members from the library, the modified library and/or the shuffled library or the isolated donor diversity scaffold domain with a pharmaceutically acceptable excipient.

The term “pharmaceutically acceptable” as used herein pertains to compounds, materials, compositions, and/or dosage forms which are, within the scope of sound medical judgement, suitable for use in contact with the tissues of a subject (e.g., human) without excessive toxicity, irritation, allergic response, or other problem or complication, commensurate with a reasonable benefit/risk ratio. Each carrier, excipient, etc. must also be “acceptable” in the sense of being compatible with the other ingredients of the formulation. Suitable carriers, excipients, etc. can be found in standard pharmaceutical texts, for example, Remington’s Pharmaceutical Sciences, 18th edition, Mack Publishing Company, Easton, Pa., 1990.

Another aspect of the invention provides a nucleic acid encoding a fusion protein or a binding member described herein.

Nucleic acid may comprise DNA or RNA and may be wholly or partially synthetic. Reference to a nucleotide sequence as set out herein encompasses a DNA molecule with the specified sequence, and encompasses a RNA molecule with the specified sequence in which U is substituted for T, unless context requires otherwise.

Another aspect of the invention provides a vector comprising a nucleic acid described herein, as well as transcription or expression cassettes comprising the nucleic acid. Vectors may be plasmids, viral e.g. 'phage, or phagemid, as appropriate. For further details see, for example,

Molecular Cloning: a Laboratory Manual: 3rd edition, Russell et al., 2001, Cold Spring Harbor Laboratory Press.

5 Another aspect of the invention provides a population of nucleic acids encoding a library of binding members described herein.

The nucleic acids encoding the library may be contained in expression vectors, such as phage or phagemid vectors.

10 Another aspect of the invention provides a population of particles comprising a library described herein and/or a population of nucleic acids encoding a library described herein.

The library may be displayed on the surface of the viral particles. Each binding member in the library may further comprise a phage coat protein to facilitate display. Each viral particle
15 may comprise nucleic acid encoding the binding member displayed on the particle. Suitable viral particles include bacteriophage, for example filamentous bacteriophage such as M13 and Fd. Techniques for the production of phage display libraries are well known in the art.

20 Other aspects of the invention provide a host cell comprising a binding member, nucleic acid or vector as described herein, and a population of host cells comprising a library, population of nucleic acids and/or population of viral particles described herein.

25 Another aspect of the invention provides a pharmaceutical composition comprising a fusion protein or a binding member described herein and a pharmaceutically acceptable excipient.

The pharmaceutical composition may conveniently be presented in unit dosage form and may be prepared by any methods well-known in the art of pharmacy. Such methods include the step of bringing the binding member into association with a carrier which may constitute one or more accessory ingredients. In general, pharmaceutical compositions are prepared by
30 uniformly and intimately bringing into association the active compound with liquid carriers or finely divided solid carriers or both, and then if necessary shaping the product.

Pharmaceutical compositions may be in the form of liquids, solutions, suspensions, emulsions, elixirs, syrups, tablets, lozenges, granules, powders, capsules, cachets, pills,

ampoules, suppositories, pessaries, ointments, gels, pastes, creams, sprays, mists, foams, lotions, oils, boluses, electuaries, or aerosols.

- A binding member or pharmaceutical composition comprising the binding member may be administered to a subject by any convenient route of administration, whether systemically/peripherally or at the site of desired action, including but not limited to, oral (e.g. by ingestion); topical (including e.g. transdermal, intranasal, ocular, buccal, and sublingual); pulmonary (e.g. by inhalation or insufflation therapy using, e.g. an aerosol, e.g. through mouth or nose); rectal; vaginal; parenteral, for example, by injection, including subcutaneous, intradermal, intramuscular, intravenous, intraarterial, intracardiac, intrathecal, intraspinal, intracapsular, subcapsular, intraorbital, intraperitoneal, intratracheal, subcuticular, intraarticular, subarachnoid, and intrasternal; by implant of a depot, for example, subcutaneously or intramuscularly.
- Pharmaceutical compositions suitable for oral administration (e.g., by ingestion) may be presented as discrete units such as capsules, cachets or tablets, each containing a predetermined amount of the active compound; as a powder or granules; as a solution or suspension in an aqueous or non-aqueous liquid; or as an oil-in-water liquid emulsion or a water-in-oil liquid emulsion; as a bolus; as an electuary; or as a paste.
- Pharmaceutical compositions suitable for parenteral administration (e.g. by injection, including cutaneous, subcutaneous, intramuscular, intravenous and intradermal), include aqueous and non-aqueous isotonic, pyrogen-free, sterile injection solutions which may contain anti-oxidants, buffers, preservatives, stabilisers, bacteriostats, and solutes which render the formulation isotonic with the blood of the intended recipient; and aqueous and non-aqueous sterile suspensions which may include suspending agents and thickening agents, and liposomes or other microparticulate systems which are designed to target the compound to blood components or one or more organs. Examples of suitable isotonic vehicles for use in such formulations include Sodium Chloride Injection, Ringer's Solution, or Lactated Ringer's Injection. Typically, the concentration of the active compound in the solution is from about 1 ng/ml to about 10 µg/ml, for example, from about 10 ng/ml to about 1 µg/ml. The formulations may be presented in unit-dose or multi-dose sealed containers, for example, ampoules and vials, and may be stored in a freeze-dried (lyophilised) condition requiring only

the addition of the sterile liquid carrier, for example water for injections, immediately prior to use.

It will be appreciated that appropriate dosages of the binding member, can vary from patient to patient. Determining the optimal dosage will generally involve the balancing of the level of diagnostic benefit against any risk or deleterious side effects of the administration. The selected dosage level will depend on a variety of factors including, but not limited to, the route of administration, the time of administration, the rate of excretion of the imaging agent, the amount of contrast required, other drugs, compounds, and/or materials used in combination, and the age, sex, weight, condition, general health, and prior medical history of the patient. The amount of imaging agent and route of administration will ultimately be at the discretion of the physician, although generally the dosage will be to achieve concentrations of the imaging agent at a site, such as a tumour, a tissue of interest or the whole body, which allow for imaging without causing substantial harmful or deleterious side-effects.

Administration in vivo can be effected in one dose, continuously or intermittently (e.g., in divided doses at appropriate intervals). Methods of determining the most effective means and dosage of administration are well known to those of skill in the art and will vary with the formulation used for therapy, the purpose of the therapy, the target cell being treated, and the subject being treated. Single or multiple administrations can be carried out with the dose level and pattern being selected by the physician.

Binding members described herein may be used in methods of diagnosis or treatment in human or animal subjects, e.g. human. The subject to be treated may be an adult human, aged 18 years or over, and may be male or female. Paediatric patients under 18 years of age may also be treated, with adjustments to the administered dose as appropriate. A paediatric patient may optionally be aged at least 12 months, at least 24 months or at least 36 months. Methods of administering binding members to human subjects are described herein.

Binding members for a target molecule, such as an ion channel may be used to treat disorders associated with the target molecule.

Other aspects of the invention provide a fusion protein, binding member or composition described herein for use as a medicament; a fusion protein, binding member or composition described herein for use in the treatment of pain or autoimmune disease; and the use of a fusion protein, binding member or composition described herein in the manufacture of a medicament for the treatment of a condition associated with ion channel activity or dysfunction.

Another aspect of the invention provides a method of treatment comprising administration of a binding member or composition described herein to an individual in need thereof, optionally for the treatment of a condition associated with ion channel activity or dysfunction.

An effective amount of a binding member or composition described herein alone or in a combined therapeutic regimen with another appropriate medicament known in the art or described herein may be used to treat or reduce the severity of at least one symptom of any of a disease or disorder associated with the target molecule in a patient in need thereof, such that the severity of at least one symptom of any of the above disorders is reduced.

Other aspects and embodiments of the invention provide the aspects and embodiments described above with the term “comprising” replaced by the term “consisting of” and the aspects and embodiments described above with the term “comprising” replaced by the term “consisting essentially of”.

It is to be understood that the application discloses all combinations of any of the above aspects and embodiments described above with each other, unless the context demands otherwise. Similarly, the application discloses all combinations of the preferred and/or optional features either singly or together with any of the other aspects, unless the context demands otherwise.

Modifications of the above embodiments, further embodiments and modifications thereof will be apparent to the skilled person on reading this disclosure, and as such, these are within the scope of the present invention.

The contents of all documents, websites, databases and sequence database entries mentioned in this specification, including the amino acid and nucleotide sequences disclosed therein, are incorporated herein by reference in their entirety for all purposes.

- 5 “and/or” where used herein is to be taken as specific disclosure of each of the two specified features or components with or without the other. For example “A and/or B” is to be taken as specific disclosure of each of (i) A, (ii) B and (iii) A and B, just as if each is set out individually herein.
- 10 The following numbered clauses, statements and configurations set out further embodiments of the invention and are part of the present description.

Clauses:

1. A method of screening comprising;
15 (i) providing a founder library of binding members,
each binding member in the library comprising a fusion protein and optionally, a partner domain associated with the fusion protein,
wherein the fusion protein comprises a donor diversity scaffold domain inserted within a recipient diversity scaffold domain, optionally wherein the N and C terminals of the
20 donor diversity scaffold domain are linked to the recipient diversity scaffold domain with linkers of up to 4 amino acids,
wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, and one, two or all three of the donor
25 interaction sequence, the recipient interaction sequence and the linkers are diverse in said founder library,
(ii) screening the founder library for binding members which display a binding activity, and
(iii) identifying one or more binding members in the founder library which display the
30 binding activity.
2. A method according to clause 1 wherein the binding members in the founder library have diverse donor interaction sequences and the same recipient interaction sequence.
3. A method according to clause 1 wherein the binding members in the founder library have diverse recipient interaction sequences and the same donor interaction sequence.

4. A method according to clause 1 wherein the binding members in the founder library have diverse recipient and donor interaction sequences
5. A method according to any one of clauses 1 to 4 wherein the binding members in the founder library have diverse linker sequences.
- 5 6. A method according to clause 5 wherein the binding members in the founder library have the same recipient and donor interaction sequences.
7. A method according to any one of the preceding clauses comprising further enriching the one or more binding members by;
 - (a) recovering the one or more binding members,
 - 10 (b) subjecting the recovered binding members to selection for the binding activity,
 - (c) recovering the one or more selected binding members
 - (d) optionally repeating steps (b) and (c) one or more times.
8. A method according to any one of the preceding clauses further comprising;
 - 15 (iv) introducing diverse amino acid residues at one or more positions in the amino acid sequence of one or more identified founder binding members to produce a modified library of binding members,
 - (v) screening the modified library for modified binding members which display a binding activity and
 - 20 (vi) identifying one or more modified binding members in the modified library which display the binding activity.
9. A method according to any one of clauses 1 to 8 wherein the diverse amino acids are introduced by random mutagenesis or site directed mutagenesis.
10. A method according to clause 8 or clause 9 wherein the one or more positions are
25 within the amino acid sequence of the donor scaffold, donor interaction sequence, recipient scaffold, recipient interaction sequence, linker or partner domain of the one or more identified binding members.
11. A method according to any one of clauses 8 to 10 wherein the binding activity of one or more of the modified binding members is improved relative to the one or more founder
30 binding members identified in step (iii).
12. A method according to any one of the clauses 8 to 11 comprising further enriching the one or more binding members by;
 - (e) recovering the one or more modified binding members,

(f) subjecting the recovered modified binding members to selection for the binding activity,

(g) recovering the one or more selected binding modified members and

(h) optionally repeating steps (f) and (g) one or more times.

- 5 13. A method according to any one of the preceding clauses comprising replacing the donor diversity scaffold domain in the one or more identified binding members or modified binding members with a substitute donor diversity scaffold domain.
14. A method according to clause 13 wherein the donor diversity scaffold domain and the substitute donor diversity scaffold domain comprise the same scaffold class.
- 10 15. A method according to clause 14 wherein the donor diversity scaffold domain and the substitute donor diversity scaffold domain comprise the same donor scaffold and different donor interaction sequences.
16. A method according to clause 14 or clause 15 wherein the donor diversity scaffold domain and the substitute donor diversity scaffold domain are both knottins.
- 15 17. A method according to clause 14 wherein the donor diversity scaffold and the substitute donor diversity scaffold comprise a different donor scaffold and a different donor interaction sequence.
18. A method according to any one of clauses 13-17 wherein the substitute donor diversity scaffold comprises a diverse donor interaction sequence.
- 20 19. A method according to any one of the preceding clauses comprising;
- (vii) associating the fusion protein from the one or more identified binding members or modified binding members with a diverse population of binding partners to produce a shuffled library of binding members,
- (viii) screening the shuffled library for shuffled binding members which display a
- 25 binding activity,
- (ix) identifying one or more shuffled binding members which display the binding activity.
20. A method according to clause 19 comprising further enriching the one or more shuffled binding members by;
- 30 (i) recovering the one or more shuffled binding members,
- (j) subjecting the recovered shuffled binding members to selection for the binding activity,
- (k) recovering the one or more selected binding modified members and
- (l) optionally repeating steps (j) and (k) one or more times.

21. A method according to clause 19 or clause 20 wherein the binding activity of the shuffled binding members is improved relative to the one or more binding members identified in step (iii) and/or step (vi).
22. A method according to any one of the preceding clauses comprising introducing an additional amino acid sequence into the fusion proteins or partner domains of the one or more identified binding members from the founder library, modified library and/or shuffled library.
23. A method according to clause 22 wherein the additional amino acid sequence is a target binding sequence.
24. A method according to any one of the preceding clauses wherein both the donor and recipient diversity scaffolds of the fusion protein contribute to the binding activity of the fusion protein.
25. A method according to any one of the preceding clauses wherein the binding activity is binding to a target molecule.
26. A method according to clause 25 wherein the binding member is an antagonist or inhibitor of the target molecule.
27. A method according to clause 25 wherein the binding member is an agonist, enhancer or activator of the target molecule.
28. A method according to any one of clauses wherein one of the donor diversity scaffold domain, recipient diversity scaffold domain and partner domain binds to the target molecule and the method comprises modifying or replacing said donor diversity scaffold domain, recipient diversity scaffold domain or partner domain in the one or more identified binding members.
29. A method according to any one of the preceding clauses wherein the founder library modified library or shuffled library is screened by determining the binding of the binding members in the library to a target molecule, wherein one of the target molecule and the founder library, modified library or shuffled library is immobilised.
30. A method according to any one of clauses 1 to 29 wherein the founder library, modified library or shuffled library is screened by expressing the library in reporter cells and identifying one or more reporter cells with an altered phenotype.
31. A method according to clause 29 or 30 wherein binding to the target molecule or an altered phenotype are detected by flow cytometry, immunohistochemistry or ELISA.
32. A method according to any one of the preceding clauses further comprising subjecting the one or more identified binding members to selection for stability.

33. A method according to any one of the preceding clauses wherein the method comprises subjecting the founder library, modified library and/or shuffled library to selection for binding members in which the donor diversity scaffold and/or the recipient diversity scaffold adopt active conformations.
- 5 34. A method according to clause 33 wherein the recipient diversity scaffold domain is an immunoglobulin sequence and the method further comprises screening the library using an immunoglobulin binding molecule.
35. A method according to clause 34 wherein the immunoglobulin binding molecule is protein L, protein A or an anti-Ig antibody or antibody fragment.
- 10 36. A method according to any one of the preceding clauses wherein the method comprises isolating and/or purifying the one or more identified binding members from the library, the modified library and/or the shuffled library.
37. A method according to any one of the preceding clauses wherein the binding members in the library are displayed on the surface of a ribosome, cell or virus which
- 15 comprises the nucleic acid encoding the binding member.
38. A method according to clause 37 wherein the method comprises isolating and/or purifying the ribosome, cell or virus displaying the one or more identified binding members from the library, the modified library and/or the shuffled library
39. A method according to clause 37 or 38 wherein the method comprises isolating and/or
- 20 purifying the nucleic acid encoding the one or more identified binding members from the library, the modified library and/or the shuffled library
40. A method according to any one of clauses 37 to 39 wherein the method comprises amplifying and/or cloning the nucleic acid encoding the one or more identified binding members from the library, the modified library and/or the shuffled library.
- 25 41. A method according to any one of clauses 37 to 40 wherein the method comprises sequencing the nucleic acid encoding the one or more identified binding members from the library, the modified library and/or the shuffled library.
42. A method according to any one of the preceding clauses comprising synthesising or recombinantly expressing one or more identified binding members from the library, the
- 30 modified library and/or the shuffled library.
43. A method according to any one of the preceding clauses comprising determining the effect of the one or more binding members identified from the library, the modified library and/or the shuffled library on the activity of the target molecule.

44. A method according to clause 43 wherein the target molecule is an ion channel and the effect of the one or more identified binding members on ion flow through the channel is determined
45. A method according to any one of clauses 1 to 44 comprising synthesising or
5 recombinantly expressing an isolated donor diversity scaffold domain from one or more of the identified binding members from the founder library, the modified library and/or the shuffled library.
46. A method according to any one of clauses 1 to 45 comprising re-formatting one or more of the identified binding members as an scFv, Fab, scFv-Fc, Fc, IgA, IgD, IgM or IgG.
- 10 47. A method according to any one of the preceding clauses comprising attaching a therapeutic moiety, half-life extension moiety or detectable label to the one or more identified binding members.
48. A method according to any one of the preceding clauses comprising formulating the one or more identified binding members from the founder library, the modified library and/or
15 the shuffled library or the isolated donor diversity scaffold domain with a pharmaceutically acceptable excipient.
49. A method of producing a library of binding members comprising;
providing a population of nucleic acids encoding a diverse population of fusion proteins comprising a donor diversity scaffold domain inserted into a recipient diversity
20 scaffold domain,
wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, optionally wherein the N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain with
25 linkers of up to 4 amino acids, and one, two or all three of the donor interaction sequence, the recipient interaction sequence and the linkers are diverse in said population,
expressing said population of nucleic acids to produce the diverse population, and
optionally associating the fusion proteins with a population of partner domains,
thereby producing a library of binding members.
- 30 50. A method according to clause 49 wherein the nucleic acids are expressed in a cell or cell-free ribosome.
51. A method according to clause 50 wherein the cell is a prokaryotic cell.
52. A method according to clause 50 wherein the cell is a eukaryotic cell.

53. A method according to clause 52 wherein the eukaryotic cell is a plant, yeast, insect or mammalian cell.

54. A library of binding members comprising;

a diverse population of fusion proteins comprising a donor diversity scaffold domain

5 inserted into a recipient diversity scaffold domain,

wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, optionally wherein the N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain with

10 linkers of up to 4 amino acids, and

one, two or all three the donor interaction sequence, the recipient interaction sequence and the linkers are diverse in said population, and

optionally wherein the fusion proteins are associated with binding partners to form heterodimers.

15 55. A library according to clause 54 wherein the binding members in the library comprises;

(i) diverse donor interaction sequences and the same recipient interaction sequence,

(ii) diverse recipient interaction sequences and the same donor interaction sequence,

or

20 (iii) diverse recipient and donor interaction sequences.

56. A library according to clause 55 wherein the binding members in the library have diverse linker sequences.

57. A library according to clause 56 wherein the binding members in the library have the same recipient and donor interaction sequences and diverse linker sequences.

25 58. A library according to any one of clauses 54 to 57 wherein the binding members in the library have diverse partner domains.

59. A library according to any one of clauses 54 to 58 which is produced by a method according to any one of clauses 49 to 53.

60. A method or library according to any one of the clauses 49 to 59 wherein each
30 binding member in the library is displayed on the surface of a ribosome, cell or virus which comprises nucleic acid encoding the binding member.

61. A method or library according to clause 60 wherein the binding members are displayed on the surface of a bacteriophage or a eukaryotic cell.

62. A method or library according to any one of clauses 54 to 61 wherein the fusion protein of the binding members is fused to a coat protein of a filamentous phage.
63. A fusion protein comprising a donor diversity scaffold domain inserted into a recipient diversity scaffold domain wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence.
64. A binding member comprising a fusion protein according to clause 63 and a partner domain.
65. A method of producing a binding member comprising;
inserting a nucleic acid encoding a donor diversity scaffold domain into a nucleic acid encoding a recipient diversity scaffold domain to produce a chimeric nucleic acid encoding a fusion protein;
wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence;
expressing said chimeric nucleic acid to produce the fusion protein, and
optionally, associating the fusion protein with a partner domain.
66. A method, library, fusion protein or binding member according to any one of the preceding clauses wherein the binding member or fusion protein has increased half-life *in vivo* relative to the isolated donor diversity scaffold domain.
67. A method, library, fusion protein or binding member according to any one of the preceding clauses wherein the fusion protein is associated with the partner domain through a covalent or non-covalent bond.
68. A method, library, fusion protein or binding member according to clause 67 wherein the recipient diversity scaffold domain of the fusion protein is associated with a partner domain
69. A method, library, fusion protein or binding member according to clause 67 wherein donor diversity scaffold domain of the fusion protein is associated with a partner domain.
70. A method, library fusion protein or binding member according to any one of the preceding clauses wherein the binding member is heterodimeric.
71. A method, library fusion protein or binding member according to any of clauses 1 to 69 wherein the binding member comprises multiple partner domains.
72. A method, library, fusion protein or binding member according to clause 71 wherein the binding member is multimeric.

73. A method, library, fusion protein or binding member according to any one of the preceding clauses wherein the interaction sequences of the donor and recipient diversity scaffold domains interact with the same epitope on the target molecule.
74. A method, library fusion protein or binding member according to any one of the preceding clauses wherein the fusion protein and the partner domain bind to the same target molecule.
75. A method, library fusion protein or binding member according to any one of the preceding clauses wherein the target molecule is an integral membrane protein.
76. A method, library fusion protein or binding member according to clause 75 wherein the integral membrane protein is an ion channel, GPCR or Type I receptor.
77. A method, library fusion protein or binding member according to any one of clauses 1 to 76 wherein the binding member binds to a first target molecule and a second target molecule.
78. A method, library fusion protein or binding member according to any one of clauses 1 to 76 wherein one of the fusion protein and the partner domain binds to a first target molecule and the other of the fusion protein and the partner domain binds to a second target molecule.
79. A method, library fusion protein or binding member according to clause 77 or clause 78 wherein the target molecules are on the surface of the same cell.
80. A method, library fusion protein or binding member according to clause 79 wherein binding of the binding member to the first target molecule increases the binding of the binding member to the second target molecule.
81. A method, library fusion protein or binding member according to any one of clauses 77 to 80 wherein the first target molecule is a Blood Brain Barrier receptor or Blood Neuron Barrier receptor.
82. A method, library fusion protein or binding member according to any one of the preceding clauses wherein one or both of the diversity scaffold domains comprise multiple disulphide bonds.
83. A method, library fusion protein or binding member according to any one of the preceding clauses wherein the recipient diversity scaffold domain is selected from the group consisting of: an immunoglobulin, an immunoglobulin domain, a VH domain, a VL domain, a knottin, a Protein A, a "Designed ankyrin repeat protein" (DARPin), an adhiron, a fibronectin domain, an anticalin and a T7 phage gene 2 protein (Gp2).
84. A method, library fusion protein or binding member according to clause 83 wherein the recipient diversity scaffold domain is all or part of an immunoglobulin.

85. A method, library fusion protein or binding member according to clause 84 wherein the recipient diversity scaffold domain is all or part of an antibody variable domain.
86. A method, library fusion protein or binding member according to clause 85 wherein the recipient diversity scaffold domain is an antibody light chain variable (VL) domain.
- 5 87. A method, library fusion protein or binding member according to clause 86 wherein the antibody light chain variable (VL) domain has the amino acid sequence shown in Table 23 (SEQ ID NO: 270) or a variant thereof.
88. A method, library fusion protein or binding member according to clause 86 or 87 wherein the partner domain is an antibody heavy chain variable (VH) domain.
- 10 89. A method, library fusion protein or binding member according to clause 88 wherein the antibody heavy chain variable (VH) domain has an amino acid sequence shown in Table 20 (SEQ ID NOS: 249-257) or a variant thereof.
90. A method, library fusion protein or binding member according to clause 85 wherein the recipient diversity scaffold domain is an antibody heavy chain variable (VH) domain.
- 15 91. A method, library fusion protein or binding member according to clause 90 wherein the partner domain is an antibody light chain variable (VL) domain.
92. A method, library fusion protein or binding member according to clause 88 or clause 91 wherein the VL domain and the VH domain are connected by a flexible linker
93. A method, library fusion protein or binding member according to any one of clauses 20 83 to 90 wherein therein the donor diversity scaffold domain replaces all or part of VH CDR1, VH CDR2, VH CDR3, VL CDR1, VL CDR2 or VL CDR3 of the antibody variable domain.
94. A method, library fusion protein or binding member according to clause 91 wherein the donor diversity scaffold domain replaces all or part of the CDR1 or CDR2 of the antibody 25 VL domain.
95. A method, library fusion protein or binding member according to any one of clauses 85 to 94 wherein the interaction sequence of the donor diversity scaffold domain and one or more CDRs of the antibody variable domain interact with the same epitope on the target molecule.
- 30 96. A method, library fusion protein or binding member according to clause 95 wherein the interaction sequence of the donor diversity scaffold domain and the CDR3 of the antibody variable domain interact with the same epitope on the target molecule.

97. A method, library fusion protein or binding member according to any one of the preceding clauses wherein the donor diversity scaffold domain consists of at least 15 amino acids, preferably at least 20 amino acids.
98. A method, library fusion protein or binding member according to any one of the preceding clauses wherein the donor diversity scaffold domain is selected from the group consisting of: an immunoglobulin, an immunoglobulin domain, a VH domain, a VL domain, a Protein A, cysteine-rich peptide, such as a venom peptide or knottin, a “Designed ankyrin repeat protein” (DARPin), an adhiron, a fibronectin domain, an anticalin and a T7 phage gene 2 protein (Gp2).
99. A method, library fusion protein or binding member according to clause 98 wherein the donor diversity scaffold domain is a cysteine-rich peptide.
100. A method, library fusion protein or binding member according to clause 99 wherein donor diversity scaffold domain is a venom peptide.
101. A method, library fusion protein or binding member according to any one of clauses 97 to 100 wherein the donor diversity scaffold domain is a knottin.
102. A method, library, fusion protein or binding member according to clause 101 wherein the knottin is Ecballium elaterium trypsin inhibitor-II (EETI-II), MCoTI-II, Huwentoxin-IV, ProTx-II, SSm6a, Kaliotoxin, MoKa-1, Shk, PcTx1 and Conotoxin- ω , or a variant thereof.
103. A method, library, fusion protein or binding member according to any one of clauses 97 to 102 wherein the native N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain.
104. A method, library fusion protein or binding member according to clause 103 wherein the knottin comprises an amino acid sequence shown in Table 17A (SEQ ID NOS: 211-233), Table 17B (SEQ ID NOS: 234-244), or Figure 29 (SEQ ID NO: 342) or a variant thereof.
105. A method, library, fusion protein or binding member according to any one of clauses 97 to 104 wherein the recipient diversity scaffold domain comprises the amino acid sequence of a recipient binding domain shown in Table 1 and optionally the linker comprises the amino acid sequence of a linker shown in Table 1
106. A method, library fusion protein or binding member according to any one of clauses 103 to 105 wherein the fusion protein comprises the amino acid sequence shown in Table 1 (SEQ ID NOS: 84-139) or Table 8B (SEQ ID NOS: 31 to 35) or a variant thereof.
107. A method, library, fusion protein or binding member according to any one of clauses 97 to 102 wherein artificial N and C terminals generated by cyclisation and linearization of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain.

108. A method, library fusion protein or binding member according to clause 107 wherein the donor diversity scaffold domain is a knottin comprising an amino acid sequence shown in Table 28 (SEQ ID NOS: 302-307) or a variant thereof.

109. A method, library fusion protein or binding member according to clause 107 or 108
5 wherein the fusion protein comprises the amino acid sequence shown in Table 29 (SEQ ID NOS: 308-317) or Figure 29 (SEQ ID NOS 349 and 351) or a variant thereof.

110. A method, library fusion protein or binding member according to clause 106 or clause 109 wherein the binding member comprises a partner domain, said partner domain being a VH domain.

10 111. A method, library, fusion protein or binding member according to clause 97 or 86 wherein the donor diversity scaffold domain is an adhiron.

112. A nucleic acid encoding a fusion protein according to any one of clauses 63 and 66 to 111 or a binding member according to any one of clauses 64 and 66 to 111.

113. A vector encoding a nucleic acid according to clause 112.

15 114. A method of producing a fusion protein or binding member comprising;
expressing a nucleic acid according to clause 112.

115. A population of nucleic acids encoding a library according to any one of clauses 54 to 62 and 65 to 111.

116. A population according to clause 115 wherein the nucleic acids encoding the library
20 are contained in expression vectors.

117. A population of viral particles comprising a library according to any one of clauses 54 to 62 and 65 to 111 and/or a population according to clause 115 or clause 116.

118. A population of host cells comprising a library according to any one of clauses 54 to 62 and 65 to 111 or a population according to clause 115 or clause 116.

25 119. A fusion protein according to any one of clauses 63 and 66 to 111 or a binding member according to any one of clauses 64 and 66 to 111 that is fused or conjugated to a toxin, therapeutic moiety, half-life extension moiety or detectable label

120. A pharmaceutical composition comprising fusion protein according to any one of clauses 63, 66 to 111 and 119 or a binding member according to any one of clauses 64, 66 to
30 111 and 119 and a pharmaceutically acceptable excipient.

121. A fusion protein according to any one of clauses 63, 66 to 111 and 119 or a binding member according to any one of clauses 64, 66 to 111 and 119 or composition according to clause 120 for use as a medicament.

122. A fusion protein according to any one of clauses 63, 66 to 111 and 119 or a binding member according to any one of clauses 64, 66 to 111 and 119 or composition according to clause 120 for use the treatment of a disease or condition associated with or characterised by ion channel dysfunction.

5 123. A fusion protein, binding member or composition according to clause 122 wherein the disease or condition is pain, cancer, infectious disease, or autoimmune disease.

124. Use of a fusion protein according to any one of clauses 63, 66 to 111 and 119 or a binding member according to any one of clauses 64, 66 to 111 and 119 or composition according to clause 120 in the manufacture of a medicament for the treatment of a disease or
10 condition associated with or characterised by ion channel dysfunction.

125. Use according to clause 124 wherein the disease or condition is pain, cancer, infectious disease, or autoimmune disease.

126. A method of treatment of a disease or condition associated with or characterised by ion channel dysfunction comprising administration of a fusion protein according to any one
15 of clauses 63, 66 to 111 and 119 or a binding member according to any one of clauses 64, 66 to 111 and 119 or composition according to clause 120 to an individual in need thereof.

127. A method of treatment according to clause 126 for the treatment of pain or autoimmune disease.

Statements:

20 1. A binding member that binds and inhibits a human sodium or calcium channel, the binding member comprising a fusion protein and optionally a partner domain, wherein
the fusion protein comprises a donor diversity scaffold domain inserted into a recipient diversity scaffold domain wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain
25 comprises a recipient scaffold and a recipient interaction sequence, wherein

the donor diversity scaffold domain is a knottin that binds an alpha subunit of a human sodium channel (e.g., Nav1.7) or a human calcium channel.

2. A binding member according to statement 1, wherein the knottin binds domain 2 of the Nav1.7 alpha subunit.

30 3. A binding member according to statement 1 or statement 2, wherein the binding member inhibits ion flux through the channel by at least 20 % as determined by a whole cell patch clamp assay.

4. A fusion protein comprising a donor diversity scaffold domain inserted into a recipient diversity scaffold domain wherein the donor diversity scaffold domain comprises a

donor scaffold and a donor interaction sequence and the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, wherein

the donor diversity scaffold domain is a knottin that binds domain 2 of a human sodium channel Nav1.7 alpha subunit, the knottin comprising an amino acid sequence shown in Table 31 or comprising a variant having between one and five amino acid alterations in said sequence, alteration being a substitution, insertion or deletion of an amino acid.

5. A fusion protein according to statement 4, wherein the knottin is ProTx-III 2M, HwTx-IV 3M, GpTx-1 4M or ProTx-111.

6. A fusion protein according to statement 5 wherein the knottin has an amino acid sequence shown in Table 31 or 32.

7. A fusion protein according to any of statements 4 to 6, wherein the donor diversity scaffold domain comprises the knottin sequence with the addition of a glycine residue at the native C terminus of the knottin.

8. A fusion protein according to any of statements 4 to 7, wherein the N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain with linkers of up to 4 amino acids, optionally wherein the linker comprises the amino acid sequence of a linker shown in Table 1.

9. A fusion protein according to any of statements 4 to 8, wherein the native N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain.

10. A fusion protein according to any of statements 4 to 8, wherein artificial N and C terminals generated by cyclisation and linearization of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain.

11. A fusion protein according to any of statements 4 to 10, wherein the recipient diversity scaffold domain is all or part of an immunoglobulin.

12. A fusion protein according to statement 11 wherein the recipient diversity scaffold domain is all or part of an antibody variable domain.

13. A fusion protein according to statement 12, wherein therein the donor diversity scaffold domain replaces all or part of VH CDR1, VH CDR2, VH CDR3, VL CDR1, VL CDR2 or VL CDR3 of the antibody variable domain.

14. A fusion protein according to statement 12 or statement 13, wherein the recipient diversity scaffold domain is an antibody light chain variable (VL) domain.

15. A fusion protein according to statement 14, wherein the donor diversity scaffold domain replaces all or part of the CDR1 or CDR2 of the VL domain.

16. A fusion protein according to statement 14 or statement 15, wherein the VL domain has the amino acid sequence of the D1A12 VL domain shown herein or a variant comprising between one and ten amino acid alterations in said sequence, alteration being a substitution, insertion or deletion of an amino acid.
- 5 17. A fusion protein according to statement 16, wherein the donor diversity scaffold domain is inserted in CDR2 of the VL domain, optionally wherein the donor diversity scaffold domain replaces CDR2 of the D1A12 VL domain.
18. A fusion protein according to statement 17, comprising an amino acid sequence encoded by a DNA sequence shown in Table 33 or comprising a variant amino acid sequence
- 10 at least 90 % identical to said amino acid sequence.
19. A fusion protein according to any of statements 4 to 13, wherein the recipient diversity scaffold domain is an antibody heavy chain variable (VH) domain.
20. A binding member according to any of statements 1 to 3, comprising the fusion protein of any of statements 4 to 19.
- 15 21. A binding member comprising a fusion protein according to any of statements 4 to 19 and a partner domain.
22. A binding member according to statement 20 or statement 21, comprising a fusion protein according to any of statements 4 to 19, wherein the partner domain is an antibody heavy chain variable (VH) domain.
- 20 23. A binding member according to statement 22, wherein the VH domain has the amino acid sequence of the antibody D1A12 VH domain shown herein, or a variant comprising between one and ten amino acid alterations in said sequence, alteration being a substitution, insertion or deletion of an amino acid.
24. A binding member according to statement 20 or statement 21, comprising a fusion
- 25 protein according to any of statements 4 to 13, wherein the partner domain is an antibody light chain variable (VL) domain.
25. A binding member according to any of statements 20 to 24, further comprising a human antibody constant region, e.g., a human IgG Fc.
26. A binding member according to any of statements 20 to 25, wherein the VL domain
- 30 and the VH domain are connected by a flexible linker.
27. A binding member according to any of statements 20 to 26, wherein the partner domain binds to the channel.

28. A binding member according to statement 27, wherein the partner domain and the interaction sequence of the donor diversity scaffold domain bind to the same domain of the channel.
29. A binding member according to statement 28, wherein the partner domain and the interaction sequence of the donor diversity scaffold domain bind to different domains of the channel.
30. A binding member according to any one of statements 27-29, wherein the partner domain binds domain 1 of a sodium or calcium channel alpha subunit (e.g., Nav1.7 alpha subunit).
31. A binding member according to any one of statements 27-29, wherein the partner domain binds domain 2 of a sodium or calcium channel alpha subunit (e.g., Nav1.7 alpha subunit).
32. A binding member according to any one of statements 27-29, wherein the partner domain binds domain 3 of a sodium or calcium channel alpha subunit (e.g., Nav1.7 alpha subunit).
33. A binding member according to any one of statements 27-29, wherein the partner domain binds domain 4 of a sodium or calcium channel alpha subunit (e.g., Nav1.7 alpha subunit).
34. A binding member according to any of statements 27 to 33, wherein the partner domain binds to a sequence within the S1 to S4 region of a sodium or calcium channel alpha subunit domain (e.g., of Nav1.7).
35. A binding member according to any of statements 27 to 34, wherein the partner domain binds to a sequence within the S1 to S2 region of a sodium or calcium channel alpha subunit domain (e.g., of Nav1.7).
36. A binding member according to any of statements 27 to 34, wherein the partner domain binds to a sequence within the S3 to S4 region of a sodium or calcium channel alpha subunit domain (e.g., of Nav1.7).
37. A binding member according to any of statements 27 to 36, wherein the partner domain binds specifically to the channel.
38. A binding member according to any of statements 27 to 37, wherein presence of the partner domain increases the specificity or selectivity of the binding member for the channel relative to the fusion protein.
39. A binding member according to any of statements 27 to 38, wherein the partner domain binds specifically to Nav 1.7.

40. A binding member according to any of statements 27 to 39, wherein the partner domain binds to Nav1.7 and does not bind to other human sodium channels (e.g. Nav1.1, Nav1.2, Nav1.3 or Nav1.6).
41. A binding member according to statement 39 or statement 40, wherein the partner domain specifically binds to a sequence within the S1 to S2 region of Nav1.7.
42. A binding member according to statement 41, wherein the partner domain specifically binds to the sequence EHHPMTEEFKNV.
43. A binding member according to statement 39 or statement 40, wherein the partner domain specifically binds to a sequence within the S3 to S4 region of Nav1.7.
44. A binding member according to statement 43, wherein the partner domain specifically binds to the sequence ELFLADVEGL.
45. A binding member according to any of statements 27 to 44, wherein the partner domain is an antibody variable domain and one or more CDRs of the antibody variable domain bind the channel.
46. A fusion protein or binding member according to any preceding statement, wherein the recipient diversity scaffold domain is all or part of an antibody variable domain and wherein the interaction sequence of the donor diversity scaffold domain and one or more CDRs of the antibody variable domain bind the channel.
47. A fusion protein or binding member according to statement 46, wherein the interaction sequence of the donor diversity scaffold domain and one or more CDRs of the antibody variable domain bind to the same domain of the channel.
48. A fusion protein or binding member according to statement 46 or statement 47, wherein the interaction sequence of the donor diversity scaffold domain and the CDR3 of the antibody variable domain interact with the same epitope on the target molecule.
49. A binding member according to any of statements 20 to 49, wherein the binding member binds to the channel and a second target molecule.
50. A binding member according to statement 49 comprising a partner domain that binds to the second target molecule.
51. A binding member according to statement 49 or statement 50 wherein the target molecule is expressed on neuronal cells.
52. A binding member according to statement 51 wherein binding of the binding member to the sodium channel increases the binding of the binding member to the second target molecule.

53. A binding member according to any one of statements 50 to 52 wherein the second target molecule is a Blood Brain Barrier receptor or Blood Neuron Barrier receptor.
54. A binding member according to any of statements 20 to 53 which is fused or conjugated to a toxin, therapeutic moiety, half-life extension moiety or detectable label.
- 5 55. A composition comprising a binding member according to any of statements 20 to 54 and a pharmaceutically acceptable excipient.
56. A binding member according to any of statements 20 to 54 or composition according to statement 55 for use in treatment of the human body by therapy.
57. A binding member according to any of statements 20 to 54 or composition according
10 to statement 55 for use in treatment of a disease or condition associated with or characterised by sodium or calcium channel dysfunction.
58. A binding member according to any of statements 20 to 54 or composition according to statement 55 for use in treatment of pain or epilepsy.
59. Use of a binding member according to any of statements 20 to 54 or a composition
15 according to statement 55 in the manufacture of a medicament for the treatment of a disease or condition associated with or characterised by sodium or calcium channel dysfunction.
60. Use of a binding member according to any of statements 20 to 54 or a composition according to statement 55 in the manufacture of a medicament for the treatment of pain or epilepsy.
- 20 61. A method of treatment of a disease or condition associated with or characterised by sodium or calcium channel dysfunction comprising administration of a binding member according to any of statements 20 to 54 or composition according to statement 55 to an individual in need thereof.
62. A method of treatment of pain or epilepsy comprising administration of a binding
25 member according to any of statements 20 to 54 or composition according to statement 55 to an individual in need thereof.
63. A binding member or composition for use according to any of statements 56 to 58, use according to statement 59 or statement 60, or a method of treatment according to statement 61 or statement 62, wherein the treatment comprises administering the binding
30 member or composition to a human to relieve acute pain, chronic pain, neuropathic pain (e.g., peripheral neuropathic pain), post-operative pain, cancer pain, acute inflammatory pain, or pain hypersensitivity (e.g., erythromelalgia or paroxysmal extreme pain disorder).
64. A method of producing a binding member according to any of statements 20 to 54, comprising;

inserting a nucleic acid encoding the donor diversity scaffold domain into a nucleic acid encoding the recipient diversity scaffold domain to produce a chimaeric nucleic acid encoding a fusion protein;

expressing said chimaeric nucleic acid to produce the fusion protein;

5 optionally, associating the fusion protein with a partner domain; and

isolating a binding member comprising the fusion protein and optionally the partner domain.

65. A method according to statement 64, wherein the donor diversity scaffold domain comprises a knottin sequence shown in Table 31.

10 66. A method according to statement 64 or statement 65, wherein the donor diversity scaffold domain comprises a glycine residue at the native C terminus of the knottin.

67. A method according to statement 64 or statement 65, wherein the nucleic acid encoding the donor diversity scaffold domain encodes a rotated knottin sequence producible by linking the native N and C termini of the selected knottin sequence (directly or optionally
15 via one, two or three amino acids or by a peptide linker) and linearising at a different position to generate new N and C termini.

Configurations:

1. A binding member that binds and inhibits human sodium channel Nav1.7, the binding member comprising a fusion protein and a partner domain, wherein

20 the fusion protein comprises a donor diversity scaffold domain inserted into a recipient diversity scaffold domain, wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence, and wherein the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, wherein

wherein the donor diversity scaffold domain is a cysteine-rich peptide, such as an ion-
25 channel modulating peptide, venom toxin peptide or knottin, which binds to the voltage sensing domain of Nav1.7, wherein

the recipient diversity scaffold domain is an antibody variable domain, wherein

the partner domain is an antibody variable domain, wherein

30 the binding member is a whole immunoglobulin comprising paired heavy and light chains, and wherein

the immunoglobulin is a human IgG1 comprising an effector null Fc region or wherein the immunoglobulin is a human IgG4.

2. A binding member according to configuration 1, wherein the donor diversity scaffold domain is a peptide having at least 95 % sequence identity to (i) ProTx-III, (ii) ProTx-II, (iii) Huwentoxin-IV, (iv) Ssm6a, or (v) GpTx-1.
3. A binding member or fusion protein according to configuration 1 or configuration 2,
5 wherein the donor diversity scaffold domain replaces all or part of a complementarity determining region (CDR) of the recipient diversity scaffold antibody variable domain.
4. A binding member according to any preceding configuration, wherein the recipient diversity scaffold domain is an antibody VL domain.
5. A binding member according to configuration 4, wherein the donor diversity scaffold
10 domain replaces all or part of CDR1 or CDR2 of the antibody VL domain.
6. A binding member according to any preceding configuration, wherein the partner domain is an antibody VH domain.
7. A binding member according to configuration any preceding configuration, wherein the binding member inhibits ion flux through the channel by at least 20 % as determined by a
15 whole cell patch clamp assay.
8. A binding member according to any preceding configuration, wherein the donor diversity scaffold domain is ProTx-III 2M, HwTx-IV 3M, GpTx-1 4M or ProTx-III or wherein the donor diversity scaffold domain comprises an amino acid sequence shown in Table 31 or 32.
- 20 9. A binding member according to any preceding configuration, wherein the donor diversity scaffold domain comprises a cysteine rich peptide sequence with the addition of a glycine residue at the native C terminus of the peptide sequence.
10. A binding member according to configuration 9, wherein the donor diversity scaffold domain comprises a cysteine rich peptide sequence with the addition of two glycine residues
25 at the native C terminus of the peptide sequence.
11. A binding member according to any preceding configuration, wherein the N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain with linkers of up to 4 amino acids, optionally wherein the linker comprises the amino acid sequence of a linker shown in Table 1.
- 30 12. A binding member according to any preceding configuration, wherein the native N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain.

13. A binding member according to any of configurations 1 to 11, wherein artificial N and C terminals generated by cyclisation and linearization of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain.
14. A binding member according to any preceding configuration, wherein the recipient
5 diversity scaffold domain is an antibody light chain variable domain having the amino acid sequence of the D1A12 VL domain shown herein or a variant comprising between one and ten amino acid alterations in said sequence, alteration being a substitution, insertion or deletion of an amino acid.
15. A binding member according to configuration 14, wherein the donor diversity
10 scaffold domain replaces CDR2 of the D1A12 VL domain.
16. A binding member according to configuration 15, wherein the fusion protein comprises
- (i) an amino acid sequence encoded by a DNA sequence shown in Table 33 or Table 37;
 - (ii) a variant amino acid sequence at least 90 % identical to (i);
 - 15 (iii) an amino acid sequence shown in Table 36; or
 - (iv) a variant amino acid sequence at least 90 % identical to the amino acid sequence of (iii).
17. A binding member according to any preceding configuration, wherein the VH domain has the amino acid sequence of the antibody D1A12 VH domain shown herein, or a variant comprising between one and ten amino acid alterations in said sequence, alteration being a
20 substitution, insertion or deletion of an amino acid.
18. A binding member according to configuration 17, wherein the partner domain is an antibody VH domain comprising amino acid sequence SEQ ID NO: 30.
19. A binding member according to any of configurations 1 to 16, wherein the partner domain binds to the human sodium channel Nav1.7.
20. A binding member according to configuration 19, wherein presence of the partner domain increases the specificity or selectivity of the binding member for the channel relative to the fusion protein.
21. A binding member according to configuration 19 or configuration 20, wherein the partner domain and the interaction sequence of the donor diversity scaffold domain bind to
30 the same domain of the channel.
22. A binding member according to configuration 19 or configuration 20, wherein the partner domain binds domain 2 of a Nav1.7 alpha subunit.

23. A binding member according to configuration 19 or configuration 20, wherein the partner domain and the interaction sequence of the donor diversity scaffold domain bind to different domains of the channel.
24. A binding member according to configuration 23, wherein the partner domain binds domain 1 of a Nav1.7 alpha subunit.
25. A binding member according to configuration 23, wherein the partner domain binds domain 3 of a Nav1.7 alpha subunit.
26. A binding member according to configuration 23, wherein the partner domain binds domain 4 of a Nav1.7 alpha subunit.
27. A binding member according to any of configurations 19 to 26, wherein the partner domain binds to a sequence within the S1 to S4 region of Nav1.7.
28. A binding member according to configuration 27, wherein the partner domain binds to a sequence within the S1 to S2 region of Nav1.7.
29. A binding member according to configuration 28, wherein the partner domain specifically binds to the sequence EHHPMTEEFKNV.
30. A binding member according to configuration 27, wherein the partner domain binds to a sequence within the S3 to S4 region of Nav1.7.
31. A binding member according to configuration 30, wherein the partner domain specifically binds to the sequence ELFLADVEGL.
32. A binding member according to any of configurations 19 to 31, wherein the partner domain binds to Nav1.7 and does not bind to other human sodium channels (e.g. Nav1.1, Nav1.2, Nav1.3 or Nav1.6).
33. A binding member according to any preceding configuration, wherein the binding member binds to the channel and a second target molecule.
34. A binding member according to configuration 33, wherein binding of the binding member to the sodium channel increases the binding of the binding member to the second target molecule.
35. A binding member according to configuration 33 or configuration 34, wherein the second target molecule is expressed on neuronal cells.
36. A binding member according to any of configurations 33 to 35, wherein the second target molecule is a Blood Brain Barrier receptor or Blood Neuron Barrier receptor.
37. A binding member according to any preceding configuration which is fused or conjugated to a toxin, therapeutic moiety, half-life extension moiety or detectable label.

38. A binding member that binds and inhibits human sodium channel Nav1.7, the binding member comprising a fusion protein and a partner domain, wherein

the fusion protein comprises a donor diversity scaffold domain inserted into a recipient diversity scaffold domain, wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence, and wherein the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, wherein

wherein the donor diversity scaffold domain is a cysteine-rich peptide, such as an ion-channel modulating peptide, venom toxin peptide or knottin, which binds to the voltage sensing domain of Nav1.7, wherein

the recipient diversity scaffold domain is an antibody variable domain, and wherein the partner domain binds to the human sodium channel Nav1.7 and increases the specificity or selectivity of the binding member for the channel.

39. A binding member according to configuration 38 or configuration 39, wherein the partner domain is an antibody variable domain, optionally an antibody VH domain.

40. A binding member according to configuration 38, wherein the fusion protein is as defined in any of configurations 1 to 16.

41. A composition comprising a binding member according to any preceding configuration and a pharmaceutically acceptable excipient.

42. Nucleic acid encoding a binding member according to any preceding configuration.

43. A binding member according to any of configurations 1 to 40 or a composition according to configuration 41 for use in treatment of the human body by therapy.

44. A binding member according to any of configurations 1 to 40 or a composition according to configuration 41 for use in treatment of a disease or condition associated with or characterised by sodium or calcium channel dysfunction.

45. A binding member according to any of configurations 1 to 40 or a composition according to configuration 41 for use in treatment of pain or epilepsy.

46. Use of a binding member according to any of configurations 1 to 40 or a composition according to configuration 41 for the manufacture of a medicament for the treatment of a disease or condition associated with or characterised by sodium or calcium channel dysfunction.

47. Use of a binding member according to any of configurations 1 to 40 or a composition according to configuration 41 for the manufacture of a medicament for the treatment of pain or epilepsy.

48. A method of treatment of a disease or condition associated with or characterised by sodium or calcium channel dysfunction, comprising administration of a binding member according to any of configurations 1 to 40 or a composition according to configuration 41 to an individual in need thereof.

5 49. A method of treatment of pain or epilepsy comprising administration of a binding member according to any of configurations 1 to 40 or a composition according to configuration 41 to an individual in need thereof.

50. A binding member or composition for use according to any of configurations 43 to 45, use according to configuration 46 or configuration 47, or a method of treatment according
10 to configuration 48 or configuration 49, wherein the treatment comprises administering the binding member or composition to a human to relieve acute pain, chronic pain, neuropathic pain (e.g., peripheral neuropathic pain), post-operative pain, cancer pain, acute inflammatory pain, or pain hypersensitivity (e.g., erythromelalgia or paroxysmal extreme pain disorder).

51. A method of producing a binding member according to any of configurations 1 to 40,
15 comprising;

inserting a nucleic acid encoding the donor diversity scaffold domain into a nucleic acid encoding the recipient diversity scaffold domain to produce a chimaeric nucleic acid encoding a fusion protein;

expressing said chimaeric nucleic acid to produce the fusion protein;

20 associating the fusion protein with a partner domain; and

isolating a binding member comprising the fusion protein and the partner domain.

52. A method according to configuration 51, wherein the donor diversity scaffold domain comprises a sequence shown in Table 31.

53. A method according to configuration 51 or configuration 52, wherein the donor
25 diversity scaffold domain comprises a glycine residue at the native C terminus of the cysteine rich peptide.

54. A method according to configuration 51 or configuration 52, wherein the nucleic acid encoding the donor diversity scaffold domain encodes a rotated sequence producable by linking the native N and C termini of the selected sequence (directly or optionally via one,
30 two or three amino acids or by a peptide linker) and linearising at a different position to generate new N and C termini.

Certain aspects and embodiments of the invention will now be illustrated by way of example and with reference to the Figures described above.

Experiments

1. Summary

The fusion of a donor diversity scaffold (e.g. a knottin) into a recipient diversity scaffold domain (e.g. an antibody VL domain) was first exemplified herein using the trypsin inhibitor; Ecballium elaterium trypsin inhibitor-II (EETI-II). In this knottin scaffold, high affinity binding to trypsin is dependent on correct folding of the knottin. The knottin gene was cloned into either CDR1 or CDR2 of an antibody light chain recipient (demonstrated for both kappa and lambda light chains). A library of variants of the recipient was created to allow selection of those recipient variants which could accommodate the incoming donor. The donor and recipient domains were in close apposition. In the example below, the incoming donor replaced a CDR loop and the ends of the incoming donor domain were fused to the flanking antibody framework residues i.e. β strand sequences of the core structure. In some examples below, framework residues were replaced by random sequences. The binding member was thus constructed in a way that limited the length of sequence joining the donor and recipient scaffold such that few or no additional residues were added. In some cases, there were fewer residues within the junction between framework residues and the donor domain compared to what would be have been generated by a direct fusion of the secondary structural elements of donor and recipient. A library of variants was created wherein the sequence of amino acid residues at the N and C terminal boundary of the incoming domain was varied while maintaining a short linker length to limit conformational flexibility. This library was designed to identify correct fusion combinations having a fixed kappa or lambda sequence preceding the knottin with diversity introduced from a natural light chain repertoire in the region that followed the knottin insertion. Thus, for knottin insertion into CDR1, the sequence from framework 2 (FW2) to the end of the VL domain was from a natural repertoire. Likewise insertion into CDR2 was followed from framework 3 to the end of the VL domain by sequences from a natural repertoire.

The population of genes encoding the fusion of the donor and recipient diversity scaffolds was cloned into a phage display vector, phage particles displaying the fusion were recovered and the population selected on immobilized trypsin using phage display technology^{28,100}. In this way, selections were carried out for retained trypsin binding and therefore correct folding of the knottin donor. As well as affinity based selection for the correct folding of the donor, phage display provides additional selectivity for correct folding of the recipient since it has

been shown that phage display enriches for fusions with superior structural integrity⁹⁴. Thus, if the donor was correctly folded (and therefore capable of binding trypsin) but folding of the recipient was compromised, then display of the donor would still be compromised (possibly through degradation of the misfolded fusion). Selectivity for folding of an antibody recipient
5 may thus be further enhanced by preselecting on protein L or protein A which have both been shown to bind to certain VL and VH domains respectively⁹⁵ with a requirement for correct folding. The stringency of the system may be improved further by subjecting the phage population to more disruptive conditions ^{94,96}.

10 A panel of light chain variants which support folding and trypsin binding of EETI-II was selected. Once a scaffold has been selected for one member of a donor diversity scaffold family (knottins, in this case) it may be used for additional members of the same donor diversity scaffold family given the shared structural constraints within the donor family. Using two of the selected recipient antibody light chain scaffolds a range of other knottins
15 which block sodium channels ^{71 72 70}, potassium channels ^{25,73,74} and acid sensitive ion channels ^{118, 122} were used as donors within the previously selected recipient antibody domain. Some of these were shown to retain blocking activity on the target ion channel, in the case of the voltage gated potassium channel Kv1.3 and the acid sensitive ion channel 1a. Thus the selected recipient domain was shown to provide a generic scaffold which can be
20 used for multiple, distinct donors of the same class of diversity scaffold.

The two binding scaffolds were joined by short, non-flexible linkers to limit flexibility and relative movement between the domains. Given the close proximity of the fused binding scaffolds there is an opportunity for amino acids on the surface of both donor and recipient
25 diversity scaffolds to contribute to the paratope involved in interaction with the same epitope on a single protein. Likewise the surface of partner domains of either donor or recipient diversity scaffolds may contribute to binding of target. Alternatively, both scaffolds may contact closely apposed sites on a target protein complex. Conformational flexibility carries a thermodynamic “entropic penalty” for binding interactions. For the same reason, fixing the
30 conformational relationship between the two fused domains is advantageous, and so it is preferable to avoid flexible linker sequences to join the two domains.

A binding member comprising a donor knottin inserted into a recipient antibody variable domain were crystallised and the protein structure determined. This confirmed the correct

folding of the knottin and showed that the knottin presented within the recipient antibody variable domain had the same structure as shown previously for the free knottin. The structure also confirmed correct folding of the antibody and the close apposition of the two domains. Both domains showed the expected structure and the expectation of a relative rigid conformation between the domains is supported by the crystal structure. The fusion of a cysteine-rich donor domain to an antibody recipient domain is hereafter referred to as a KnotBody™

Example 1: Construction of Knottin-VL CDR fusion phage display libraries

The phage display vector pSANG4²⁸ is a phagemid-based phage display vector which allows the facile cloning of single chain Fv (scFv) formatted antibodies. In the scFv format the VH gene and the VL gene are joined by DNA encoding a flexible linker peptide. With pSANG4 scFv genes are cloned into the Nco1 and Not 1 sites to create an in-frame fusion with the M13 leader sequence which precedes the Nco1 site and the minor coat protein encoded by gene 3 which follows the Not1 site (Figure 1A).

A pair of synthetic scFv gene encompassing a fixed VH gene (D12) which does not interact with trypsin (Figure 2) were synthesised (from Genscript). This D12 VH gene¹⁰¹ binds to the “TNF alpha converting enzyme” (TACE) and originates from the IGHV3-23 germ line gene (also known as DP47) which is frequently used in antibody responses¹⁰².

The VH gene is coupled to a synthetic gene encoding the N terminal part of either the IGKV1D-39 germline gene (a member of the V kappa 1 family) or the IGLV1-36 germline gene (a member of the V lambda 1 family) up to the end of FR2 segment followed by a Not 1 restriction site.

This synthetic gene encompassing a partial VL gene will allow the insertion of a knottin gene at either the CDR1 position or the CDR2 position (Figure 1B, C). The gene introduces a Pml1 restriction site at the end of FR1 which is used to clone a repertoire of knottins flanked at their 5' and 3' ends by a Pml1 and Mfe1 site respectively (Figure 1B). The Pml site was introduced near the end of FW1 as a result of a silent mutation in the kappa gene. A Ser to Thr mutation was introduced into the FW1 region of the lambda gene to accommodate this same restriction enzyme site. The synthetic genes also introduced a Pst1 site at the end of FW2 which is used to introduce a knottin gene into the CDR2 position using restriction sites

PstI and BspEI at the 5' and 3' ends of the knottin gene (Figure 1C). In assembling a functional VL gene, the remainder of the VL domain (from FR2 in the case of a CDR1 knottin insertion and from FW3 in the case of a CDR2 insertion) was generated by PCR from a light chain repertoire²⁸ to complete the fusions (see example 2).

These 2 synthetic gene encoding either a kappa or lambda light chain germline gene segment were amplified using primers 2561 (GGTACCTCGCGAATGCATCTAG; SEQ ID NO: 43) and 2562 (CATGCAGGCCTCTGCAGTCG; SEQ ID NO: 44). Purified PCR products were digested with NcoI and NotI before ligating into pSANG4 vector²⁸ cut with the same restriction enzymes. Ligations were transformed into *E.coli* DH5-alpha cells (Life technologies) according to manufacturer's instructions. Plasmid DNA was prepared from the sequence confirmed transformants using Macherey Nagel Midi prep kit (according to the manufacturer's instructions). These vector were named as "pIONTAS1_KB_Kappa" and "pIONTAS1_KB_lambda" and the sequences from the the NcoI site to the NotI site are shown in Figure 2A and 2B respectively.

To demonstrate the potential of fusing a folded knottin donor with an antibody recipient, Ecballium elaterium trypsin inhibitor-II (EETI-II), a plant derived knottin with trypsin inhibitory activity was used. EETI-II has free N and C termini and trypsin binding is driven by the constrained sequence "PRIL" present in loop 1 (Figure 3A)¹⁰³. The high affinity for trypsin in the correctly folded state¹⁰⁴ offers the potential to identify donor knottins which retain trypsin binding despite being cloned into a recipient VL domain. The construction of a phage display library where variable fusion sequence have been introduced between the donor and recipient will allow selection of functional knottin-CDR-VL combinations from the libraries based on trypsin binding.

This knottin donor diversity scaffold was fused into either the CDR1 or CDR2 position of either kappa or lambda VL domains. This was done by replacing residues within the incoming knottin donor and the VL recipient with random amino acids in a way that limited the number of added amino acids between the 2 domains or even reduced them (Figure 3B). We also introduced a repertoire of light chain fragments encompassing the segment of the VL gene following the point of insertion (example 2).

Insertion of knottins into CDR1

A synthetic EETI-II Knottin donor gene was made and was used to replace the CDR1 positions in the light chain recipient by creating a PCR fragment with Pml1 and Mfe sites (which were introduced by PCR) and cloning into pIONTAS1_KB_Kappa and pIONTAS1_KB_lambda. Framework and CDR designations are as described by the International Immunogenetics Information System (IMGT)²⁹. The PCR primers also introduced variable amino acid sequences between the restriction sites and the knottin gene. The PCR primers Pml1-5EETa and Pml1-5EETb each introduced 3 variable codons encoded by the sequence VNS (V=AC or G, N=ACG or T, S=C or G) immediately after the Pml1 restriction site. The “VNS” degenerate codons encode 16 amino acids (excluding cysteine, tyrosine, tryptophan, phenylalanine and stop codons) at each randomised position from 24 codon combinations.

Pml1-5EETa GTGT VNS VNS VNS TGC CCG CGT ATC CTG ATG CGT TGC (SEQ ID NO: 45)

Pml1-5EETb GTGT gga VNS VNS VNS TGC CCG CGT ATC CTG ATG CGT TGC (SEQ ID NO: 46)

The 5' end of these sequences represents the site created by Pml1, a restriction enzyme recognising the sequence “CACGTG” (SEQ NO: 47) to create a blunt end. To facilitate blunt end cloning of the PCR product primers with 5' phosphorylated termini were synthesised.

The introduction of the PCR products at this point has the effect of replacing the last 3 residues of FW1 and the first residue of EETI-II (which forms part of a β sheet within the knottin) with 3 randomised residues. The net effect is the loss of an amino acid in the join between the framework and donor. Primer Pml1-5EETb encodes an additional Gly residue which restores the number of residues between them (Figure 3B).

At the 3' end of the knottin gene the antisense primers 1-5EETMfe (encoding an Mfe1 site) was used to amplify EETI-II. The Mfe1 site used for cloning encodes the 2 and 3rd amino acids of FW2 (Asn-Trp). This primer also retained the terminal glycine found in EETI-II and introduced 2 random amino acids encoded by VNS or VNC codons followed by an Mfe1 site. The consequence of this strategy for introducing a knottin donor gene is to remove the first amino acid of FW2 and join the 2 domains using 2 randomised amino acids (Figure 3B) with a net addition of 1 amino acid between the donor and framework.

1-5EETMfe GTCAGTCCAATTGNBSNBCCCGCA GAAGCCGTTTCGGACCGCA (SEQ ID NO: 48)

Sequences encoding the MfeI site are underlined. As an example, the constructs resulting from amplification with Pml1-5EETa and 1-5EETMfe followed by cloning into either pIONTAS1_KB_lambda and pIONTAS1_KB_Kappa are shown in Figure 3C and 3D respectively.

Insertion of knottins into CDR2

The knottin donor was introduced into the CDR2 positions of pIONTAS1_KB_lambda and pIONTAS1_KB_Kappa by creating a PCR fragment with PstI and BspEI sites which was introduced by PCR. It was possible to introduce a PstI site into the first two residues of the CDR2 region of the IGKV1D-39 V kappa gene (within the Ala-Ala sequence). For convenience in cloning the same restriction site and encoded residues were introduced at the end of framework 2 of the V lambda germline gene IGLV1-36. In the lambda germline it was also possible to introduce a BspEI site into the 4th and 5th residues of the FW3 region encoding Ser-Gly) (Figure 3E). Again this restriction site and encoded amino acids were also introduced into the V kappa gene (Figure 3F).

The PCR primers PST1-5EETa was used to amplify EETI-II and introduces 2 Ala codons encompassing a PstI site for cloning (underlined) followed by 2 variable codons encoded by the sequence GNS (encoding Val, Ala, Asp or Gly) and VNS (encoding 16 amino acids within 24 codons) immediately after the PstI restriction site and preceding the knottin sequence. The VNS codon replaces the first amino acid of EETI-II with the net effect of adding 3 amino acids (2 Ala residues and one of Val, Asp, Ala or Gly) between the donor and recipient framework (Figure 3B).

PST1-5EETa ATC TAT GCT GCA GNS VNS TGC CCG CGT ATC CTG ATG CGT TGC (SEQ ID NO: 49)

At the 3' end of the incoming knottin donor, The PCR primers -5EETBse was used to amplify EETI-II. This introduces a BspEI site for cloning. The PCR product introduces the knottin donor followed by the glycine which naturally follows the last cysteine of EETI-II (Figure 3A). This is followed by 2 randomised amino acids which adjoin to the 4th and 5th

amino acids of FW3 after cloning. This has the effect of replacing the first three residues of FW3 with two randomised amino acids and retains the terminal glycine of the knottin (Figure 3B). The net effect is the loss of an amino acid between donor and framework 3.

5 1-5EETBse GTCAGAGACTTCCGGASNBSNBCCCGCA GAAGCCGTTCCGGACCGCA
(SEQ ID NO: 50)

As an example, the constructs resulting from amplification with PST1-5EETa and 1-5EETBse followed by cloning into either pIONTAS1_KB_Kappa or
10 pIONTAS1_KB_lambda are shown in Figure 3E and 3F respectively.

Example 2. Introduction of additional diversity into the recipient VL domain.

In humans there are 2 different classes of antibody light chain, (kappa or lambda) which are encoded by approximately 50 and 40 germline genes respectively. These can each be
15 arranged into families on the basis of sequence homology with 7 different kappa families (V kappa 1- V kappa 7) and 11 different lambda families (V lambda 1- V lambda 11). Examination of the germline sequences²⁹ permits the design of sense strand primers (“forward primers”) specific for different germline VL gene families.

20 In the course of antibody maturation individual VL germline genes are recombined with approximately 5 different kappa or lambda-specific J segments at their 3’ end. It is possible therefore to design a small number of forward and reverse primers to enable the amplification of re-arranged VL genes from human donors for construction of antibody phage display libraries as described for example in Schofield et al (2007)²⁸. In this example we demonstrate
25 how a similar approach can be used to amplify fragments of VL genes beginning at either FW2 or FW3 to the end of the VL gene. This allows introduction of diversity into recipient VL domains which have donor insertions in either CDR1 or CDR2. This approach therefore allows the introduction of additional diversity into a recipient domain downstream of the inserted donor.

30

Amplification of VL repertoires beginning at Framework 2.

Sequences of the families of V kappa and V lambda germline genes were aligned (data from IMGT²⁹) and PCR primers were designed to allow amplification of VL repertoires from the beginning at Framework 2. Lambda-specific primers (“Mfelam”) capable of amplifying from

the FW2 region of V lambda 1, 2 and 3 were designed. These primers were also designed to introduce an MfeI site (underlined) which is compatible and in frame with the MfeI site introduced at the end of the knottin gene described above. In a similar way, kappa-specific primers ("Mfekap") capable of amplifying from the FW2 region of V kappa 1, 2 and 3, were designed.

Mfelam 1 GTGTGGAGGTGGC AAT TGG TAC CAG CAG CTC CCA GG (SEQ ID NO: 51)

Mfelam 2 GTGTGGAGGTGGC AAT TGG TAC CAA CAG CAC CCA GG (SEQ ID NO: 52)

Mfelam 3 GTGTGGAGGTGGC AAT TGG TAC CAG CAG AAG CCA GG (SEQ ID NO: 53)

Mfekap1 GTGTGGAGGTGGC AAT TGG TAT CAG CAG AAA CCA GG (SEQ ID NO: 54)

Mfekap2 GTGTGGAGGTGGC AAT TGG TAC CTG CAG AAG CCA GG (SEQ ID NO: 55)

Mfekap3 GTGTGGAGGTGGC AAT TGG TAC CAG CAG AAA CCT GG (SEQ ID NO: 56)

These sense strand forward primers were used to amplify a repertoire of VL genes from a library which had previously been pre-cloned into the NheI/NotI site of a phage display vector (as shown in Figure 1). The introduced MfeI site is underlined and the sequence of Mfelam1 and Mfekap1 are represented at the beginning of FW2 in Figures 3E and 3F respectively. For kappa light chains a single reverse primer (JKFOR_Thr2) was designed which straddled the original cloning junction encompassing NotI including homology to the phagemid vector as well as the beginning of the cloned J kappa segment. For lambda light chains, a single primer (JLFORQP2) was designed which hybridised within the phagemid plasmid sequence, across the NotI cloning site and into the beginning of J lambda segment.

JLFORQP2 TGAGATGAGTTTTTGTCTGCGGCCGCGGGCTGACCTAG (SEQ ID NO: 57)

JKFOR_Thr2 TGAGATGAGTTTTTGTCTGCGGCCGCGGTACGTTTGAT (SEQ ID NO: 58)

Amplification with the paired kappa or lambda forward and reverse primers generated a PCR product encoding:

Mfe1-FW2-CDR2-FW3-CDR3-FW4-Not1. (SEQ ID NO: 59)

5

The primers introduce an Mfe1 site at the 5' end and a Not 1 site at the 3' end, compatible and in frame with the knottin PCR products described above and the phagemid display vector shown in Figure 1. This will allow the amplification of libraries of VL genes which can be fused to constructs encoding a knottin insertions at CDR1 by using restriction enzymes Mfe1 and Not 1. This introduces additional CDR2 and CDR3 diversity into the recipient VL domain. JLFORQP2 and JKFOR_Thr2 are anti-sense reverse primers and the reverse complementary encoding sense strand is represented in Figures 3C, 3D, 3E and 3F respectively as the FW4-Not1 region in the final construct.

10

15 *Amplification of VL repertoires beginning at Framework 3*

By a similar approach, sense strand forward primers were designed which hybridised with the beginning of FW3 of lambda VL genes ("Bsplam" primers) or kappa ("BspKap" primers) while introducing a BspE1 restriction site compatible with the BspE1 site introduced into the knottin constructs described above. The introduced BspE1 site is underlined and the sequence of Bsplam1a and BspKap1a are represented at the beginning of FW3 in Figures 3E and 3F respectively.

20

Bsplam1a ATCTATGCTGCAGGAGGTGGC TCC GGA GTC TCT GAC CGA TTC TCT GG (SEQ ID NO: 60)

25

Bsplam1e ATCTATGCTGCAGGAGGTGGC TCC GGA GTC cCT GAC CGA TTC TCT GG (SEQ ID NO: 61)

Bsplam2 ATCTATGCTGCAGGAGGTGGC TCC GGA TCC AAG TCT GGC AAC ACG GG (SEQ ID NO: 62)

Bsplam3 ATCTATGCTGCAGGAGGTGGC TCC GGA ATC CCT GAG CGA TTC TCT GG (SEQ ID NO: 63)

30

BspKap1a ATCTATGCTGCAGGAGGTGGC TCC GGA GTC CCA TCA AGG TTC AGT GG (SEQ ID NO: 64)

BspKap1b ATCTATGCTGCAGGAGGTGGC TCC GGA GTC CCA TCA AGG TTC AGC
GG (SEQ ID NO: 65)

BspKap2 ATCTATGCTGCAGGAGGTGGC TCC GGA GTC CCA GAC AGG TTC AGT
GG (SEQ ID NO: 66)

5 BspKap3 ATCTATGCTGCAGGAGGTGGC TCC GGA ATC CCA GcC AGG TTC AGT
GG (SEQ ID NO: 67)

When lambda –specific forward primers were used with the lambda-specific reverse primer (JLFORQP2) or when kappa –specific forward primers were used with the kappa-specific reverse primers ((JKFOR_Thr2) then a PCR product encoding the sequence below was produced.

BspE1-FW3-CDR3-FW4-Not1

15 This allowed the amplification of libraries of VL genes which can be fused to constructs with a knottin gene insertions at CDR2 by using restriction enzymes BspE1 and Not 1. This introduced additional CDR3 diversity into the recipient VL domain.

Using standard molecular biology techniques, constructs (as depicted in Figure 3) were created using gene fragments created as described above. These were cloned into
20 pIONTAS1_KB_Kappa” and “pIONTAS1_KB_lambda and were electroporated into E.coli TG1 cells and KnotBody library sizes of $3.5\text{-}6.6 \times 10^8$ were constructed using standard molecular biology techniques e.g. Schofield et al 2007²⁸.

25 Example 3: Isolation and characterisation of functional knottin-antibody fusion clones from the KnotBody libraries using phage display technology.

Phage display technology facilitates isolation of binders to any given target from large combinatorial repertoires based on proteins and peptides that can be presented on the surface of filamentous phage¹⁰⁵. In order to isolate functional knottin-antibody fusions from the
30 KnotBody libraries multiple rounds of phage display selections on trypsin (cognate antigen for the EETI-II donor) were carried out. Phage particles were prepared by rescuing KnotBody libraries using trypsin cleavable helper phage^{102,106}Two rounds of phage display selections were performed on 10 µg/ml biotinylated trypsin immobilised on Streptavidin (for Round-1) or Neutravidin (for round-2) coated Maxisorp™ immunotubes (Thermo Scientific,

Cat No. 444202). In both rounds of selection, phage libraries were pre-incubated with streptavidin coated paramagnetic beads (Thermo Fisher Scientific, Cat. No. 11205D). These beads were removed prior to the addition the phage to the antigen tubes to limit the streptavidin binders entering the selection. Polyclonal phage preparations from round-2
5 selection outputs were analysed for trypsin binding using a time resolved fluorescence (TRF) binding assay. In this assay, polyclonal phage binding to biotinylated trypsin immobilised on neutravidin (Thermo Fisher Scientific, Cat. No 31000) coated Maxisorp™ plates (Thermo Scientific, Cat. No. 437111) was detected using a mouse anti-M13 antibody (GE Healthcare, Cat. No. 27-9420-01) followed by europium conjugated anti-mouse antibody (Perkin Elmer,
10 Cat. No. AD0124).

Polyclonal phage from both EETI-II libraries showed good binding to trypsin in this assay, demonstrating the success of phage display selection in enriching KnotBodies that bind to trypsin (Figure 4). To investigate whether presentation of EETI-II by standard phage display
15 approach would work the EETI-II gene was cloned into a phagemid display vector²⁸ where it was directly fused to the N-terminus of gene III. Surprisingly EETI-II presented on phage, as a direct N-terminus gene-III fusion showed no detectable binding to trypsin while selected polyclonal phage from both EETI-II CDR fusion libraries showed trypsin binding. Importantly this result demonstrates that indirect presentation of knottins on phage via
20 antibody CDR loops (which is fused to gene-III) could be a superior alternative to direct knottin-gene III fusion.

In order to identify monoclonal KnotBodies with desired binding characteristics, 94 individual clones derived from 2 rounds of selection using EETI-II CDR1 or CDR2 libraries
25 were picked into 96 well culture plates and phage were prepared from each clone. Methods for screening by monoclonal phage ELISA are known in the art ¹⁰⁷. The phage supernatant from each clone was tested for binding to biotinylated trypsin immobilised on neutravidin coated Maxisorp™ plates using a TRF assay (as described above). A representative example of the monoclonal binding assay is shown in Figure 5. Clones with >3x binding signal above
30 background were picked as positive clones and sequenced to identify unique clones. 14 and 42 unique binders were identified from EETI-II CDR1 and EETI-II CDR2 libraries respectively (Table 1). 18 binders from the EETI-II CDR2 library and 3 binders from the EETI-II-CDR1 library were chosen for further characterisation based on their VL and linker sequence diversity. These binders were assigned new clone identification numbers (Table 2).

The trypsin binding capability of EETI-II is attributed to proline (Pro3) and arginine (Arg4) residues present in its loop1 (GCPRILMRC; SEQ ID NO: 68). In order to show that the selected KnotBodies bind to trypsin via a fully folded EETI-II displayed as a VL CDR fusion (ie not via other CDR loops or C or N-terminal fusion sequences), trypsin-binding residues (Pro3 and Arg4) of EETI-II were substituted for glycine (Gly) and alanine (Ala) respectively. Monoclonal phage was prepared from the 21 selected clones and their mutant equivalents. The phage supernatant from each clone was tested for binding to biotinylated trypsin (immobilised on streptavidin coated Maxisorp™ plates) using a TRF binding assay (as described above). Replacement of the trypsin-binding residues of EETI-II abolished the ability of all KnotBody clones to bind to trypsin (Table 3). In order to confirm that the loss of trypsin binding was not due to reduced expression or display of pIII fusion phage was prepared from 11 (randomly chosen) KnotBodies and their GlyAla variants were analysed on a western blot using an antibody which recognises the product of gene 3 (pIII) using an anti-pIII antibody (MoBiTec GmbH) (Figure 6). No significant difference in the amount of pIII fusion displayed was observed between any KnotBody clone and its GlyAla substituted variant. These data confirm that the trypsin binding functionality of these Knotody clones is resultant of correct display of the knottin donor (EETI-II) as VL CDR fusion and confirms that trypsin binding is directed by the EETI-II knottin donor.

Example 4. Crystal structure of KnotBodies selected from EETI-II CDR2 library

In order to generate crystal structures of KnotBodies, 18 clones isolated from the EETI-II CDR2 library (Table 3) were reformatted as Fabs. In this format the VH (from D1A12) gene is fused to a human IgG1 heavy chain constant domain 1(CH1) and the recipient VL chains containing the EETI-II are fused to a light chain constant domain (CL). Methods for expressing antibodies by transient expression in mammalian cells are well known to those skilled in the art¹⁰⁸. In order to enable the expression of these KnotBody Fabs in mammalian cells, VL chains encoding the knottin were PCR amplified using primers LLINK2 (CTCTGGCGGTGGCGCTAGC; SEQ ID NO: 69) and NotMycSeq (GGCCCCATTGAGATCCTCTTCTGAGATGAG; SEQ ID NO: 70). Amplified VL genes were digested with restriction enzymes *NheI* and *NotI* and ligated into the pINT12 vector (encoding D1A12 heavy chain) pre-digested with the same enzymes. The pINT12 vector (Figure 7) has a dual promoter expression cassette in which the heavy chain expression is

controlled by the cytomegalovirus (CMV) promoter and the light chain expression is driven by elongation factor-1 alpha (EF1-alpha) promoter.

In order to express the KnotBody Fabs in HEK-293F cells, transfection quality DNA was prepared using Plasmid Plus Kit (Qiagen, Cat. No. 12945). 24 µg of plasmid DNA was incubated with 48 µg of polyethylenimine (PEI) in 2 mls of Freestyle 293 expression medium (Thermo Fisher Scientific, Cat. No. 12338-018) for 15 minutes. After the incubation, DNA:PEI mix was added to 20 mls of HEK-293F cells (Thermo Fisher Scientific, Cat. No. R790-07) seeded at a density of 1×10^6 cells/ml in 125 ml tissue culture flasks. Culture flasks were incubated at 37°C for 5 days (with 5% CO₂, 75% humidity and shaking at 800 rpm). All transfection except KB_A03 successfully expressed KnotBody Fabs. Expressed proteins were purified from the cell culture supernatants using CaptureSelect IgG-CH1 affinity matrix (Life Technologies, Cat. No. 194320005) according to manufacturer's instructions. Purified proteins were dialysed against 2x PBS overnight and dialysed samples were visualised on a SDS-PAGE gel using Quick Coomassie staining (Generon, product reference, GEN-QC-STAIN). A representative example is shown in Figure 8A. The monomeric state of the purified KnotBody Fabs was confirmed by analytical size exclusion chromatography using a Superdex200 2.4mL column (GE HealthCare, 17-1089-01) and Akta Purifier system (GE Healthcare). All KnotBody Fabs showed chromatographic profiles corresponding to monomeric Fab species (Figure 8B).

In order to confirm the trypsin binding ability of KnotBodies in Fab format, purified proteins were tested for binding to trypsin using a TRF binding assay. In this assay binding of KnotBody Fabs (at 10 µg/ml, 2.4 µg/ml and 0.5 µg/ml) to biotinylated trypsin (immobilised on streptavidin coated Maxisorp™ plates) was detected using a mouse anti-CH1 antibody followed by a europium conjugated anti-mouse antibody (Table 4).

7 KnotBodies (KB_A04, KB_A01, KB_A05, KB_A07, KB_A08, KB_A10, KB_A12) were chosen for crystallisation. DNA prepared for these clones were transfected into 500 ml HEK-293F cells as described before. Expressed proteins were purified using CaptureSelect IgG-CH1 affinity matrix. Purified proteins were initially subjected to crystallisation trials using commercially available crystallisation screens (Supplier). Well-defined crystals were readily obtained for KB_A12 and KB_A05. Crystallisation conditions for these two clones were further optimised and the following condition was used to generate diffraction quality crystals: 0.1 M MES pH=6.5, 25 %w/v PEG MME 2000 and 0.1M Tris.Cl, 50% PEG MME,

10mM NiCl₂. Complete diffraction data was collected on these crystals at 100K under liquid nitrogen stream. Collected data was processed using PROTEUM2 software (Bruker). The crystal structure of the knottin-fused Fab antibodies was resolved using molecular replacement technique ¹⁰⁹ using Phenix software v 1.8.1-1168 ¹¹⁰. Resulting structure was further refined using Phenix.Refine ¹¹¹. The templates for molecular replacement were downloaded from PDB website (www.rcsb.org/pdb, PDB codes: 3G04 for light chain and 3QOS for heavy chain). KnotBody KB_A12 and KB_A05 sequences are given below. An additional AlaSer sequence is introduced at the N terminus of the light chain from the NheI site used in cloning.

10

KB_A12_Heavy chain

EVQLVESGGGLVRPGGSLRLSCAASGFTFSSYAMSWVRQAPGKGLEWVSAISGSGG
STYYADSVKGRFTISRDN TKNSLYLQMTSLRADDTAFYYCVDFGPGYGTGWFDYW
GPGTLTVSSASTKGPSVFPLAPSSKSTSGGTAALGCLVKDYFPEPVTVSWNSGALTS
15 GVHTFPAVLQSSGLYSLSSVVTVPSSSLGTQTYICNVNHKPSNTKVDKKVEPKSC
(SEQ ID NO: 71)

KB_A12_Light chain

QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGRCPRI
20 LMRCKQDSDCLAGCVCGPNGFCGANSGVSDRFSAAKSGTSASLAINGLRSEDEADYY
CAAWDDSLNGYVFGTGTKLTVLGQPAAAPSVTLFPPSSEELQANKATLVCLISDFYP
GAVTVAWKADSSPVKAGVETTPSKQSNNKYAASSYLSLTPEQWKSHKSYSCQVTH
EGSTVEKTVAPTECS (SEQ ID NO: 72)

25 KB_A05 Heavy chain

Evqlvesggglvrpggslrlscaasgftfssyamswvrqapgglewvsaisgsggstyyadsvkgrftisrdntknslylqmtslr
addtafyycvdfgpgygtgwfdywgpgtlvtvssastkgpsvfplapsskstsggtaalgclvkdyfpepvtvswngaltsgvh
tfpavlqssglyslssvvtvpssslgtqtyicnvnhkpsntkvdkkvepksc (SEQ ID NO: 73)

30 KB_A05 Light chain

QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAADKCPRI
LMRCKQDSDCLAGCVCGPNGFCGGGSGIPERFSGSKSGTSASLAISGLRSEDEADYYC
ATWDDNLNGVVFGGGTKLTVLGQPAAAPSVTLFPPSSEELQANKATLVCLISDFYPG

AVTVAWKADSSPVKAGVETTTTPSKQSNNKYAASSYLSLTPEQWKSHKSYSCQVTHE
GSTVEKTVAPTECS (SEQ ID NO: 74)

For both the data sets, molecular replacement solutions were successful indicating that the
5 overall fold of the knottin-fused Fab did not change. Upon fine refinement (Figure 9), it was
evident that the knottin-fused Fab antibody was correctly folded and the disulfide pattern of
the knottin part within the antibody was exactly same as that of EETI-II (Figure 10A), which
has been reported earlier (PDB ID: 1H9I). In addition the relative arrangement of the EETI-
II part from the Fab indicates that the CDR regions of the heavy chain are accessible for
10 potential binding to other antigen. Lack of electron density for VH CDR3 residues (Figure
10B) further strengthens this possibility. PDB coordinates

Example 5: Demonstration of bi-specific binding capability of the KnotBody format.

The concept of bi-specific antibodies that can bind to two different target antigens is
15 increasingly popular in drug development¹¹². Conventional bi-specific antibodies are
typically composed of two VH-VL pairs with different specificities (i.e. two distinct VH-VL
domain pairs that each recognise a different antigen). In this example, we describe the
development of a bi-specific KnotBody format. In this format, the binding determinants
required for recognition of two distinct antigens are incorporated within a single VH-VL pair.
20 This was achieved by using the VH to mediate one binding specificity and the knottin-VL
fusion to mediate the other binding specificity.

Two well-characterised KnotBody trypsin binders (KB_A07 and KB_A12, see example 3)
were used here as model scaffolds for engineering the bi-specific functionality. These
25 KnotBodies contains a common heavy chain gene from D1A12 antibody (anti-TACE
antibody)¹⁰¹ and two distinct light chain genes displaying EETI-II as a CDR2 fusion. The
trypsin binding capability of these KnotBodies is completely attributed to the VL domain
displaying EETI-II. Therefore, these fusions of recipient VL:donor knottin were recombined
with a large repertoire of naïve VH genes²⁸ to generate a library from which novel molecules
30 with additional VH mediated binding specificities can be isolated.

In a previous work Schofield and colleagues described the cloning of VH and VL gene
repertoires into an intermediate antibody library²⁸. This intermediate antibody library was
used to create a functional antibody phage display library ("McCafferty library" and the

“Iontas antibody library”²⁸). The same repertoire of VH genes was used in this example for the construction of the KnotBody heavy chain shuffled library. This was achieved by PCR amplifying VH genes from the Iontas antibody library bacterial stocks using primers M13 leaderseq (AAATTATTATTCGCAATTCCTTTGGTTGTTTCCT; SEQ ID NO: 75) and
5 HLINK3 (CTGAACCGCCTCCACCACTCGA; SEQ ID NO: 76). Amplified VH genes were digested with restriction enzymes *NcoI* and *XhoI* and ligated into the pIONTAS1_KB vector (encoding KB_A017 and KB_A12 light chain) pre-digested with the same enzymes. The ligation product was purified using MiniElute PCR purification kit (Qiagen, Cat. No. 28004) and electroporated into E.coli TG1 cells (Lucigen, Cat. No. 60502-2). Phage was rescued
10 from this library as described in example 3¹⁰⁷

In order to identify bi-specific KnotBodies with novel binding specificities mediated by the VH domain, two rounds of phage display selections were carried out against 5 different antigens (human-cMET-Fc fusion, mouse-FGFR4-CD4 fusion, human-GAS6-CD4 fusion,
15 human-urokinase type plasminogen activator and β -galactosidase). cMET-Fc, FGFR4-CD4, GAS6-CD4 and urokinase type plasminogen activator (UPA) were immobilised directly on MaxisorpTM immunotubes. biotinylated β -galactosidase (bio-B-gal) was indirectly immobilised on MaxisorpTM immunotubes coated with streptavidin (round-1) or neutravidin (round-2). Phage selections were performed as described in example 3. Polyclonal phage
20 prepared from the round-2 selection outputs were tested in a TRF binding assay (as described in example 3) against all 5 antigens, trypsin and the immobilisation partners (streptavidin and neutravidin). All polyclonal phage populations showed specific binding to trypsin and the antigen they were selected against but not other antigens (Figure 11). For example, the binding signals obtained for polyclonal phage prepared from cMET-Fc selection were
25 specific to trypsin and cMET. This result demonstrates the success of phage display selection in enriching bi-specific binders. In order to identify monoclonal binders, 48 individual clones were picked from each selection output and monoclonal phage was prepared from each clone (as described in example 3). Monoclonal phage supernatant from each clone was tested for binding to trypsin and the antigen used for selection (representative example of the screen is
30 shown in Figure 12). Any clone that showed a binding signal above 15000 fluorescent units on both trypsin and the selection antigen was considered to be a bi-specific binder. Large panels of bi-specific binders were identified from each selection output (Table 5).

Example 6: Demonstration of bi-epitopic binding capability of the KnotBody format

In the previous example we demonstrated the capability of a knottin scaffold to bind to two different antigens via distinct paratopes, one located on the recipient-donor fusion (ie VL-knottin) and the other on the VH. The same principle can be applied to target two different epitopes within a single target antigen where VH directed binding could be used for increasing the affinity and/or specificity of the original interaction (mediated by the knottin). By this approach, the additional binding properties of the VH domain can be utilised to improve the potency or specificity of knottin based drugs. Alternatively, such additional contribution to binding can also be directed by VL CDR3 using the approach described in example 2. In this example, we demonstrate bi-epitopic binding capability of the knottin scaffolds by improving the affinity of anti-trypsin KnotBodies (KB_A07 and KB_A12, see example 3) by introducing novel heavy chain partners that bind independently to trypsin. KB_A07 and KB_A12 contain a common VH domain (D12) that binds to the dis-cys domain of tumour necrosis factor- α converting enzyme¹⁰¹ and a VL domain that binds to trypsin via EETI-II (displayed at the CDR2 position). In order to identify novel heavy chain partners that bind to a distinct epitope on trypsin (and improve the overall affinity), a phage display library was generated by replacing the D1A12 VH of these two KnotBodies with a large repertoire of naïve heavy chains (see example 5). Affinity improved clones were isolated from this “chain-shuffled” library by performing three rounds of phage display selections on trypsin under stringent conditions that favour preferential enrichment of high affinity clones. The stringency of selection was controlled by using decreasing amounts of trypsin in each round of selection (Figure 13). The optimum antigen concentration for each round was determined empirically by selecting the KnotBodies against a range of antigen concentrations and comparing the phage output numbers with a no-antigen control. Round 1 selection was carried out by panning on antigen immobilised on Maxisorb immunotubes as described in example 5. The population from round 2 selections, carried out at 20nM antigen concentration, was chose for a further round 3rd round.

KnotBody genes from round 2 (20 nM selection) and round 3 (2 nM and 0.2 nM selections) outputs were PCR amplified using primers M13 leaderseq (See example 4) and NotMycSeq (GGCCCCATTCAGATCCTCTTCTGAGATGAG; SEQ ID NO: 70). PCR products were digested with *Nco*I and *Not*I restriction enzymes and cloned into the pBIOCAM5-3F vector via *Nco*I and *Not*I. The pBIOCAM5-3F allows the expression of antibodies as soluble scFv-Fc fusion proteins in mammalian cells¹¹³, hence facilitating the screening for affinity

improved KnotBody binders. 352 clones (resulting from the pBIOCAM5-3F cloning) were picked into 4x96 well cultural plates. Transfection quality plasmid DNA was prepared for each clone using the Plasmid Plus 96 kit (Qiagen. Cat. No.16181). 600 ng of each plasmid DNA was incubated with 1.44 µg of polyethylenimine (PEI) in Freestyle HEK-293F

5 expression medium (Thermo Fisher Scientific, Cat. No. R790-07) for 15 minutes before adding to 96-well deep well plates containing 500 µl/well of exponentially growing HEK-293F cells at a density of 1×10^6 cells/ml. Plates were sealed with gas permeable seals and incubated at 37°C for 5 days (with 5% CO₂, 75% humidity and shaking at 800 rpm). Cell culture supernatant containing KnotBody-Fc fusion proteins was used for screening to
10 identify affinity-improved clones.

The binding signal observed for a particular clone in the primary binding screen (e.g. TRF binding assay using monoclonal phage supernatant) is a combined function of affinity and expression. Since protein expression can vary significantly from clone to clone, ranking

15 KnotBodies by their binding signal in the primary screen might not necessarily correlate with their affinities. Therefore two expression-independent screening assays were used to rank the KnotBody clones by affinity and compare to them with parent clones. There were (i) TRF capture assay and (ii) Biacore off-rate screen. In the “TRF capture assay” (Figure 14), KnotBody-scFv-Fcs were captured on Maxisorp™ plates coated with an anti-Fc antibody
20 (Abcam, Cat. No. ab113636) and the binding of biotinylated trypsin to KnotBodies was detected using streptavidin conjugated europium (Perkin Elmer, Cat. No 1244-360). To normalise for differences in KnotBody (scFv-Fc) expression, limiting amounts of anti-Fc antibody was coated on each well. For example, a well coated with 50 µl of anti-Fc antibody at a concentration of 2.5 µg/ml (32nM) has a maximum (theoretical) capture capacity of 1.6
25 fmoles of scFv-Fc. However, the average scFv-Fc expression in HEK-293F cells using pBIOCAM5-3F vector system is 10-20 mg/l (83-166 nM) and 50 µl of the raw supernatant used for the assay will have 4.1-8.2 fmoles of scFv-Fc on average, hence saturating the immobilised anti-Fc antibody coated on each well. The majority of the KnotBodies selected from VH shuffled libraries showed higher binding signal against trypsin than the parent
30 clones (representative example is shown in Figure 15). 90 KnotBodies that gave the highest binding signal in the capture assay were cherry-picked and tested in the “Biacore off-rate screen”. In the “Biacore off-rate screen” the dissociation constants (off-rates) of the KnotBody clones were analysed by surface plasmon resonance (using Biacore T100 from GE healthcare). The dissociation constant of an antibody-antigen interaction is concentration

independent and therefore normalisation for differential expression was not required. In this assay, a CM5 sensor chip (GE healthcare, Cat. No. BR-1005-30) was coupled to approximately 3000 resonance units (RU) of anti-Fc antibody (human antibody capture kit, GE healthcare, Cat. No. BR-1008-39). Approximately 1200-1600 RU of KnotBody-scFv-Fc was captured on the anti-FC antibody. The trypsin solution (400 nM) was injected for 60 seconds. The dissociation phase of each KnotBody trypsin interaction was monitored for 300 seconds. After each cycle, the chip surface was regenerated by injecting 3M MgCl₂. The dissociation constant (K_d) for each KnotBody was determined using 1:1 Langmuir binding model (using Biacore T100 evaluation software). Clones that showed 1.5 fold slower dissociation constants than their parent clones were considered to have improved affinity (Table 6). Overall, 22 affinity improved clones were identified using capture assay and the off-rate screen. A representative example of a clone that showed improved off-rate compared to the parent clones is shown in Figure 16. This improvement in the affinity of the KB_A07 and KB_A12 clones by heavy chain shuffling demonstrates the bi-epitopic binding capability of the KnotBody format.

Example 7: Cloning, expression and purification of various cysteine-rich toxin donors within CDR3 of an antibody VL recipient scaffold.

Aberrations in normal ion channel functioning are involved in the pathogenesis of number of disease conditions including pain disorders and auto-immunity. For example defects in the function of the voltage gated sodium channel 1.7 (Nav1.7) play a major role in both hypersensitivity and insensitivity to pain. The voltage gated potassium channel 1.3 (Kv1.3) is implicated in T-cell mediated autoimmunity. The acid sensitive ion channel 1a (ASIC1a) is involved in the sensing and processing of pain signals. Thus, specific modulators of ion channels offer a great therapeutic potential in the treatment of pain and various autoimmune disorders. Number of naturally occurring knottins function as ion channel blocking toxins. As discussed earlier, the only knottin based drug (Ziconotide) approved for therapy is an N-type voltage gated calcium channel blocker derived from the venom of the conus snail.

This example describes the fusion of alternative cysteine-rich toxin donors into the previously selected recipient VL scaffolds to create KnotBodies directed towards ion channels (Table 7). This was achieved by cloning three Nav1.7 blockers, three Kv1.3 blockers and three acid sensing ion channel 1a (ASIC 1a) blocker into the CDR2 position of two KnotBodies KB_A07 and KB_A12 (i.e. replacing the EETI-II gene at that position, as described in

example 3). Genes encoding all toxins (Table 8) were synthesised as gene fragments (from Integrated DNA Technologies). Each toxin gene was PCR amplified using primer sets that encodes junctional sequences specific to KB_A07 and KB_A12 (Table 9). An additional variant of Ssm6a (Ssm6s_GGS) incorporating linker sequences (GGS at the N-terminus and SGG at the C-terminus) was also PCR amplified. In this example, the KnotBody constructs were formatted as IgG molecules where the VH gene is fused to IgG1 heavy chain constant domains (CH1-CH2-CH3) and the recipient VL chains containing the new donor toxins are fused to a light chain constant domain (CL). In order to express these KnotBody constructs in mammalian cells, PCR fragments were cloned into the PstI and BspEI sites of KB_A12 and KB_A07 VL chain (encoded by the pINT3-hg1 vector, Figure 17). The pINT3-hg1 vector has a dual promoter expression cassette in which the heavy chain expression is controlled by the cytomegalovirus (CMV) promoter and the light chain expression is driven by elongation factor-1 alpha (EF1-alpha) promoter.

In order to express the KnotBodies in mammalian cells, transfection quality DNA was prepared using Plasmid Plus Kit (Qiagen, Cat. No 12945). 60 µg of plasmid DNA was incubated with 120 µg of polyethylenimine (PEI) in 5 mls Freestyle 293 expression medium (Thermo Fisher Scientific, Cat. No. 12338-018) for 15 minutes before adding to 50 mls of HEK-293F cells (Thermo Fisher Scientific, Cat. No. R790-07) seeded at a density of 1×10^6 cells/ml in a 250 ml tissue culture flask. Culture flasks were incubated at 37°C for 5 days (with 5% CO₂, 75% humidity and shaking at 800 rpm). Expressed proteins were purified from the cell culture supernatants using Protein-A affinity chromatography (Protein-A sepharose from Generon, Cat. No. PC-A5). Purified proteins were dialysed against 2x PBS and dialysed samples were visualised on a SDS-PAGE gel using Quick Coomassie staining (Generon, product reference, GEN-QC-STAIN). A representative example is shown in Figure 18. The average expression levels (7.7 mg/l) obtained for these fusion molecules in HEK293F cells were comparable to that of conventional antibodies produced using the same vector system (4 mg/l). Protein yield after purification is given in Table 10. In the case of mambalgin fusions, DNA was transfected into CHO-Expi cells as described in example 11 and these yields are given.

In summary, results described in this example illustrate that (i) ion channel blocking toxins can be expressed as donors within a fusion with VL domain recipients (e.g. KnotBodies); (ii) knottin scaffolds other than EETI-II can be formatted as KnotBodies or in other words, the

KnotBody format is capable of functional presentation of multiple knottins (ii) These fusion molecules can be expressed and purified efficiently as IgGs.

Example 8: Functional validation of Kv1.3 and ASIC1a blockers expressed as KnotBodies

- 5 Knottin Kv 1.3 and ASIC1a blockers expressed in the KnotBody format (see examples 6 and 7) were tested for their ability to inhibit the function of the ion channel targets. The effect of these KnotBodies on cells expressing the human Kv 1.3 (huKv1.3) or human ASIC1a channels was assessed using QPatch automated whole-cell patch-clamp electrophysiology (Sophion).
- 10 For the testing of Kv1.3, CHO cells stably expressing huKv1.3 (Charles River Lab) were analysed using the QPatch electrophysiology assay in the presence or absence of the KnotBody fusions or the antibody isotypes (negative) controls. Internal and external physiological solutions were freshly prepared prior to the assay. The extracellular solution contained 145 mM NaCl, 4 mM KCl, 2 mM CaCl₂, 1 mM MgCl₂, 10 mM HEPES and 10
- 15 mM glucose; the pH was adjusted to 7.4 with NaOH; the osmolarity was ~ 305 mOsm/L. The intracellular solution contained: KF (120 mM), KCl (20 mM), HEPES (10 mM) and EGTA (10 mM); the pH was adjusted to 7.2 with KOH; osmolarity was ~ 320 mOsm/L.

- A series of depolarising voltage (channel activating) pulses were used to monitor the channel currents upon adding control (extracellular solution) to define a control baseline of current
- 20 activity. To these measured control currents ascending concentrations of KnotBodies or parental antibody isotypes (control molecules) were applied to the external bathing solution (2.2 μ M - 0.5 nM, diluted in the extracellular solution). KnotBodies KB_A12 and KB_A07 (EETI-II fusions) were used as isotype controls for the testing. From a holding voltage of -80 mV a depolarising, activating voltage pulses of +30 or +80 mV were applied for 300 ms,
- 25 every 5 or 10 seconds. The elicited, maximum outward current values measured during the activating step for each solution exchange period were averaged (n = 3 – 8 for each concentration applied) and plotted as concentration-response curves. From these concentration-response curves (see example plots in Figure 21) IC₅₀ values were calculated (summarised in Table 11A). KB_A07_Shk, KB_A12_Shk and KB_A07_Kaliotoxin (KTX)
- 30 fusion proteins all inhibited the huKv1.3 currents in a concentration dependent manner with IC₅₀s of approximately 20 nM, 40 nM and 900 nM respectively. In comparison, the parental KnotBodies, KB_A12, KB_A07, Moka-1 on both recipient scaffolds and Kaliotoxin on

KB_12 showed no significant reduction in measured current ($\sim IC_{50}$ extrapolated to $> 10 \mu M$), which were similar in magnitude to the reduction in current recordings made in control external solution additions over the same time period (four applications each of four minutes duration, 16 minutes in total).

- 5 To functionally assess the ASIC1a KnotBodies, HEK293 cells stably expressing huASIC1a (Sophion) were analysed using a QPatch electrophysiology assay in the presence or absence of the KnotBody fusions (using KB_A12 as a recipient and replacing the original EETI-II donor as shown in Table 8). The “parental” KB_A12 with the EETI-II donor was used as a negative control. Internal and external physiological solutions were freshly prepared prior to
10 the assay. The extracellular solution contained 145 mM NaCl, 4 mM KCl, 2 mM $CaCl_2$, 1 mM $MgCl_2$, 10 mM HEPES and 10 mM glucose; the pH was adjusted to 7.4 with NaOH (for control, resting-state pH) or 6.0 with MES (for acidic, activating-state pH); the osmolarity was ~ 305 mOsm/L. The intracellular solution contained: CsF (140 mM), HEPES (10 mM), NaCl (10 mM) and EGTA/CsOH (1 mM/5 mM); the pH was adjusted to 7.3 with CsOH;
15 osmolarity was ~ 320 mOsm/L.

- Throughout ASIC1a recordings the recording cell membrane voltage was clamped at -60 mV. ASIC1a baseline control currents were elicited by applying external solution at activating pH 6.0 for 3000 ms. This activating pH application was repeated three further times, giving four baseline control ASIC1a currents. The recording cells were then pre-incubated with
20 KnotBody diluted in external solution at pH 7.4 for 15-20 minutes. Following this KnotBody pre-incubation the same concentration of KnotBody in external solution at activating pH 6.0 was applied to the cell recording.

- At the end of each KnotBody incubation and subsequent ASIC1a current activation, a full blocking concentration (300 nM) of the ASIC1a knottin inhibitor PcTx1 (positive control)
25 was perfused onto the cell recording and a final activating pH 6.0 external solution was applied. The percentage remaining signal between activating pH 6.0 baseline (i.e. pre-KnotBody) and post-KnotBody incubation was determined. From these figures (see Table 11B), it can be seen that KnotBodies KB_A12_PcTx1 and KB_A07_PcTx1 were active, reducing the ASIC1a current to 4.8% which is the same level as seen with positive control
30 application of PcTx1 (1.9-3.8%). KB_A12_Mba-1 and KB_A12_Mba-2 showed the same level of current as the KB_A12 negative control or the “buffer only” control.

The data above illustrates the potential to fuse knottins which have therapeutic potential (i.e. ion channel blockers) into a recipient antibody scaffold which was originally selected for fusing to a different knottin (i.e. EETI-II).

5 Example 9: Functional fusion of non- knottin donors to recipient VL domains of antibodies.

This example describes the fusion of a non-knottin donor diversity scaffold domain to a recipient VL domain. Non-knottin donor diversity scaffold domains that lack disulfide bonds could be valuable alternative to knottins. As discussed before a diverse number of protein scaffolds have been engineered for novel binding specificities^{38, 114}. Here we use a small
10 protein scaffold (approx. 100 amino acids) called an Adhiron, which is based on consensus sequence of plant-derived phytostatins (protein inhibitors of cysteine proteases). Adhiron shows high thermal stability and express well in *E.coli*⁴⁶. They are structurally distinct from knottins and do not contain any cysteine residues.

15 As donors we chose two engineered adhiron, which bind the lectin-like oxidized low-density lipoprotein receptor-1 (LOX-1) to replace EETI-II at the VL CDR2 position of VL chains (recipients) from KB_A07 and KB_A12 (example 3). Sequences for these adhiron (referred to as Ad-LOX1-A and Ad-LOX1-B, Table 12) were obtained from patent WO2014125290 A1 and were as synthesised as gene fragments to enable cloning (Table 13). Each adhiron
20 gene was amplified using primer sets specific for KB_A07 and KB_A12 (Table 14) using PCR. PCR products were cloned into the PstI and BspEI sites of the pIONTAS1_KB phage display vector (Figure 1) encoding KB_A12 and KB_A07 genes.

In order to test the functionality of these adhiron-antibody fusions, monoclonal phage
25 prepared from each clone was assessed for binding to LOX-1 in a TRF binding assay. In this assay, LOX-1 (immobilised directly on Maxisorp™ plates) binding of phage displaying adhiron-antibody fusion was detected using a mouse anti-M13 antibody (GE Healthcare) followed by europium conjugated anti-mouse antibody (Perkin Elmer). Parent KnotBodies KB_A07 and KB_A12 (EETI-II fusions) were included as controls. Proteins cMET-FC,
30 GAS6-CD4, FGFR4-CD4, UPA and B-gal were used to examine non-specific binding. The result from this assay (Figure 19) shows that all adhiron antibody fusions specifically bind to the LOX-1. The parent clones, KB_A07 and KB_A12, showed no detectable binding to the LOX-1 confirming that LOX-1 binding shown by the adhiron-antibody fusion molecules is mediated by the adhiron (displayed in the VL CDR2 loops of these antibodies).

In this example, we have demonstrated that non-knottin donor diversity scaffolds can be inserted into a recipient VL scaffolds to create alternative KnotBody formats.

5 Example 10. Identification of loop regions for insertion of donor sequence or introduction of diversity in donor, recipient or partner sequences

The method described in example 1 to insert a donor knottin sequence into a recipient Ig domain can be applied to the identification of sequences which join secondary structural elements of other scaffolds as potential sites for donor insertion.

10

For Ig domains, the framework and CDR designations are as described by the International Immunogenetics Information System (IMGT) database. According to the IMGT v3.1.10, numbering CDR1, CDR2 and CDR3 sequences occupy amino acid positions 27-38, 56-65 and 105-117 respectively (for all VH and VL sequences). FW1, FW2 and FW3 residues
15 occupy 1-26, 39-55 and 66-104. At the end of the re-arranged V gene FW4 is encode by 6 J segments for VH, 5 J segments for V kappa and 7 J segments for V lambda (in each case encoding 11, 10 and 10 amino acids respectively for each FW4).

In one approach, an individual CDR may be removed in its entirety and replaced by an
20 incoming donor sequence which is flanked by linkers of no more than 4 amino acid residues at each of the N and C termini. In another approach, some CDR residues may be retained but the total number of residues, including CDR residues, which link the incoming donor diversity scaffold to the scaffold of the recipient Ig diversity scaffold may not exceed 4 amino acids at each terminus (to retain close proximity between donor and recipient). In yet another
25 approach, variation framework residues at the boundary of the junction may be removed from the donor or recipient scaffolds and replaced by randomized codons encompassing some or all amino acids. The overall linkage at N and C termini (excluding the replacement framework residues) shall not exceed 4 amino acids.

30 The gene or population of genes encoding the fusion designed in this way can be created using methods known to those skilled in the art (also exemplified in examples herein). The gene may be made entirely as a synthetic gene or created from gene fragments arising from restriction digestion or PCR and incorporated into the final fusion gene by PCR assembly or ligation. Gene fragments and/or PCR products can be joined ligation independent cloning,

Gibson cloning, NEB Builder (NEB) or other methods known to those skilled in the art. The resultant genes can then be cloned into an appropriate expression vector as discussed above.

5 The approach above takes advantage of the IMGT database as a curated source of sequence information on Ig domains. The same approach described above may be used to cover all domains with a known structure. References to the pdb files which describe individual protein structures can be found in original citations (e.g. in references cited herein or references therein). The RCSB protein data bank (“pdb server”) represents a portal to structural information on biological macromolecules such as protein domains. Other sources
10 for accessing structural data, including PDBSUM have been summarised¹¹⁵. The data associated with such files also allows identification of secondary structure elements by viewing 3D structures or by using software such as DSSB or websites running such software¹¹⁶. Using this approach, secondary structural representations upon a primary amino acid sequence may be derived. Alternatively, structural model or direct sequence alignment
15 between a desired recipient domain and orthologues or paralogues with known structure could be used to identify secondary structure elements. Alternatively, algorithms for prediction of secondary structure elements could be used

20 The structure of the 10th type III cell adhesion domain of fibronectin ¹¹⁷ may be used to exemplify an approach to identify potential sites within a candidate recipient domain for insertion donor sequences. The same approach can be used to identify regions which could be amenable to diversification in both donor, recipient and partner chains.

25 As an example, the pdb file describing the 10th type III cell adhesion domain of fibronectin (FnIII-10) is “1FNA”. Using the pdb file (e.g. by viewing on the pdb server) a representation of the linear amino acid sequence of FnIII-10 annotated with secondary structural elements can be generated (Figure 20A). The regions which form beta strands are underlined and the residues which join them on the upper face of the domain are shown in lower case. In a further example the gp2 ⁵¹ has a structure represented by pdb file 2WMN. A linear
30 representation of the secondary structure elements is represented in Figure 20B. Residues joining beta strands or a beta strand-alpha helix junction are underlined.

These “joining sequence” represented in lower case represent regions which could be replaced partially or in their entirety while maintaining a short linker between donor and

recipient. As discussed above, framework residues may be removed at the boundary of the junction of the recipient scaffolds and replaced by randomized codons encompassing some or all amino acids. These same residues represented in Figure 20 also represent possible sites amenable to introduction of diversity as described above.

5

Gp2 is a small protein domain of 64 amino acids with N and C termini which are in proximity and so this molecule also represents an ideal candidate for a donor domain. In addition it has been shown that the N and C termini of Gp2 can be truncated without affecting folding of the domain allowing fusion in close proximity to a recipient domain.

10

Example 11. Selected linkers are required for functional expression of knottin donor domains within an antibody recipient domain.

In contrast to peptide fusion approaches employed by others which utilise long flexible linkers for joining domains, the KnotBody format uses short non-flexible linker sequences to limit the relative movement between the donor and recipient domains. This is an important aspect of the invention. In order to identify suitable linkers permitting correct folding of 2 fused structural domains we have adopted the approach of making a library with variation in the linker. In example 3 and example 12 we have described the isolation of several functional KnotBody molecules with selected, short, non-flexible linker sequences joining the EETI-II (donor domain) with framework residues of VL or VH domains (recipient).

20

To demonstrate the importance of linker selection the selected short linkers of two well characterised KnotBodies, KB_A07 and KB_A12, were replaced with the long flexible N- and C terminal linkers typically used by others^{11, 13, 15} (See table 15). The performance of these linker variants were then compared to that of the original KnotBodies with short non-flexible linkers selected from the library using a trypsin binding assay.

25

In this example, the KnotBody variants were formatted as Fabs where the VH gene is fused to the heavy chain constant domain-1 (CH1) and the VL chains containing KnotBody linker variants are fused to the light chain constant domain (CL). The VL genes encoding the knottin and linker sequences were synthesised as gene fragments (Integrated DNA Technologies, See table 16). In order to express the KnotBody linker variants in mammalian cells, these gene fragments were cloned into the pINT12 expression vector (encoding D1A12 heavy chain) using *NheI* and *NotI* restriction sites.

30

The pINT12 vector (Figure 7) has a dual promoter expression cassette in which the heavy chain expression is controlled by the cytomegalovirus (CMV) promoter and the light chain expression is driven by elongation factor-1 alpha (EF1-alpha) promoter.

5

In order to express the KnotBodies in mammalian cells transfection quality DNA was prepared using NucleoBond Xtra Midi plus kit (Macherey Nagel, Cat. No. 740412.50). 25 µg of plasmid DNA was incubated with 80 µl of ExpiFectamine CHO transfection reagent (Thermo Fisher scientific, Cat. No. A29129) in 2 mls of OptiPRO Serum Free Medium (Thermo Fisher Scientific, Cat.No. 12309050) for 5 minutes before adding to 25 mls of Expi-CHO cells (Thermo Fisher Scientific, Cat. No. A29133) seeded at a density of 6×10^6 cells/ml in a 125 ml tissue culture flask. Culture flasks were incubated at 37°C for 7 days (with 5% CO₂, 75% humidity and shaking at 800 rpm) with a single feed 18-22 hour post transfection. The feed included 6 mls of ExpiCHO feed containing 150 µl of enhancer solution. Expressed proteins were purified from cell culture supernatants using CaptureSelect IgG-CH1 affinity matrix (Thermo Fisher Scientific, Cat. No. 194320005) according to manufacturer's instructions. Purified proteins were dialysed against 2x PBS overnight. Protein concentrations were determined using absorbance at 280 nm and theoretical extinction co-efficient.

10

15

20

25

In order to compare the performance of the KnotBodies with short and long linkers, purified Fabs were tested for binding to trypsin by ELISA. In this assay binding of KnotBody Fabs (at 0.5 µg/ml) to biotinylated trypsin (5 µg/ml immobilised on streptavidin coated Maxisorp™ plates) was detected using a mouse anti-CH1 antibody (Hybridoma Reagent Laboratories) followed by a europium conjugated anti-mouse antibody (Perkin Elmer, Cat. No. AD0124). The trypsin binding capability of KB_A07 and KB_A12 KnotBodies were greatly diminished when the short selected linkers were replaced with long and flexible linkers (Figure 22). This example clearly demonstrates the importance of short non-flexible linkers for generating optimal donor-recipient fusions.

30

Example 12. Introduction of diversity into donor domain by randomising donor interaction domains

Examples 5 and 6 showed the use of VH shuffling to generate sequence diversity within the binding partner domain of a KnotBody to select for variants with additional specificity or improved binding kinetics. In both examples, diversification was performed on the partner

domain (VH domain) and the original binding specificity of the donor domain (knottin) was unchanged. In examples 2 and 3 we illustrated the introduction of diversity into the VL recipient domain. In this example, we demonstrate a different approach to introduce sequence diversity in the donor domain of a KnotBody: replacing the existing loops in the donor

5 knottin with random amino acid sequences. The trypsin binding capability of the KnotBodies described in this patent was conferred by the loop 1 sequences (PRILMR) of the knottin-EETI-II. Here we replaced the loop 1 sequences of KB_A12 KnotBody with randomised sequences of varying lengths (6, 8, 9 and 10 residues) to increase diversity as well as potential binding surface. The resulting loop libraries were then used to generate cMET and

10 β -galactosidase binding specificities using phage display technology.

In order to create large phage display libraries with high proportion of loop substituted variants an oligonucleotide-directed mutagenesis approach using Kunkel mutagenesis (Kunkel, T. A., et al. *Meth. Enzymol.* 154, 367–382 (1987), and selective rolling circle amplification Huovinen, T. *et al. PLoS ONE* 7, e31817 (2012) was used. Oligonucleotides

15 used encoded VNS codons (V = A/C/G, N = A/G/C/T and S = G/C) that encode 16 amino acids (excludes cysteine, tyrosine, tryptophan, phenylalanine and stop codons) at a given position. The mutagenic oligonucleotides used, representing the antisense strand (where B=TGC), are given in Table 18.

20 The template DNA encoding KB_A12 (in the phage display vector, pSANG4²⁸) was purified as uracil containing single stranded DNA (dU-ss DNA) from phage rescued from *E.coli* CJ236 (a *dut/ung⁻* strain). The antisense oligonucleotides described above were annealed to the dU-ssDNA template and extended using T7 polymerase to produce the complementary strand. Newly synthesised heteroduplex DNA was subjected to rolling circle amplification

25 using random hexamers (Thermo Fisher Scientific, Cat. No. S0142) and Phi29 polymerase (Thermo Fisher Scientific, Cat. No. EP0091) to selectively amplify the mutant strand. The product of rolling circle amplification was cut to plasmid size units using *NotI* restriction endonuclease (New England Bio labs, Cat. No. R3189S) and re-circularised by self-ligation. The ligation product was purified using MiniElute PCR purification kit (Qiagen, Cat. No.

30 28004) and electroporated into *E.coli* TG1 cells (Lucigen, Cat. No. 60502-2). Methods for kunkel mutagenesis and selective rolling circle amplification are known to those skilled in the art. Phage was rescued from this library as described in example 3.

In order to isolate KnotBody loop binders with novel specificities, two rounds of phage display selections were carried out against human cMET and β -galactosidase immobilised directly on directly on Maxisorp™ immunotubes. Phage selections were performed as described in example 3. KnotBody VL genes from round 2 outputs were PCR amplified using primers LLINK2 (SEQ ID NO: 69) and NotMycSeq (SEQ ID NO: 70). Amplified KnotBody VL genes were digested with *NheI* and *NotI* and ligated into the pSANG4 vector (encoding D1A12 heavy chain) pre-digested with the same enzymes. The ligation products were transformed into *E.coli* TG1 cells. In order to identify monoclonal binders, 47 individual clones were picked from each transformation and monoclonal phage was prepared from each clone (as described in example 3). Monoclonal phage supernatant from each clone was tested for binding to the antigen used for selection using a TRF binding assay. 30/47 clones tested bound c-Met and 37/47 clones bound β -galactosidase (Figure 23). Binders from this assay were sequenced using the primer LMB3 (CAGGAAACAGCTATGACC: SEQ ID NO: 77). 23 unique sequences were identified for cMET (Table 17A) and 11 unique sequences identified for β -galactosidase (Table 17B). Although the natural length of loop 1 of EETI-II is 6 residues, all novel binders isolated from the loop library possessed a loop size of either 8 or 9 amino acids.

This example clearly demonstrates that additional diversity can be introduced on to a KnotBody by substituting the existing knottin loops with random sequences of varying lengths. This loop substitution/randomisation approach can be used to acquire a new specificity (as described in examples 5) or fine tune the existing specificity or affinity mediated by the donor or recipient domain.

Example 13: Generation of bi-specific KnotBodies that can cross the blood brain barrier (BBB) via Receptor Mediated Transcytosis (RMT)

Crossing the blood-brain barrier (BBB) constitutes a major challenge for the delivery of peptides and antibodies into the brain for the treatment of neurological disorders (e.g. chronic pain, Alzheimers disease, multiple sclerosis, epilepsy). For example, approximately 0.1% of circulating antibodies cross into the brain (Zuchero, Y. J. Y. et al. Neuron 89 p70-82 (2015). Alternatively, therapeutics such as Ziconotide (a knottin from Conus snail venom) are administrated using intrusive and expensive intrathecal injection procedures. Hence, the development of effective strategies to deliver molecules across the BBB has been a long-standing goal for the pharmaceutical industry (Niewoehner, J. et al. Neuron 81, 49-60 (2014).

In recent years, the main focus of this research has been the generation of molecules capable of shuttling drug moieties across the BBB by taking advantage of endogenous nutrient transport systems for example receptor mediated transcytosis (RMT). This is generally achieved using a bi-specific format that includes a “molecular shuttle” and an active the drug moiety. For example, Yu and co-workers have reported a conventional bi-specific antibody which transports an anti-Beta secretase-1 (BACE) inhibitor across the BBB using a “molecular shuttle” that binds transferrin receptor (TFR) (Yu, Y. J. et al. Sci Transl Med 3, 84ra44–84ra44 (2011)). This bi-specific antibody format consists of 2 distinct VH: VL pairs (ie 2 different Fab arms) which individually recognise either TFR or BACE. In example 5, we have demonstrated the generation of bi-specific KnotBodies where the binding determinants required for recognition of two distinct antigens are incorporated within a single VH-VL pair. In this example, we describe the generation of bi-specific KnotBodies in the same format where VH domains selected against TFR shuttle their partner Knottin-VL fusion domains across the BBB via RMT.

Example 5 describes VH shuffled libraries composed of trypsin binding KnotBody light chains (KB_A07 and KB_A12) partnered with a repertoire of VH genes isolated from non-immunised donors. Anti-TFR bi-specific KnotBodies were selected from these libraries using 2-3 rounds of phage display selections on TFR antigen directly immobilised on Maxisorp™ immunotubes. Round 1 selection was carried out on mouse TFR followed by round 2 selection on rat TFR. In another case, 3 rounds of selections were carried on mouse TFR- mouse TFR- rat TFR (representing antigens used in rounds 1, 2 and 3 respectively). Alternatively, selections were carried out on mouse TFR - human TFR – mouse TFR. 736 individual clones were then picked from the final round of selections and monoclonal phage was prepared from each clone (as described in example 3). Monoclonal phage supernatant from each clone was tested for binding to rat TFR by ELISA (a representative example of the screen is shown in Figure 24). 376 clones that showed a binding signal above 10,000 fluorescent units were picked and sequenced to identify unique clones. Based on the analysis of VH CDR sequences, 65 unique binders were identified.

In order to enable the expression of these TFR binding KnotBodies as Fabs, VH genes were PCR amplified using primers M13 leaderseq (see example 4) and HLINK3 (CTGAACCGCCTCCACCACTCGA: SEQ ID 76). Amplified VH genes were digested with restriction enzymes *NcoI* and *XhoI* and ligated into the pINT12 vector (encoding KB_A07 or

KB_A12 light chain) pre-digested with the same enzymes. The pINT12 vector (Figure 7) has a dual promoter expression cassette in which the heavy chain expression is controlled by the cytomegalovirus (CMV) promoter and the light chain expression is driven by elongation factor-1 alpha (EF1-alpha) promoter. In order to express these KnotBody Fabs in mammalian cells transfection quality DNA was prepared using Plasmid Plus Kit (Qiagen, Cat. No 12945). 15 µg of plasmid DNA was incubated with 48 µl of ExpiFectamine CHO transfection reagent (Thermo Fisher scientific, Cat. No. A29129) in 1 ml of OptiPRO Serum Free Medium (Thermo Fisher Scientific, Cat.No. 12309050) for 5 minutes before adding to 15 mls of Expi-CHO cells (Thermo Fisher Scientific, Cat. No. A29133) seeded at a density of 6x10⁶ cells/ml in a 125 ml tissue culture flask. Culture flasks were incubated at 37°C for 7 days (with 5% CO₂, 75% humidity and shaking at 800 rpm) with a single feed 18-22 hour post transfection. The feed included 3.6 mls of ExpiCHO feed supplemented with 90 µl of enhancer solution. Expressed proteins were purified from cell culture supernatants using CaptureSelect IgG-CH1 affinity resin (Thermo Fisher Scientific, Cat. No. 194320005) according to manufacturer's instructions. Purified proteins were dialysed against 2x PBS overnight. Protein concentrations were determined using absorbance at 280 nm and theoretical extinction co-efficient.

In order to assess the ability of these KnotBodies to cross the BBB, a ready to use *in vitro* rat BBB model system (Pharmacocell, Cat. No. RBT-24H) was used. In this model system rat brain endothelial cells were co-cultured with pericytes and astrocytes to mimic the *in vivo* BBB anatomy (Nakagawa, S. *et al.* (2009) *Neurochem. Int.* 54, 253–263). The *in vitro* rat BBB kit was cultured according to manufacturer's instructions and transendothelial electrical resistance (TEER) was measured prior to testing of KnotBodies to verify the integrity of the barrier. All wells had a TEER measurement of >200 Ω/cm². 21 KnotBody Fabs were tested for their ability to cross the *in vitro* BBB model system. OX-26, a well characterised anti-rat TFR antibody that has been shown to cross BBB *in vivo* models (albeit at low levels) was used as a positive control (Jefferies, W. A., Brandon, M. R., Williams, A. F. & Hunt, S. V. *Immunology* 54, 333–341 (1985), Moos, T. & Morgan, E. H. *Journal of Neurochemistry* 79, 119–129 (2001)). The parent KnotBody KB_A12 was used as a negative control. Both positive and negative controls were expressed and purified in the Fab format as described above. For the assay, test KnotBodies were prepared as 7 oligoclonal mixes each containing 3 different Fab antibodies at a final concentration of 2 µM in the assay buffer (DMEM-F12 with 15 mM HEPES, 0.5% BSA, 500 nM hydrocortisone and 10 µg/ml Na-F). The positive

and negative controls were prepared at 1 μ M in the same assay buffer. These Fab oligoclonal mixes and controls were added to the upper chamber (referred as blood side) of the co-culture kit and incubated at 37°C for 6 hours (with 5% CO₂ and 75% humidity). The concentration of transcytosed Fabs in the lower chamber (referred as brain side) was determined using a sandwich ELISA. In this ELISA, Fabs were captured using an anti-CH1 antibody (provided by Hybridoma Reagent Laboratories) and detected using rabbit anti-human IgG Kappa light chain antibody (Abcam, Cat. No. ab195576) or anti-human IgG Lambda light chain antibody (Abcam, Cat. No. ab124719) followed by europium conjugated anti-rabbit antibody (Perkin Elmer, Cat. No. AD0105). Oligoclonal KnotBody Fab mixes in wells C2, C3, and C4 showed significant levels of transcytosis compared to the negative controls (see table 19). VH sequences of KnotBodies present in these wells are shown in Table 20. This example demonstrates the use of a VH domain specific to a receptor (i.e. TFR) involved in macromolecule transport into the brain to deliver a Knottin-VL fusion with a different specificity (trypsin binding in this example). The same approach could be used to generate functional Knottin-VL fusions that can modulate the activity of targets that are expressed in the brain (e.g. ion channels inside central nervous system, proteases such as BACE). The level of transcytosis observed can be further improved by optimising the VH domain specificity and/or affinity using methods known to those skilled in the art.

Example 14: Comparison of a KnotBody and a bovine antibody with a natural “ultra long VH CDR3 (cow ULVC-Ab) presenting a knottin insertion (EETI-II cow ULVC-Ab)

Bovine antibodies have been described with natural ultra-long VH CDR3s containing a solvent exposed double stranded antiparallel sheet approximately 20 Å in length (referred to as the stalk) presenting a folded domain stabilised by 3 disulfide bonds (referred to as the Knob)¹⁰. Zhang and colleagues have shown that the Knob domains of these cow ultra-long VH CDR3 antibodies (ULVC-Ab) can be replaced with other folded proteins such as erythropoietin¹³. In this example, we assess the ability of a cow ULVC-Ab to present functional knottin fusions on phage in comparison with a KnotBody. In order to create a Knottin-cow UCLA fusion, the sequence between the first and the last cysteines of the knob region of the Cow ULVC-Ab BLV1H12 was replaced with the sequence of the trypsin binding knottin; EETI-II (EETI-II cow ULVC-Ab). A gene fragment encoding this construct was synthesised (Integrated DNA technologies, Table 21). This synthetic gene was cloned into the phage display vector pSANG4 using restriction sites *NcoI* and *NotI* and transformed into *E.coli* TG1 cells. The performance of the Knottin-Cow ULVC-Ab fusion was then

compared to the KnotBody KB_A12 (which presents the knottin EETI-II as VL CDR2 fusion) using a trypsin binding assay. In this assay, the binding of phage rescued from EETI-II cow ULVC-Ab and KB_A12 to trypsin was detected using an anti-M13 antibody followed by europium conjugated anti-mouse antibody (as described in example 3). The KnotBody KB_A12 exhibited superior binding to trypsin compared to the EET-II-Cow ULVC-Ab fusion (Figure 25).

Example 15. Functional display of KnotBodies on the surface of mammalian cells

In examples 1, 2, 3, 5, 6, 9, 12 and 13 phage display technology was employed to enable the display of KnotBodies or derivative libraries and their selection. As an alternative to phage display, display of binders has been carried out on bacterial, yeast and mammalian cells. In these methods, it is possible to use flow sorting to measure binding and expression of the binding molecule as well as binding to target. Thus, the display of libraries of KnotBodies on the surface of cells e.g. mammalian cells will enable the screening and selection of tens of millions of clones by fluorescent activated cell sorting (FACS) for increased affinity to the target and expression level in their final scFv-Fc, Fab or IgG format. Methods for constructing and using display libraries in other systems are known to those skilled in the art.

Libraries of KnotBodies, (e.g. within recipient, donor, linkers or partner domains) may also be used for direct functional screening for altered cellular phenotypes in mammalian cells as described above. Thus, libraries of displayed or secreted KnotBodies in mammalian cells may provide an efficient route to discovery of the drug candidates or lead molecules. Methods for the construction of libraries in mammalian cells by nuclease directed integration are provided, for example, in WO2015166272 and the references cited therein, all of which are incorporated herein by reference. In this example, we demonstrate that it is possible to display a membrane anchored KnotBody scFv-Fc on the surface of mammalian cells. This was achieved by cloning the KnotBodies KB_A07 and KB_A12 scFv into the targeting vector pD6 (Figure 26), performing nuclease mediated gene integration into HEK293 cells followed by flow cytometry analysis. The flow cytometry results showed that expression was achieved when staining with labelled anti-Fc and that the displayed knottin was correctly folded because staining was also achieved with fluorophore-labelled trypsin.

The KnotBody genes KB_A07 and KB_A12 were prepared for insertion into a mammalian display vector in a way that can be modified to create linker libraries. 3 fragments were

produced and assembled by PCR using overlap at the boundaries to drive the association. In an N terminal to C terminal direction fragment 1 consists of a PCR product encoding the N terminal part of the scFv gene up to the donor insertion point (encoding in this case *NcoI* site, entire VH, scFv linker, FW1, CDR1, FW2, overlap). Fragment 2 consists of overlap, incoming knottin donor, overlap. Fragment 3 consists of overlap, FW3, CDR3, FW4 Not 1 site). Description of potential linker sizes and sites are given below. The position of the overlap can be chosen but will typically be homologous to the antibody framework or the donor coding region (allowing diversity to be introduced in one or other fragment internally to the overlap. In examples below the fragments include between 18 to 27 nucleotide homology overlaps to enable their assembly and amplification by PCR. The final scFv product, encompassing the donor is generated by a 3-fragment assembly. This 3-fragment assembly approach is described in detail using the parental KnotBody (without diversification).

Primers described are listed in Table 22. KB_A07 scFv fragment 1 (569 bp) was created by PCR with forward primer 2985 and reverse primer 2999 and DNA template pIONTAS1 harbouring the KB_A07 gene. KB_A07 scFv fragment 2 was created by PCR with primers 2979 and 2980 in the absence of template. Here the primers simply annealed and extended to yield the 137 bp KB_A07 fragment 2. KB_A07 scFv fragment 3 (170 bp) was created by PCR with forward primer 3000 and reverse primer 2995 and DNA template pIONTAS1 harbouring the KB_A07. KB_A12 scFv fragment 1 (572 bp) was created by PCR with forward primer 2985 and reverse primer 3003 and DNA template pIONTAS1 harbouring the KnotBody A12. KB_A12 scFv fragment 2 was created by PCR with primers 2983 and 2984 in the absence of template. Here, the primers simply annealed and extended to yield the 137 bp A12 fragment 2. KB_A12 scFv fragment 3 (179 bp) was created by PCR with forward primer 3004 and reverse primer 3002) and DNA template pIONTAS1 harbouring the KB_A12. Fragments 2 and 3 were gel purified and fragment 1 was purified by spin column. The three fragments were then combined (100 nM each in 10 mM Tris-HCl (pH8)) in a total volume of 10 µl, To this was added 10µl of KOD Hot Start Master Mix (Merck Millipore, catalogue number 71842). The fragments were then assembled by incubation at 95°C for 2 minutes followed by 20 cycles of 95°C (20s), 60°C (1min, 40s) and 70°C (30s). 1 µl of this assembly reaction product was then used as a template in a PCR reaction mix with the outer primers 2985 and 2995 (A07) or 2985 and 3002 (A12). The assembled PCR products encoding the KB_A07 and KB_A12 scFv genes were then digested with *NcoI* and *NotI*, gel

purified and cloned into the mammalian display targeting vector pD6 (Figure 26) pre-digested with the same enzymes. Transfection quality plasmid DNA was prepared using the NucleoBond Xtra Midi plus kit (Macherey Nagel, Cat. No. 740412.50).

5 Electroporation is an efficient way of introducing DNA into cells and the protocols developed by Maxcyte combine high efficiency transfection of mammalian cells combined with high cell viability. HEK293 cells were centrifuged and re-suspended in a final volume of 10^8 cells/ml in the manufacturer's electroporation buffer (Maxcyte Electroporation buffer, Thermo Fisher Scientific Cat. No. NC0856428)). An aliquot of 4×10^7 cells (0.4ml) was
10 added to an OC-400 electroporation cuvette (Maxcyte, Cat. No. OC400R10) with 88 μ g DNA (i.e., 2.2 μ g/ 10^6 cells). The DNA mix consisted of 80 μ g of plasmid DNA encoding AAVS-SBI TALENs (pZT-AAVS1 L1 and pZT-AAVS R1 Systems Bioscience Cat. No. GE601A-1) as an equimolar mix and 8 μ g of the "donor" plasmid pD6 DNA encoding the KB_A07 or KB_A12. Control electroporations were also performed where the TALEN or donor DNA
15 was replaced by pcDNA3.0. Electroporations were performed according to the manufacturer's instructions (Maxcyte). 2 days after transfection (2dpt) blasticidin selection was initiated (5 μ g/ml). After 13 days (15 dpt) cells were analysed by flow cytometry for scFv-Fc expression using an anti-Fc phycoerythrin (PE) labelled antibody. The presence of correctly folded knottin was detected by staining the cells with biotinylated trypsin pre-
20 conjugated with allophycocyanin (APC) labeled streptavidin. Analysis was focused on viable cells using forward scatter and 7AAD staining in the FL3 channel. Cells positive for staining in the FL3 channel (representing non-viable cells which took up 7-AAD) were excluded.

Purified trypsin was biotinylated using EZ-Link Sulfo-NHS-LC-Biotin kit (Pierce Cat. No. 25 21327) according to manufacturer's instructions. Biotinylated trypsin (1.25 μ l, 0.1 mg/ml, 4.3 μ M) and streptavidin-APC (Molecular Probes, Cat. No. SA1005, 1 μ l, 0.2 mg/ml, 3.8 μ M) were pre-incubated in PBS/1% BSA (100 μ l) for 30 min at room temperature. Cells (10^6) per sample, pre-washed with PBS, were re-suspended in the biotinylated trypsin/streptavidin-APC mix prepared above and to this was added anti-human Fc-PE
30 (BioLegend, Cat# 409304, 200 μ g/ml, 0.5 μ l) and incubated for 30 minutes at 4°C. The cells were washed twice in PBS/0.1% BSA, re-suspended in PBS/0.1% BSA containing 7-AAD Viability Staining Solution (eBioscience, Cat # 00-6993-50 and analysed using a flow cytometer (Intellicyt iQUE screener).

Figure 27 shows that after 13 days of blasticidin selection (15 dpt), 34% and 11% of the KB_A07 and KB_A12 transfected HEK293 cells were dual stained for Fc and trypsin. No staining of untransfected HEK293 cells was observed. This demonstrates that it is possible to display membrane tethered KnotBodies on the surface of mammalian cells where the knottin donor is correctly folded.

Example 16. Insertion of knottins into antibody VH CDR1, VH CDR2, VH CDR3, VL CDR1, VL CDR2 and VL CDR3, with variable linker sequences, their display on phage and selection of functional KnotBodies

Examples 1, 2 and 3 demonstrated knottin insertion into antibody VL CDR1 and VL CDR2, display of the resultant KnotBody on the surface of phage and the selection of functional knotbodies. In Examples 1, 2 and 3 libraries were created where variable fusion sequences were introduced between the donor and recipient which were then selected by phage display and screened to identify the optimal fusion sequences for the display of functional knottins. This identified short linker sequences, which were superior to long flexible linkers for the display of functional knottins, as described in Example 11. Insertion of a knottin into VL CDR1 or VL CDR2 enables additional binding contributions from VL and VH CDRs. For some applications there may be an advantage in alternative configurations where the knottin is inserted into alternative CDRs on either VH or VL. It is likely, as described in Example 3, that only a fraction of variable fusion sequences, linking the donor knottin, to each CDR enable the functional display of knottins. To demonstrate that it is possible to display functional knottin in all the antibody CDRs, variants of D1A12 formatted as a scFv (Tape, C. J. *et al.* (2011) PNAS USA 108, p5578–5583), were designed with knottin insertions in VH CDR1, VH CDR2, VH CDR3, VL CDR1, VL CDR2 and VL CDR3 where the two codons flanking the knottin were randomised to enable the creation of “linker library” knottin constructs as shown in Figure 28. The sequence of the parental anti-TACE scFv¹⁰¹ is shown in Table 23. In addition, a linker library was created for KB_A07 where the EETI-II donor knottin was inserted into VL CDR2 as shown in Figure 28. The inserts encoding the knottins, with randomised linker sequences, inserted into each of the six CDRs of D1A12, and a linker library of KB_A07 where the knottin with randomised flanking amino acids was inserted into VL CDR2, was created by a three fragment assembly as described in Example 15, using standard molecular biology techniques known to those skilled in the art e.g. Schofield et al 2007²⁸. Phage display libraries were created by cloning into the phage display vector

pSANG4 (Schofield et al, 2007), phage rescued, as described in Example 3, selected for binding to trypsin and monoclonal phage ELISA was performed with individual clones. Positive clones were obtained demonstrating that functional display of knottin is possible within all the CDR loops in both the antibody variable heavy and light chains.

5

The strategy and methodology for the preparation of the scFv knottin linker library inserts by a three fragment PCR assembly is detailed in Example 15 and the primers to create the inserts are listed in Tables 22 and 24. The primer pairs required to create the three fragments for each of the libraries, the DNA template (if required) and product sizes are listed in Table 25 and the method to prepare and purify the individual inserts is described in Example 15. The three fragments for each of the libraries A to G, listed in Table 25, were then combined in an equimolar ratio (e.g. fragments A1, A2 and A3 were combined to create library A) and assembled as described in example 15. It was possible to create fragment E (where diversification was near the end of the scFv gene) using a 2 fragment assembly. The products were amplified by PCR with the forward primer 2985 and either reverse primers D1A12 NotI Rev (libraries A to F) or 2995 (library G). . The assembled PCR products encoding libraries A to G were then digested with *NcoI* and *NotI*, gel purified and ligated into the phage display vector pSANG4 (pre-digested with the same enzymes) and the ligated product electroporated into E.coli TG1 cells (Lucigen, Cat. No. 60502-2) as described in Example 2. Library sizes of between 0.7 to 1.6×10^8 were achieved. Phage was rescued from the libraries as described in Example 3 to create seven libraries: library A (knottin linker library inserted into D1A12 VH CDR1); library B (knottin linker library inserted into D1A12 VH CDR2); library C (knottin linker library inserted into D1A12 VH CDR3); library D (knottin linker library inserted into D1A12 VL CDR1); library E (knottin linker library inserted into D1A12 VL CDR2); library F (knottin linker library inserted into D1A12 VL CDR3); and library G (knottin linker library inserted into KB_A07 VL CDR2).

To isolate functional knottin-antibody fusions, each of the knottin-antibody linker phage display libraries A to G, described above, were subject to two rounds of phage display selection with biotinylated trypsin as described in Example 3. Individual clones (46 per selection) were picked into 96 well culture plates, phage produced and the phage supernatant from each clone was tested for binding to biotinylated trypsin immobilised on Streptavidin coated Maxisorp™ plates with binding detected using a TRF assay as described in Example 3 (using a coating concentration of biotinylated trypsin of 2.5 µg/ml). The ELISA signals on

30

each 96-well plate were background subtracted with the signal obtained from the average of two negative control readings on the same plate where no phage was added to the well.

Specificity for trypsin was confirmed by lack of binding to Streptavidin coated Maxisorp™ in the absence of added trypsin. Screening of clones picked from the unselected knottin

5 linker antibody libraries C, E and G gave 0%, 1% and 32% positive clones respectively indicating that a limited proportion of library members are capable of displaying a functional knottin donor. The hit-rates of clones obtained after phage display selection and monoclonal phage ELISA for libraries A, B, C, D, E, F and G was 11%, 17%, 28%, 4%, 74%, 24% and 93% respectively, demonstrated an enrichment for KnotBodies that display a functional
10 knottin.

Positive clones were sequenced to determine the flanking linker sequences that enabled the display of functional knottins with VH CDR1, VH CDR2, VH CDR3, VL CDR1, VL CDR2 and VL CDR3. The sequences of the linkers sequences identified are listed in Tables 26 and
15 27. Examples of functional KnotBodies with unique linker sequences were isolated (Table 26) thus demonstrating the insertion of functional knottins into antibody VH CDR1, VH CDR2, VH CDR3, VL CDR1, VL CDR2 and VL CDR3.

Example 17. Alternative framing of knottins inserted into antibody VL CDR1 and VL CDR2 domains
20

In the examples above the native N terminus and C terminus of cys-rich peptides (hereafter referred to as knottins irrespective of structure and disulphide bond pattern) are inserted into an antibody CDR residues in a way that retains the natural linear sequence of the knottin with native N and C termini fused to the antibody frameworks. Alternative “framing” strategies
25 between the recipient antibody and donor knottin are possible however and this is exemplified here. In the following description, the sequences between sequential cysteines in the donor are referred to as “loops” and are numbered 1-5 based on their natural order. For example loop 1 extends between the first cysteine and the second cysteine. Loop 5 extends between the 5th and 6th cysteine. Some cysteine-rich peptides, such as cyclotides are found in
30 a cyclic form where the N and C termini are joined by a peptide sequence. For example MoCoT can be found in a “linear” form (i.e. with free N and C termini) or a cyclic form. The additional peptide sequence joining the first (N terminal) and 6th (C terminal) cysteine in the cyclic form is referred to as “loop 6” (Jagadish et al, (2010) Peptide Science 94 p611-616) and is used in the examples below to join the original N and C termini.

From one perspective the N and C termini of the donor knottin in a KnotBody are joined by an antibody which might be considered the equivalent of “loop 6” “joining” the N and C terminal cysteines in a cyclic knottin. From that same perspective one could consider alternative “framings” where the antibody replaces alternative loops. In this arrangement the native N and C termini of the donor could be linked by an additional “loop 6” peptide as found in cyclic MoCoTI-II. These alternative framing strategies would allow variation in the juxtaposition of different loops relative to the antibody recipient with potential benefits in creation of optimal bi-specific orientations and in engineering strategies e.g. improving affinity or specificity through contact of both donor and recipient with target proteins or complexes. The effective “rotation” of the donor relative to the recipient could increase availability of certain critical loops eg the trypsin binding loop in EET 5-3 is moved to a more central location within the donor relative to EET 1-5 (see below). The addition of an alternative “loop 6” further increases the possibilities for additional contact with target proteins. Finally such framing alternatives could provide superior expression or folding compared to the native KnotBody construct in some cases.

When a knottin is inserted in its native configuration as described in earlier examples the N terminal segment of the antibody recipient is followed by the first cysteine and loop 1 of the donor knottin. The donor ends at loop 5 followed by the terminal cysteine. In the nomenclature adopted here this is referred to as a “1-5” configuration, representing the order of knottin loops 1, 2, 3, 4, 5. In this case the antibody may be considered as the equivalent of loop 6 of a cyclic knottin. Table 28 illustrates different potential strategies for altering the framing between a knottin and antibody. In Table 28, the natural loop 1 is underlined in each case. The original N and C termini of EETI-II are joined to create “loop 6” and the peptide sequence of loop 6 of MoCOTI-II is used (represented in italics). A more detailed representation of the arrangement of loops in the EET_5-3 configuration is given in figure 29A. This shows that in alternative configuration EET_5-3 the order of loops is loop 5, 6, 1, 2 and 3 (with the antibody “replacing” loop 4).

To exemplify selection of knottins inserted in an alternative frame, a knottin donor with framing in a EET_5-3 configuration was fused into either the CDR1 or CDR2 position of either kappa or lambda VL domains. This was done by replacing residues within the VL recipient with random amino acids in a way that limited the number of added amino acids between the 2 domains (figure 29B).

Insertion of knottins with modified framings into CDR1

A synthetic EETI-II Knottin donor gene with 5-3 framing was made and was used to replace the CDR1 positions in the light chain recipient by creating a PCR fragment with Pml1 and Mfe sites (which were introduced by PCR) and cloning into pIONTAS1_KB_Kappa and pIONTAS1_KB_lambda. Framework and CDR designations are as described by the International Immunogenetics Information System (IMGT)²⁹. The PCR primers also introduced variable amino acid sequences between the restriction sites and the knottin gene. The PCR primers Pml5-3EETa and Pml5-3EETb each introduced 3 variable codons encoded by the sequence VNS (V=A, C or G, N=A, C, G or T, S=C or G) immediately after the Pml restriction site. The “VNS” degenerate codons encode 16 amino acids (excluding cysteine, tyrosine, tryptophan, phenylalanine and stop codons) at each randomised position from 24 codon combinations. Pml5-3EETb also introduces an additional glycine residue between donor and recipient compared to Pml5-3EETa.

Pml5-3EETa GTGT VNS VNS VNS TGC GGT CCG AAC GGC TTC TGC (SEQ ID NO: 79)
 Pml5-3EETb GTGT gga VNS VNS VNS TGC GGT CCG AAC GGC TTC TGC (SEQ ID NO: 80)

The 5' end of these sequences represents the site created by Pml1, a restriction enzyme recognising the sequence “CACGTG” to create a blunt end. To facilitate blunt end cloning of the PCR product primers with 5' phosphorylated termini were synthesised.

At the 3' end of the knottin gene the antisense primers 5-3EETMfe (encoding an Mfe1 site) was used to amplify the 5-3 frame of EETI-II. The Mfe1 site used for cloning encodes the 2 and 3rd amino acids of FW2 (Asn-Trp). This primer introduces 2 random amino acids encoded by VNS or VNC codons followed by an Mfe1 site (underlined).

5-3EETMfe GTCAGTCCAATTGNBSNBGCAGCCGGCCAGGCAGTCTGA (SEQ ID NO: 81)

Figure 29C depicts the sequence following insertion of a 5-3 formatted EETI-II into CDR1 of the lambda light chain IGKV1D-39 using primer Pml5-3EETa. A repertoire of light chain fragments encompassing Framework 2-framework 4 was also cloned after the knottin donor as previously described in example 2 using restriction sites Mfe1 and Not1 (underlined).

Insertion of knottins into CDR2

The knottin donor was introduced into the CDR2 positions of pIONTAS1_KB_ lambda and pIONTAS1_KB_ Kappa by creating a PCR fragment with PstI and BspEI sites which were introduced by PCR. It was possible to introduce a PstI site into the first two residues of the CDR2 region of the IGKV1D-39 V kappa gene (within the Ala-Ala sequence). For convenience in cloning the same restriction site and encoded residues were introduced at the end of framework 2 of the V lambda germline gene IGLV1-36. In the lambda germline it was also possible to introduce a BspEI site into the 4th and 5th residues of the FW3 region encoding Ser-Gly) (Figure 3E). Again this restriction site and encoded amino acids were also introduced into the V kappa gene (Figure 3F).

The PCR primers PST5-3EETa was used to amplify EETI-II and introduces 2 Ala codons encompassing a PstI site for cloning (underlined) followed by 2 variable codons encoded by the sequence GNS (encoding Val, Ala, Asp or Gly) and VNS (encoding 16 amino acids within 24 codons) immediately after the PstI restriction site and preceding the knottin sequence. The VNS codon replaces the first amino acid of EETI-II with the net effect of adding 3 amino acids (2 Ala residues and one of Val, Asp, Ala or Gly) between the donor and recipient framework (Figure 29 B, D).

PST5-3EETa ATC TAT GCT GCA GNS VNS TGC GGT CCG AAC GGC TTC TGC (SEQ ID NO: 82)

At the 3' end of the incoming knottin donor, The PCR primers 5-3EETBse was used to amplify the 5-3 framed EETI-II. This introduces a BspEI site for cloning. The PCR product introduces the knottin donor followed by the glycine which naturally follows the last cysteine of EETI-II (Figure 3a). This is followed by 2 randomised amino acids which adjoin to the 4th and 5th amino acids of FW3 after cloning. This has the effect of replacing the first three residues of FW3 with two randomised amino acids and retains the terminal glycine of the knottin (Figure 3B).

5-3EETBse GTCAGAGACTTCCGGASNBSNBCCCGCAGCCGGCCAGGCAGTCTGA (SEQ ID NO: 83)

A repertoire of light chain fragments encompassing Framework 3-framework 4 was also cloned after the knottin donor as previously described in example 2.

Figure 29D depicts the sequence following insertion of a 5-3 formatted EETI-II into CDR2 of the lambda light chain IGKV1D-39 using primer 5-3EETBse. A repertoire of light chain fragments encompassing Framework 3-framework 4 was also cloned after the knottin donor as previously described in example 2 using restriction sites BspE1 and Not1.

Using standard molecular biology techniques known to those skilled in the art e.g. Schofield et al 2007²⁸, constructs (as depicted in Figure 29B, C and D)) were created using gene fragments created as described above. These were cloned into pIONTAS1_KB_Kappa” and “pIONTAS1_KB_lambda and were electroporated into E.coli TG1 cells and KnotBody library sizes of $3.5\text{--}6.6 \times 10^8$ members were constructed

Following selection on trypsin, as described in example 3, positive clones were identified by monoclonal phage ELISA and their sequences determined. Examples of positive clones in CDR1 or CDR 2 of kappa and lambda light chains are shown in Table 29 with the linker sequences shown in lower case and the knottin donor in a 5-3 frame shown in italics. Also shown is the value of ELISA signal attained from monoclonal phage ELISA. The specificity of interaction was further confirmed by mutating the pair of Proline-Arginine residues involved in interaction with trypsin to alanine-alanine which diminished binding (as described in example 3).

Example 18: Evaluating the immunomodulatory function of anti-Kv1.3 KnotBodies.

Kv1.3 plays a key role in maintenance of calcium signalling following activation of T cell receptors thereby modulating T cell activation, proliferation and cytokine release in effector memory T (T_{EM}) cells. T_{EM} cells play an important role in the pathogenesis of T lymphocyte mediated autoimmune diseases and so blockade of Kv1.3 activity represents a potential point of therapeutic intervention.

Example 7 describes the generation of Kv1.3 blockers by replacing the trypsin binding knottin EETI-II at the CDR2 position of KnotBodies KB_A07 and KB_A12 with the cysteine rich miniproteins Shk or Kaliotoxin (naturally occurring Kv1.3 blockers from sea anemone venom and scorpion venom respectively). Example 8 demonstrates the blocking activity of

these KnotBodies on Kv1.3 determined by electrophysiology. In this example, we assess the ability of KB_A12 Shk to modulate the cytokine secretion by activated T cells.

5 Methods for measuring cytokine release from T cells are well known to those skilled in the art (eg Tarcha et al, (2012) J Pharmacology and Experimental Therapeutics, 342 p642-653). Peripheral blood mononuclear cells (PBMCs) were isolated from 5 healthy donors and were simulated by culturing in 96-well plates pre-coated with 500ng/ml of the anti-CD3 antibody OKT3 (ebioscience, Cat. No. 16-0037-85). PBMCs were suspended at 2×10^6 cells/ml and 100ul of cells suspension mixed with 100ul of test sample (KB_A12_ShK) or positive control
10 (free Shk toxin, Alomone labs, STS-400) or negative control (parental KnotBody KB_A12) at a final concentration of 100nM. (Samples were in triplicate for KB_A12_Shk or duplicate for KB_A12 and free Shk). Cells were incubated at 37°C for 72 hours, centrifuged at 1500rpm for 5 mins at room temperature before removing 150ul of supernatant. After 72 hours incubation, the concentration of cytokines and Granzyme-B was determined using a
15 Luminex bead based assay according to manufacturer's instructions (Thermo Fisher).

Secretion of Interferon gamma, Granzyme B, interleukin-17A and TNF-alpha was reduced in PBMCs from all 5 different donors when incubated with KB_A12_Shk compared to controls incubated with a control KnotBody (KB_A12) (Figures 30A to D). This demonstrates that
20 KB_A12_ShK not only blocks Kv1.3 function as measured by electrophysiology (example 8) but also directly interferes with T cell activation as determined in a T cell functional assay.

Example 19: Generation of Nav1.7 blocking KnotBodies

In this example, three Nav1.7 blockers (ProTx-III, GpTx-1, and Huwentoxin-IV, see Table
25 31) were inserted into the CDR2 position of the KnotBody KB_A12 (i.e., replacing the EETI-II gene at that position – see Example 3). The knottins used for VL CDR2 insertion were:

- an engineered variant of GpTx1 containing mutations F5A/M6F/T26L/K28R, herein referred to as GpTx-1 4M;
- 30 - an engineered variant of Huwentoxin-IV containing mutations E1G/E4G/Y33W, herein referred to as HwTx-IV 3M;
- ProTx-III;
- an engineered variant of ProTx-III containing mutations D1G/L31W, hereinafter referred to as ProTx-III 2M.

Sequences and reference information for these toxins is shown in Table 31 and Table 32.

Glycine extended versions of the GpTx1, ProTx-III and Huwentoxin-IV knottins were used for antibody fusion. It is known that the wild type sequences of these toxins undergo post translational C-terminal amidation^{149, 154-155}. Recombinant or synthetic versions of these peptides lacking C-terminal amidation are known to show diminished ion channel blocking activity compared with the native peptides¹⁵⁴. Addition of glycine residue at the C-terminus has been reported to mimic the carboxymide and recover some of the lost potency¹⁵⁵.

KnotBody VL genes encoding the inserted knottin toxins were synthesised as gene fragments. See Table 33. For expression of the KnotBody constructs as IgGs, the gene fragments were cloned into the pINT3-hg expression vector encoding the D1A12 heavy chain using *NheI* and *NotI* restriction sites, as described in Example 7.

In order to express the KnotBodies in mammalian cells, transfection quality DNA was prepared using Plasmid Plus Kit (Qiagen, Cat. No 12945). 90 µg of plasmid DNA was incubated with 3.6 ml of OptiPRO Serum Free Medium (Thermo Fisher Scientific, Cat.No. 12309050) and was mixed with 3.6 ml of OptiPRO Serum Free Medium containing 288 µl of ExpiFectamine CHO transfection reagent (Thermo Fisher scientific, Cat. No. A29129). This mix was incubated for 5 minutes before adding to 83 mls of Expi-CHO cells (Thermo Fisher Scientific, Cat. No. A29133) seeded at a density of 6×10^6 cells/ml in a 500 ml tissue culture flask. Culture flasks were incubated at 37°C for 7 days (with 5% CO₂, 75% humidity and shaking at 800 rpm) with a single feed 18-22 hour post transfection. The feed included 27 mls of ExpiCHO feed containing 540 µl of enhancer solution. Expressed proteins were purified from cell culture supernatants using CaptureSelect IgG-CH1 affinity matrix (Thermo Fisher Scientific, Cat. No. 194320005) according to manufacturer's instructions. Purified proteins were dialysed against EC00 buffer (145 mM NaCl, 4 mM KCl, 2 mM CaCl₂, 1 mM MgCl₂, 10mM HEPES and 10 mM glucose; the pH was adjusted to 7.4 with NaOH; the osmolarity was ~ 305 mOsm/L). Protein concentrations were determined using absorbance at 280 nm and theoretical extinction co-efficient.

The effect of these KnotBodies on cells expressing human Nav1.7 (huNav1.7) channel was assessed using QPatch automated patch-clamp platform (Sophion). For the testing of Nav1.7

ion channel currents, CHO cells stably expressing human Nav1.7 (GenBank accession number NM_002977; cell line catalogue number CT6003, Charles River Discovery, Cleveland, USA) were subjected to the QPatch electrophysiology assay in the presence or absence of the KnotBody fusions or the antibody isotypes (negative controls). Internal and external physiological solutions were freshly prepared prior to the assay. The extracellular solution contained 145mM NaCl, 4 mM KCl, 2 mM CaCl₂, 1 mM MgCl₂, 10mM HEPES and 10 mM glucose; the pH was adjusted to 7.4 with NaOH; the osmolarity was ~ 305 mOsm/L. The intracellular solution contained: KF (120 mM), KCl (20 mM), HEPES (10 mM) EGTA (10 mM); the pH was adjusted to 7.2 with KOH; osmolarity was ~ 300 mOsm/L.

A series of depolarising voltage (channel activating) pulses were used to monitor the channel currents upon adding control (extracellular solution) to define a control baseline of current activity. To these measured control channel currents KnotBody or parental antibody isotypes (control molecules) were applied to the external bathing solution. The parental KnotBody KB_A12 (with trypsin inhibitor knottin EETI-II at CDR2) were used as test molecule isotype controls for the testing. From a holding voltage of -100 mV a depolarising, channel activating voltage pulses of -10 mV were applied for 30 ms, every 10 or 30 seconds. The elicited, maximum outward current values measured during the -10 mV activating step for each solution period (a control, baseline level of current was determined at 10 minutes after application of the control external recording solution and a test level of current was determined after 20 minutes of application of KnotBody or its isotype) and average inhibition was determined between the current from the 10 minute baseline control current and the subsequent 20 minute KnotBody application. Over 20 minutes of recording the current reduction was also determined for 'test' applications where control, external solution was applied – this non-specific reduction or 'run-down' of current was averaged and subtracted from the KnotBody or isotype inhibitions to avoid this non-specific reduction in current being included in the KnotBody or isotype dependent inhibition measured. The average inhibition values (with external control reduction subtracted) for KnotBodies and isotypes was calculated. Using a t-test, statistical significance was determined comparing average inhibitions between a KnotBody and its isotype: all KnotBodies tested showed statistically significant difference to the isotype, with p values <0.01. In comparison, the isotype (parental KnotBody) KB_A12 showed small inhibition in measured current, which was not statistically significant when compared to the reduction in current recordings made in control external

solution applications over the same 20 minute test time period. The results are shown in Table 35.

Example 20: Selectivity and potency engineering of Nav1.7 KnotBodies

5 A number of small molecule inhibitors targeting Nav1.7 are approved for the treatment of pain. However, due to the high homology between the members of Nav family, these molecules suffer from poor selectivity for Nav1.7 leading to dose limiting side effects and modest clinical efficacy. Despite the attractiveness of targeting Nav1.7 channel with antibodies which generally provide high specificity in target binding, no antibody molecule
10 targeting Nav1.7 has been progressed to clinical use. Creating functional antibody blockers to Nav1.7 is very challenging because voltage gated ion channels offer very limited epitope space outside the lipid membrane for antibody binding and functional epitopes that are buried in the lipid bilayer cannot be accessed by a relatively flat binding surface formed by antibody CDR loops. In contrast, several knottins from animal venom, aided by their compact structure
15 and membrane interacting properties, potentially block Nav1.7 by binding epitopes on voltage sensing domains that may be partially buried in the lipid bilayer. However, these toxins lack the exquisite specificity required for therapeutic use and often require further engineering. For example, HwTx-IV 3M used for generating functional KnotBodies (see example 19) blocks Nav1.7 by interacting with the S3-S4 loop of domain-II (DII) voltage sensor, but it
20 also inhibits Nav1.1, Nav1.2, Nav1.3 and Nav1.6 channels¹⁵⁸. There is high sequence homology shared by these Nav subtypes at this binding site in the S3-S4 loop (Figure 33A) which makes selectivity engineering without compromising potency very challenging.

This example describes the utilisation of the modular binding surface of the KnotBody format
25 to generate potent and selective ion channel inhibitors, such as Nav1.7 inhibitors. A KnotBody (e.g. a VL containing a donor Knottin such as HwTx-IV or ProTx-III) provides the Nav1.7 blocking functionality by targeting functional epitopes of the ion channel (which may be partially buried or in the lipid bilayer). The VH partner chains of the KnotBody provide Nav1.7 selectivity by binding to extracellular epitopes that are distinct between different Nav
30 subtypes. For example, extracellular linker sequences connecting S1-S2 transmembrane regions of the Domain II of Nav1.7 are substantially different from the equivalent sequences on Nav1.1, Nav1.2, Nav1.3 and Nav1.6 (Figure 33B). In addition, the S1-S2 linker of Nav channels is longer and more solvent exposed than the functional epitopes, thus making it accessible for binder generation. Therefore, antibody VHs specific to S1-S2 linker of DII can

be generated and paired with KnotBody VLs containing donor domains which target functional epitopes on the S3-S4 linker of the same domain (e.g. HwTx-IV 3M). The resulting KnotBody molecules (with additional VH mediated contacts to “specific targeting sites” on Nav1.7) will preferentially bind to Nav1.7 over other Nav subtypes thereby simultaneously improving the selectivity and potency of the ion channel inhibition. Moreover, such “bi-epitopic” approach was previously used to improve the affinity of trypsin binding KnotBody KB_A12 (See example 6).

In order to aid antibody VH generation to these particular epitopes of interest, the extracellular loops connecting S1-S2 transmembrane regions of DII and S3-S4 transmembrane regions of DII of human Nav1.7 may be grafted onto the bacterial channel (NavAb) to create a chimeric ion channel protein. The resulting chimera has been shown to form functional single domain homo tetramers that can be expressed and purified¹⁵⁹. Since the use “bi-epitopic” approach to improve selectivity and potency could also be applied to S1-S2 linkers of other domains, similar chimeras can be created for DI, DIII and DIV domains. This allows generation of VH binders to regions of interest on specific Nav1.7 domains rather than random regions on the entire Nav1.7 protein. The binder generation can be achieved using *in vitro* display technologies (phage display, ribosome display, mRNA display etc) or cell surface display technologies (mammalian display, yeast display etc). Enrichment of unwanted binders to bacterial segments of the chimera during selections can be easily excluded by performing cross selection on cells expressing native human Nav1.7 channel or by ‘deselecting’ against the native NavAb channel (methods for such cross selection and deselection are well known to those skilled in the art). Similarly, chimeras of other Nav subtypes can be generated and used for “deselection” of cross-reactive/non-selective binders and specificity screening. The methods for expressing and purifying of DII and DIV chimeras has been described previously^{159,160}. Moreover, such chimeras may be expressed using bacterial, baculovirus, mammalian (example: HEK293 or CHO cells), or insect (example: drosophila eye) expression systems using previously described methods¹⁶¹⁻

Example 21: Creation and characterisation of additional ProTx-III KnotBody variants

This example describes the generation and detailed characterisation of two additional Nav1.7 KnotBodies based on ProTx-III. These KnotBodies were generated by cloning ProTx-III variants (Table 36) into the VL CDR2 position of KnotBody KB_A12 or KB_A07 and tested

along with KB_A12_ProTx-III 2M Gly (described in Example 19) for the inhibition of human Nav1.7 currents.

Materials & Methods:

5 KnotBody VL genes encoding the ProTx-III variants (Table 37) were synthesised as gene fragments (from Integrated DNA Technologies). For expression of the KnotBody constructs as IgGs, the gene fragments were cloned into the pINT3-hg expression vector and expressed in ExpiCHO cells (Thermo Fisher Scientific, Cat. No. A29133), as described in Example 19. Expressed KnotBodies were purified in a 3 step process using the Äkta Pure system (GE
10 Healthcare). The initial purification was performed using HiTrap MabSelect SuRe 5 ml column (GE Healthcare, Cat. No. 11-0034-94) and 0.1M Citrate buffer (pH3.0) was used for elution. Eluted proteins were subsequently desalted using HiTrap 5ml desalting column (GE Healthcare, Cat. No. 17-0031-01) equilibrated with EC000 buffer (145mM NaCl, 4 mM KCl, 2 mM CaCl₂, 1 mM MgCl₂, 10mM HEPES and 10 mM glucose; the pH was adjusted to 7.4
15 with NaOH; the osmolarity was ~ 305 mOsm/L). Finally, the desalted proteins were subjected to size exclusion chromatography using Superdex 200 Increase 10/300 GL column (GE Healthcare, Cat. No. 28-9909-44). Protein concentrations were determined using absorbance at 280 nm and theoretical extinction co-efficient.

The effect of these KnotBodies on cells expressing human Nav1.7 (huNav1.7) channel was
20 then assessed using QPatch automated patch-clamp platform (Sophion). For the testing of Nav1.7 ion channel currents, CHO cells stably expressing human Nav1.7 (GenBank accession number NM_002977; cell line catalogue number CT6003, Charles River Discovery, Cleveland, USA) were subjected to the QPatch electrophysiology assay in the presence or absence of the KnotBody fusions or the antibody isotypes (negative controls).
25 Internal and external physiological solutions were freshly prepared prior to the assay. The extracellular solution contained 145mM NaCl, 4 mM KCl, 2 mM CaCl₂, 1 mM MgCl₂, 10mM HEPES and 10 mM glucose; the pH was adjusted to 7.4 with NaOH; the osmolarity was ~ 305 mOsm/L. The intracellular solution contained: KF (120 mM), KCl (20 mM), HEPES (10 mM) EGTA (10 mM); the pH was adjusted to 7.2 with KOH; osmolarity was ~
30 300 mOsm/L. A series of depolarising voltage (channel activating) pulses were used to monitor the channel currents upon adding control (extracellular solution) to define a control baseline of current activity. To these measured control currents four ascending concentrations (0.37, 1.1, 3.3 and 10 µM) of KnotBody or parental antibody isotypes (control molecules)

were applied to the external bathing solution containing 0.1% BSA. The parental KnotBody KB_A12 (with trypsin inhibitor knottin EETI-II at CDR2) was used as an isotype control for the testing. From a holding voltage of -100 mV a depolarising, channel activating voltage pulses of -10 mV were applied for 30 ms, every 30 seconds. The elicited, maximum outward current values measured during the -10 mV activating step for each solution period (a control, baseline level of current was determined at 15 minutes after application of the control external recording solution and a test level of current was determined after 15 minutes of application of each concentration of KnotBody or its isotype control) and average inhibition was determined. The elicited, maximum outward current values measured during the activating step for each solution exchange period were averaged and plotted as concentration-response (% current remaining) curves. From these concentration-response curves IC₅₀ values were calculated.

Results:

Concentration-response curves (Figure 34) produced IC₅₀ values of 1 to 1.5 μ M for the three ProTx-III KnotBody variants (Table 38). In comparison, the parental KnotBody, KB_A12 (isotype control) showed minimal reduction in measured current ($\sim$ IC₅₀ extrapolated to > 100 μ M; every 15-minute application of equivalent concentrations showed $\sim$ 5% cumulative current loss), similar in magnitude to the reduction in current recordings made in control external solution additions over the same time period (four applications each of 15 minutes duration, 60 minutes in total).

Tables

Clone ID	Sequence
CDR1_F_10	QSVLTQPPSVSEAPRQRTITTCGERPCPRILMRCKQSDCLAGCVCGPNGFCGANNWYQQLP GSSPTTVIYEDNQRPSPGVPDRFSGSIDSSSNSASLTISGLKTEDEADYYCQSYDSSNQVFGGGT KVTVLGQP (SEQ ID NO: 84)
CDR1_B_01	QSVLTQPPSVSEAPRQRTITTCGGGRCPRILMRCKQSDCLAGCVCGPNGFCGTPNWXQQLP GSSPTTVIYEDNQRPSPGVPDRFSGSIDSSSNSASLTISGLKTGDEADYYCQSYDSSNQVFGGGT QLTVLGQP (SEQ ID NO: 85)
CDR1_F_02	QSVLTQPPSVSEAPRQRTITTCGRPCPRILMRCKQSDCLAGCVCGPNGFCGSHNWYQQLP GSSPTTVIYEDNQRPSPGVPDRFSGSIDSSSNSASLTISGLKTEDEADYYCQSYDSSNHRVVFVG GTKLTVLGQP (SEQ ID NO: 86)
CDR1_F_05	QSVLTQPPSVSEAPRQRTITTCGGGRCPRILMRCKQSDCLAGCVCGPNGFCGTGNWYQQLP GRSPTNVVYEDNQRPSPGVPDRFSGSIDSSSNSASLTISGLKTEDEADYYCQSYDSSNQVFGGG TKLTVLGQP (SEQ ID NO: 87)
CDR1_C_12	QSVLTQLPSVSEAPRQRTITTCGRAMCPRILMRCKQSDCLAGCVCGPNGFCGTGNWYQQH PGKAPKLIIFDVSKRPSGVPDRFSASKSGNTASLTISGLQAEDEADYYCNSYTSSNTWVFGGG TQLTVLGQP (SEQ ID NO: 88)
CDR1_G_05	QSVLTQPPSVSEAPRQRTITCDRKCPRILMRCKQSDCLAGCVCGPNGFCGTGNWYQQLPG SSPTTVIYENFQRPSPGVPDRFSGSIDSSSNSASLTISGLKTEDEADYYCQSYDSYNQVFGSGTKL TVLGQP (SEQ ID NO: 89)
CDR1_C_06	QSVLTQPPSVSEAPRQRTITTCGRRGCPRILMRCKQSDCLAGCVCGPNGFCGGDNWYQQHP GSSPTTVIYEDNQRPSPGVPDRFSGSIDSSSNSASLTISGLKPEDEADYYCQSHDGSNPWFVGGG TKLTVLGQP (SEQ ID NO: 90)
CDR1_A_03	QSVLTQPPSVSEAPRQRTITTCGGRCPRILMRCKQSDCLAGCVCGPNGFCGSANWYQQLPD SAPATVIYEDNQRPSPGVPDRFSGSIDSSSNSASLTISGLKTEDEADYYCQSYDSSNHWVFVGGG TKLTVLGQP (SEQ ID NO: 91)
CDR1_D_06	QSVLTQPPSVSEAPRQRTITCRGGCPRILMRCKQSDCLAGCVCGPNGFCGSPNWYQQKPG QAPVLVIYGKNNRPSGIPDRFSGSRSGTPASLTITGAQAEDEADYYCNSRDNDNNHVFVGGG TKLTVLGQP (SEQ ID NO: 92)
CDR1_E_08	QSVLTQPPSVSEAPRQRTITTCGGTGCPRILMRCKQSDCLAGCVCGPNGFCGSANWYQQLP GSSPTNVIYEDNQRPSPGVPDRFSGSIDSSSNSASLTISGLKTEDEADYYCQSNMGTVNMFVGGGT KVTVLGQP (SEQ ID NO: 93)
CDR1_A_12	QSVLTQPPSVSEAPRQRTITTCGARPCPRILMRCKQSDCLAGCVCGPNGFCGASNWYQQLP GSSPTTVIYEDNQRPSPGVPDRFSGSIDSSSNSASLTISGLKTEDEADYYCQSYDSINRGVFVGGTQ LTVLGQP (SEQ ID NO: 94)
CDR1_H_03	QSVLTQPPSVSEAPRQRTITTCGRGCPRILMRCKQSDCLAGCVCGPNGFCGTNVWYQQLP GSAPTTVIYEDNQRPSPGVPDRFSGPIDSSSNSAPLTISGLKTEDEADYYCQSYDRNNVIFVGGGT KLTVLGQP (SEQ ID NO: 95)
CDR1_E_10	QSVLTQPPSVSEAPRQRTITTCGRGCPRILMRCKQSDCLAGCVCGPNGFCGSNNWYQQLP GSSPTTVIYEDNQRPSPGVPDRFYGSIDSSSDSASLTISGLETEDEADYFCHSYDSKDWVFVGGGT QLTVLGQP (SEQ ID NO: 96)
CDR1_E_03	QSVLTQPPSVSEAPRQRTITTCGMPCPRILMRCKQSDCLAGCVCGPNGFCGATNWYQQLP GSSPTTVIYEDNQRPSPGVPDRFSGSIDSSSNSASLTISGLKTEDEADYYCQSYDSSNPKVVFVG GTKLTVLGQP (SEQ ID NO: 97)

CDR2_D_02	QSVLTQPPSVSEAPGQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAAKCPRILMRCK QSDCLAGCVCGPNGFCGTRSGVSDRFSGSKSGTSASLAISGLQSEDEADYYCAAWDDSLSG YVFGTGKLTVLGQP (SEQ ID NO: 98)
CDR2_D_09	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAADKCPRILMRCK QSDCLAGCVCGPNGFCGGSGIPERFSGSKSGTSASLAISGLRSEDEADYYCATWDDNLNG VVFGGGKLTVLGQP (SEQ ID NO: 99)
CDR2_H_09	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAVGCPRILMRCK QSDCLAGCVCGPNGFCGTGSGIPERFSGSKSGNTASLTISGLQAEDEGDYYCAAWDDSLSG PVFGGGKLTVLGQP (SEQ ID NO: 100)
CDR2_F_02	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGRCPRILMRCK QSDCLAGCVCGPNGFCGARSGIPERFSASKSGTSASLVISGLQSEDEADYYCAAWDDSLNG WVFGGGKLTVLGQP (SEQ ID NO: 101)
CDR2_C_07	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAAVCPRILMRCK QSDCLAGCVCGPNGFCGTRSGIPERFSGSKSGTSAFLAISGLRSEDEADYYCAAWDDSLSGV VFGGGKLTVLGQP (SEQ ID NO: 102)
CDR2_B_07	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAARCPRILMRCK QSDCLAGCVCGPNGFCGHTSGIPERFSGSKSGTSASLAISGLQSEDEADYYCAAWDDSLNG VVFGGGKLTVLGQP (SEQ ID NO: 103)
CDR2_G_05	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGRCPRILMRCK QSDCLAGCVCGPNGFCGGRSGVSDRFSGSKSGTSASLAISGLQSEDEADYYCAAWDDSLN GYVFGTGKLTVLGQP (SEQ ID NO: 104)
CDR2_H_04	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGRCPRILMRCK QSDCLAGCVCGPNGFCGANSGVSDRFSAAKSGTSASLAINGLRSEDEADYYCAAWDDSLN GYVFGTGKLTVLGQP (SEQ ID NO: 105)
CDR2_A_01	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAEPCPRILMRCK QSDCLAGCVCGPNGFCGAPSGVPDRFSGSKSGTSASLAITGLQSEDEAHYYCAAWDDSLSA WVFGGGKLTVLGQP (SEQ ID NO: 106)
CDR2_H_07	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAAGCPRILMRCK QSDCLAGCVCGPNGFCGTRSGVSDRFSGSKSGTSASLAISGLRSEDEADYYCAAWDDSLRA YVFGTGKLTVLGQP (SEQ ID NO: 107)
CDR2_B_06	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAADRCPRILMRCK QSDCLAGCVCGPNGFCGTDSGIPERFSGSKSGNTASLTISGLQAEDEADYYCAAWDDSLSG PVFGGGKLTVLGQP (SEQ ID NO: 108)
CDR2_F_09	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAVICPRILMRCK QSDCLAGCVCGPNGFCGTGSGVSDRFSGSKSGTSASLAISGLQSEDEADYYCAAWDDSLNG VVFGGGKLTVLGQP (SEQ ID NO: 109)
CDR2_F_11	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAERCPRILMRCK QSDCLAGCVCGPNGFCGGSSGVSDRFSGSKSGTSASLAISGLRSEDEADYYCATWDDNLNG PVFGGGKLTVLGQP (SEQ ID NO: 110)
CDR2_C_02	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAVGCPRILMRCK QSDCLAGCVCGPNGFCGSASGVSDRFSGSKSGTSASLAISGLRSEDEADYYCASWDDSLRG YVFGTGKLTVLGQP (SEQ ID NO: 111)
CDR2_D_08	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGPCPRILMRCK QSDCLAGCVCGPNGFCGTASGVSDRFSGSKSGTSASLAISGLRSEDEADYYCAAWDDSLSG VVFGGGKLTVLGQP (SEQ ID NO: 112)

CDR2_E_10	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAARCPRLMRCK QSDCLAGCVCGPNGFCGTPSGVPDRFSGSGSGTSASLAISGLQSEDEADYYCAAWDDSLSG YVFGTGKLTVLGQP (SEQ ID NO: 113)
CDR2_F_05	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGGCPRLMRCK QSDCLAGCVCGPNGFCGSNSGVDRFSGSGSGNTASLTISGLQSEDEADYYCAAWDDSLSG VVFGGGTQLTVLGQP (SEQ ID NO: 114)
CDR2_G_04	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGMCPRLMRCK QSDCLAGCVCGPNGFCGHSVSDRFSGSGSGTSASLAISGLQSEDEADYYCAAWDDSLN GYVFGTGQLTVLGQP (SEQ ID NO: 115)
CDR2_A_08	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAARCPRLMRCK QSDCLAGCVCGPNGFCGTRSGVSDRFSGSGSGTSASLAISGLQSGDEADYYCAAWDDSLN GWVFGGGTKLTVLGQP (SEQ ID NO: 116)
CDR2_E_06	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAADKCPRLMRCK QSDCLAGCVCGPNGFCGLTSGVSDRFSGSGSGTSASLAISGLRSEDEADYYCATWDDSLNG VVFGGGTCLTVLGQP (SEQ ID NO: 117)
CDR2_B_11	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAAKCPRLMRCK QSDCLAGCVCGPNGFCGGASGVSDRFSGSIDSSSNSASLTISGLKPEDEGDYYCQSYDSSNR WVFGGGTKVTVLGQP (SEQ ID NO: 118)
CDR2_G_09	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAARCPRLMRCK QSDCLAGCVCGPNGFCGTTSGVPDRFSGSIDSSSNSASLTISELKTEDEADYYCQSYDSSNQ GWVFGGGTKLTVLGQP (SEQ ID NO: 119)
CDR2_C_08	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGRCPRILMRCK QSDCLAGCVCGPNGFCGGSGVPDRFSGSIDSSSNSASLTISGLRAEDEADYYCQSYDSSNH WVFGGGTKLTVLGQP (SEQ ID NO: 120)
CDR2_E_09	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGPCPRILMRCK QSDCLAGCVCGPNGFCGPRSGVPDRFSGSIDSSSNSASLTISGLKTEDEADYYCQSYDSNNH WVFGGGTKLTVLGQP (SEQ ID NO: 121)
CDR2_F_04	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAERCPRILMRCK QSDCLAGCVCGPNGFCGTPSGVPDRFSGSIDTFSNSASLTISGLKTEDEADYYCQSYDSSHH WVFGGGTKLTVLGQP (SEQ ID NO: 122)
CDR2_E_05	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGPCPRILMRCK QSDCLAGCVCGPNGFCGADSGVSDRFSGSGSGTSASLAITGLQAEDEGDYYCAAWDDSLN GLVFGGGTKVTVLGQP (SEQ ID NO: 123)
CDR2_D_07	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGRCPRILMRCK QSDCLAGCVCGPNGFCGTASGVDRFSGSIDTFSNSASLTISGLKTEDEADYYCQSYDSSNH WVFGGGTKLTVLGQP (SEQ ID NO: 124)
CDR2_G_03	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAGRCPRILMRCK QSDCLAGCVCGPNGFCGTNSGIPERFSGSGSGNTASLTISGLQAEDEADYYCQSYDSSLSGW VFGGGTQLTVLGQP (SEQ ID NO: 125)
CDR2_A_09	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAAPCPRLMRCK QSDCLAGCVCGPNGFCGAHSGVPDRFSGSIDRSSNSASLTISGLKIEDEADYYCQSYDSSNH VVFGGGTCKVTVLGQP (SEQ ID NO: 126)
CDR2_D_11	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYAAVRCPRILMRCK QSDCLAGCVCGPNGFCGTPSGIPERFSGSIDRSTNSASLTISGLKTEDEADYYCQSYDSSNLN WVFGGGTKLTVLGQP (SEQ ID NO: 127)

CDR2_C_06	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLINAADRCPRILMRCK QSDCLAGCVCGPNGFCGTNSGVPRFSGSSSGNTASLTITGAQAEDEADYYCNSRDSSGNN WVFGGGTKVTVLGQP (SEQ ID NO: 128)
CDR2_F_01	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAGLCPRILMRCKQ DSDCLAGCVCGPNGFCGTSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQSYSTPYTFG QGTKVDIKRT (SEQ ID NO: 129)
CDR2_F_12	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAAPCPRILMRCKQ DSDCLAGCVCGPNGFCGTSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQSYSTPYTFGQ GTKVDIKRT (SEQ ID NO: 130)
CDR2_E_04	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAARCPRILMRCKQ DSDCLAGCVCGPNGFCGTSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQSYSTPYTFGQ GTKVEIKRT (SEQ ID NO: 131)
CDR2_F_03	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAAKCPRILMRCKQ DSDCLAGCVCGPNGFCGTSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQSYSTPYTFGQ GTKVEIKRT (SEQ ID NO: 132)
CDR2_D_03	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAVVCPRILMRCKQ DSDCLAGCVCGPNGFCGTSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQSYSTPYTFGQ GTKLEIKRT (SEQ ID NO: 133)
CDR2_D_06	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAGRCPRILMRCKQ DSDCLAGCVCGPNGFCGTASGVPSRFSGGSGTDFTLTISLQPEDFATYYCQSYSTPYTFG QGTKVDIKRT (SEQ ID NO: 134)
CDR2_C_09	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAGGCPRILMRCKQ DSDCLAGCVCGPNGFCGTSGVPSRFSGSGSGTDFTLTISGLQPEDFGTYCQSYSTPLTFG GGTKLEIKRT (SEQ ID NO: 135)
CDR2_E_08	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAGVCPRILMRCKQ DSDCLAGCVCGPNGFCGSRSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQSGASPPYTFG QGTKVEIKRT (SEQ ID NO: 136)
CDR2_G_11	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAGRCPRILMRCKQ DSDCLAGCVCGPNGFCGHSVPSRFSGSGSGTDFTLTISLQPEDFATYYCQSYSTPPTFGQ GTKLEIKRT (SEQ ID NO: 137)
CDR2_B_03	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAEVCPRILMRCKQ DSDCLAGCVCGPNGFCGTSGVPSRFSRSGTEFTLTISLQPEDFATYYCQKVDDYPLTFG GGTKVEIKRT (SEQ ID NO: 138)
CDR2_H_02	DIQMTQSPSSLSASVGDRVITITCRASQSISSYLNWYQQKPGKAPKLLIYAAEICPRILMRCKQD SDCLAGCVCGPNGFCGPSSGIPARFSGSGYGTDFLTINNIESEDAAYYFCLQHDNFPYTFGQG TKVEIKRT (SEQ ID NO: 139)

Table 1: Sequence of unique EETI-II CDR1 and CDR2 KnotBody binders derived from EETI-II CDR1 and CDR2 libraries

Clone number	Clone ID	Library	Trypsin binding signal (FU)	N-terminal linker sequence	C-terminal linker sequence
1	KB_A01	CDR2_B_03	20173	EV	GT
2	KB_A02	CDR2_B_11	183150	AK	GA
3	KB_A03	CDR2_C_06	28711	DR	TN
4	KB_A04	CDR2_D_03	47015	VV	SG
5	KB_A05	CDR2_D_09	121458	DK	GG
6	KB_A06	CDR2_D_11	24427	VR	TP
7	KB_A07	CDR2_E_08	21448	GV	SR
8	KB_A08	CDR2_F_01	167526	GL	GE
9	KB_A09	CDR2_F_04	57732	ER	TP
10	KB_A10	CDR2_F_05	38794	GG	SN
11	KB_A11	CDR2_H_02	16399	EI	PS
12	KB_A12	CDR2_H_04	69349	GR	AN
13	KB_B01	CDR2_H_07	57667	AG	TR
14	KB_B02	CDR2_H_09	115848	VG	GTG
15	KB_C07	CDR2_C_02	43304	VG	SA
16	KB_C08	CDR2_C_07	76810	AV	TR
17	KB_C09	CDR2_C_08	89424	GR	GG
18	KB_C10	CDR2_E_05	118631	GP	AD
19	KB_B10	CDR1_C_12	9268	GRAM (SEQ ID NO: 140)	TG
20	KB_B11	CDR1_F_02	10286	GSRP (SEQ ID NO: 141)	SH
21	KB_B12	CDR1_F_10	17356	GERP (SEQ ID NO: 142)	AN

5

Table 2: KnotBodies selected for detailed characterisation.

Clone number	Library	Clone ID	% reduction in binding signal
1		KB_A01	93
2		KB_A02	96
3		KB_A03	90
4		KB_A04	100
5		KB_A05	100
6		KB_A06	100
7		KB_A07	98
8		KB_A08	99
9		KB_A09	100
10		KB_A10	100
11		KB_A11	100
12		KB_A12	99
13		KB_B01	95
14		KB_B02	98
15		KB_C07	100
16		KB_C08	100
17		KB_C09	100
18	EETI-II CDR2	KB_C10	100
19	EETI-II CDR1	KB_B10	100
20		KB_B11	100
21		KB_B12	97

Table 3: Analysis of trypsin binding of KnotBody GlyAla mutants.

Sample ID	TRF signal for 10 ug/mL Fab	TRF signal for 2.4 ug/mL Fab	TRF signal for 0.6 ug/mL Fab
Background (No Fab control)	420	406	431
KB_A01	55581	16598	2392
KB_A02	255452	220577	93759
KB_A04	264243	220697	111314
KB_A05	217918	65386	46706
KB_A06	241777	211701	108395
KB_A07	226082	201003	107814
KB_A08	152699	106949	36568
KB_A09	161164	84131	20987
KB_A10	68660	71860	14572
KB_A11	212086	140605	48852
KB_A12	252832	221989	102132
KB_B01	256957	152908	54794
KB_B02	56567	15884	2344
KB_C07	276261	247038	153317
KB_C08	182923	131246	51143
KB_C09	288988	204878	46788
KB_C10	238066	146488	41709

5 Table 4: Trypsin binding of KnotBody Fabs.

Selection antigen	Number of bi-specific binders	Percentage of bi-specific binders
cMET-FC	33	68.8
GAS6-CD4	36	75.0
FGFR4-CD4	42	87.5
UPA	48	100.0
B-gal	19	39.6

Table 5: Bi-specific KnotBodies identified from phage display selections.

5

Clone ID	Parent Clone	VH germline (DP numbering)	Heavy chain CDR3 sequence	Capture assay signal	Fold improvement in capture assay signal (x)	kd (1/s)	Fold Improvement in kd (x)
KB_Tr_F03	KB_A12	Vh1_DP-8,75_(1-02)	HAANWEEPGFDP	359729	8.3	0.0006	4.4
KB_Tr_E05	KB_A12	Vh1_DP-8,75_(1-02)	RSSAGDGAYFDY	437719	10.1	0.0011	2.6
KB_Tr_E02	KB_A07	Vh1_DP-10_(1-69)	DRGLGTSTYYGMDV	140056	9.0	0.0013	2.3
KB_Tr_D10	KB_A12	Vh1_DP-15_(1-08)	SQSGVGGTGFD	401740	9.3	0.0014	1.9
KB_Tr_A08	KB_A12	Vh6_DP-74_(6-1)	QLGGTFDV	182731	4.2	0.0015	1.8
KB_Tr_E10	KB_A12	Vh1_DP-10_(1-69)	ALDGAWTDYGSHEAYGMDV	125996	2.9	0.0016	1.7
KB_Tr_B08	KB_A12	Vh2_DP-27,28_(2-70)	SFDYGDYFDY	209098	4.8	0.0016	1.7
KB_Tr_C12	KB_A12	Vh1_DP-10_(1-69)	SGAVGARDAFDI	116225	2.7	0.0016	1.7
KB_Tr_F01	KB_A12	Vh1_DP-8,75_(1-02)	DRIGEGIPMDV	278828	6.5	0.0016	1.7
KB_Tr_A10	KB_A12	Vh1_DP-5_(1-24)	GGIVGATNDAFDI	74429	1.7	0.0016	1.7
KB_Tr_B02	KB_A12	Vh1_DP-15_(1-08)	AGAGEGGMDV	339089	7.9	0.0016	1.7
KB_Tr_H03	KB_A07	Vh1_DP-5_(1-24)	DNPLRGMDV	217117	14.0	0.0017	1.7
KB_Tr_A07	KB_A12	Vh3_DP-47_(3-23)	ESGGTNGWDAFDM	99305	2.3	0.0017	1.6
KB_Tr_B07	KB_A12	Vh1_DP-10_(1-69)	GERPDYYYGMDV	218284	5.1	0.0017	1.6
KB_Tr_C04	KB_A12	Vh6_DP-74_(6-1)	EPGGDSYFDY	203206	4.7	0.0017	1.5
KB_Tr_D05	KB_A12	Vh1_DP-5_(1-24)	MRGYNGGFDL	220428	5.1	0.0018	1.5
KB_Tr_D01	KB_A12	Vh1_DP-88_(1-e)	SGGEGVRAYGMDV	227897	5.3	0.0018	1.5
KB_Tr_B03	KB_A12	Vh1_DP-10_(1-69)	DGNVRGMDV	168630	3.9	0.0018	1.5
KB_Tr_D03	KB_A12	Vh1_DP-10_(1-69)	GGSDYYMDV	237382	5.5	0.0018	1.5
KB_Tr_H07	KB_A12	Vh3_DP-47_(3-23)	GDSSGYGSFDI	209783	4.9	0.0018	1.5
KB_Tr_G09	KB_A12	Vh1_DP-10_(1-69)	SGGLGDAFDI	237406	5.5	0.0018	1.5
KB_Tr_D07	KB_A07	Vh4_DP-63_(4-34)	VSTYSGSQPFYD	205899	13.2	0.0018	1.6
KB_Tr_D09	KB_A12	Vh6_DP-74_(6-1)	GAGEGYFDY	320628	7.4	0.0018	1.5

Table 6: KnotBody heavy chain shuffled clones with improved binding to trypsin (HCDR3-SEQ NOs: 143-165)

Toxin	Target Ion channel	Reference	Database Accession
Huwentoxin-IV	Nav 1.7	71	AAP33074.1 GI:30575584
ProTx-II	Nav 1.7	72	P83476.1 GI:25091451
Ssm6a	Nav 1.7	70	2MUN_A GI:848130036
Kaliootoxin (KTX)	Kv 1.3	73,107	AAB20997.1 GI:242975
MoKa-1	Kv 1.3	25	2KIR_A GI:282403522
Shk	Kv 1.3	74,109	4LFS_A GI:530537696
Psalmotoxin (PcTX1)	ASIC1a	118	P60514.1 GI:44888346
EETI-II	n/a	24	P12071.2 GI:547744
Conotoxin- ω	Cav 2.2	58-60	1TTK_A GI:253723132
MCoTI-II	n/a	119	P82409.1 GI:8928147
Mambalgin-1 (Mba-1)	ASIC1a/2a/2b	121	P0DKR6 (AFT65615.1)
Mambalgin-2 (Mba-2)	ASIC1a/2a/2b	121	P0DKS3

Table 7: Ion channel blocking knottins used for antibody VL CDR2 insertion.

Toxin	Sequence
	GAGTGCCTGGAAATCTTCAAGGCCTGCAACCCCAGCAACGACCAGTGCTGCAA GAGCAGCAAGCTCGTGTGCAGCAGAAAGACCCGGTGGTGAAGTACCAGATC TCCAGATGACCCAGAGCCCAAGCAGCCTGAGCGCCA ((SEQ ID NO: 7)
Huwentoxin-IV	ECLEIFKA CNPSNDQCK SSKLVCSRKT RWCKYQIGK (SEQ ID NO: 8)
	TACTGCCAGAAATGGATGTGGACCTGCGACAGCGAGCGGAAGTGCTGCGAGG GCATGGTGTGCCGGCTGTGGTGAAGAAAAAGCTGTGGTCCAGATGACCCAG AGCCCAAGCAGCCTGAGCGCCA (SEQ ID NO: 9)
ProTx-II	YCQKWMWTC D SERKCCEGMV CRLWCKKKLW (SEQ ID NO: 10)
	GCCGACAACAAGTGCGAGAACAGCCTGCGGAGAGAGATCGCCTGCGGCCAGT GCCGGGACAAAGTGAAAACCGACGGCTACTTCTACGAGTGCTGCACCAGCGA CAGCACCTTCAAGAAGTGCCAGGACCTGCTGCACTCCAGATGACCCAGAGCCC AAGCAGCCTGAGCGCCA (SEQ ID NO: 11)
Ssm6a	ADNKCENSLR REIACGQCRD KVKTDGYFYE CCTSDSTFKK CQDLLH (SEQ ID NO: 12)
	ATCTATGCTGCAGGGAGGGGTGTGGAAATTAACGTGAAGTGTAAGCGGGAGCC CACAGTGCCTTAAACCATGCAAAGATGCGGGGATGCGCTTTGGAAAGTGATG AACCGTAAATGCCACTGCACGCCGAAGGCCAACTCCGGAGTCTC (SEQ ID NO: 13)
Kaliotoxin (KTX)	GVEINVKCSG SPQCLKPKD AGMRFGKCMN RKCHCTP (SEQ ID NO: 14)
	ATCAACGTGAAGTGACGCTGCCCCAGCAGTGATCAAGCCCTGCAAGGACG CCGGCATGAGATTTCGCAAGTGATGAACAAGAAATGCCGGTGCTACAGCTC CAGATGACCCAGAGCCCAAGCAGCCTGAGCGCCA (SEQ ID NO: 15)
Mokatoin-1 (MoKa-1)	INVKCSLPQQ CIKPKDAGM RFGKCMNKKC RCYS (SEQ ID NO: 16)
	AGAAGCTGCATCGACACCATCCCCAAGAGCAGATGCACCGCCTTCCAGTGCAA GCACAGCATGAAGTACCGGCTGAGCTTCTGTAGAAAGACCTGCGGCACCTGTT CCAGATGACCCAGAGCCCAAGCAGCCTGAGCGCCA (SEQ ID NO: 17)
Shk	RSCIDTIPKS RCTAFQCKHS MKYRLSFCRK TCGTC (SEQ ID NO: 18)
	GAGGACTGCATCCCCAAGTGGAAGGGCTGCGTGAACAGACACGGCGACTGTT GCGAGGGCCTGGAATGCTGGAAGCGGAGGCGGAGCTTCGAAGTGTCGTGCC CAAGACCCCTAAGACCTCCAGATGACCCAGAGCCCAAGCAGCCTGAGCGCCA (SEQ ID NO: 19)
PcTX1	EDCIPKWKGC VNRHGDCEG LECWKRRRSF EVCVPKTPKT (SEQ ID NO: 20)
EETI-II	GCPRILMRCK QSDCLAGCV CGPNGFCGSP (SEQ ID NO: 21)
Conotoxin-omega	CKGKGAKCSR LMYDCCTGSC RSGKCX (SEQ ID NO: 22)
MCoTI-II	SGSDGGVCPK ILKKCRRSD CPGACICRGN GYCG (SEQ ID NO: 23)
Mambalgin-1 (Mba-1)	LKCYQHKGKVVTCRDMKFCYHNTGMPFRNLKLILQGCSSSCSETENNKCCSTDR CNK (SEQ ID NO: 24)
Mambalgin-2 (Mba-1)	LKCFQHGKVVTCRDMKFCYHNTGMPFRNLKLILQGCSSSCSETENNKCCSTDRC NK (SEQ ID NO: 25)

Table 8A: DNA and amino acid sequences of ion channel blocking knottins.

KnotBody domain	Sequence
D1_A12 (VH)	EVQLVESGGGLVPRPGSLRLSCAASGFTFSSYAMSWVRQAPGKGL EWVSAISGSGGSTYYADSVKGRFTISRDN TKNSLYLQMTSLRADD TAFYYCVKDFGPGYGTGWFDYWGPGLTVTVSS (SEQ ID NO: 30)
KB_A07 ShK (VL)	DIQMTQSPSSLSASVGDRVTITCRASQSISSYLNWYQQKPGKAPKL LIYAAGVRSCTIDTIPKSRCTAFQCKHSMKYRLSFCRKTCGTCRSRG VPSRFSGSGSGTDFTLTISLQPEDFATYYCQQGASPPYTFGQGTKV EIKR (SEQ ID NO: 31)
KB_A12 ShK (VL)	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPK LLIYAAGRSCIDTIPKSRCTAFQCKHSMKYRLSFCRKTCGTCANS GVSDRFSAAKSGTSASLAINGLRSEDEADYYCAAWDDSLNGYVFG TGTKLTVLG (SEQ ID NO: 32)
KB_A07 Kaliotoxin (VL)	DIQMTQSPSSLSASVGDRVTITCRASQSISSYLNWYQQKPGKAPKL LIYAAGVGVEINVKCSGSPQCLKPKCDAGMRFGKCMNRKCHCTP KSRSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQQGASPPYTFG QGTKVEIKR (SEQ ID NO: 33)
KB_A12 PcTx1 (VL)	QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPGKAPK LLIYAAGREDCIPKWKGCVNRHGDCCEGLECWKRRRSFEVCPKTP PKTANSQGVSDRFSAAKSGTSASLAINGLRSEDEADYYCAAWDDSL NGYVFGTGTKLTVLG (SEQ ID NO: 34)
KB_A07 PcTx1 (VL)	DIQMTQSPSSLSASVGDRVTITCRASQSISSYLNWYQQKPGKAPKL LIYAAGVEDCIPKWKGCVNRHGDCCEGLECWKRRRSFEVCPKTP KTSRSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQQGASPPYTF GQGTKVEIKR (SEQ ID NO: 35)

Table 8B: Sequences of ion channel blocking recipient: donor fusions (knottin sequence underlined)

Primer	Sequence
Huwen_ A07 Fwd	TATGCTGCAGGGGTCGAGTGCCTGGAAATCTTCAAGGCCTGC (SEQ ID NO: 166)
Huwen_ A07 Rev	TGGGACTCCGGAGCGGCTGATCTGGTACTTGCACCACCGGGT (SEQ ID NO: 167)
ProTx-II A07 Rev	TGGGACTCCGGAGCGGCTCCACAGCTTTTCTTGCACCACAG (SEQ ID NO: 168)
ProTx_ II A07 fwd	TATGCTGCAGGGGTCTACTGCCAGAAATGGATGTGGACCTG (SEQ ID NO: 169)
Ssm6_ A07 Fwd	TATGCTGCAGGGGTCGCCGACAACAAGTGCAGAGAACAGCCTG (SEQ ID NO: 170)
SSm6_ A07 Rev	TGGGACTCCGGAGCGGCTGTGCAGCAGGTCCTGGCACTTCTT (SEQ ID NO: 171)
Ssm6_ GGS_ A07 Fwd	TATGCTGCAGGGGTCGGCGGTAGCGCCGACAACAAGTGCAGAGAACAGCC TG (SEQ ID NO: 172)
Ssm6_ GGS_ A07 Rev	GACTCCGGAGCGGCTACCGCCGCTGTGCAGCAGGTCCTGGCACTTCTTGA A (SEQ ID NO: 173)
Kalio_ A07_ Fwd_ B	ATCTATGCTGCAGGGGTCGGTGTGGAAATTAACGTGAAGTGT (SEQ ID NO: 174)
Kalio_ A07 Rev	TGGGACTCCGGAGCGGCTCTTCGGCGTGCAGTGGCATTACG (SEQ ID NO: 175)
Moka-1 A07 Fwd	TATGCTGCAGGGGTCATCAACGTGAAGTGCAGCCTGCCCCAG (SEQ ID NO: 176)
Moka-1 A07 Rev	TGGGACTCCGGAGCGGCTGCTGTAGCACCGGCATTTCTTGTT (SEQ ID NO: 177)
Shk_ A07 Fwd	TATGCTGCAGGGGTCAGAAGCTGCATCGACACCATCCCCAAGA (SEQ ID NO: 178)
Shk_ A07_ Rev	TGGGACTCCGGAGCGGCTACAGGTGCCGCAGGTCTTTCTACA (SEQ ID NO: 179)
PcTx-I A07 Fwd	TATGCTGCAGGGGTCGAGGACTGCATCCCCAAGTGGAAGGGC (SEQ ID NO: 180)
PcTx-I A07 Rev	TGGGACTCCGGAGCGGCTGGTCTTAGGGGTCTTGGGCACGCA (SEQ ID NO: 181)

Table 9A: Primers used for the cloning of ion channel blockers (toxins) into the VL CDR2 of KB_ A07. Primer name identifies the toxin used for the fusion (e.g. Huwen_ A07 Rev is a reverse primer used for cloning Huwentoxin-IV into KB_ A07)

Primer	Sequence
Huwen A12 Rev	GACTCCGGAGTTGGCGATCTGGTACTTGCAACCACCGGGTCTTTCT(SEQ ID NO: 182)
Huwen_A12 Fwd	TATGCTGCAGGGAGGGAGTGCCTGGAAATCTTCAAGGCCTGC(SEQ ID NO: 183)
ProTx-II A12 fwd	TATGCTGCAGGGAGGTACTGCCAGAAATGGATGTGGACCTGC(SEQ ID NO: 184)
ProTx-II A12 Rev	GACTCCGGAGTTGGCCACAGCTTTTTCTTGCAACCACAGCCG(SEQ ID NO: 185)
Ssm6a_A12 Fwd	TATGCTGCAGGGAGGGCCGACAACAAGTGCAGAGAACAGCCTG(SEQ ID NO: 186)
Ssm6a_A12 Rev	GACTCCGGAGTTGGCGTGCAGCAGGTCCTGGCACTTCTTGAAG(SEQ ID NO: 187)
Ssm6a_GGS_A12 Fwd	TATGCTGCAGGGAGGGGCGGTAGCGCCGACAACAAGTGCAGAGAACAGCC TG(SEQ ID NO: 188)
Ssm6a_GGS_A12 Rev	ACTCCGGAGTTGGCACCGCCGCTGTGCAGCAGGTCCTGGCACTTCTTGAA G(SEQ ID NO: 189)
Kalio_A12_Fwd_B	ATCTATGCTGCAGGGAGGGGTGTGGAAATTAACGTGAAGTGT(SEQ ID NO: 190)
Kalio_A12 Rev	GAGACTCCGGAGTTGGCCTTCGGCGTGCAGTGGCATTTACG(SEQ ID NO: 191)
Moka1 A12 Fwd	TATGCTGCAGGGAGGATCAACGTGAAGTGCAGCCTGCCCCAG(SEQ ID NO: 192)
Moka1_A12 Rev	GACTCCGGAGTTGGCGCTGTAGCACCGGCATTTCTTGTTCAT(SEQ ID NO: 193)
Shk_A12 Fwd	TATGCTGCAGGGAGGAGAAGCTGCATCGACACCATCCCCAAG(SEQ ID NO: 194)
Shk_A12 rev	GACTCCGGAGTTGGCACAGGTGCCGCAGGTCTTTCTACAGAAG(SEQ ID NO: 195)
PcTx-1 A12 Fwd	TATGCTGCAGGGAGGGAGGACTGCATCCCCAAGTGGAAGGGC(SEQ ID NO: 196)
PcTX-1 A12 Rev	GACTCCGGAGTTGGCGGTCTTAGGGGTCTTGGGCACGCACAC(SEQ ID NO: 197)

Table 9B: Primers used for the cloning of ion channel blockers (toxins) into the VL CDR2 of KB_A12. Primer name identifies the toxin used for the fusion (e.g Huwen_A12 Fwd is a forward primer used for cloning Huwentoxin-IV into KB_A07).

Toxin/Knottin	Antibody	IgG1 Yield (mg/L)
Huwentoxin-IV	KB_A07	6.0
ProTx-II		1.3
Ssm6a		11.6
Ssm6a_GGS		9.8
PcTx-I		11.5
Shk		9.4
Moka-1		3.7
Kalimotoxin (KTX)		5.0
Huwentoxin-IV	KB_A12	10.7
ProTx-II		5.1
Ssm6a		7.4
Ssm6a_GGS		6.2
PcTx-I		11.9
Shk		11.8
Moka-1		3.9
Kalimotoxin (KTX)		5.3
Mambalgin-1 (Mba-1)	KB_A12	14.4
Mambalgin-2 (Mba-1)		7.8
EETI-II (Control)	KB_A07	9.4
EETI-II (Control)	KB_A12	11.8

Table 10: KnotBody yield after the Protein-A purification of Toxin-antibody fusions.

Sample type	Toxin	Antibody	IC ₅₀ (nM)
Toxin fusion	Shk	KB_A07	40
	MoKa-1		N/E*
	Kaliotoxin (KTX)		900
	Shk	KB_A12	20
	MoKa-1		N/E*
	Kaliotoxin (KTX)		N/E*
Isotype control	None	KB_A07	N/E*
	None	KB_A12	N/E*

Table 11A: Summary IC₅₀ data for eight samples tested against Kv1.3 channels. N/E*= no detectable effect.

5

KnotBody/Antibody	Concentration (μM)	% current remaining	% current remaining PcTx1 (300nM)	n
KB_A07_PcTx1	6.6	6.2	3.6	5
KB_A12_PcTx1	5	4.8	3.8	7
KB_A12_Mba-1	3	69.2	2	5
KB_A12_Mba-2	2.3	72.4	1.9	5
KB_A07 (control)	6	70.9	1.9	3
KB_A12 (control)	3.3	67.4	2.7	6
Buffer only (control)	0	74.9	3.8	6

Table 11B: Percentage ASIC1a current remaining in response to KB_A12 and KB_A07 based KnotBody applications followed by a full blocking concentration of PcTx1

10

Adhiron	Protein Sequence
Ad-LOX1-A	ATGVRAVPGNENSLEIEELARFAVDEHNKKENALLEFVRVVKAKEQT AHLDPMDTMYYLTLLEAKDGGKKKLYEAKVWVKFWMISDLIFNFKE LQEFKPVGDA (SEQ ID NO: 26)
Ad-LOX1-B	ATGVRAVPGNENSLEIEELARFAVDEHNKKENALLEFVRVVKAKEQE QPIGEHPVNDTMYYLTLLEAKDGGKKKLYEAKVWVKRWLRFTEIYNF KELQEFKPVGDA (SEQ ID NO: 27)

Table 12: Amino acid sequences of the LOX-1 binding adhiron.

Adhiron	gene*sequence
Ad#LOX1#A	GCTACAGGCGTGCGGGCTGTGCCCCGCAATGAGAACAGCCTGGAA ATCGAGGAAGTGGCCAGATTCGCGGTGGACGAGCACAACAAGAAAG AGAACGCCCTGCTGGAATTCGTGCGGGTCGTGAAGGCCAAAGAGCA GTGGAGCGAGGCCGACAACGACTGGCACACCATGTACTACCTGACC CTGGAAGCCAAGGACGGCGCAAGAAGAAGCTGTACGAGGCCAAA GTGTGGGTCAAGCTGGACCTGGAAACCTGGCAGCACTTCAACTCAA AGAGCTCCAGGAATTCAAGCCCGTGGGCGACGCT
Ad#LOX1#B	GCTACAGGCGTGCGGGCTGTGCCCCGCAATGAGAACAGCCTGGAA ATCGAGGAAGTGGCCAGATTCGCGGTGGACGAGCACAACAAGAAAG AGAACGCCCTGCTGGAATTCGTGCGGGTCGTGAAGGCCAAAGAGCA GGAACAGCCCATCGGCGAGCACCCCGTGAACGACACCATGTACTAC CTGACCCTGGAAGCCAAGGACGGCGCAAGAAGAAGCTGTACGAG GCCAAAGTGTGGGTCAAGCGGTGGCTGCGGTTACCGAGATCTACA ACTCAAAGAGCTCCAGGAATTCAAGCCCGTGGGCGACGCT

Table 13: Nucleotide sequences of the two adhiron used for this work (SEQ ID NOS: 198, 199)

Antibody	Primer-name	Sequence
KB_A07	Ad_SUMO_10_A07_Fwd	ATCTATGCTGCAGGGGTCGCTACAGGCGTGCGGGCTGTGCCCCGC
	Ad_SUMO10_A07_Rev	GGGACTCCGGAGCGGCTTGCCTCGCCACGGGCTTGAATTCCTGG
KB_A12	Ad_SUMO_10_A12_Fwd	ATCTATGCTGCAGGGAGGGCTACAGGCGTGCGGGCTGTGCCCCGC
	Ad_SUMO10_A12_Rev	GAGACTCCGGAGTTGGCGGCGTCGCCACGGGCTTGAATTCCTGG

Table 14: sequences of the primers used for cloning adhiron into the CDR2 position of antibodies KB_A07 (SEQ ID NOS: 200 & 201) and KB_A12 (SEQ ID NOS: 202 & 203).

KnotBody construct	N-terminal linker sequence	C-terminal linker sequence
KB_A07 (Parent)	GV	SR
KB_A07 Gly4Ser	GGGGS (SEQ ID NO: 1)	GGGGS(SEQ ID NO: 1)
KB_A07 (Gly4Ser)2	GGGSGGGGS(SEQ ID NO: 204)	GGGSGGGGS(SEQ ID NO: 204)
KB_A12 (Parent)	GR	AN
KB_A12 Gly4Ser	GGGGS(SEQ ID NO: 1)	GGGGS(SEQ ID NO: 1)
KB_A12 (Gly4Ser)2	GGGSGGGGS(SEQ ID NO: 204)	GGGSGGGGS(SEQ ID NO: 204)

Table 15: N and C terminal linker sequences of “selected” KnotBodies and their variants.

KnotBody construct	Sequence
KB_A07	GGTGGCGCTAGCGACATACAAATGACCCAATCACCTAGCTCTCTTAGTGCCTCTGTTGGGGATCGGGT CACCATCACTTGTAGAGCGAGCCAGAGTATCTCATCATACTTGAAGTGGTACCAGCAGAAGCCAGGG AAGGCCCCCAAGCTGTTGATTTACGCGGCTGGGGTCTGCCCGGCATCTTGATGAGGTGCAAACAAGA CTCAGACTGCCTGGCTGGATGTGTTTGGCGACCAAATGGTTTCTGCGGAAGCCGCTCAGGCGTGCCAT CAAGATTTAGTGGTTCAGGAAGTGGTACGGACTTCACGCTGACGATTTTCATCTTCAACCCGAAGAT TTCGCCACGTACTACTGTCAACAGGGTGCTTCTCCACCTTATACTTTCGGTCAGGGTACCAAGGTTGAG ATTAAGCGCACCGCGGCCCAATC (SEQ ID NO: 205)
KB_A07 Gly ₄ Ser	GGTGGCGCTAGCGACATACAAATGACCCAAAGTCCGAGCTCCTTGAGTGCCTCCGTAGGTGATAGGG TCACTATTACTTGCAGAGCGTCTCAGTCCATCTCCTCTATTGGAATTGGTACCAACAGAAACCGGGG AAAGCCCCCAAGCTCCTGATCTACGCCGCTGGGGGAGGCGGGAGTGGGGGGGGCGGGTCTGTCCGC GCATCCTTATGCGGTGTAAACAGGACAGTGATTGCCTTGCTGTTGTGTCTGCGGCCCAATGGTTTTT GCGGGGGTGGGGGGGACAGCGGTGGGGGCGGTTCTCCGGGTGCCATCTCGCTTTAGCGGTTTCAGG TAGTGAACGGAATTTACACTGACAATATCATCTTTGCAACCAGAGGATTGCCACGTACTACTGTC AGCAAGGTGCTCTCCACCTTACACGTTTGGACAAGGCACCAAGTAGAGATTAAGCGGACCGCGGC CGCAATC (SEQ ID NO: 206)
KB_A07 (Gly ₄ Ser) ₂	GGTGGCGCTAGCGACATACAAATGACCCAATCACCTAGCTCTCTTAGTGCCTCTGTTGGGGATCGGGT CACCATCACTTGTAGAGCGAGCCAGAGTATCTCATCATACTTGAAGTGGTACCAGCAGAAGCCAGGG AAGGCCCCCAAGCTGTTGATTTACGCGGCTGGCGGAGGAGGGTCTGCCCGGCATCTTGATGAGGT GCAAACAAGACTCAGACTGCCTGGCTGGATGTGTTTGGCGACCAAATGGTTTCTGCGGAGGAGGCGG AGGTTCTCAGGCGTGCCATCAAGATTTAGTGGTTCAGGAAGTGGTACGGACTTCACGCTGACGATT CATCTCTTCAACCCGAAGATTTGCCACGTACTACTGTCAACAGGGTGCTTCTCCACCTTATACTTTTCG GTCAGGGTACCAAGGTTGAGATTAAGCGCACCGCGGCCCAATC (SEQ ID NO: 207)
KB_A12	GGTGGCGCTAGCCAGAGTGTCTTGACGCAGCCACCTTCTGTGTCAGCGAGGCCCCACGCCAGAGGGTTA CCATAACATGTTCCGGGTCCAGCTCTAACATAGGGAATAACGCGGTAAACTGGTATCAGCAATTGCC GGCAAAGCACCAGAACTCTTGATCTATGCAGCGGGGAGGTGTCTCGAATACTGATGCGATGTAAAC AGGACTCCGATTGTCTTGCGGGATGTGTGTGTGGTCCGAATGGGTTTTGCGGCGCCAACAGCGGCGTA AGTGATCGATTCTCAGCGGCGAAAATCCGGCACATCCGCCTCACTGGCGATCAACGGATTGCGAAGTG AGGACGAAGCTGACTATTATTGCGCGGCCTGGGATGATTCTTGAACGGGTATGTATTTGGCACAGGA ACGAAGCTGACTGTGCTGGGACAACCCGCGGCCCAATC (SEQ ID NO: 208)
KB_A12 Gly ₄ Ser	GGTGGCGCTAGCCAGAGCGTACTGACGCAGCCGCTTCTGTTAGCGAGGCTCCCCGACAGCGAGTAA CGATAACGTGCAGCGGTTCAAGCAGTAATATCGGGAATAATGCAGTAAATTGGTATCAGCAACTGCC TGGAAAAGCGCCCAAGCTGCTCATATATGCGGCCGGGGGCGGGGTAGCGGCGGAGGGGAAGCTG CCCAAGAATCTTGATGCGGTGTAAACAAGATTACAGACTGTTTGCCCGGTTGCGTATGCGGTCCAAATG GGTTCTGCGGAGGTGGTGGTGGGTCCGGTGGAGGAGGTAGTAGCGGGGTAGTGATCGATTCTCCGC GGCGAAGTCCGGCACCAAGTCAAGTCTCGCTATAAACGGGCTCAGGTCAGAAGATGAGGCAGATTAT TACTGTGCCGATGGGACGACAGTTTGAACGGCTATGTCTTCGGAACGGGGACTAAACTTACCGTACT TGGACAGCCCGCGGCCCAATC (SEQ ID NO: 209)
KB_A12 (Gly ₄ Ser) ₂	GGTGGCGCTAGCCAGAGTGTCTTGACGCAGCCACCTTCTGTGTCAGCGAGGCCCCACGCCAGAGGGTTA CCATAACATGTTCCGGGTCCAGCTCTAACATAGGGAATAACGCGGTAAACTGGTATCAGCAATTGCC GGCAAAGCACCAGAACTCTTGATCTATGCAGCGGGAGGGGGAGGCTCTTGCTCTCGAATACTGATGC GATGTAAACAGGACTCCGATTGTCTTGCGGGATGTGTGTGTGGTCCGAATGGGTTTTGCGGCGGTGGG GGCGGCTTAGCGGCGTAAGTGATCGATTCTCAGCGGCGAAATCCGGCACATCCGCCTCACTGGCGA TCAACGGATTGCGAAGTGAGGACGAAGCTGACTATTATTGCGCGGCCTGGGATGATTCTTGAACGG GTATGTATTTGGCACAGGAACGAAGCTGACTGTGCTGGGACAACCCGCGGCCCAATC (SEQ ID NO: 210)

Table 16: Sequences of KnotBody linker variants.

Clone ID	Loop 1 sequence	TRF signal
KB_A12_cMET_H01	C HRMSGT GRC (SEQ ID NO: 211)	131578
KB_A12_cMET_F05	C KRLMSGAG R C (SEQ ID NO: 212)	59604
KB_A12_cMET_G01	C QRQSGT GRC (SEQ ID NO: 213)	98924
KB_A12_cMET_G07	C RASSGT GRC (SEQ ID NO: 214)	57958
KB_A12_cMET_E07	C PKRHTGT GRC (SEQ ID NO: 215)	95275
KB_A12_cMET_E04	C GHLSGT GRC (SEQ ID NO: 216)	41255
KB_A12_cMET_F02	C GRASGT GRC (SEQ ID NO: 217)	98503
KB_A12_cMET_H05	C NRASGAG R C (SEQ ID NO: 218)	152852
KB_A12_cMET_H03	C RGMTGV GRC (SEQ ID NO: 219)	54161
KB_A12_cMET_H08	C QTGRSGT GRC (SEQ ID NO: 220)	6730
KB_A12_cMET_E05	C DRKAGT GRC (SEQ ID NO: 221)	115765
KB_A12_cMET_E11	C AKKSGT GRC (SEQ ID NO: 222)	158497
KB_A12_cMET_E12	C AKRSGT GRC (SEQ ID NO: 223)	95895
KB_A12_cMET_H04	C PQMTGT GRC (SEQ ID NO: 224)	112989
KB_A12_cMET_E01	C NLTSGT GRC (SEQ ID NO: 225)	22439
KB_A12_cMET_G10	C EKHSGT GRC (SEQ ID NO: 226)	64760
KB_A12_cMET_H02	C AKRTGT GRC (SEQ ID NO: 227)	35448
KB_A12_cMET_F06	C PHQTGT GRC (SEQ ID NO: 228)	56209
KB_A12_cMET_F10	C RSLMSGT GRC (SEQ ID NO: 229)	51323
KB_A12_cMET_F12	C KAQSGSG R C (SEQ ID NO: 230)	119476
KB_A12_cMET_G06	C NKSGGT GRC (SEQ ID NO: 231)	62077
KB_A12_cMET_E02	C RKKSGAN R C (SEQ ID NO: 232)	9482
KB_A12_cMET_G08	C ARLSGSG R C (SEQ ID NO: 233)	27930

Table 17A: Loop1 sequences of unique cMET binders isolated from the KnotBody loop library. Cysteines flanking the loop 1 residues are highlighted in bold.

Test well	Clones	% transcytosis after 6h
C1	KB_TFR_B01	0.0
	KB_TFR_B02	
	KB_TFR_B03	
C2	KB_TFR_B05	1.3
	KB_TFR_B07	
	KB_TFR_B09	
C3	KB_TFR_B11	0.9
	KB_TFR_C01	
	KB_TFR_C03	
C4	KB_TFR_C05	0.7
	KB_TFR_C06	
	KB_TFR_C07	
C5	KB_TFR_D02	0.0
	KB_TFR_D05	
	KB_TFR_D07	
C6	KB_TFR_D10	0.1
	KB_TFR_E03	
	KB_TFR_E06	
B1	KB_TFR_A05	0.0
	KB_TFR_A06	
	KB_TFR_A07	
OX26-Fab	Positive Control	0.2
KB_A12	Negative control	0.1

Table 19: Percentage transcytosis of 21 test KnotBodies and controls across the BBB in an *in vitro* model system.

Name	Sequence
KB_TFR_B05	QVQLVQSGAEVKKPGSSVKVSKASGGTFSSYAIWVRQAPGQGLEWM GRNIPILGIANYAQKSRGRVTITADESTSTAYMELSSLRSED TAVYYCARVAPYSSGWANVDAFDIWGQGTLTVSS _(SEQ ID NO: 249)
KB_TFR_B07	QVQLVQSEPEVKKPGASVKVSKASGYTFTSYGISWVRQAPGQGLEWMG RIIPIFGIANYAQKFQGRVTITADKSTSTAYMELSSLRSED TAVYYCAGITGTNGPHDAFDIWGQGTMTVSS _(SEQ ID NO: 250)
KB_TFR_B09	QVQLVQSGAEVKKPGSSVKVSKASGGTFSSYTISWVRQAPGQGLEWM GRIIPILSIANYAQKFQSRVTITADESTSTAYMELSSLRSED TAVYYCARVRPYDSSADLDAFDIWGQGTMTVSS _(SEQ ID NO: 251)
KB_TFR_B11	EVQLVQFGAEVKKPGASVKVSKASGYTFTGYMHVVRQAPGQGLEW MGRINPNSGGTNYAQKFQGRVTMTTRDTSISTAYMELSLRSED TAVYYCARGRGPLSYWGQGTMTVSS _(SEQ ID NO: 252)
KB_TFR_C01	QVQLVQSGAEVKKPGSSVKVSKASGGTYSSNTFTWVRQAPGQGLEWM GRIIPVLDLTNSAVNFQDRVITITADESTSTVYMELSSLRSED TAVYYCASTTAMVPTDAFDIWGQGTMTVSS _(SEQ ID NO: 253)
KB_TFR_C03	EVQLVESGAEVKKPGSSVKVSKASGGTVSSYAIWVRQAPGQGLEWMG GIIPIFGTANYAQKFQGRVTITADESTSTAYMELSSLRSED TAVYYCARDLFQRSGSYPIYYYYYGMDVWGQGTMTVSS _(SEQ ID NO: 254)
KB_TFR_C05	QVQLVQSGAEVKKPGSSVKVSKASGGTYSSNTFTWVRQAPGQGLEWM GRIIPILGIANYAQKFQGRVTITADESTSTAYMVLSSLRSED TAVYYCARVRPYYDSSADLDAFDIWGQGTMTVSS _(SEQ ID NO: 255)
KB_TFR_C06	QVQLVESGAEVKKPGSSVKVSKASGGTFSSYAIWVRQAPGQGLEWMG GIIPIFGTANYAQKFQGRVTITADESTSTAYMELSSLRSED TAVYYCAIALRDSSGYTDAFDIWGQGTMTVSS _(SEQ ID NO: 256)
KB_TFR_C07	QMQLVQSGAEVKKPGASVKVSKASGYTFTSYGISWVRQAPGQGLEWM GGIIPIFGTANYAQKFQGRVTITADESTGTAYMELSSLRSED TAVYYCAGPGGYDILTGYPTDAFDIWGQGTMTVSS _(SEQ ID NO: 257)

Table 20: Amino acid sequences of anti-TFR VHs that could potentially cross BBB.

Name	Sequence
EETI-II Cow ULVC-Ab	CAGCCGGCCATGGCCCAAGTGCAACTTCGCGAAAGCGGGCCTTCCTTGGTTAA ACCATCGCAGACCCTGAGTCTTACGTGCACGGCCAGCGGTTTTCCCTGTCCGA TAAAGCAGTAGGGTGGGTGCGCCAAGCGCCGGGAAAGGCATTAGAGTGGCTTG GTTCCATTGATACGGGGGGGAACACAGGATACAATCCCGGCTTGAAGTCTCGC CTTTCAATCACCAAAGACAACCTCAAAGTCTCAAGTCTCCCTGAGCGTCTCATCG GTTACCACCGAGGACTCAGCCACGTACTACTGCACATCCGTTTCATCAGGAGAC CAAAAAATACCAATCTTGTCCCCGCATCCTGATGCGTTGTAAACAAGACAGCG ACTGCCTGGCAGGTTGTGTATGCGGTCTTAATGGGTTTTGTGGATTAACCACTC TGCCAGTCTCATATTCTTACACTTATAATTATGAGTGGCATGTTGATGTCTGGG GGCAGGGGCTTCTTGTACGGTCTCGAGTGGTGGAGGCGGTTTCAGGCGGAGGT GGCTCTGGCGGTGGCGCTAGCCAGGCTGTTTTAAACCAACCCAGCTCGGTTAGT GGATCGTTGGGGCAGCGCGTCTCAATCACTTGTTCGGCTCCTCCTCGAATGTT GGTAATGGATATGTTTCTGGTACCAGCTTATCCCCGGTAGCGCTCCTCGCACC TTAATTTATGGTGACACGTCCCGTGCCAGCGGTGTCCCTGATCGTTTCTCTGGG AGCCGTTCCGGGAACACCGCCACACTTACAATTAGTAGCCTTCAAGCTGAGGA CGAAGCGGACTATTTTGTGCCTCTGCAGAGGATTATCCTCTAACGCTGTGTT TGGCAGTGGCACCACCCTTACTGTGTTAGGGGCGGCCGCAGAT (SEQ ID NO: 258)

Table 21. Nucleotide sequences of EETI-II-Cow ULVC-Ab synthetic gene.

Primer	Sequence
2979	CTAAGCTCCTGATCTATGCTGCAGGGGTCTGCCCCGCGTATCCTGATGCGTTGCAAACA GGACTCAGACTGCCTGG (SEQ ID NO: 259)
2980	GAACCTTGATGGGACTCCGGAGCGGCTCCCGCAGAAGCCGTTTCGGACCGCATACGCA GCCGGCCAGGCAGTCTGAGTCCTG (SEQ ID NO: 260)
2983	CTAAGCTCCTGATCTATGCTGCAGGGAGGTGCCCCGCGTATCCTGATGCGTTGCAAAC AGGACTCAGACTGCCTGG (SEQ ID NO: 261)
2984	GAATCGGTCAGAGACTCCGGAGTTGGCCCCGCAGAAGCCGTTTCGGACCGCATACGCA GCCGGCCAGGCAGTCTGAGTCCTG (SEQ ID NO: 262)
2985	TTTTTTCCATGGCTGAAGTCCAACCTG (SEQ ID NO: 263)
2995	TTTTTTGCGGCCGCGGTACGTTTG (SEQ ID NO: 264)
2999	TGCAGCATAGATCAGGAGCTTAG (SEQ ID NO: 265)
3000	TCCGGAGTCCCATCAAGGTTT (SEQ ID NO: 266)
3002	TTTTTTGCGGCCGCGAGGCTGACCTAG (SEQ ID NO: 267)
3003	TGCAGCATAGATCAGGAGCTTAG (SEQ ID NO: 268)
3004	TCCGGAGTCTCTGACCGATTTC (SEQ ID NO: 269)

- 5 Table 22: Primers used to create inserts for the cloning of KnotBodies and linker libraries for mammalian display.

EVQLVESGGGLVPRPGSLRLSCAASGFTFSSYAMSWVRQAPGKGLEWVSAISGSGGSTY
YADSVKGRFTISRDN TKNSLYLQMTSLRADDTAFYYCVDFGPGYGTGWFDYWGPGLVTV
SSGGGGSGGGGSGGGASDIQMTQSPSSLSASVGDRTITCRASQSISSYLNWYQQKPGK
APKLLIHDASSLQSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQQSFSLPTFGGGTKM
DIKRT (SEQ ID NO: 270)

Table 23: Amino acid sequence of the parental anti-TACE D1A12 scFv¹⁰¹ used for knottin linker library insertion into VH and VL CDRs 1 to 3.

Primer	Sequence
2965	GCGTCGGGTTTTACCTTTAGCVNSVNSTGTCCCCGGATACTTATGAGATGTAAGCAAG ATAGTGATTGCCTCGC (SEQ ID NO: 271)
2966	CGGAGCCTGACGAACCCASNBSNBGCCACAAAACCCGTTGGGACCACAGACACATCC GGCGAGGCAATCACTATCTTGC (SEQ ID NO: 272)
2967	GTAAAGGCCTGGAATGGGTCTCCVNSVNSTGTCCCCGGATACTTATGAGATGTAAGC AAGATAGTGATTGCCTCGC (SEQ ID NO: 273)
2968	GTCGCGAGAGATGGTGAAACGSNBSNBGCCACAAAACCCGTTGGGACCACAGACAC ATCCGGCGAGGCAATCACTATCTTGC (SEQ ID NO: 274)
2969	CACGGCTTTTTATTACTGCGTTGATVNSVNSTGTCCCCGGATACTTATGAGATGTAAG CAAGATAGTGATTGCCTCGC (SEQ ID NO: 275)
2970	CAGGGTGCCCGGACCCASNBSNBGCCACAAAACCCGTTGGGACCACAGACACATCC GGCGAGGCAATCACTATCTTGC (SEQ ID NO: 276)
2971	GAGACAGAGTCACCATCACTTGCVNSVNSTGTCCCCGGATACTTATGAGATGTAAGC AAGATAGTGATTGCCTCGC (SEQ ID NO: 277)
2972	CCTGGCTTCTGCTGATACCASNBSNBGCCACAAAACCCGTTGGGACCACAGACACAT CCGGCGAGGCAATCACTATCTTGC (SEQ ID NO: 278)
2973	CCCTAAGCTCCTGATCCATGATVNSVNSTGTCCCCGGATACTTATGAGATGTAAGCAA GATAGTGATTGCCTCGC (SEQ ID NO: 279)
2974	CTGAACCTTGATGGGACCCASNBSNBGCCACAAAACCCGTTGGGACCACAGACACAT CCGGCGAGGCAATCACTATCTTGC (SEQ ID NO: 280)
2975	CCTGAAGATTTTGCAACTTACTACTGTVNSVNSTGTCCCCGGATACTTATGAGATGTA AGCAAGATAGTGATTGCCTCGC (SEQ ID NO: 281)
2976	CATTTTGGTCCCTCCGCCGAASNBSNBGCCACAAAACCCGTTGGGACCACAGACACA TCCGGCGAGGCAATCACTATCTTGC (SEQ ID NO: 282)
2977	CTAAGCTCCTGATCTATGCTGCAVNSVNSTGCCCGCGTATCCTGATGCGTTGCAAACA GGA CT CAGACTGCCTGG (SEQ ID NO: 283)
2978	GAACCTTGATGGGACTCCGGASNBSNBCCCGCAGAAGCCGTTCCGACCGCATAACGCA GCCGGCCAGGCAGTCTGAGTCCTG (SEQ ID NO: 284)
2981	CTAAGCTCCTGATCTATGCTGCAVNSVNSTGCCCGCGTATCCTGATGCGTTGCAAACA GGA CT CAGACTGCCTGG (SEQ ID NO: 285)
2982	GAATCGGTCAGAGACTCCGGAGTTGGCCCCGCAGAAGCCGTTCCGACCGCATAACGCA GCCGGCCAGGCAGTCTGAGTCCTG (SEQ ID NO: 286)
2986	GCTAAAGGTAAAACCCGACGC (SEQ ID NO: 287)
2987	TGGGTTCGTCAGGCTCCG (SEQ ID NO: 288)
2988	TTTTTTCTCGAGACGGTCACCAGG (SEQ ID NO: 289)
2989	GGAGACCCATTCCAGGCCTTTAC (SEQ ID NO: 290)
2990	CGTTTCACCATCTCTCGCGAC (SEQ ID NO: 291)

2991	ATCAACGCAGTAATAAAAAGCCGTG(SEQ ID NO: 292)
2992	TTTTTT GCTAGCGACATCCAGATGACC (SEQ ID NO: 293)
2993	GCAAGTGATGGTGACTCTGTCTC(SEQ ID NO: 294)
2994	TGGTATCAGCAGAAGCCAGG(SEQ ID NO: 295)
2996	ATCATGGATCAGGAGCTTAGGG(SEQ ID NO: 296)
2997	GGGGTCCCATCAAGGTTTCAG(SEQ ID NO: 297)
2998	ACAGTAGTAAGTTGCAAAATCTTCAGG(SEQ ID NO: 298)
3001	TTTTTT GCTAGCCAGTCTGTGCTGAC(SEQ ID NO: 299)
3005	AAATTTACTCGAGACGGTCACCAGGGTGCCCGGACCCCA(SEQ ID NO: 300)
3006	TTTTTTGCGGCCGCGGTACGTTTGATATCCATTTTGGTCCCTCCGCCGAA(SEQ ID NO: 318)
3012	TGGGGTCCGGGCACCCTG(SEQ ID NO: 301)
D1A12 NotI Rev	TTCTGCGGCCGCGGTACGTTTGATATCCATT (SEQ ID NO: 78)

Table 24: Primers used to create inserts for the cloning of KnotBodies and linker libraries for phage display selection.

Library	CDR insertion	Insert	Primer pairs	Template scFv	PCR size (bp)
A	VH CDR1	A1	2985/2986	D1A12	98
		A2	2965/2966	None	132
		A3	2987/2995	D1A12	638
B	VH CDR2	B1	2985/2989	D1A12	155
		B2	2967/2968	None	137
		B3	2990/2995	D1A12	545
C	VH CDR3	C1	2985/2991	D1A12	302
		C2	2969/2970	None	136
		C3	3012/2995	D1A12	413
D	VL CDR1	D1	2985/2993	D1A12	485
		D2	2971/2972	None	136
		D3	2994/2995	D1A12	233
E	VL CDR2	E1	2985/2996	D1A12	566
		E2	2973/2974	None	135
		E3	2997/2995	D1A12	167
F	VL CDR3	F1	2985/2998	D1A12	680
		F2	2975/2976	None	141
		N/A			
G	KB_A07	G1	2985/2999	A07-knotbody	569
		G2	2977/2978	None	137
		G3	3000/2995	A07-knotbody	170

Table 25: Primers pairs required to create the DNA inserts needed for the three fragment assembly to create the knottin linker libraries. The VL CDR3 knottin linker library was created by a 2 fragment assembly with inserts F1 and F2.

Clone	CDR insertion	N-term XX	C-term XX
A_A01	VH CDR1	AV	TK
A_A02	VH CDR1	KM	SD
A_A03	VH CDR1	PI	LP
A_A04	VH CDR1	EK	PR
B_A05	VH CDR2	GK	TP
B_A06	VH CDR2	RL	ED
B_A07	VH CDR2	PK	GN
B_A08	VH CDR2	RP	TP
B_A10	VH CDR2	VP	SL
B_A11	VH CDR2	KG	TN
B_A12	VH CDR2	GT	SD
C_B01	VH CDR3	KP	TK
C_B02	VH CDR3	RP	SQ
C_B03	VH CDR3	PT	TV
C_B04	VH CDR3	KG	QG
C_B05	VH CDR3	RP	GP
C_B06	VH CDR3	KG	QG
C_B07	VH CDR3	RP	DN
C_B08	VH CDR3	KG	QG
D_B09	VL CDR1	RG	QD
D_B10	VL CDR1	IS	HM
E_B11	VL CDR2	RA	AQ
E_B12	VL CDR2	RK	SR
E_C01	VL CDR2	QP	TR
E_C02	VL CDR2	RP	SR
E_C03	VL CDR2	RK	VN
E_C04	VL CDR2	KA	HQ
E_C05	VL CDR2	VP	HT
E_C06	VL CDR2	EK	TP
E_C08	VL CDR2	KV	TE
E_C09	VL CDR2	RR	GE
E_C10	VL CDR2	KP	AN
E_C11	VL CDR2	LP	SI
E_C12	VL CDR2	HP	SS
E_D01	VL CDR2	KP	AT
E_D02	VL CDR2	AP	VD
E_D03	VL CDR2	LK	SP
E_D04	VL CDR2	HR	DT
E_D05	VL CDR2	KG	TN
E_D06	VL CDR2	RP	DH

E_D07	VL CDR2	KP	HK
E_D08	VL CDR2	QP	HE
E_D09	VL CDR2	TK	AR
E_D10	VL CDR2	VK	NP
E_D11	VL CDR2	TK	TT
E_D12	VL CDR2	KP	AN
E_E01	VL CDR2	TK	DT
E_E02	VL CDR2	QP	TT
E_E03	VL CDR2	RV	DD
E_E04	VL CDR2	RK	SN
E_E05	VL CDR2	RG	HS
E_E06	VL CDR2	QP	SH
E_E07	VL CDR2	AK	TR
E_E08	VL CDR2	RP	TS
F_E09	VL CDR3	RG	QH
F_E10	VL CDR3	RG	ND
F_E11	VL CDR3	PK	TR
F_E12	VL CDR3	KP	GQ
F_F01	VL CDR3	QI	SR
F_F02	VL CDR3	EK	SN
F_F03	VL CDR3	RG	TH
F_F04	VL CDR3	EK	TH
F_F05	VL CDR3	PI	SE
F_F06	VL CDR3	KG	QH
F_F07	VL CDR3	KG	HE

Table 26: Sequences of linkers capable of functional knottin display embedded in D1A12 VH CDR1, VH CDR2, VH CDR3, VL CDR1, VL CDR2 and VL CDR3. XX represents the randomised residues indicated in figure 28.

Clone	CDR insertion	N-term linker	C-term linker	DELFI A signal
G_F08	VL CDR2	EK	AH	15940
G_F09	VL CDR2	PR	AS	13431
G_F10	VL CDR2	PP	TK	11667
G_F11	VL CDR2	HK	SR	14160
G_F12	VL CDR2	GK	SR	11209
G_G01	VL CDR2	QK	TV	10863
G_G03	VL CDR2	TP	ST	14493
G_G04	VL CDR2	LP	AR	14330
G_G05	VL CDR2	GV	GE	10429
G_G06	VL CDR2	NK	AP	10255
G_G07	VL CDR2	KP	TR	26510
G_G08	VL CDR2	KP	HR	13848
G_G09	VL CDR2	KP	TE	24701
G_G10	VL CDR2	RP	NS	12258
G_G11	VL CDR2	PR	SD	15883
G_G12	VL CDR2	PR	TS	14911
G_H01	VL CDR2	TK	AA	10714
G_H02	VL CDR2	RR	TR	11930
G_H03	VL CDR2	RV	SG	12457
G_H04	VL CDR2	RR	TE	20675
G_H05	VL CDR2	TR	TT	10654
G_H06	VL CDR2	PG	TL	17126

Table 27: Sequences of linkers capable of functional knottin display embedded in KB_A07 VL CDR2. XX represents the randomised residues indicated in figure 28.

Name of format	Sequence	SEQ ID
EET 1-5	CPRILMRCKQDSDCLAGCVC GPNGFC	302
EET 2-6	CKQDSDCLAGCVC GPNGFCGSGSDGGVC	303
EET 3-1	CLAGCVC GPNGFCGSGSDGGVCPRILMRC	304
EET 4-2	CVC GPNGFCGSGSDGGVCPRILMRCKQDSDC	305
EET 5-3	CGPNGFCGSGSDGGVCPRILMRCKQDSDCLAGC	306
EET 6-4	CGSGSDGGVCPRILMRCKQDSDCLAGCVC	307

5

Table 28. Alternative framings of EETI-II donor

C09 (9820)

QSVLTQPPSVSEAPRQRTITCg^{gkr}CGPNGFCGSGSDGGVCPRILMRCKQDSDCLAGC^{tsN}
 WYQQKPGQAPVLVQDDSVRPSGIPERFSGSNSGNTATLTISRVEAGDGADYYCQVWDISSD
 LGVFGGGTKLTVLGQP (SEQ ID NO: 308)

5

E01 (127988)

QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYaaggCGPNGFCG
 SGSDGGVCPRILMRCKQDSDCLAGC^{gih}SGVSDRFSDSKSGTSASLAISGLQSEDEADYYCA
 AWDDSLNGYVFGTGTKLTVLGQP (SEQ ID NO: 309)

10

E08 (121047)

QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYaaggCGPNGFCG
 SGSDGGVCPRILMRCKQDSDCLAGC^{giq}SGIPERFSGSKSGTSASLAISGLRSEDEADYYCA
 AWDDNLSGYVFGTGTKLTVLGQP (SEQ ID NO: 310)

15

E05 (118631)

QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYaaggCGPNGFCG
 SGSDGGVCPRILMRCKQDSDCLAGC^{gaq}SGIPERFSGSKSGTSASLAISGLQSEDEAHYYCA
 AWDDSLNGYVFGTGTKVTVLGQP (SEQ ID NO: 311)

20

F01 (101798)

DIQMTQSPSSLSASVGDRTITCRASQSISSYLNWYQQKPGKAPKLLIDaageCGPNGFCGS
 GSDGGVCPRINMRCKQDSDCLAGC^{grd}SGVPSRFSGSGSGTDFTLTISSLQPEDFATYYCQQ
 SYSTPWTFTGQGTKVEIKRT (SEQ ID NO: 312)

25

E03 (82495)

QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYaaggCGPNGFCG
 SGSDGGVCPRILMRCKQDSDCLAGC^{grn}SGIPERFSGSKSGHTATLTISRVEAGDEADYYCQ
 VWDSSSDHVLFGGGTKLTVLGQP (SEQ ID NO: 313)

30

F07 (72824)

QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYaaggCGPNGFCG
 SGSDGGVCPRILMRCKQDSDCLAGC^{ggq}SGVPDRFSGSKSGTSASLAISRLQSEDEADYYCA
 AWDDSLNAYVFGTGTKVTVLGQP (SEQ ID NO: 314)

35

E09 (70274)

QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYaaggCGPNGFCG
 SGSDGGVCPRILMRCKQDSDCLAGC^{gtq}SGIPERFSGSKSGTSASLAISGLRSEDEADYYCA
 AWDDSLRAYVFGTGTLTVLGQP (SEQ ID NO: 315)

40

F03 (67972)

QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGRAPKLLIYaaggCGPNGFCG
 SGGDGGVCPRILMRCKQDSDCLAGC^{gah}SGIPERFSGSKSGTSASLAISGLRSEDEADYYCA
 AWDDSLNGWVFGGGTKVTVLGQP (SEQ ID NO: 316)

45

G11 (27650)

QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNAVNWYQQLPGKAPKLLIYaaggCGPNGFCG
 SGSDGGVCPRILMRCKQDSDCLAGC^{gqs}SGVSDRFSGSKSGTSATLDITGLQTGDEADYYCG
 TWDNSLSVGTVFGGGTKVTVLGQP (SEQ ID NO: 317)

50

Table 29. Sequence of KnotBodies with alternative framing of EETI_II

Ion channel	Gene	Tissue localisation	TTX-s or -r	Disease channelopathy	Clinical indications
Nav1.1	SCN1A	CNS/PNS	TTX-s	Epilepsy	Pain, seizures, neurodegeneration
Nav1.2	SCN2A	CNS	TTX-s	Epilepsy	Epilepsy, neurodegeneration
Nav1.3	SCN3A	CNS	TTX-s	ND	Pain
Nav1.4	SCN4A	Skeletal muscle	TTX-s	Myotonia	Myotonia
Nav1.5	SCN5A	Cardiac	TTX-s	Arrhythmia	Arrhythmia
Nav1.6	SCN8A	CNS/PNS	TTX-r	ND	Pain, movement disorders
Nav1.7	SCN9A	PNS	TTX-s	IEM/PEPD/CIP	Pain
Nav1.8	SCN10A	PNS	TTX-r	Painful neuropathy	Pain
Nav1.9	SCN11A	PNS	TTX-r	Familial episodic pain	Pain

Table 30. Features of Nav1.x channels. Based on sensitivity to the inhibitory toxin tetrodotoxin, VGSCs can be divided into tetrodotoxin-sensitive (TTX-s) or tetrodotoxin-resistant (TTX-r).

Knottin Donor	Knottin donor sequence	Reference
GPTx-1_4M	DCLGAFRKCI PDNDKCCRPNLVCSRLHRWCKYVF	149
HwTx-IV_3M	GCLGIFKACNPSNDQCKSSKLVCSRKTRWCKWQI	153
ProTx-III	DCLKFGWKCNP RNDKCCSGLKCGSNHNWCKLHI	154
ProTx-III_2M	GCLKFGWKCNP RNDKCCSGLKCGSNHNWCKWHI	–

Table 31. Knottin donors used for generating Nav1.7 inhibitors (Example 19)

Knottin Donor	Antibody Acceptor	Knottin donor sequence
GPTx-1_4M	KB_A12	DCLGAFRKCI PDNDKCCRPNLVCSRLHRWCKYVF
HwTx-IV_3M	KB_A12	GCLGIFKACNPSNDQCKSSKLVCSRKTRWCKWQI
ProTx-III	KB_A12	DCLKFGWKCNP RNDKCCSGLKCGSNHNWCKLHI
ProTx-III_2M	KB_A12	GCLKFGWKCNP RNDKCCSGLKCGSNHNWCKWHI

Table 32. Knottin donors and corresponding recipient scaffolds for Nav1.7 inhibitors (Example 19)

KnotBody	VL Sequence
KB_A12 ProTx-III Gly	GGTGGCGCTAGCCAGAGTGTACTTACCCAGCCTCCCTCAGTGTGAGAGGCACCTAGA CAGAGAGTGACGATTACCTGCTCTGGGAGTAGCAGTAACATCGGTAACAACGCCGTC AATTGGTACCAGCAACTCCCAGGGAAGGCCCTAAGCTTCTCATTTACGCAGCGGGA AGGGACTGCCTCAAGTTTCGGGTGGAAATGCAACCCAAGAAACGATAAAATGCTGCTCA GGAATCAAGTGCGGCAGCAACCACAACCTGGTGCAAACTCCACATCGGGCGCAAACAGT GGCGTCAGTGACCGCTTTTCCGCCGCCAAGTCTGGTACGTCAGCGTCTCTGGCAATT AACGGCCTGAGATCAGAAGACGAGGCAGATTACTACTGTGCCGCATGGGACGACAGT CTGAATGGTTACGTGTTTGGTACTGGTACCAAGCTTACGGTCCTCGGTCAACCCGCG GCCGCAATC
KB_A12 ProTx-III 2M Gly	GGTGGCGCTAGCCAGAGTGTACTTACCCAGCCTCCCTCAGTGTGAGAGGCACCTAGA CAGAGAGTGACGATTACCTGCTCTGGGAGTAGCAGTAACATCGGTAACAACGCCGTC AATTGGTACCAGCAACTCCCAGGGAAGGCCCTAAGCTTCTCATTTACGCAGCGGGA AGGGGATGCCTCAAGTTTCGGGTGGAAATGCAACCCAAGAAACGATAAAATGCTGCTCA GGAATCAAGTGCGGCAGCAACCACAACCTGGTGCAAAATGGCACATCGGGCGCAAACAGT GGCGTCAGTGACCGCTTTTCCGCCGCCAAGTCTGGTACGTCAGCGTCTCTGGCAATT AACGGCCTGAGATCAGAAGACGAGGCAGATTACTACTGTGCCGCATGGGACGACAGT CTGAATGGTTACGTGTTTGGTACTGGTACCAAGCTTACGGTCCTCGGTCAACCCGCG GCCGCAATC
KB_A12 HwTx-IV 3M Gly	GGTGGCGCTAGCCAGAGTGTCTTGACGCAGCCACCTTCTGTGAGCGAGGCCCCACGC CAGAGGGTTACCATAACATGTTCCGGGTCCAGCTCTAACATAGGGGAATAACGCGGTA AACTGGTATCAGCAATTGCCCGGCAAAAGCACCGAAACTCTTGATCTATGCAGCGGGG AGGGGATGCCTGGGAATCTTCAAGGCCTGCAACCCCAGCAACGACCAAGTGTGCAAG AGCAGCAAGCTCGTGTGCAGCAGAAAGACCCGGTGGTGCAAGTGGCAGATCGGGCGCC AACAGCGGCGTAAGTGATCGATTCTCAGCGGCGAAATCCGGCACATCCGCCTCACTG GCGATCAACGGATTGCGAAGTGAGGACGAAGCTGACTATTATTGCGCGGCCCTGGGAT GATTCCCTTGAACGGGTATGTATTTGGCACAGGAACGAAGCTGACTGTGCTGGGACAA CCCGCGGCCGCAATC
KB_A12 GPTx-1 4M Gly	GGTGGCGCTAGCCAGAGTGTACTTACCCAGCCTCCCTCAGTGTGAGAGGCACCTAGA CAGAGAGTGACGATTACCTGCTCTGGGAGTAGCAGTAACATCGGTAACAACGCCGTC AATTGGTACCAGCAACTCCCAGGGAAGGCCCTAAGCTTCTCATTTACGCAGCGGGA AGGGATTGTCTCGGGCGCCTTCAGAAAGTGTATACCCGACAACGACAAATGTTGTGCGC CCTAACTTGGTCTGCTCCAGACTGCACCGGTGGTGTAAGTACGTGTTTGGTGCAAAAC AGTGGCGTCAGTGACCGCTTTTCCGCCGCCAAGTCTGGTACGTCAGCGTCTCTGGCA ATTAACGGCCTGAGATCAGAAGACGAGGCAGATTACTACTGTGCCGCATGGGACGAC AGTCTGAATGGTTACGTGTTTGGTACTGGTACCAAGCTTACGGTCCTCGGTCAACCC GCGGCCGCAATC

Table 33. DNA sequences of KnotBody VL synthetic genes (Example 19)

D1A12 VH:

EVQLVESGGGLVLRPGGSLRLSCAASGFTFSSYAMSWVRQAPGKGLEWVSAISGSGGSTYYAD
SVKGRFTISRDN TKNSLYLQMTSLRADDTAFYYCVKDFGPGYGTGWFDYWGPGLTVTVSS

KB_A07 VL (Knottin EETI-II sequence underlined)

DIQMTQSPSSLSASVGDRVTITCRASQSISSYLNWYQQKPGKAPKLLIYAAGVCPRIIMRCK
QDSDCLAGCVCGPNGFCGSRSGVPSRFSGSGSGTDFTLTISLQPEDFATYYCQQGASPPYT
FGQGTKVEIKR

KB_A12 VL (Knottin EETI-II sequence underlined)

QSVLTQPPSVSEAPRQRVTITCSGSSSNIGNNAVNWYQQLPKAPKLLIYAAGRCPRIIMRCK
KQDSDCLAGCVCGPNGFCGANSVSDRFSAAKSGTSASLAINGLRSEDEADYYCAAWDDSLN
GYVFGTGTKLTVLG

Table 34. Sequences of A12 VH and VL domain and A07 VL domain. A12 VH domain may be paired with a VL domain generated from A07 VL or A12 VL.

KnotBody	Concentration tested (μ M)	Mean % inhibition	Std.Dev.	n
KB_A12_ProTx-III Gly	22.3	26.6	5.3	7
KB_A12_ProTx-III 2M Gly	15.4	63.5	10.1	7
KB_A12_HwTx-IV 3M Gly	27.0	67.4	14.3	9
KB_A12_GpTx-1 4M Gly	16.4	32.5	13.7	6

Table 35. KnotBody inhibition of Nav1.7 currents

KnotBody	VL Sequence
KB_A12_GpTx-1 4M Gly	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNA VNWYQQLP GKAPKLLIYAAGRDC LGAFRKCI PD NDKCCRP NLVCSRLHRWCKYVFGANSGVSDRFS AAKSGTSASLAINGLRSEDEADYYCAAWDDSLN GYVFGTGTKLTVLG
KB_A12_HwTx-IV 3M Gly	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNA VNWYQQLP GKAPKLLIYAAGRGCLGIFKACNPS NDQCKSSKLVC SRKTRWCKWQIGANSGVSDRF SAAKSGTSASLAINGLRSEDEADYYCAAWDDSL NGYVFGTGTKLTVLG
KB_A12_ProTx-III 2M Gly	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNA VNWYQQLP GKAPKLLIYAAGRGCLKFGWKCNP NDKCCSGLKCGSNHNWCKWHIGANSGVSDRFS AAKSGTSASLAINGLRSEDEADYYCAAWDDSLN GYVFGTGTKLTVLG
KB_A12_ProTx-III Gly	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNA VNWYQQLP GKAPKLLIYAAGRDC LKFGWKCNP NDKCCSGLKCGSNHNWCKLHIGANSGVSDRFS AAKSGTSASLAINGLRSEDEADYYCAAWDDSLN GYVFGTGTKLTVLG
KB_A07 ProTx-III 2M Gly	DIQMTQSPSSLSASVGDRVTITCRASQSISSYL NWYQQKPGKAPKLLIYAAGV <u>GCLKFGWKCNP</u> <u>NDKCCSGLKCGSNHNWCKWHIGSRSGVPSRFS</u> <u>GS</u> GTDFTLTISLQPEDFATYYCQQGASPPYTF GQGTKVEIK
KB_A12 ProTx-III 2M 2Gly	QSVLTQPPSVSEAPRQRTITCSGSSSNIGNNA VNWYQQLP GKAPKLLIYAAGRGCLKFGWKCNP <u>NDKCCSGLKCGSNHNWCKWHIG</u> ANSGVSDRFS AAKSGTSASLAINGLRSEDEADYYCAAWDDSLN GYVFGTGTKLTVLG

Table 36. Amino acid sequences of knottin-VL domain fusion proteins

KnotBody	VL Sequence
KB_A07 ProTx-III 2M Gly	GGTGGCGCTAGCGACATACAAATGACCCAATCACCTAGCTCTCT TAGTGCCCTCTGTTGGGGATCGGGTCACCATCACTTGTAGAGCGA GCCAGAGTATCTCATCATACTTGAAGTGGTACCAGCAGAAGCCA GGGAAGGCCCCCAAGCTGTTGATTTACGCGGCTGGGGTCGGATG CCTCAAGTTCGGGTGGAAATGCAACCCAAGAAACGATAAAATGCT GCTCAGGACTCAAGTGCGGCAGCAACCACAACCTGGTGCAAATGG CACATCGGCAGCCGCTCAGGCGTGCCATCAAGATTTAGTGGTTC AGGAAGTGGTACGGACTTCACGCTGACGATTTTCATCTCTTCAAC CCGAAGATTTTCGCCACGTACTACTGTCAACAGGGTGCTTCTCCA CCTTATACTTTTCGGTCAGGGTACCAAGGTTGAGATTAAGCGCAC CGCGGCCGCAATC
KB_A12 ProTx-III 2M 2Gly	GGTGGCGCTAGCCAGAGTGTACTTACCCAGCCTCCCTCAGTGTC AGAGGCACCTAGACAGAGAGTGACGATTACCTGCTCTGGGAGTA GCAGTAACATCGGTAACAACGCCGTCAATTGGTACCAGCAACTC CCAGGGAAGGCCCTAAGCTTCTCATTTACGCAGCGGGAAGGGG ATGCCTCAAGTTCGGGTGGAAATGCAACCCAAGAAACGATAAAAT GCTGCTCAGGACTCAAGTGCGGCAGCAACCACAACCTGGTGCAAA TGGCACATCGGCGGCGCAAACAGTGGCGTCAGTGACCGCTTTTC CGCCGCCAAGTCTGGTACGTCAGCGTCTCTGGCAATTAACGGCC TGAGATCAGAAGACGAGGCAGATTACTACTGTGCCGCATGGGAC GACAGTCTGAATGGTTACGTGTTTGGTACTGGTACCAAGCTTAC GGTCCTCGGTCAACCCGCGGCCGCAATC

Table 37: DNA sequences of KnotBody VL synthetic genes for generating ProTx-III KnotBodies used in Example 21

KnotBody	IC ₅₀ (μM)	<i>n</i> (each concentration)
KB_A07_ProTx-III 2M Gly	1.1	7-17
KB_A12_ProTx-III 2M Gly	1.5	11-17
KB_A12_ProTx-III 2M 2Gly	1.4	11-17

5 **Table 38:** Summary of KnotBody IC₅₀ values determined by fitting the four-point concentration curves in Figure 34

Knottin/toxin Donor	Parent Knottin/toxin	Organism of origin	Database accession (Uniprot)
GPTx-1_4M	GpTx-1 (GTx1-15)	Grammostola rosea	P0DJA9
HwTx-IV 3M	Huwentoxin-IV	Haplopelma schmidtii	P83303
ProTx-III	ProTx-III	Thrixopelma pruriens	P0DL64
ProTx-III 2M	ProTx-III	Thrixopelma pruriens	P0DL64

Table 39. Summary of origin of non-human genetic information used in development of KnotBodies described herein. Amino acid sequences for the specified peptides were obtained from the Uniprot database under the indicated accession numbers, and recipient VL domains incorporating the donor peptide sequences were designed and provided to the IDT gene fragment synthesis service for production of encoding DNA, opting for codon optimisation suitable for expression in mammalian cells.

References

1. Jones, P. T., *et al.* *Nature* 321, 522–525 (1986).
2. Barbas, C. F., *et al.* *PNAS USA* 90, 10003–10007 (1993).
3. Frederickson, S. *et al.* *PNAS USA*, 14307–14312 (2006).
4. Wrighton, N. C. *et al.* *Science (New York, N.Y)* 273, 458–464 (1996).
5. Liu, T. *et al.* *J. Am. Chem. Soc.* 136, 10557–10560 (2014).
6. Kogelberg, H. *et al.* *Journal of molecular biology* 382, 385–401 (2008).
7. Man, Y. K. S. *et al.* *PLoS ONE* 8, e70452 (2013).
8. Saini, S. S. *et al.* *Eur. J. Immunol.* 29, 2420–2426 (1999).
9. Saini, S. S., *et al.* *Int. Immunol.* 15, 845–853 (2003).
10. Wang, F. *et al.* *Cell* 153, 1379–1393 (2013).
11. Zhang, Y. *et al.* *Angew. Chem. Int. Ed. Engl.* 53, 132–135 (2014).
12. Zhang, Y. *et al.* *Angew. Chem. Int. Ed. Engl.* 52, 8295–8298 (2013).
13. Zhang, Y. *et al.* *ACS Chem. Biol.* 8, 2117–2121 (2013).
14. Liu, T. *et al.* *PNAS USA* 112, 1356–1361 (2015).
15. Peng, Y. *et al.* *Chem. Biol.* 22, 1134–1143 (2015).
16. Melidoni, A. N. *et al.* *PNAS USA* 110, 17802–17807 (2013).
17. Betton, J. M. *et al.* *Nature* (1997).
18. Collinet, B. *et al.* 275, 17428–17433 (2000).
19. Ruth, N. *et al.* *FEBS Journal* 275, 5150–5160 (2008).
20. Vandevenne, M. *et al.* *Protein Engineering Design and Selection* 21, 443–451 (2008).
21. Crasson, O. *et al.* *Protein Eng. Des. Sel.* 28, 451–460 (2015).
22. Neylon, C. *Nucleic Acids Res.* 32, 1448–1459 (2004).
23. Banta, S. *et al.* *Annu Rev Biomed Eng* 15, 93–113 (2013).
24. Kimura, R. H. *et al.* *PLoS ONE* 6, e16112 (2011).
25. Takacs, Z. *et al.* *PNAS* 106, 22211–22216 (2009).
26. Gui, J. *et al.* *Curr. Biol.* (2014). doi:10.1016/j.cub.2014.01.013
27. Dyson, M. R. *et al.* *Anal Biochem* 417, 25–35 (2011).
28. Schofield, D. J. *et al.* *Genome biology* 8, R254 (2007).
29. Lefranc, M.-P. *et al.* *Nucleic Acids Res.* 43, D413–22 (2015).
30. Katz, B. A. e. *Biochemistry* 34, 15421–15429 (1995).
31. Katz, B. A. *Annu Rev Biophys Biomol Struct* 26, 27–45 (1997).
32. Lowman, H. B. *Annu Rev Biophys Biomol Struct* 26, 401–424 (1997).
33. Giebel, L. B. *et al.* *Biochemistry* 34, 15430–15435 (1995).
34. Holler, P. D. *et al.* *PNAS USA* 97, 5387–5392 (2000).
35. Li, Y. *et al.* *Nat. Biotechnol.* 23, 349–354 (2005).
36. Wozniak-Knopp, G. *et al.* *Protein Eng. Des. Sel.* 23, 289–297 (2010).
37. Ying, T. *et al.* *Biochim. Biophys. Acta* 1844, 1977–1982 (2014).
38. Binz, H. K. *et al.* *Nature biotechnology* 23, 1257–1268 (2005).
39. Skerra, A. *Curr. Opin. Biotechnol.* 18, 295–304 (2007).
40. Gebauer, M. & Skerra, A. *Curr Opin Chem Biol* 13, 245–255 (2009).
41. Hufton, S. E. *et al.* *FEBS Lett.* 475, 225–231 (2000).
42. Nord, K. *et al.* *Nat. Biotechnol.* 15, 772–777 (1997).
43. Nygren, P.-A. & Skerra, A. *J Immunol Methods* 290, 3–28 (2004).
44. Koide, A. *et al.* *Journal of molecular biology* 415, 393–405 (2012).
45. Steiner, D. *et al.* *Journal of Molecular Biology* 382, 1211–1227 (2008).
46. Tiede, C. *et al.* *Protein Eng. Des. Sel.* 27, 145–155 (2014).

47. Gebauer, M. & Skerra, A. *Meth. Enzymol.* 503, 157–188 (2012).
48. Colas, P. *et al. Nature* 380, 548–550 (1996).
49. De Meyer, T *et al. Trends Biotechnol.* 32, 263–270 (2014).
50. Shao, C.-Y. *et al. Mol. Immunol.* 44, 656–665 (2007).
51. Kruziki, M. A., *et al. Chem. Biol.* 22, 946–956 (2015).
52. Nygren, P.-A. *FEBS J.* 275, 2668–2676 (2008).
53. Jost, C. & Plückthun, A. *Curr. Opin. Struct. Biol.* 27, 102–112 (2014).
54. Kolmar, H. *FEBS J.* 275, 2684–2690 (2008).
55. Mouhat, S. *et al Current Pharmaceutical Design* 14, 2503–2518 (2008).
56. Wang, X. *et al. Nat. Struct. Biol.* 7, 505–513 (2000).
57. Gracy, J. *et al. Nucleic Acids Res.* 36, D314–9 (2008).
58. England, S. & de Groot, M. J. *Br. J. Pharmacol.* 158, 1413–1425 (2009).
59. Clare, J. J. *Expert Opin Investig Drugs* 19, 45–62 (2010).
60. Kolmar, H. *Expert Rev Mol Diagn* 10, 361–368 (2010).
61. Gelly, J.-C. *et al. Nucleic Acids Res.* 32, D156–9 (2004).
62. Combelles, *et al. Proteins* 73, 87–103 (2008).
63. Heitz, A., *et al. Eur. J. Biochem.* 233, 837–846 (1995).
64. Cheek, S. *et al. Journal of molecular biology* 359, 215–237 (2006).
65. Yu, F. H. *Pharmacological Reviews* 57, 387–395 (2005).
66. Escoubas, P. *Mol. Divers.* 10, 545–554 (2006).
67. Klint, J. K. *et al. Toxicon* 60, 478–491 (2012).
68. Shu, Q. *et al. Protein Sci.* 11, 245–252 (2002).
69. Ueberheide, B. M. *et al PNAS USA* 106, 6910–6915 (2009).
70. Yang, S. *et al. NAS USA* (2013). doi:10.1073/pnas.1306285110
71. Peng, K. *et al. The Journal of biological chemistry* 277, 47564–47571 (2002).
72. Xiao, Y. *et al. Mol Pharmacol* 78, 1124–1134 (2010).
73. Crest, M. *et al. The Journal of biological chemistry* 267, 1640–1647 (1992).
74. Tudor, J. E. *et al. Nat. Struct. Biol.* 3, 317–320 (1996)
75. Galat, A., *et al. FEBS J.* 275, 3207–3225 (2008).
76. McCafferty, J *et al. Nature* 348, 552–554
77. Hoogenboom, H. R. *et al. Nucleic Acids Res.* 19, 4133–4137 (1991).
78. Zhang, H. *et al. PNAS USA* 109, 15728–15733 (2012).
79. Xie, J. *et al. PNAS USA* 110, 8099–8104 (2013).
80. Nishimiya, D. *Appl. Microbiol. Biotechnol.* 98, 1031–1042 (2014).
81. Vendel, M. C. *et al. Arch. Biochem. Biophys.* 526, 188–193 (2012).
82. Bagal, S. K. *et al. J. Med. Chem.* 56, 593–624 (2013).
83. Hübner, C. A. & Jentsch, T. J. *Hum. Mol. Genet.* 11, 2435–2445 (2002).
84. Jentsch, T. J., *et al. Nat. Cell Biol.* 6, 1039–1047 (2004).
85. Lü, Q. & An, W. F. *Combinatorial chemistry & high throughput screening* 11, 185–194 (2008).
86. Tate, C. G.. *FEBS Lett.* 504, 94–98 (2001).
87. Shintre, C. A. *et al. PNAS USA* 110, 9710–9715 (2013).
88. Suharni *et al. Monoclon Antib Immunodiagn Immunother* 33, 378–385 (2014).
89. Pavlidou, M. *et al. . PLoS ONE* 8, e72272 (2013).
90. Tillotson, B. J. *et al.. Protein Eng. Des. Sel.* 26, 101–112 (2013).
91. Zhang, H. *et al. Chem. Biol.* 20, 734–741 (2013).
92. Gunasekera, S. *et al. J. Med. Chem.* 51, 7697–7704 (2008).
93. Keller, T. *et al.. PLoS ONE* 10, e0127169 (2015).
94. Jung, S. & Pluckthun, A. *Protein Eng.* 10, 959–966 (1997).
95. Akerström, B. *et al. J Immunol Methods* 177, 151–163 (1994).

96. Jespers, L. *et al. Nat. Biotechnol.* 22, 1161–1165 (2004).
97. Richler, E. *et al. Nature methods* 5, 87–93 (2007).
98. Podust, V. N. *et al. J Control Release* (2015). doi:10.1016/j.jconrel.2015.10.038
99. Schlapschy, M. *et al. Protein Eng. Des. Sel.* 26, 489–501 (2013).
100. Pershad, K. *et al. Protein Engineering Design and Selection* 23, 279–288 (2010).
101. Tape, C. J. *et al. PNAS USA* 108, 5578–5583 (2011).
102. Vaughan, T. J. *et al. Nature biotechnology* 14, 309–314 (1996).
103. Favel, A. *et al. Int. J. Pept. Protein Res.* 33, 202–208 (1989).
104. Chiche, L. *et al. Current Protein & Peptide Science* 5, 341–349
105. Azzazy, H. M. E. & Highsmith, W. E.. *Clin. Biochem.* 35, 425–445 (2002).
106. Goletz, S. *et al. Journal of molecular biology* 315, 1087–1097 (2002).
107. Lee, C. M. Y., *et al. Nature Protocols* 2, 3001–3008 (2007).
108. Hacker, D. L. *et al. Protein expression and purification* 92, 67–76 (2013).
109. Phaser crystallographic software. 40, 658–674 (2007).
110. PHENIX: a comprehensive Python-based system for macromolecular structure solution. 66, 213–221 (2010).
111. Afonine, P. V. *et al. Acta Crystallogr. D Biol. Crystallogr.* 68, 352–367 (2012).
112. Spiess, C. *Mol. Immunol.* 67, 95–106 (2015).
113. Falk, R. *et al. Methods* 58, 69–78 (2012).
114. Hosse, R. J. *et al. Protein Sci.* 15, 14–27 (2006).
115. Fernández-Suárez, X. M., *et al. Nucleic Acids Res.* 42, D1–6 (2014).
116. Rocha, L.. *Journal of Molecular Structure* (2014).
117. Dickinson, C. D. *et al. Journal of molecular biology* 236, 1079–1092 (1994).
118. Dawson, R. J. P. *et al. Nat Commun* 3, 936 (2012).
119. Hernandez *et al Biochemistry* 39 (19), 5722–5730 (2000)
120. Obermeier, B *et al. Nat Med* 19, 1584–1596 (2013))
121. Ubogu, E. E.. *J. Vasc. Res.* 50, 289–303 (2013)).
122. Diochot S *et al, Nature* 490, 552–555 (2012).
123. Kawahara, M. *et al Biochem Biophys Res Commun*, 315, 132–138. (2004)
124. Kawahara, M. *et al Journal of Biotechnology*, 133, 154–161 .(2008).
125. Kawahara, M. *et al Cytokine*, 55, 402–408. (2011)
126. Wood, J. N., Boorman, J. P., Okuse, K. & Baker, M. D. Voltage-gated sodium channels and pain pathways. *J. Neurobiol.* 61, 55–71 (2004).
127. Fertleman, C. R. *et al. SCN9A mutations in paroxysmal extreme pain disorder: allelic variants underlie distinct channel defects and phenotypes. Neuron* 52, 767–774 (2006)
128. Yang, Y. *et al. Mutations in SCN9A, encoding a sodium channel alpha subunit, in patients with primary erythralgia. J. Med. Genet.* 41, 171–174 (2004)
129. Cummins, T. R., Dib-Hajj, S. D. & Waxman, S. G. Electrophysiological properties of mutant Nav1.7 sodium channels in a painful inherited neuropathy. *J. Neurosci.* 24, 8232–8236 (2004)
130. Cox, J. J. *et al. An SCN9A channelopathy causes congenital inability to experience pain. Nature* 444, 894–898 (2006)
131. Goldberg, Y. P. *et al. Loss-of-function mutations in the Nav1.7 gene underlie congenital indifference to pain in multiple human populations. Clin. Genet.* 71, 311–319 (2007)
132. Nassar, M. A. *et al. Nociceptor-specific gene deletion reveals a major role for Nav1.7 (PN1) in acute and inflammatory pain. Proc Natl Acad Sci USA* 101, 12706–12711 (2004)
133. Namadurai, S. *et al. A new look at sodium channel β subunits. Open Biology* 5, 140192–140192 (2015).

134. Payandeh, J., Scheuer, T., Zheng, N. & Catterall, W. A. Crystal structure of the NavAb voltage-gated sodium channel (Met221Cys, 2.95 Å). (2011). doi:10.2210/pdb3rw0/pdb
135. Lee, J.-H. *et al.* A Monoclonal Antibody that Targets a Nav1.7 Channel Voltage Sensor for Pain and Itch Relief. *Cell* 157, 1393–1404 (2014).
136. Liu, D. *et al.* Evaluation of recombinant monoclonal antibody SVMab1 binding to Nav1.7 target sequences and block of human Nav1.7 currents. *FI000Res* 5, 2764–20 (2016).
137. Clare, J., Tate, S., Nobbs, M. & Romanos, M. Voltage-gated sodium channels as therapeutic targets. *Drug Discov. Today* 5, 506–520 (2000).
138. Lai, J., Porreca, F., Hunter, J. C. & Gold, M. S. Voltage-gated sodium channels and hyperalgesia. *Annu. Rev. Pharmacol. Toxicol.* 44, 371–397 (2004).
139. Anger, T., Madge, D. J., Mulla, M. & Riddall, D. Medicinal chemistry of neuronal voltage-gated sodium channel blockers. *J. Med. Chem.* 44, 115–137 (2001).
140. Bhattacharya, A., Wickenden, A. D. & Chaplan, S. R. Sodium channel blockers for the treatment of neuropathic pain. *Neurotherapeutics* 6, 663–678 (2009).
141. Clare, J. J. Targeting Ion Channels for Drug Discovery. *Discovery Medicine* 9, 253–260 (2010).
142. Skerratt, S. E. & West, C. W. Ion channel therapeutics for pain. *Channels (Austin)* 9, 344–351 (2015).
143. Sun, S., J Cohen, C. & M Dehnhardt, C. Inhibitors of voltage-gated sodium channel Na v1.7: patent applications since 2010. *Pharmaceutical Patent Analyst* 3, 509–521 (2014).
144. Bell, D. C. & Dallas, M. Using automated patch clamp electrophysiology platforms in pain-related ion channel research: insights from industry and academia. *Br J Pharmacol* (2017). doi:10.1111/bph.13916
145. Bosmans, F. & Swartz, K. J. Targeting voltage sensors in sodium channels with spider toxins. *Trends in Pharmacological Sciences* 31, 175–182 (2010).
146. Knapp, O., McArthur, J. R. & Adams, D. J. Conotoxins Targeting Neuronal Voltage-Gated Sodium Channel Subtypes: Potential Analgesics? *Toxins* 4, 1236–1260 (2012).
147. Zhang, F., Xu, X., Li, T. & Liu, Z. Shellfish Toxins Targeting Voltage-Gated Sodium Channels. *Marine Drugs* 11, 4698–4723 (2013).
148. Munasinghe, N. & Christie, M. Conotoxins That Could Provide Analgesia through Voltage Gated Sodium Channel Inhibition. *Toxins* 7, 5386–5407 (2015).
149. Murray, J. K. *et al.* Engineering Potent and Selective Analogues of GpTx-1, a Tarantula Venom Peptide Antagonist of the Na V1.7 Sodium Channel. *J. Med. Chem.* 58, 2299–2314 (2015).
150. Shcherbatko, A. *et al.* Engineering Highly Potent and Selective Microproteins against Nav1.7 Sodium Channel for Treatment of Pain. *J. Biol. Chem.* 291, 13974–13986 (2016).
151. Flinspach, M. *et al.* Insensitivity to pain induced by a potent selective closed-state Nav1.7 inhibitor. *Nature Publishing Group* 1–16 (2016). doi:10.1038/srep39662
152. Murray, J. K. *et al.* Pharmaceutical Optimization of Peptide Toxins for Ion Channel Targets: Potent, Selective, and Long-Lived Antagonists of Kv1.3. *J. Med. Chem.* 58, 6784–6802 (2015).
153. Revell, J. D. *et al.* Potency optimization of Huwentoxin-IV on hNav1.7: A neurotoxin TTX-S sodium-channel antagonist from the venom of the Chinese bird-eating spider *Selenocosmia huwena*. *Peptides* 44, 40–46 (2013).
154. Cardoso, F. C. *et al.* Identification and Characterization of ProTx-III [?-TRTX-Tp1a], a New Voltage-Gated Sodium Channel Inhibitor from Venom of the Tarantula *Thrixopelma pruriens*. *Molecular Pharmacology* 88, 291–303 (2015).

155. Sermadiras, I., Revell, J., Linley, J. E., Sandercock, A. & Ravn, P. Recombinant expression and in vitro characterisation of active Huwentoxin-IV. *PLoS ONE* 8, e83202 (2013).
156. Moore & Cochran, Engineering Knottins as Novel Binding Agents, *Methods in Enzymology* 503:223-251 2012
157. Vazquez-Lombardi et al., Challenges and opportunities for non-antibody scaffold drugs, *Drug Discovery Today* 20(10):1271-1283 2015.
158. Rahnama, S. *et al.* The structure, dynamics and selectivity profile of a Nav1.7 potency-optimised huwentoxin-IV variant. *PLoS ONE* 12, e0173551 (2017).
159. Rajamani, R. *et al.* A functional Nav1.7-NavAb chimera with a reconstituted high affinity ProTx-II binding site. *Mol. Pharmacol.* mol.117.108712 (2017). doi:10.1124/mol.117.108712
160. Ahuja, S. *et al.* Structural basis of Nav1.7 inhibition by an isoform-selective small-molecule antagonist. *Science* 350, aac5464–aac5464 (2015).
161. Kol, S. *et al.* Heterologous expression and purification of an active human TRPV3 ion channel. *FEBS J.* 280, 6010–6021 (2013).
162. Madden, D. R. & Safferling, M. in *Macromolecular Crystallography Protocols* (eds. Walker, J. M. & Doublié, S.) 363, 39–58 (Humana Press, 2006).
163. Hackmann, Y., Joedicke, L., Panneels, V. & Sinning, I. *Expression of Membrane Proteins in the Eyes of Transgenic Drosophila melanogaster. Membrane Proteins â Production and Functional Characterization* 556, 219–239 (Elsevier Inc., 2015).
164. Panneels, V., Kock, I., Krijnse-Locker, J., Rezgaoui, M. & Sinning, I. Drosophila Photoreceptor Cells Exploited for the Production of Eukaryotic Membrane Proteins: Receptors, Transporters and Channels. *PLoS ONE* 6, e18478–8 (2011).
165. Clare, J. J. Functional expression of ion channels in mammalian systems. *Protein Science Encyclopedia* (2006).

Claims:

1. A binding member that binds and inhibits human sodium channel Nav1.7, the binding member comprising a fusion protein and a partner domain, wherein
the fusion protein comprises a donor diversity scaffold domain inserted into a recipient diversity scaffold domain, wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence, and wherein the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, wherein
wherein the donor diversity scaffold domain is a cysteine-rich peptide, such as an ion-channel modulating peptide, venom toxin peptide or knottin, which binds to the voltage sensing domain of Nav1.7, wherein
the recipient diversity scaffold domain is an antibody variable domain, wherein
the partner domain is an antibody variable domain, wherein
the binding member is a whole immunoglobulin comprising paired heavy and light chains, and wherein
the immunoglobulin is a human IgG1 comprising an effector null Fc region or wherein the immunoglobulin is a human IgG4.
2. A binding member according to claim 1, wherein the donor diversity scaffold domain is a peptide having at least 95 % sequence identity to (i) ProTx-III, (ii) ProTx-II, (iii) Huwentoxin-IV, (iv) Ssm6a, or (v) GpTx-1.
3. A binding member or fusion protein according to claim 1 or claim 2, wherein the donor diversity scaffold domain replaces all or part of a complementarity determining region (CDR) of the recipient diversity scaffold antibody variable domain.
4. A binding member according to any preceding claim, wherein the recipient diversity scaffold domain is an antibody VL domain.
5. A binding member according to claim 4, wherein the donor diversity scaffold domain replaces all or part of CDR1 or CDR2 of the antibody VL domain.

6. A binding member according to any preceding claim, wherein the partner domain is an antibody VH domain.
7. A binding member according to claim any preceding claim, wherein the binding member inhibits ion flux through the channel by at least 20 % as determined by a whole cell patch clamp assay.
8. A binding member according to any preceding claim, wherein the donor diversity scaffold domain is ProTx-III 2M, HwTx-IV 3M, GpTx-1 4M or ProTx-III or wherein the donor diversity scaffold domain comprises an amino acid sequence shown in Table 31 or 32.
9. A binding member according to any preceding claim, wherein the donor diversity scaffold domain comprises a cysteine rich peptide sequence with the addition of a glycine residue at the native C terminus of the peptide sequence.
10. A binding member according to claim 9, wherein the donor diversity scaffold domain comprises a cysteine rich peptide sequence with the addition of two glycine residues at the native C terminus of the peptide sequence.
11. A binding member according to any preceding claim, wherein the N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain with linkers of up to 4 amino acids, optionally wherein the linker comprises the amino acid sequence of a linker shown in Table 1.
12. A binding member according to any preceding claim, wherein the native N and C terminals of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain.
13. A binding member according to any of claims 1 to 11, wherein artificial N and C terminals generated by cyclisation and linearization of the donor diversity scaffold domain are linked to the recipient diversity scaffold domain.
14. A binding member according to any preceding claim, wherein the recipient diversity scaffold domain is an antibody light chain variable domain having the amino acid sequence

of the D1A12 VL domain shown herein or a variant comprising between one and ten amino acid alterations in said sequence, alteration being a substitution, insertion or deletion of an amino acid.

15. A binding member according to claim 14, wherein the donor diversity scaffold domain replaces CDR2 of the D1A12 VL domain.

16. A binding member according to claim 15, wherein the fusion protein comprises
(i) an amino acid sequence encoded by a DNA sequence shown in Table 33 or Table 37;
(ii) a variant amino acid sequence at least 90 % identical to (i);
(iii) an amino acid sequence shown in Table 36; or
(iv) a variant amino acid sequence at least 90 % identical to the amino acid sequence of (iii).

17. A binding member according to any preceding claim, wherein the VH domain has the amino acid sequence of the antibody D1A12 VH domain shown herein, or a variant comprising between one and ten amino acid alterations in said sequence, alteration being a substitution, insertion or deletion of an amino acid.

18. A binding member according to claim 17, wherein the partner domain is an antibody VH domain comprising amino acid sequence SEQ ID NO: 30.

19. A binding member according to any of claims 1 to 16, wherein the partner domain binds to the human sodium channel Nav1.7.

20. A binding member according to claim 19, wherein presence of the partner domain increases the specificity or selectivity of the binding member for the channel relative to the fusion protein.

21. A binding member according to claim 19 or claim 20, wherein the partner domain and the interaction sequence of the donor diversity scaffold domain bind to the same domain of the channel.

22. A binding member according to claim 19 or claim 20, wherein the partner domain binds domain 2 of a Nav1.7 alpha subunit.

23. A binding member according to claim 19 or claim 20, wherein the partner domain and the interaction sequence of the donor diversity scaffold domain bind to different domains of the channel.
24. A binding member according to claim 23, wherein the partner domain binds domain 1 of a Nav1.7 alpha subunit.
25. A binding member according to claim 23, wherein the partner domain binds domain 3 of a Nav1.7 alpha subunit.
26. A binding member according to claim 23, wherein the partner domain binds domain 4 of a Nav1.7 alpha subunit.
27. A binding member according to any of claims 19 to 26, wherein the partner domain binds to a sequence within the S1 to S4 region of Nav1.7.
28. A binding member according to claim 27, wherein the partner domain binds to a sequence within the S1 to S2 region of Nav1.7.
29. A binding member according to claim 28, wherein the partner domain specifically binds to the sequence EHHPMTEEFKNV.
30. A binding member according to claim 27, wherein the partner domain binds to a sequence within the S3 to S4 region of Nav1.7.
31. A binding member according to claim 30, wherein the partner domain specifically binds to the sequence ELFLADVEGL.
32. A binding member according to any of claims 19 to 31, wherein the partner domain binds to Nav1.7 and does not bind to other human sodium channels (e.g. Nav1.1, Nav1.2, Nav1.3 or Nav1.6).

33. A binding member according to any preceding claim, wherein the binding member binds to the channel and a second target molecule.
34. A binding member according to claim 33, wherein binding of the binding member to the sodium channel increases the binding of the binding member to the second target molecule.
35. A binding member according to claim 33 or claim 34, wherein the second target molecule is expressed on neuronal cells.
36. A binding member according to any of claims 33 to 35, wherein the second target molecule is a Blood Brain Barrier receptor or Blood Neuron Barrier receptor.
37. A binding member according to any preceding claim which is fused or conjugated to a toxin, therapeutic moiety, half-life extension moiety or detectable label.
38. A binding member that binds and inhibits human sodium channel Nav1.7, the binding member comprising a fusion protein and a partner domain, wherein
the fusion protein comprises a donor diversity scaffold domain inserted into a recipient diversity scaffold domain, wherein the donor diversity scaffold domain comprises a donor scaffold and a donor interaction sequence, and wherein the recipient diversity scaffold domain comprises a recipient scaffold and a recipient interaction sequence, wherein
wherein the donor diversity scaffold domain is a cysteine-rich peptide, such as an ion-channel modulating peptide, venom toxin peptide or knottin, which binds to the voltage sensing domain of Nav1.7, wherein
the recipient diversity scaffold domain is an antibody variable domain, and wherein
the partner domain is binds to the human sodium channel Nav1.7 and increases the specificity or selectivity of the binding member for the channel.
39. A binding member according to claim 38 or claim 39, wherein the partner domain is an antibody variable domain, optionally an antibody VH domain.
40. A binding member according to claim 38, wherein the fusion protein is as defined in any of claims 1 to 16.

41. A composition comprising a binding member according to any preceding claim and a pharmaceutically acceptable excipient.
42. Nucleic acid encoding a binding member according to any preceding claim.
43. A binding member according to any of claims 1 to 40 or a composition according to claim 41 for use in treatment of the human body by therapy.
44. A binding member according to any of claims 1 to 40 or a composition according to claim 41 for use in treatment of a disease or condition associated with or characterised by sodium or calcium channel dysfunction.
45. A binding member according to any of claims 1 to 40 or a composition according to claim 41 for use in treatment of pain or epilepsy.
46. Use of a binding member according to any of claims 1 to 40 or a composition according to claim 41 for the manufacture of a medicament for the treatment of a disease or condition associated with or characterised by sodium or calcium channel dysfunction.
47. Use of a binding member according to any of claims 1 to 40 or a composition according to claim 41 for the manufacture of a medicament for the treatment of pain or epilepsy.
48. A method of treatment of a disease or condition associated with or characterised by sodium or calcium channel dysfunction, comprising administration of a binding member according to any of claims 1 to 40 or a composition according to claim 41 to an individual in need thereof.
49. A method of treatment of pain or epilepsy comprising administration of a binding member according to any of claims 1 to 40 or a composition according to claim 41 to an individual in need thereof.
50. A binding member or composition for use according to any of claims 43 to 45, use according to claim 46 or claim 47, or a method of treatment according to claim 48 or claim 49, wherein the treatment comprises administering the binding member or composition to a

human to relieve acute pain, chronic pain, neuropathic pain (e.g., peripheral neuropathic pain), post-operative pain, cancer pain, acute inflammatory pain, or pain hypersensitivity (e.g., erythromelalgia or paroxysmal extreme pain disorder).

51. A method of producing a binding member according to any of claims 1 to 40, comprising;

inserting a nucleic acid encoding the donor diversity scaffold domain into a nucleic acid encoding the recipient diversity scaffold domain to produce a chimaeric nucleic acid encoding a fusion protein;

expressing said chimaeric nucleic acid to produce the fusion protein;

associating the fusion protein with a partner domain; and

isolating a binding member comprising the fusion protein and the partner domain.

52. A method according to claim 51, wherein the donor diversity scaffold domain comprises a sequence shown in Table 31.

53. A method according to claim 51 or claim 52, wherein the donor diversity scaffold domain comprises a glycine residue at the native C terminus of the cysteine rich peptide.

54. A method according to claim 51 or claim 52, wherein the nucleic acid encoding the donor diversity scaffold domain encodes a rotated sequence producable by linking the native N and C termini of the selected sequence (directly or optionally via one, two or three amino acids or by a peptide linker) and linearising at a different position to generate new N and C termini.

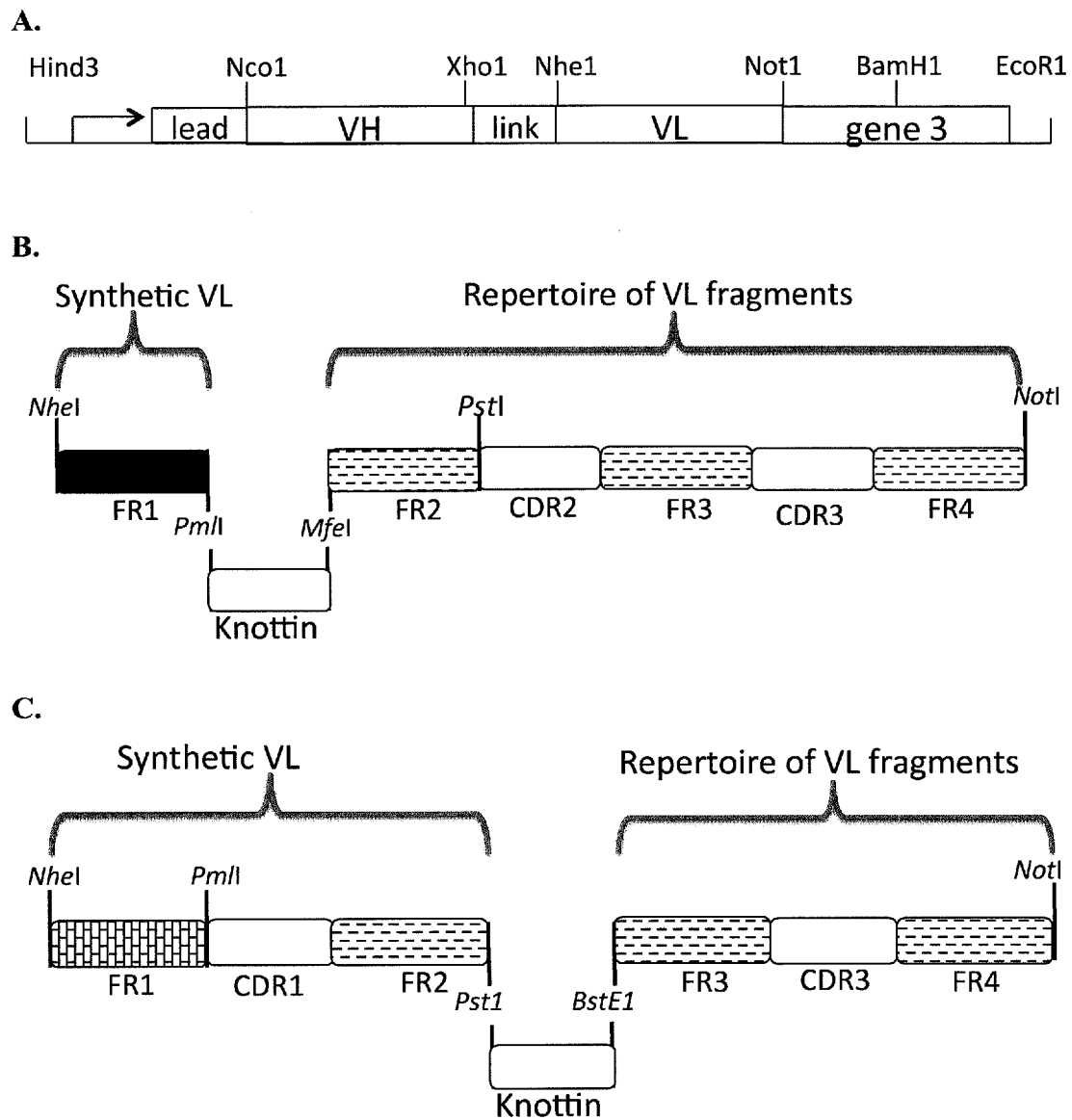


Figure 1

A.**Nco1**

gccatggctgaagtccaactgggtcgaaagcggtgggtggtctggtgcgtccggggcggtcc
 A M A E V Q L V E S G G G L V R P G G S
 ctgcgtctgtcgtgtgcggcggtcggttttaccttttagctctttatgcgatgagctgggtt
 L R L S C A A S G F T F S S Y A M S W V
 cgtcaggctccgggttaaaggcctggaatgggtctccgcaattagtggttccggcggttcg
 R Q A P G K G L E W V S A I S G S G G S
 acgtattacgctgatagcgtgaaaggcgtttcaccatctctcgcgacaacacgaaaaat
 T Y Y A D S V K G R F T I S R D N T K N
 agtctgtacctgcaaatgacctctctgcgcgcagatgacacggctttttattactgcgtt
 S L Y L Q M T S L R A D D T A F Y Y C V
 gatttcgggtccgggtatgggtaccggctgggttgactactgggggtccgggcacccctgggtg
 D F G P G Y G T G W F D Y W G P G T L V

Xho1**Nhe1**

Accgtctcgagt ggtggaggcggttcaggcggaggtggctctggcggtggcgctagc
 T V S S G G G G S G G G G S G G G A S
 cagctctgtgctgactcagccaccctcggtgtctgaagccccaggcagagggtcaccatc
 Q S V L T Q P P S V S E A P R Q R V T I

Pml1

←-----CDR1-----→

acgtgt tctggaagcagctccaacatcggaataatgctgtaaactgggtaccagcagctc
 T C S G S S S N I G N N A V N W Y Q Q L

Pst1**Not1**

Ccagggaagccccctaagctcctgatctatgctgcaggt gtgctgggt gcggccgc (SEQ ID NO: 352)
 P G K A P K L L I Y A A G A A (SEQ ID NO: 353)

Figure 2A**Nco1**

gccatggctgaagtccaactgggtcgaaagcggtgggtggtctggtgcgtccggggcggtcc
 A M A E V Q L V E S G G G L V R P G G S
 ctgcgtctgtcgtgtgcggcggtcggttttaccttttagctctttatgcgatgagctgggtt
 L R L S C A A S G F T F S S Y A M S W V
 cgtcaggctccgggttaaaggcctggaatgggtctccgcaattagtggttccggcggttcg
 R Q A P G K G L E W V S A I S G S G G S
 acgtattacgctgatagcgtgaaaggcgtttcaccatctctcgcgacaacacgaaaaat
 T Y Y A D S V K G R F T I S R D N T K N
 agtctgtacctgcaaatgacctctctgcgcgcagatgacacggctttttattactgcgtt
 S L Y L Q M T S L R A D D T A F Y Y C V
 gatttcgggtccgggtatgggtaccggctgggttgactactgggggtccgggcacccctgggtg
 D F G P G Y G T G W F D Y W G P G T L V

Xho1**Nhe1**

Accgtctcgagt ggtggaggcggttcaggcggaggtggctctggcggtggcgctagc
 T V S S G G G G S G G G G S G G G A S
 gacatccagatgacccagctctccatccctcctgtctgcatctgtaggagacagagtcacc
 D I Q M T Q S P S S L S A S V G D R V T

Pml1

←---CDR1-----→

atcacgtgc cgggcaagtcagagcatttagcagctatttaaattgggtatcagcagaaacca
 I T C R A S Q S I S Y L N W Y Q Q K P

Pst1**Not1**

Gggaaagccccctaagctcctgatctatgctgcaggt gtgctgggt gcggccgc (SEQ ID NO: 354)
 G K A P K L L I Y A A G V L G A A (SEQ ID NO: 355)

Figure 2B

ggctgcccgcgtatcctgatgcggttgcaaacaggactcagactgcctggccggctgcgta
 G **C** P R I L M R **C** K Q D S D **C** L A G **C** V
 tgcgggtccgaacggccttctgcggg (SEQ ID NO: 356)
C G P N G F **C** G (SEQ ID NO: 357)

Figure 3A

i RQRVTITCsgs ssnignna vNWYQQLP
 ii RQRVTIT**Cxxx** -CPRILMRCKQDSDCLAGCVCGPNGFCG **X** xNWYQQLP
 iiiRQRVTITCgxx xCPRILMRCKQDSDCLAGCVCGPNGFCG **X** xNWYQQLP
 iv KAPKLLIY ydd llpSGVSDRFS
 v KAPKLLIY **AAZ** xCPRILMRCKQDSDCLAGCVCGPNGFCG -XXSGVSDRFS
 (SEQ ID NOS: 358-362)

Figure 3B

Nhe1

gctagccagtcctgtgctgactcagccaccctcggtgtctgaagccccaggcagagggtc

A S Q S V L T Q P P S V S E A P R Q R V
 ←-----FW1-----

Pml1

accatcacgtgtvnsvnsvnstgcccgcgtatcctgatgcggttgcaaacaggactcagac

T I T C X X X C P R I L M R C K Q D S D
 -----→ ←-----EETI-II-----

Mfe1

tgccctggccggctgcgtatgcggtccgaacggcttctgcgggvnsvncaattggtaccag

C L A G C V C G P N G F C G X X N W Y Q
 -----→ I----FW2---

Not1

cagctcccagga ←-*Vlambda library*-> accgtcctaggtcagccccgcggccgca

Q L P G T V L G Q P A A A
 ---FW2----→ <-----FW4-----I

(SEQ ID NOS: 319 & 320)

Figure 3C

Nhe1

gctagcgacatccagatgacccagtcctccatccctccctgtctgcatctgtaggagacaga
 A S D I Q M T Q S P S S L S A S V G D R
 ←-----FW1-----→

Pml1

gtcaccatcacgtgtvnsvnsvnstgcccgcgtatcctgatgcgttgcaaacaggactca
 V T I T C X X X C P R I L M R C K Q D S
 -----→ ←-----EETI-II-----

Mfe1

gactgcctggccggctgcgtatgcgggtccgaacggcttctgcgggvnsvncaattggtat
 D C L A G C V C G P N G F C G X X N W Y
 -----→ I---FW2-

Not1

cagcagaaaccagg ←--V kappa library--→atcaaacgtaccgcgccgca
 Q Q K P I K R T A A A
 ---FW2----→ ←---FW4---I

(SEQ ID NOS: 321 & 322)

Figure 3D

Nhe1

gctagccagtcgtgtgctgactcagccaccctcggtgtctgaagccccaggcagagggtc
 A S Q S V L T Q P P S V S E A P R Q R V

←-----FW1-----

Pml1

accatcacgtgttctggaagcagctccaacatcggaataatgctgtaaactggtagcag
 T I T C S G S S S N I G N N A V N W Y Q

-----→←-----CDR1-----→←-----FW2-----

Pst1

cagctcccagggaagccccctaagctcctgatctatgctgcagnsvnstgcccgcgtatc
 Q L P G K A P K L L I Y A A X X C P R I

-----→←-----EETI-II-----

ctgatgcgttgcaaacaggactcagactgcctggccggctgcgtatgcggtcogaacggc
 L M R C K Q D S D C L A G C V C G P N G

-----EETI-II-----

BspE1

ttctgcgggvnsvnstccggagtcctctgaccgattctctggctcc<-Vlambda library->
 F C G X X S G V S D R F S G S

----→ I-----FW3-----→

Not1

accgtcctaggtcagccccggcgccgca (SEQ ID NOS: 323)

T V L G Q P A A A (SEQ ID NOS: 324)

←-----FW4-----I

Figure 3E

Nhe1

gctagcgacatccagatgacccagtcctccatccctgtctgcatctgtaggagacaga
 A S D I Q M T Q S P S S L S A S V G D R
 ←-----FW1-----

Pml1

gtcaccatcacgtgccgggcaagtcagagcattagcagctatttaaattggtatcagcag
 V T I T C R A S Q S I S S Y L N W Y Q Q
 -----→←-----CDR1-----→←-----FW2-----

Pst1

aaaccagggaagcccctaagctcctgatctatgctgcagnsvnstgcccgcgatcctg
 K P G K A P K L L I Y A A X X C P R I L
 -----→←-----EETI-II-----

atgcggttgcaaacaggactcagactgcctggccggctgcgtatgcggtccgaacggcttc
 M R C K Q D S D C L A G C V C G P N G F
 -----EETI-II-----

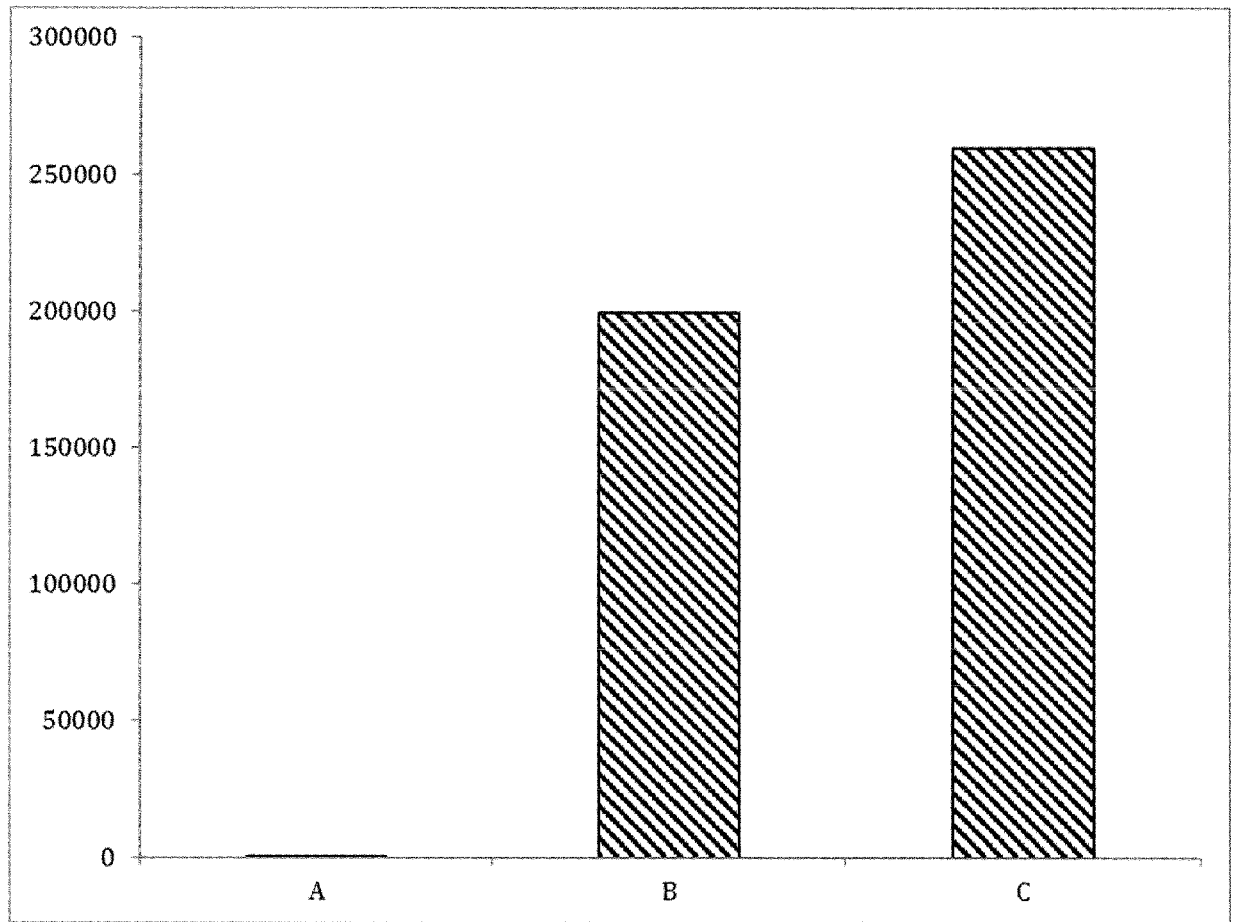
BspE1

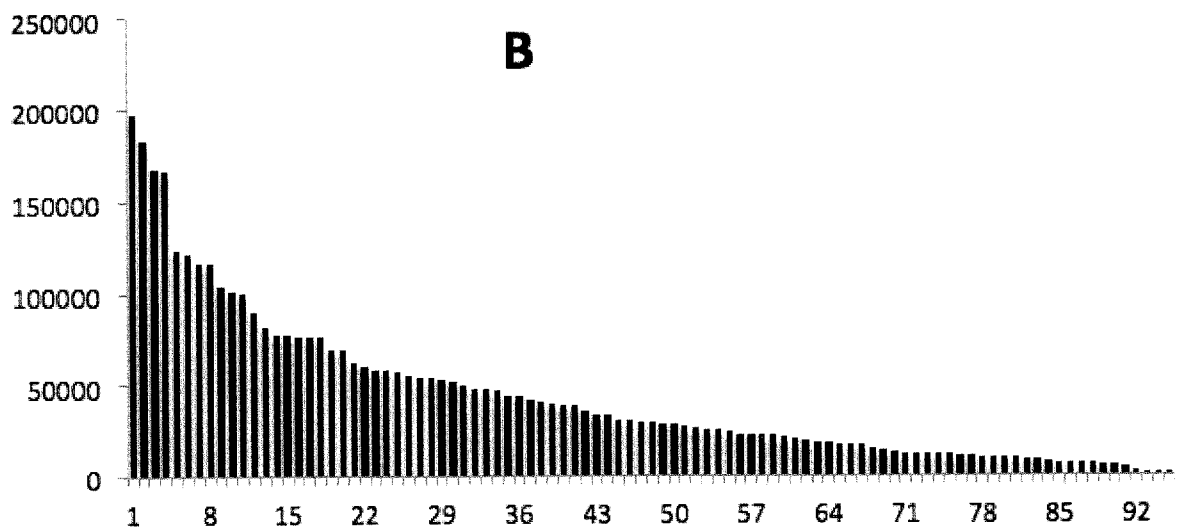
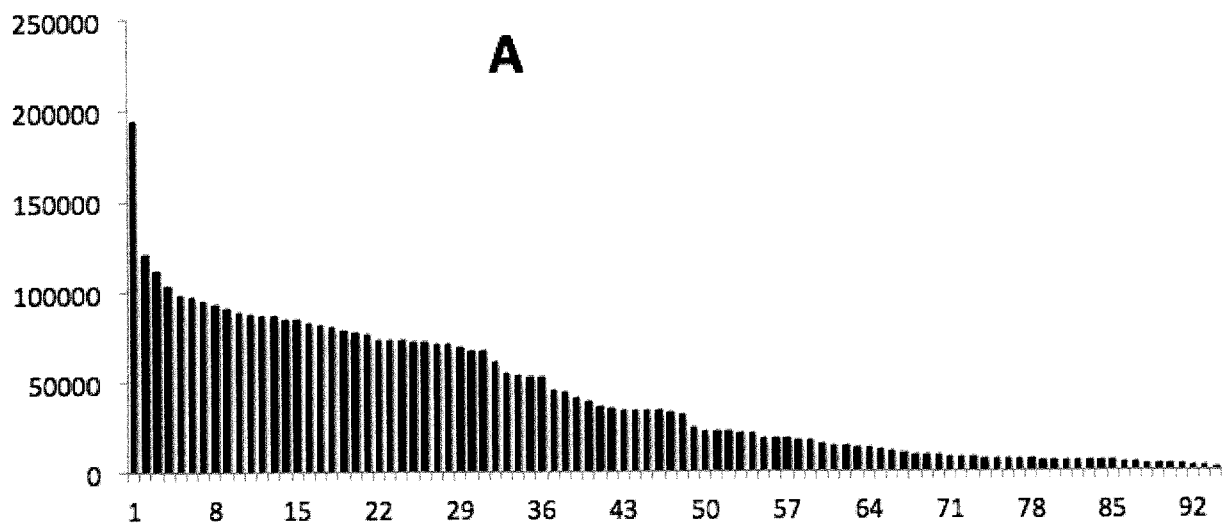
tgccgggvnsvnstccggagtcctcatcaagggttcagtggcagt<-V kappa library->
 C G X X S G V P S R F S G S
 ---→ I-----FW3-----→

Not1

Atcaaacgtaccgcgccgca (SEQ ID NOS: 325)
 I K R T A A A (SEQ ID NOS: 326)
 ←---FW4---I

Figure 3F

**Figure 4**

**Figure 5**

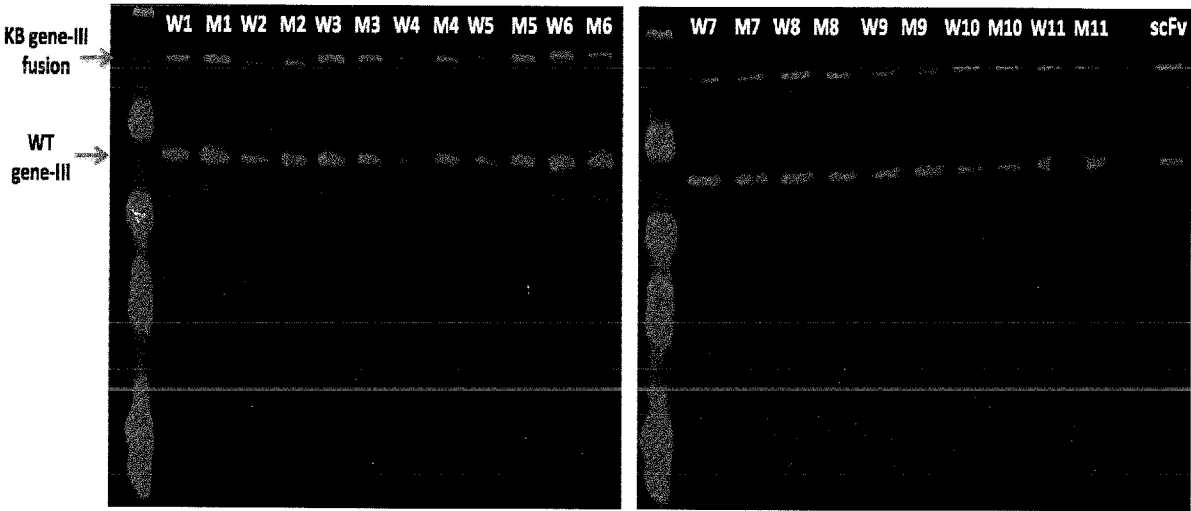


Figure 6

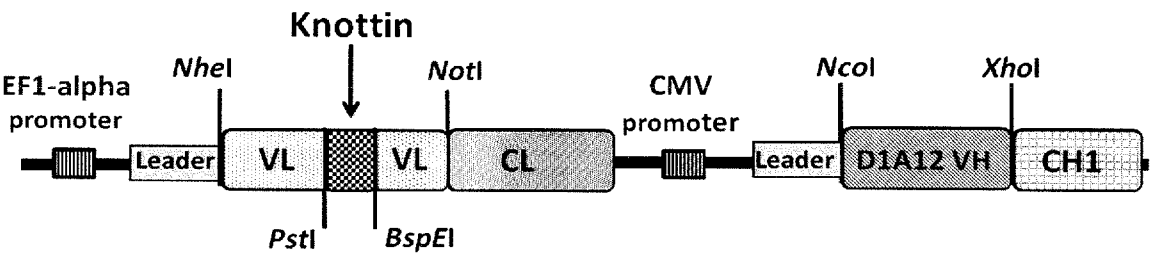


Figure 7

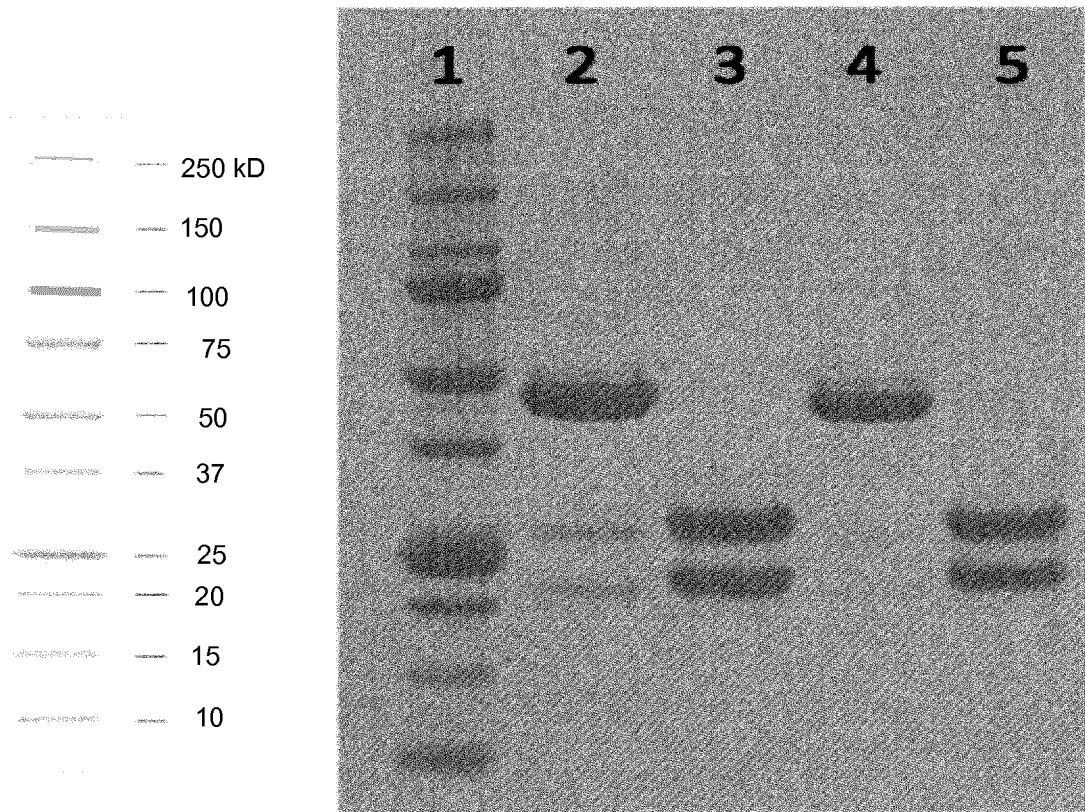
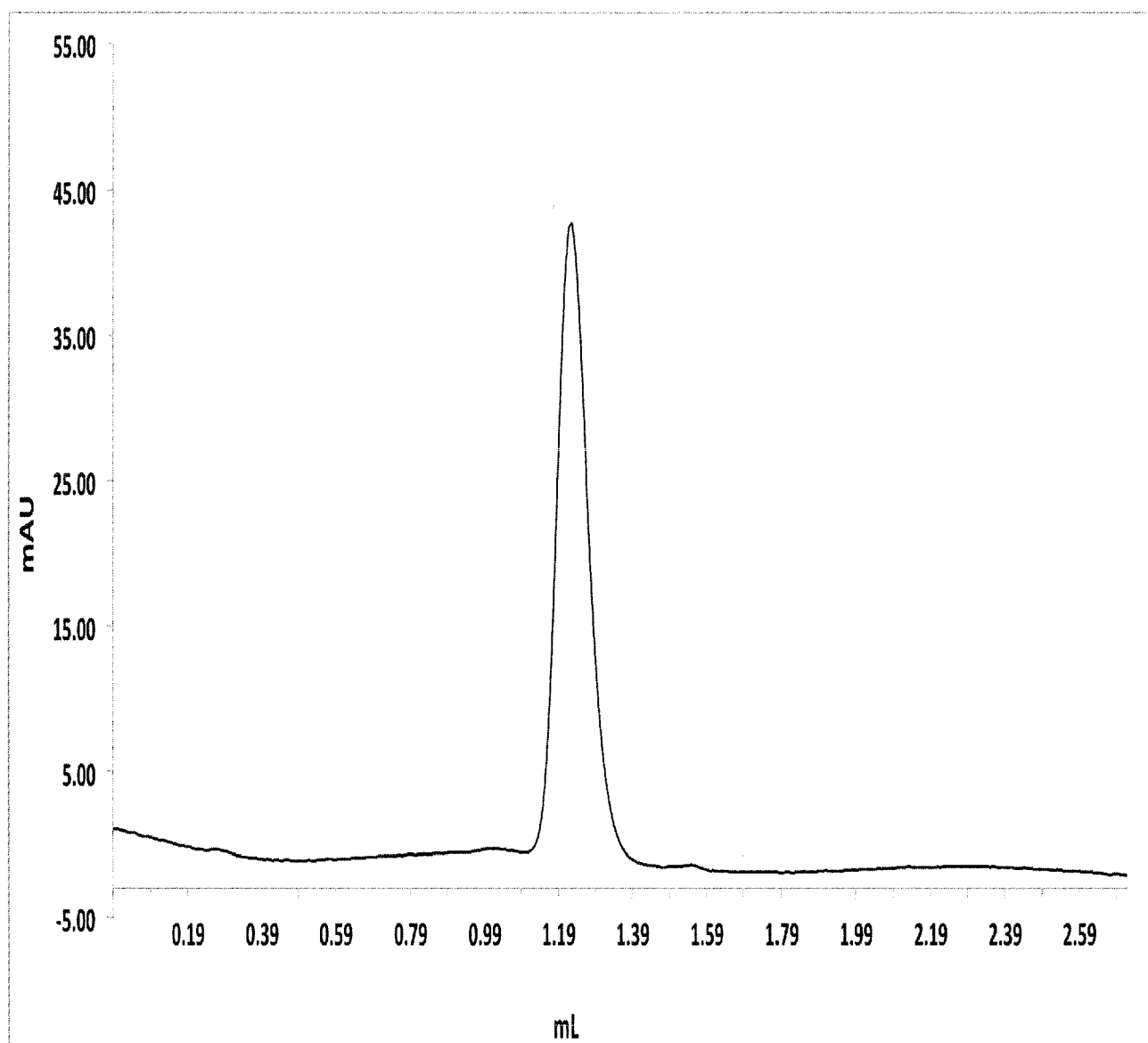
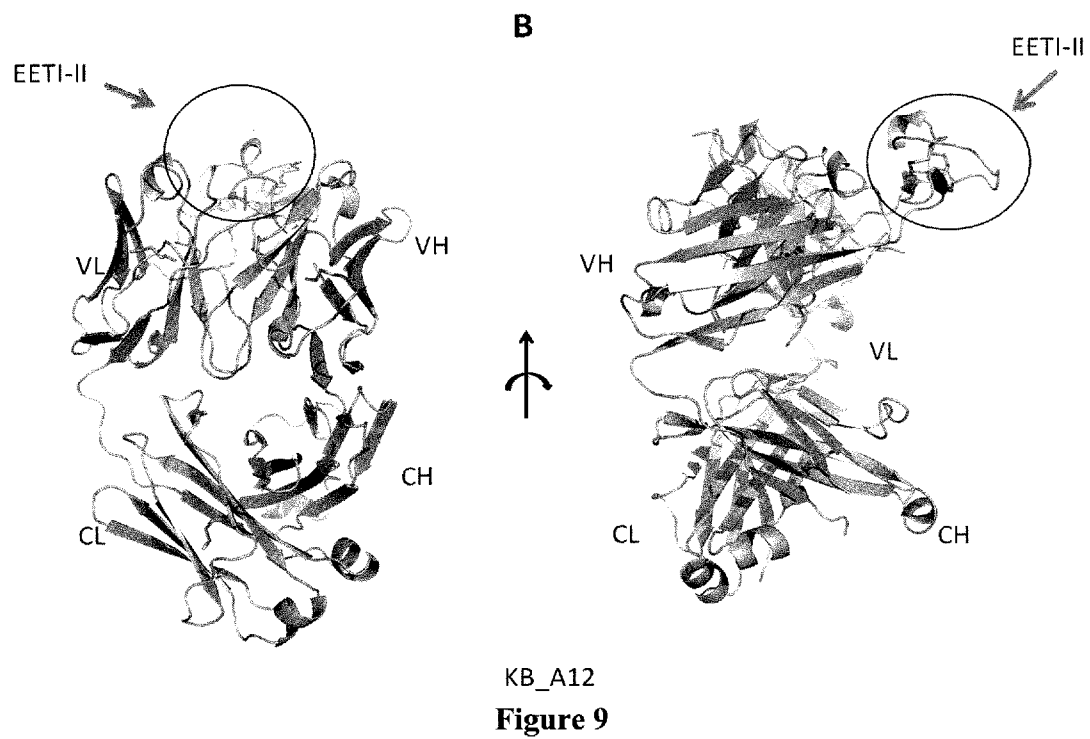
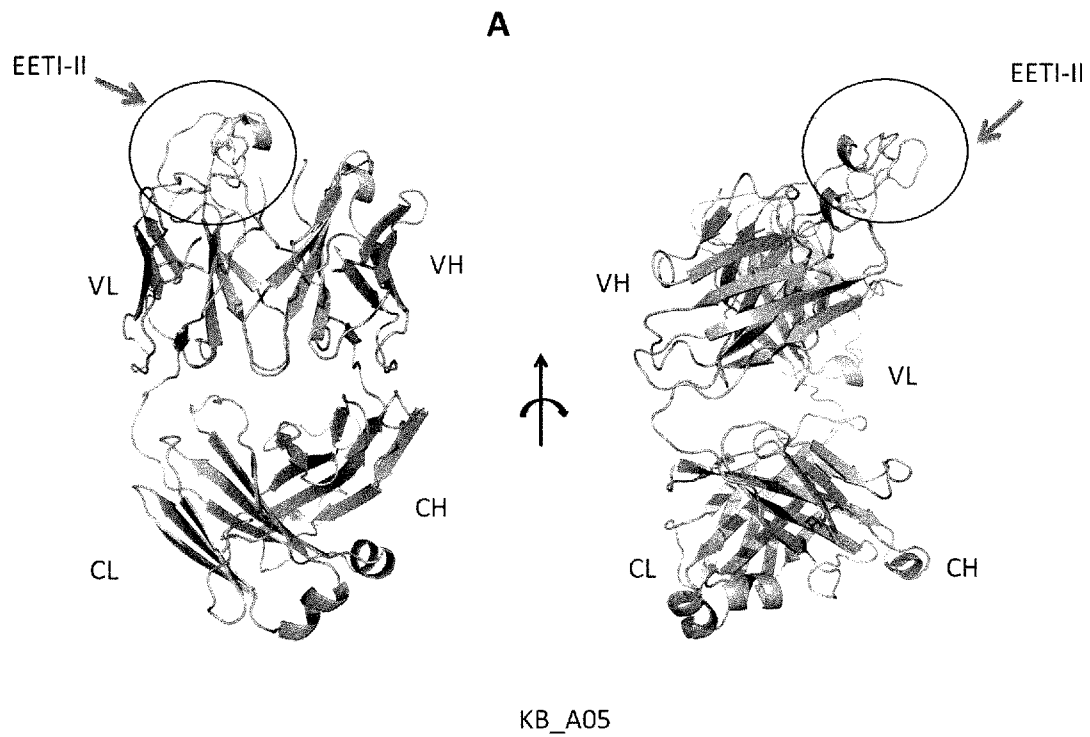


Figure 8A

**Figure 8B**



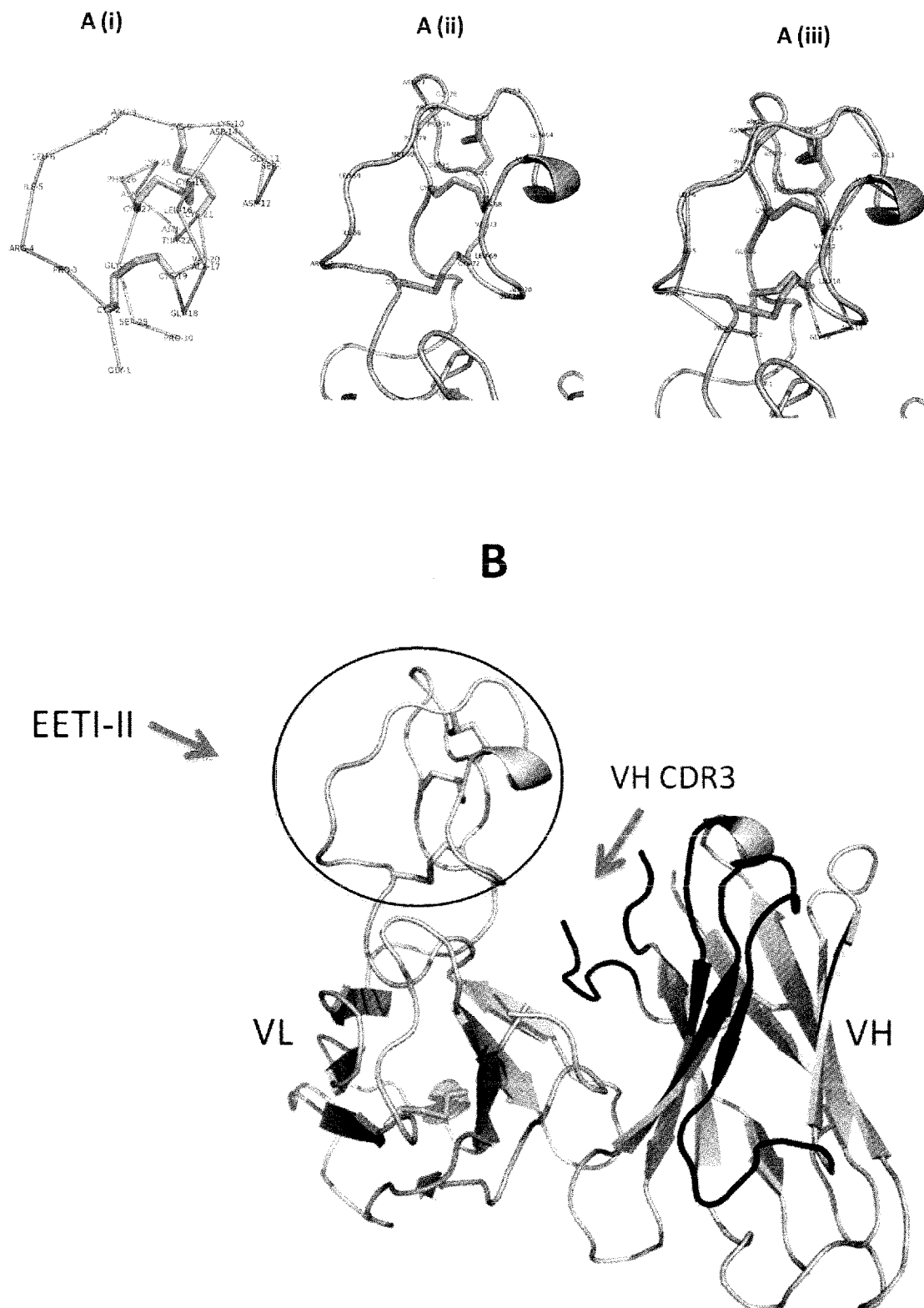


Figure 10

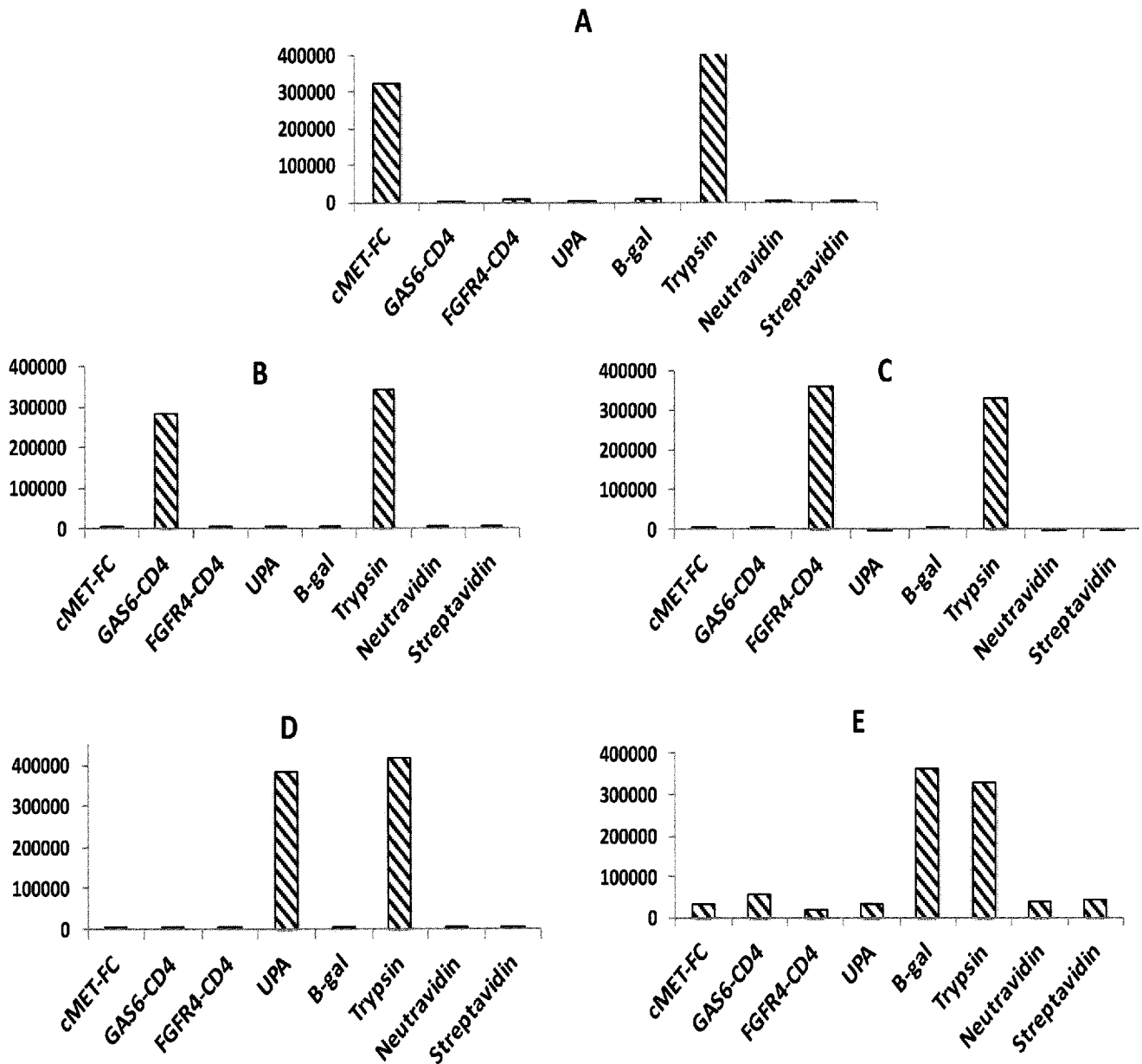


Figure 11

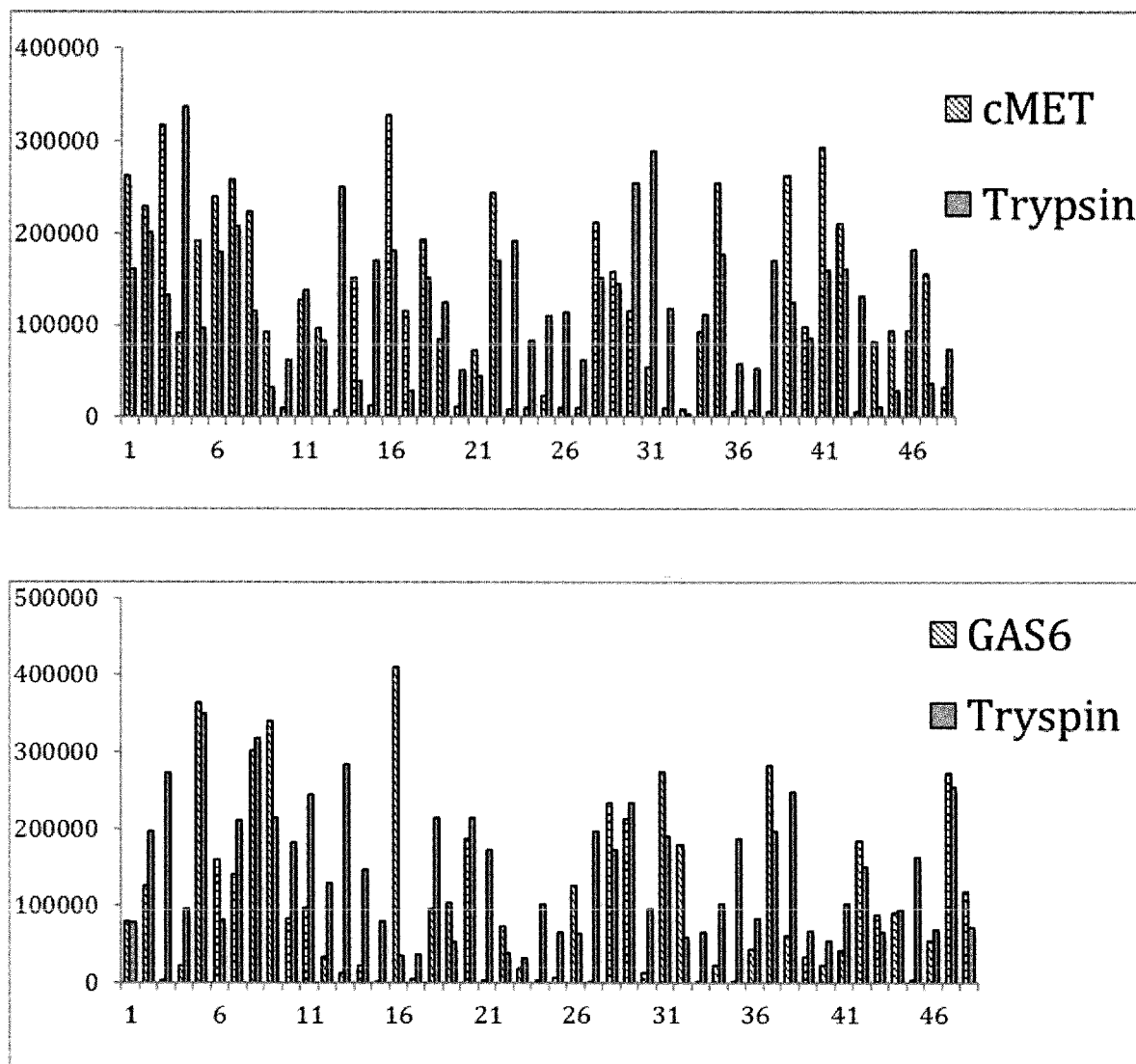


Figure 12

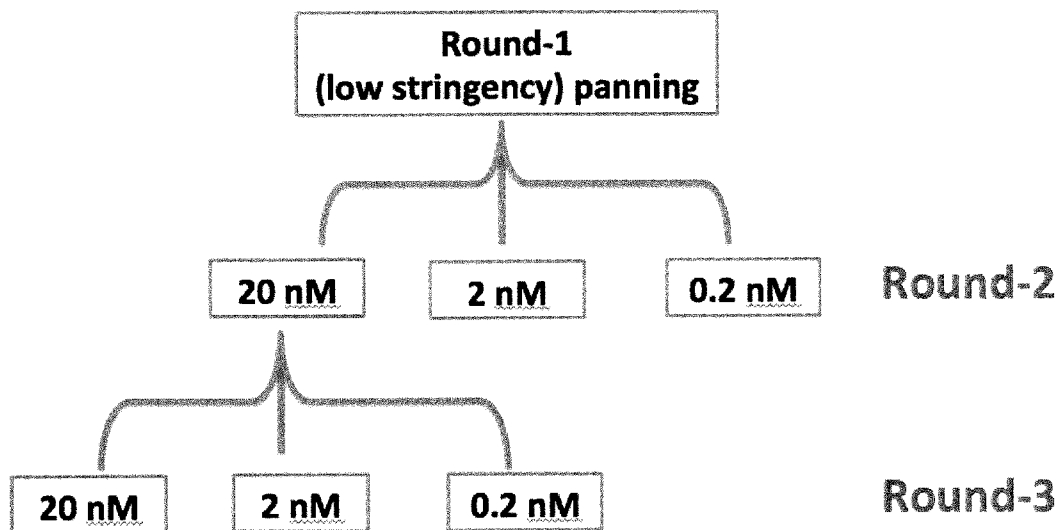


Figure 13

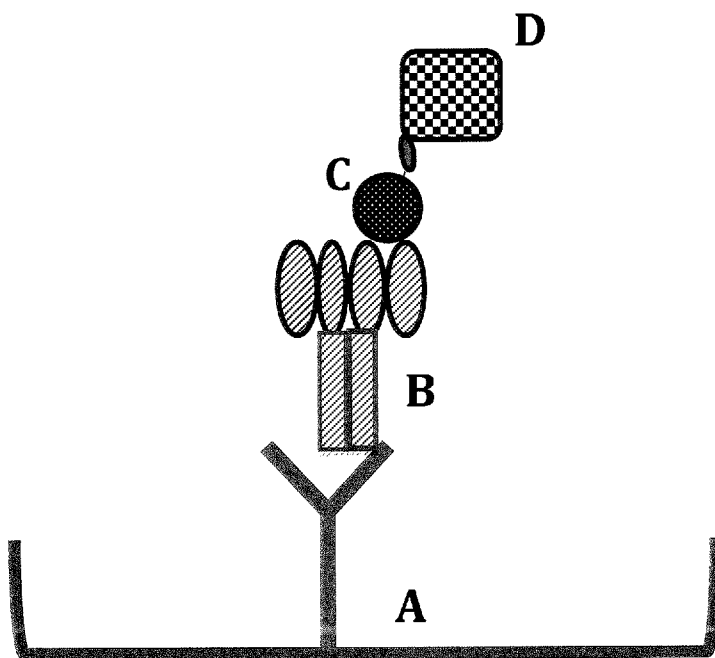


Figure 14

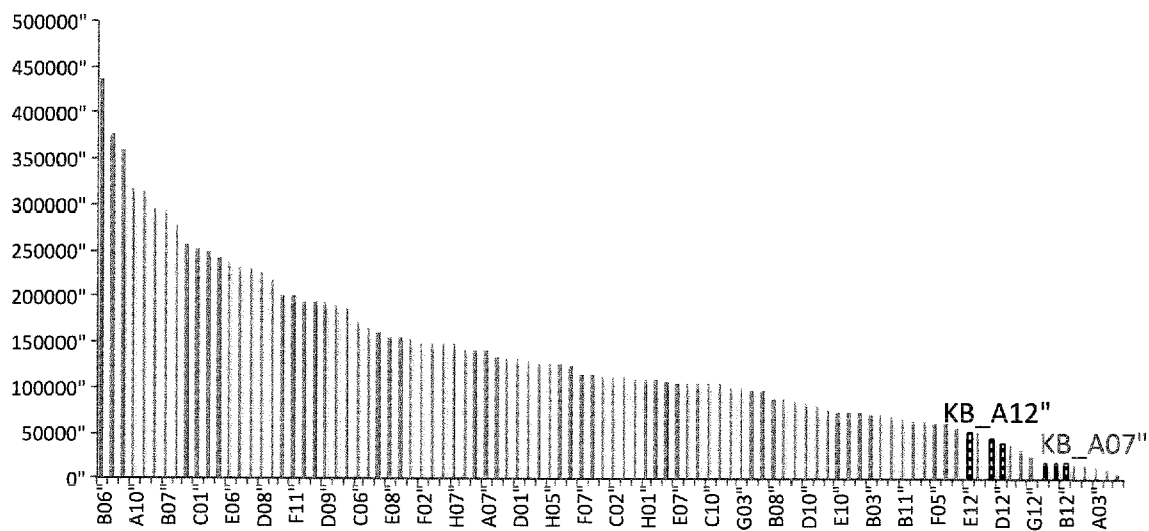


Figure 15

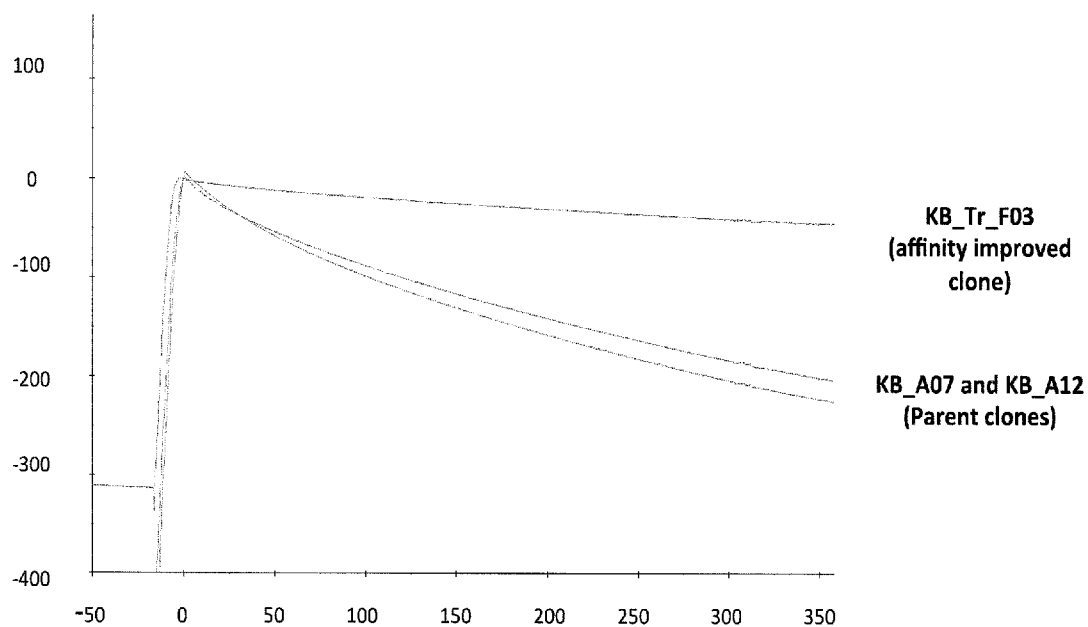


Figure 16

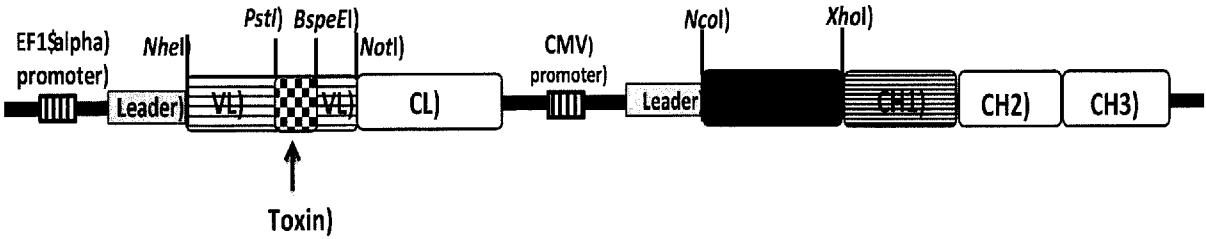


Figure 17

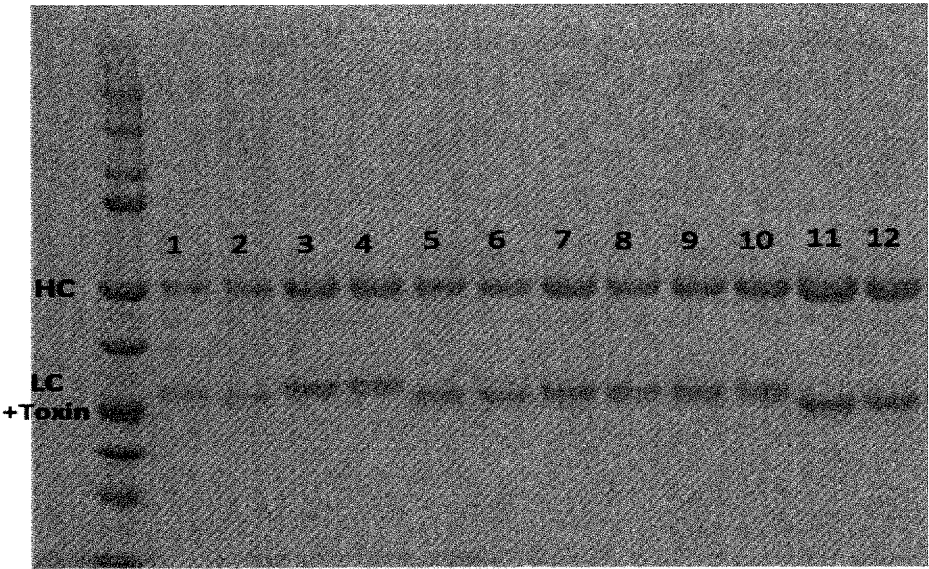


Figure 18

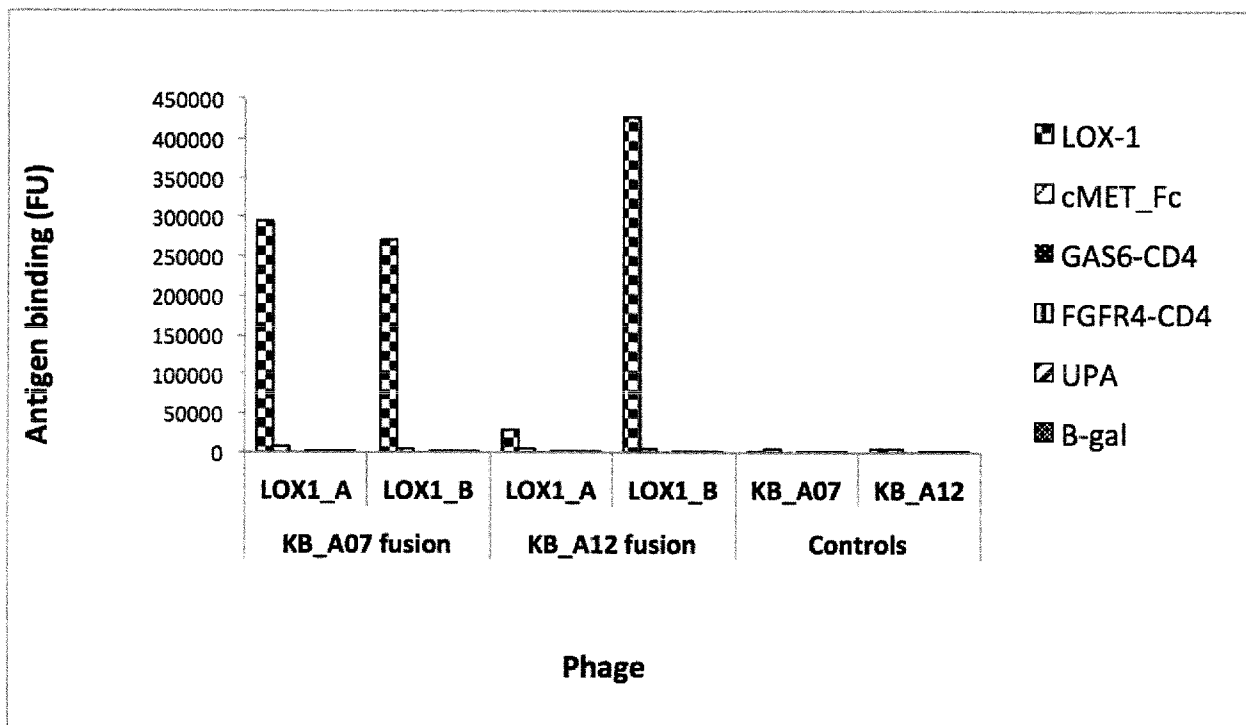


Figure 19

A

10 20 30 40 50
RDLEVVAATPTSLLISwdapavtvrYYRITYGETGGNSPVQEFTVPgsk
60 70 80 90
TATISGLKPGVDYTITVYAVtgrgdspasskpISINYRTEI (SEQ ID NO: 28)

B.

MSNVNTGSLSDNKKFWATVEssehSFEVPIYAETLDEALELAEWQYvpa
 beta beta alpha
gfEVTRVRPCVAPK (SEQ ID NO: 29)
 beta

Figure 20

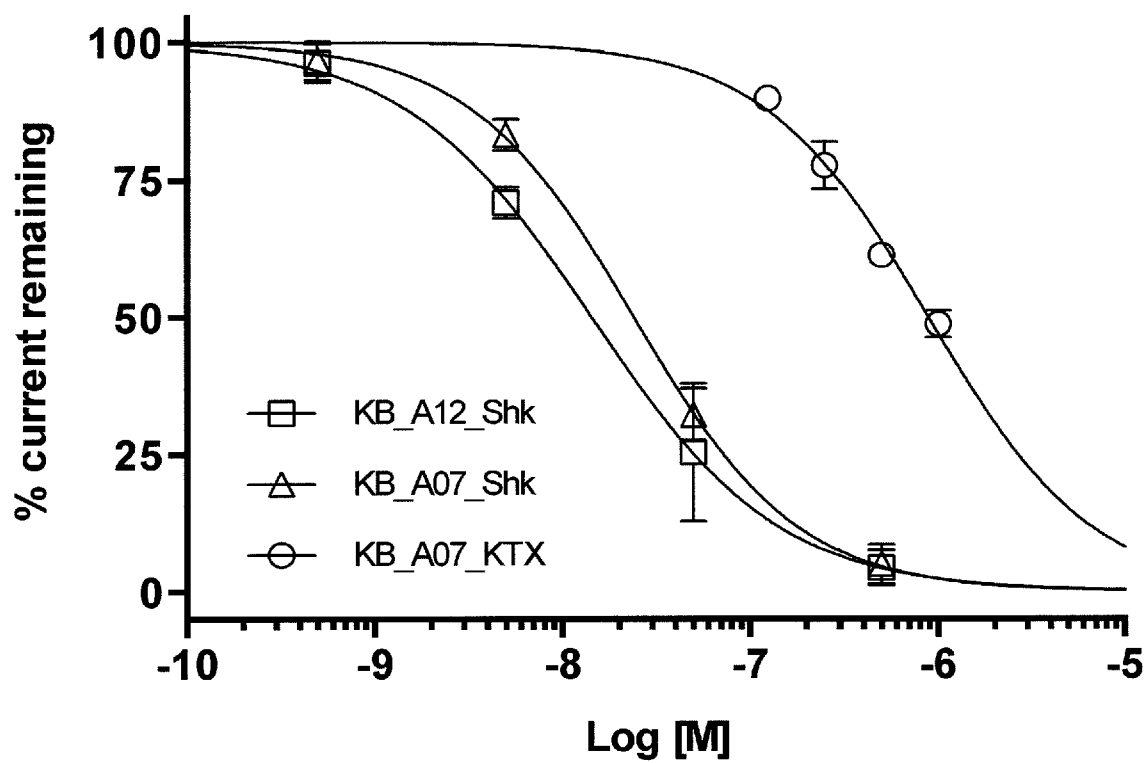


Figure 21

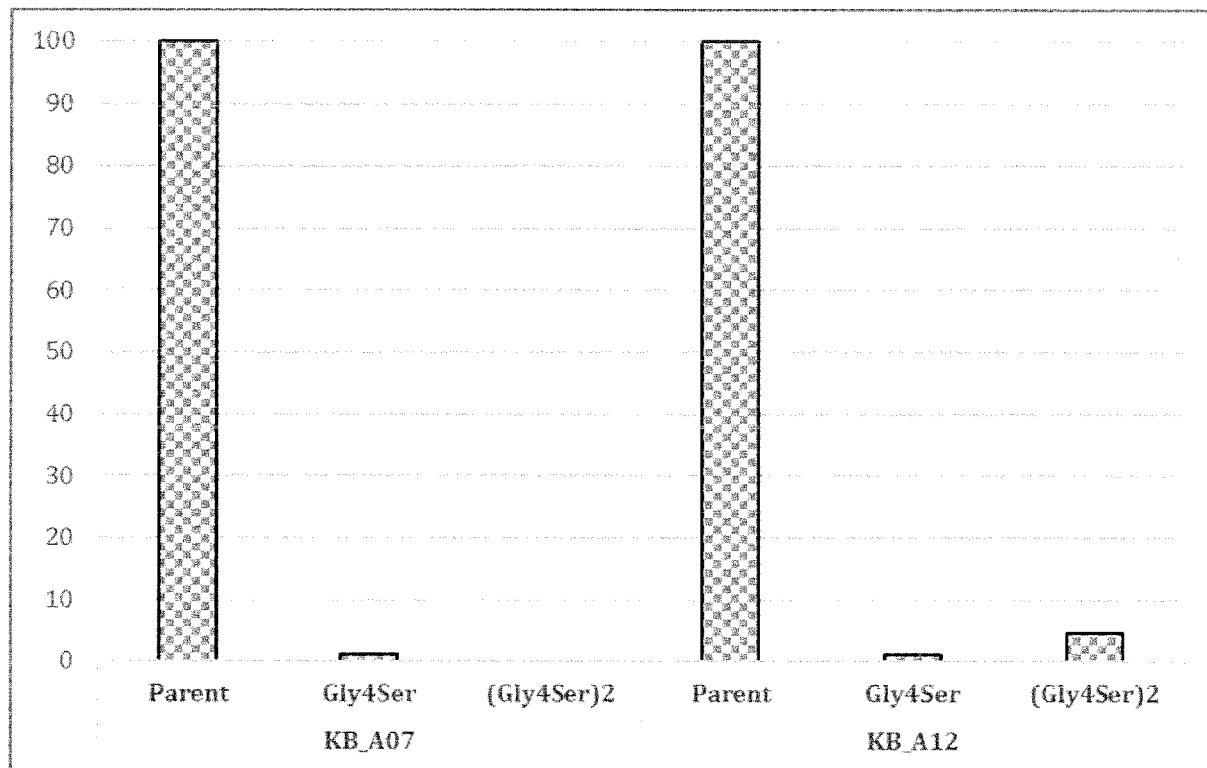


Figure 22

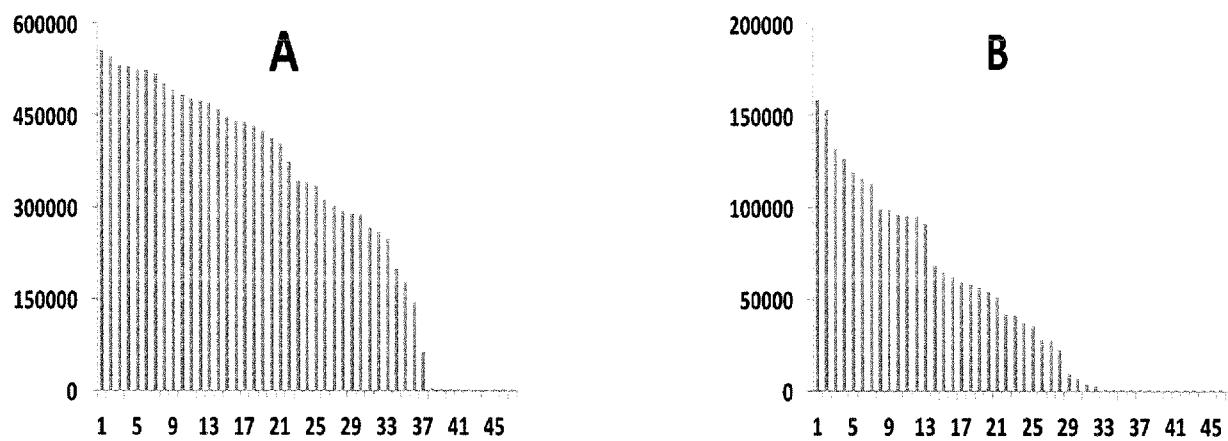


Figure 23

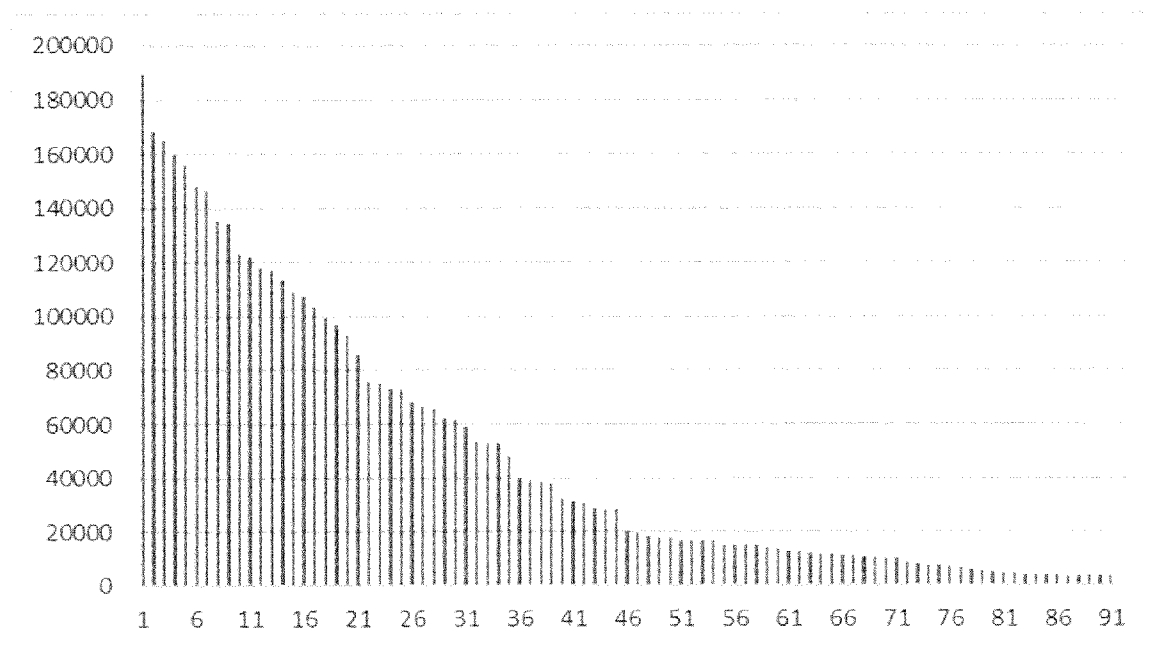


Figure 24

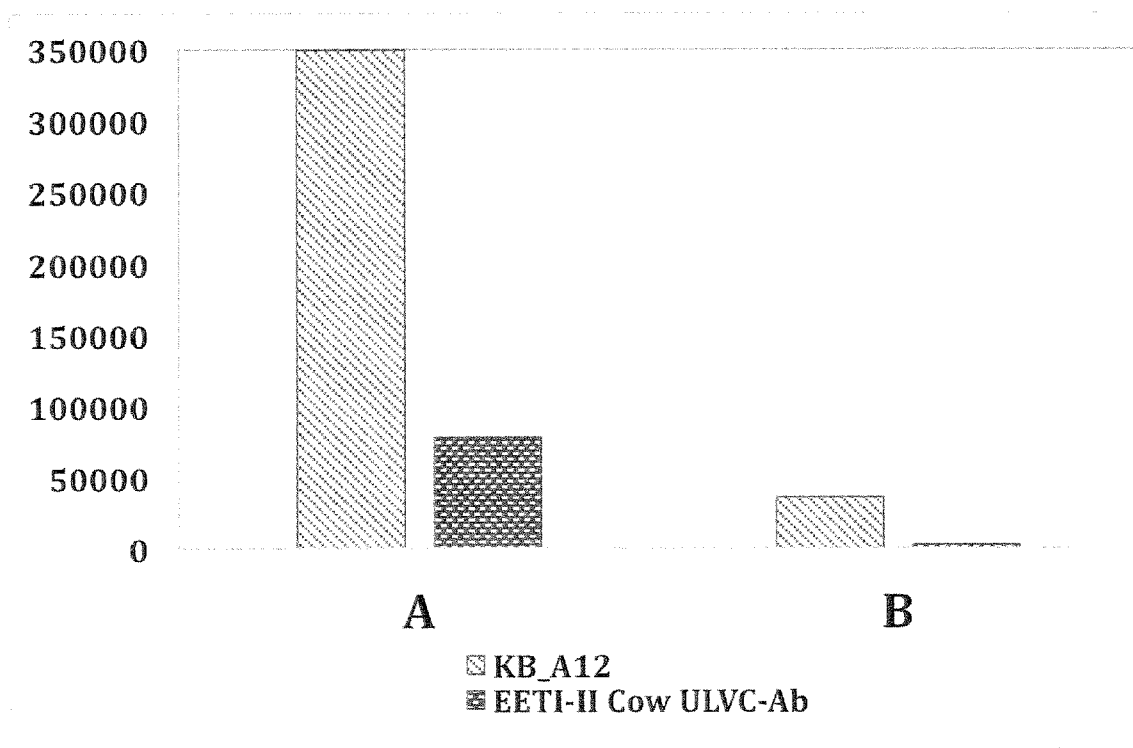


Figure 25

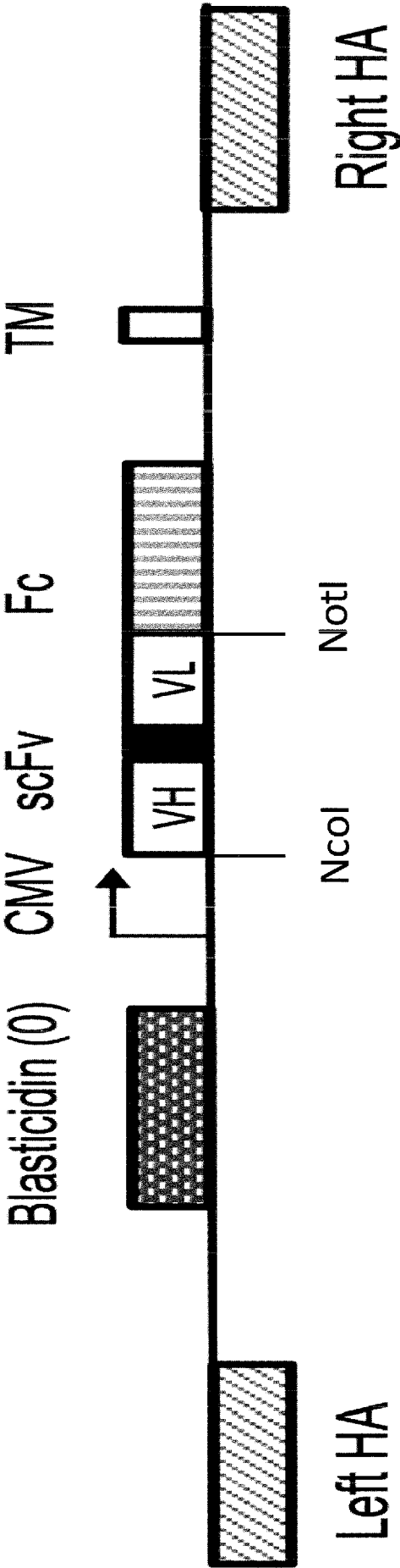


Figure 26

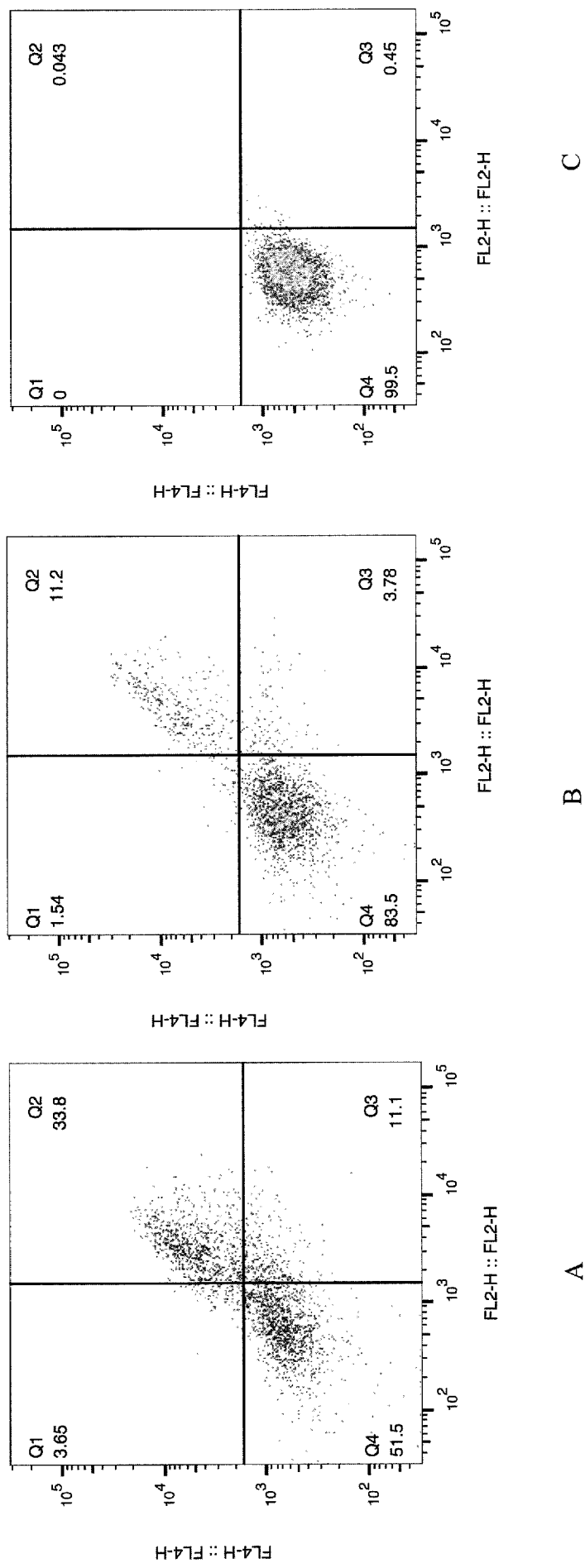


Figure 27

Ai CAASGFTFS syams WVRQAPGKG
(SEQ ID NO: 327)
Aii CAASGFTFS XX CPRILMRCKQDSDCLAGCVCGPNGFCG XX WVRQAPGKG
(SEQ ID NO: 328)

Bi PGKGLEWVS aisgsggstyyadsvkg RFTISRDNT
(SEQ ID NO: 329)
Bii PGKGLEWVS XX CPRILMRCKQDSDCLAGCVCGPNGFCG XX RFTISRDNT
(SEQ ID NO: 330)

Ci DTAFYYCVD fgpgygtgwfdy WPGGTLVTV
(SEQ ID NO: 331)
Cii DTAFYYCVD XX CPRILMRCKQDSDCLAGCVCGPNGFCG XX WPGGTLVTV
(SEQ ID NO: 332)

Di VGDRVITITC rasqsissyln WYQQKPGKA
(SEQ ID NO: 333)
Dii VGDRVITITC XX CPRILMRCKQDSDCLAGCVCGPNGFCG XX WYQQKPGKA
(SEQ ID NO: 334)

Ei KAPKLLIHD asslqs GVPSRFSGS
(SEQ ID NO: 335)
Eii KAPKLLIHD XX CPRILMRCKQDSDCLAGCVCGPNGFCG XX GVPSRFSGS
(SEQ ID NO: 336)

Fi PEDFATYYC qqsfsiplt FGGGTKMDI
(SEQ ID NO: 337)
Fii PEDFATYYC XX CPRILMRCKQDSDCLAGCVCGPNGFCG XX FGGGTKMDI
(SEQ ID NO: 338)

Gi APKLLIYAA GV CPRILMRCKQDSDCLAGCVCGPNGFCG SR SGVPSRFS
(SEQ ID NO: 339)
Gii APKLLIYAA XX CPRILMRCKQDSDCLAGCVCGPNGFCG XX SGVPSRFS
(SEQ ID NO: 340)

Figure 28

tgcgggtccgaacggccttctgcggaagcggcagcgatggcgggtgtgtgcccgcgtatcctg
 C G P N G F C G S G S D G G V C P R I L
 _____LOOP5____> <_____LOOP6_____> <_____LOOP1_____
 atgcgttgcaaacaggactcagactgcctggccggctgc(SEQ ID NO: 341)
 M R C K Q D S D C L A G C(SEQ ID NO: 342)
 _____> <_____LOOP2____> <_____LOOP3____>

Figure 29A

i RVTITCsgs ssnignna vNWyQQLP
 (SEQ ID 343)
 ii RVTITCxxx - CGPNGFCGSGSDGGVCPRILMRCKQDSDCLAGC X xNWyQQLP
 iiiRVTITCgxx X CGPNGFCGSGSDGGVCPRILMRCKQDSDCLAGC X xNWyQQLP
 (SEQ IDs 344 and 345)
 iv KLLIY ydd llpSGVSDRFS
 (SEQ ID NOS: 346)
 v KLLIY AAZ x CGPNGFCGSGSDGGVCPRILMRCKQDSDCLAGC gxxSGVSDRFS
 (SEQ ID 347)

Figure 29B

Nhe1

gctagccagtcctgtgctgactcagccaccctcggtgtctgaagccccaggcagaggggtc
 A S Q S V L T Q P P S V S E A P R Q R V
 ←-----FW1-----→

Pml1

accatcacgtgtvnsvnsvnstgcggtccgaacggccttctgcggaagcggcagcgatggc
 T I T C X X X C G P N G F C G S G S D G
 -----→ ←-----EETI-II-----→

ggtgtgtgcccgcgtatcctgatgcgttgcaaacaggactcagactgcctggccggctgc
 G V C P R I L M R C K Q D S D C L A G C
 -----→

Mfe 1**Not1**

vnsvncaattggtaccagcagctcccagga ←-Vlambda library-> gcggccgc
 (SEQ ID NO: 348)
 X X N W Y Q Q L P G (SEQ ID NO: 349)
 I----FW2-----→

Figure 29C

Nhe1

gctagccagtcgtgtgctgactcagccaccctcggtgtctgaagccccaggcagagggtc
 A S Q S V L T Q P P S V S E A P R Q R V
 ←-----FW1-----

Pml1

accatccacgtgttctggaagcagctccaacatcggaataatgctgtaaaactggtaccag
 T I T C S G S S S N I G N N A V N W Y Q
 -----→←-----CDR1-----→←-----FW2-----

Pst1

cagctcccagggaaagcccctaagctcctgatctatgctgcagnsvnstgcggtccgaac
 Q L P G K A P K L L I Y A A Z X C G P N
 -----→←-----EETI-II-----

ggcttctgcggaagcggcagcgatggcgggtgtgtgcccgcgtatcctgatgcgttgcaaa
 G F C G S G S D G G V C P R I L M R C K
 -----EETI-II-----

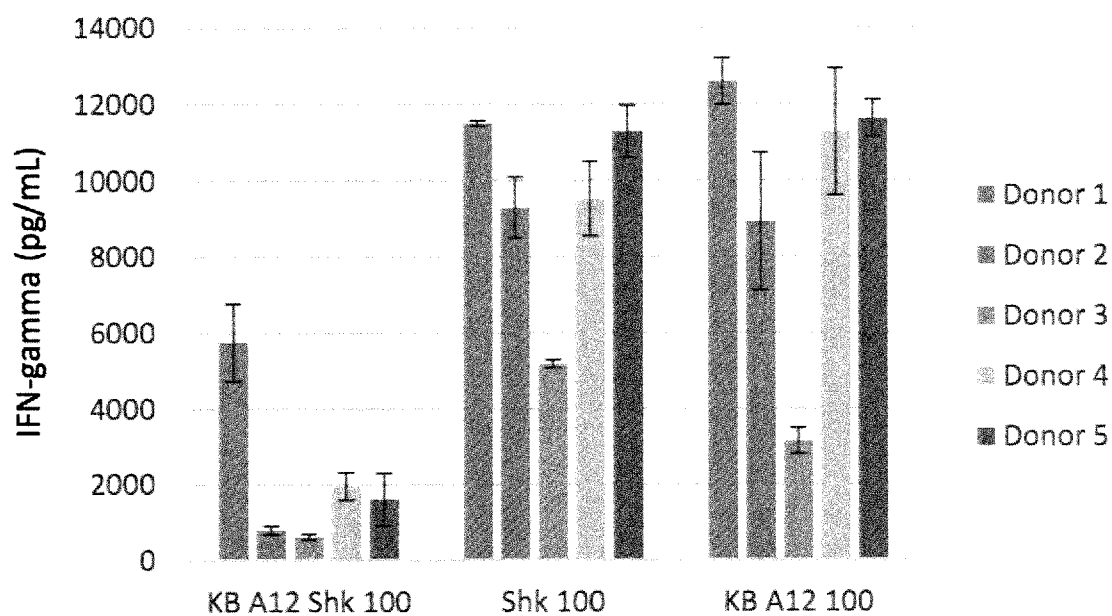
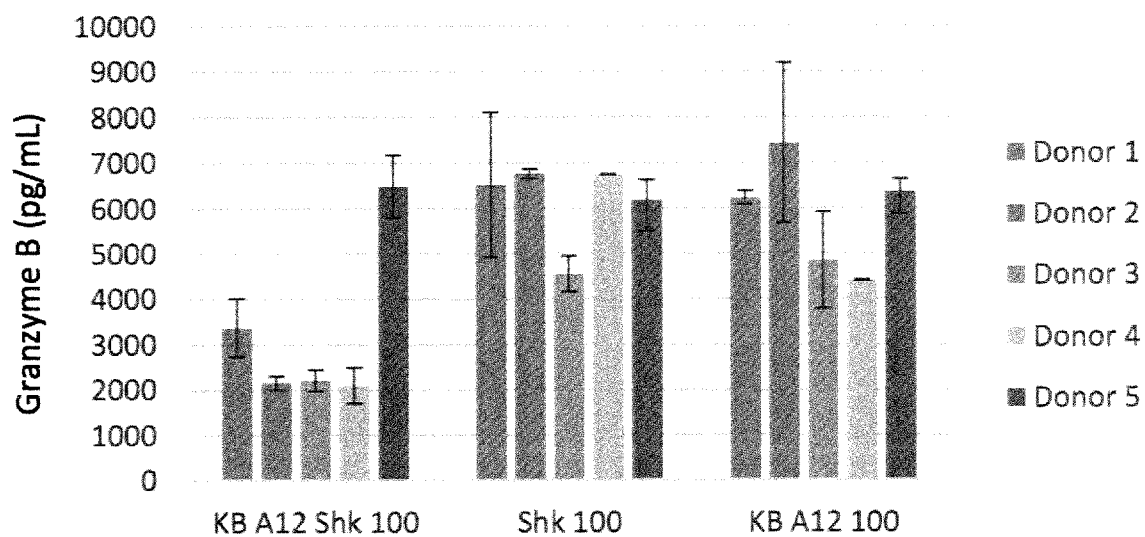
BspE1

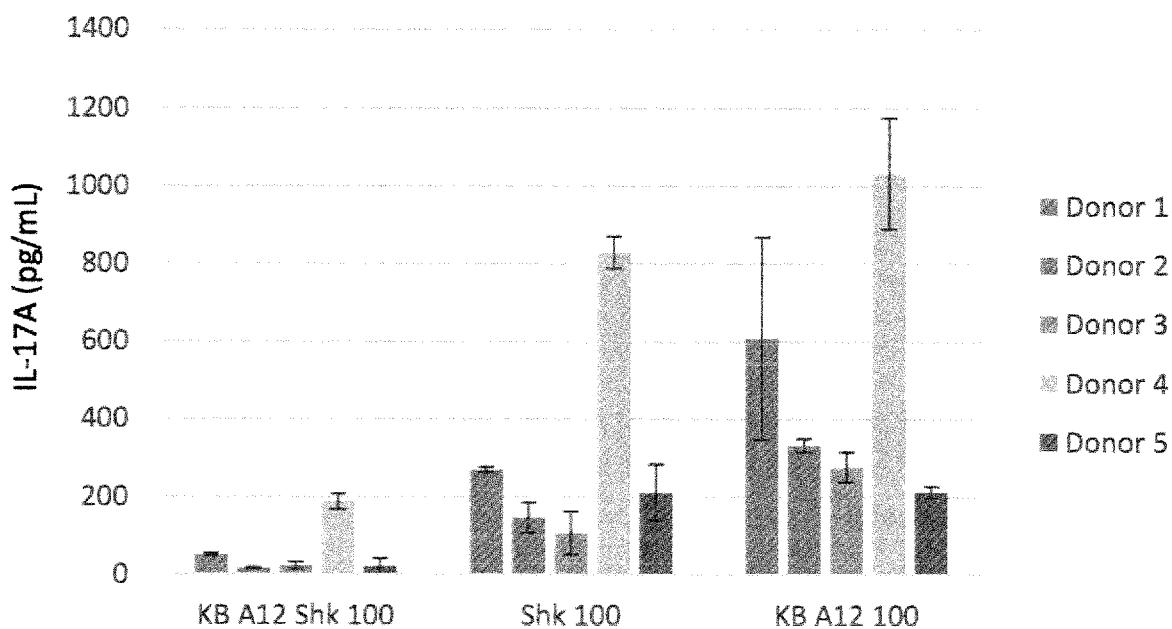
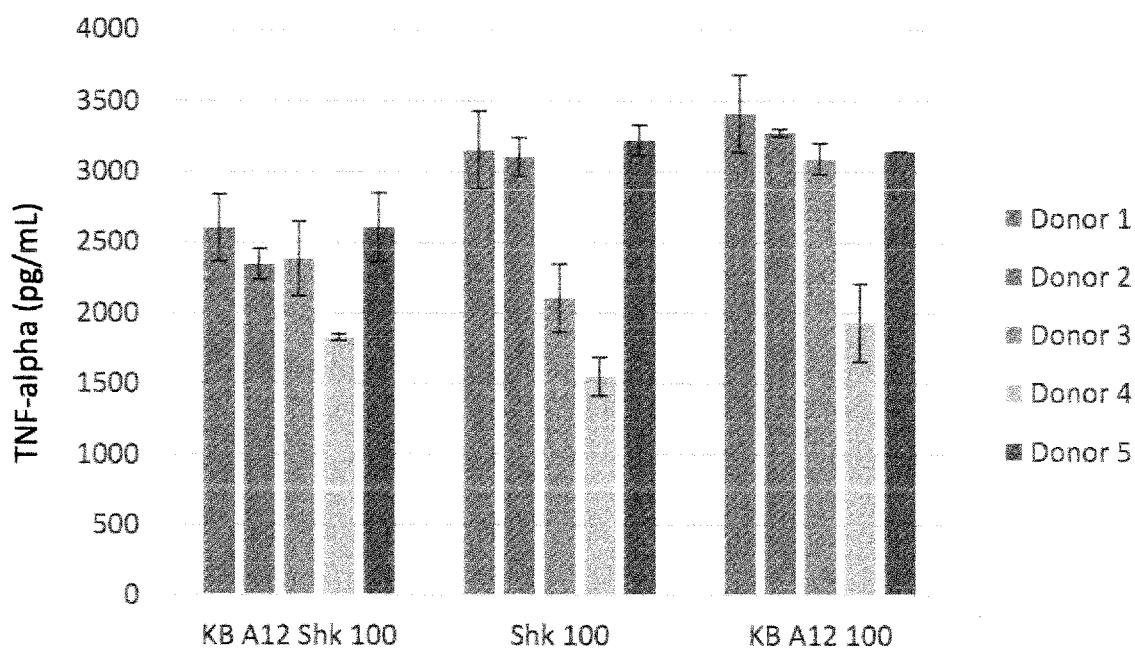
caggactcagactgcctggccggctgcgggvnsvnstccggagtctctgaccgattctct
 Q D S D C L A G C G X X S G V S D R F S
 -----→ I-----FW3-----

Not1

ggctcc<-Vlambda library->accgtcctaggtcagcccgcggcgc (SEQ ID NO: 350)
 G S T V L G Q P (SEQ ID NO: 351)
 -----→

Figure 29D

**Figure 30A****Figure 30B**

**Figure 30C****Figure 30D**

```

1   cggggctgct acctccacgg ggcgcgcctg gcaggagggg cgcagtctgc ttgcaggcgg
61  tggccagcgc tccagcggcg gctgtcggtt ttccaattcc gccagctcgg ctgaggctgg
121 gctagcctgg gtgccagtgg ctgctagcgg caggcgtccc ctgagcaaca ggagcccaga
181 gaaaaagaag cagccctgag agagcgccgg ggaaggagag gcccgcgcc tctcctggag
241 ccagattctg caggtgcact ggggtgggat gatcggcggg ctagggttgc agcctcttat
301 gtgaggagct gaagaggaat taaaatatac aggatgaaaa gatggcaatg ttgctcccc
361 caggacctca gagctttgtc catttcacaa aacagtctct tgccctcatt gaacaacgca
421 ttgctgaaag aaaatcaaag gaacccaaag aagaaaagaa agatgatgat gaagaagccc
481 caaagccaag cagtgaactg gaagctggca aacagctgcc ctcatctat ggggacattc
541 ctcccgcat ggtgtcagag cccctggagg acttggaacc ctactatgca gacaaaaaga
601 ctttcatagt attgaacaaa gggaaaaaaa tcttcggtt caatgccaca cctgctttat
661 atatgctttc tcttttcagt cctetaagaa gaatatctat taagatttta gtacactcct
721 tattcagcat gtcctcatg tgcaactatc tgacaaactg catattttatg accatgaata
781 acccaccgga ctggaccaaa aatgtcgagt acacttttac tggaaatatat acttttgaat
841 cacttgtaaa aatccttgca agaggcttct gtgtaggaga attcactttt cttcgtgacc
901 cgtggaactg gctggatttt gtcgtcattc tttttgcgta tttaacagaa ttgttaaacc
961 taggcaatgt ttcagctctt cgaactttta gagtattgag agctttgaaa actattttctg
1021 taatcccagg cctgaagaca attgtagggg ctttgatcca gtcagtgaag aagctttctg
1081 atgtcatgat cctgactgtg ttctgtctga gtgtgtttgc actaattgga ctacagctgt
1141 tcatgggaaa cctgaagcat aaatgttttc gaaattcact tgaaaaaat gaaacattag
1201 aaagcataat gaatacccta gagagtgaag aagactttag aaaatatttt tattacttgg
1261 aaggatccaa agatgctctc ctttgtgtgt tcagcacaga ttcaggtcag tgtccagagg
1321 ggtacacctg tgtgaaaatt ggcagaaacc ctgattatgg ctacacgagc tttgacactt
1381 tcagctgggc cttcttagcc ttgttttaggc taatgaccca agattactgg gaaaaccttt
1441 accaacagac gctgcgtgct gctggcaaaa cctacatgat cttctttgtc gtagtgattt
1501 tcctgggctc cttttatcta ataaacttga tcttggtgtg ggttgccatg gcatatgaag
1561 aacagaacca ggcaaacatt gaagaagcta aacagaaaaga attagaattt caacagatgt
1621 tagaccgtct taaaaagag caagaagaag ctgaggcaat tgcagcggca gcggtgaat
1681 atacaagtat taggagaagc agaattatgg gctctcaga gagttcttct gaaacatcca
1741 aactgagctc taaaagtgtt aaagaaaaga gaaacagaag aaagaaaaag aatcaaaaaga
1801 agctctccag tggagaggaa aaggagatg ctgagaaatt gtogaaatca gaatcagagg
1861 acagcatcag aagaaaaagt ttccaccttg gtgtogaagg gcataggoga gcacatgaaa
1921 agaggttgtc tacccecaat cagtcaccac tcagcattcg tggctccttg tttttgcaa
1981 ggcgaagcag cagaacaagt ctttttagtt tcaaaggcag aggaagagat ataggatctg
2041 agactgaatt tgccgatgat gagcacagca tttttggaga caatgagagc agaaggggct
2101 cactgtttgt gcccacaga cccaggagc gacgcagcag taacatcagc caagccagta
2161 ggtccccacc aatgctgccg gtgaacggga aaatgcacag tgetgtggac tgcaacgggtg
2221 tggctctcct ggttgatgga cgtcagccc tcatgctccc caatggacag cttctgccag
2281 agggcacgac caatcaaata cacaagaaaa ggcgtttagg ttctatctc ctttcagagg
2341 atatgctgaa tgatcccaac ctacagacaga gagcaatgag tagagcaagc atattaacaa
2401 aactgtgga agaacttgaa gagtccagac aaaaatgtcc accttggttg tacagatttg
2461 cacacaaatt cttgatctgg aattgctctc catattggat aaaattcaaa aagtgtatct
2521 attttattgt aatggatcct tttgtagatc ttgcaattac catttgcata gttttaaaca
2581 cattatttat ggctatggaa caccacocaa tgactgagga attcaaaaaat gtacttgcta
2641 taggaaattt ggtctttact ggaatctttg cagctgaaat ggtattaaaa ctgattgcca
2701 tggatccata tgagtatttc caagtaggct ggaatatatt tgacagcctt attgtgactt
2761 taagtttagt ggagctcttt ctacagatg tggaaggatt gtcagttctg cgatcattca
2821 gactgctccg agtcttcaag ttggcaaaat cctggccaac attgaacatg ctgattaaga
2881 tcattggtaa ctacgtaggg gctctaggta acctacott agtgttggcc atcatcgtct
2941 tcatttttgc tgtggtcggc atgcagctct ttggtaagag ctacaaagaa tgtgtctgca
3001 agatcaatga tgactgtaag ctcccacggt ggcacatgaa cgacttcttc cactccttc
3061 tgatttgatt ccgctgctg tgtggagagt ggatagagac catgtgggac tgtatggagg
3121 tgcgtgggtc agctatgtgc cttattgttt acatgatggg catggctcatt ggaacctggg
3181 tggctcctaaa cctattttctg gccttattat tgagctcatt tagttcagac aatcttacag
3241 caattgaaga agacctgat gcaaacaccc tccagattgc agtgactaga attaaaaagg
3301 gaataaatta tgtgaaacaa accttacgtg aattttattct aaaagcattt tccaaaaagc
3361 caaagatttc cagggagata agacaagcag aagatctgaa tactaagaag gaaaactata
3421 tttctaacca tacacttgct gaaatgagca aaggtcacaa tttcctcaag gaaaaagata

```

Figure 31

```

3481 aaatcagtgg ttttggaaagc agcgtggaca aacacttgat ggaagacagt gatggtcaat
3541 catttattca caatcccagc ctcacagtga cagtgccaat tgcacctggg gaatccgatt
3601 tggaaaatat gaatgotgag gaacttagca gtgattcgga tagtgaatac agcaaaagtga
3661 gattaaaccg gtcaagctcc tcagagtgcg gcacagttga taacctttg cctggagaag
3721 gagaagaagc agaggctgaa cctatgaatt cogatgagcc agaggcctgt ttcacagatg
3781 gttgtgtacg gaggtttotca tgcctgccaag ttaacataga gtcagggaaa ggaaaaatct
3841 ggtggaacat caggaaaaacc tgcatacaaga ttgttgaaca cagttggttt gaaagcttca
3901 ttgtcctcat gatcctgctc agcagtgggtg ccttggcttt tgaagatatt tatattgaaa
3961 ggaaaaagac cattaagatt atcctggagt atgcagacaa gatcttcact tacatcttca
4021 ttctggaaat gcttctaaaa tggatagcat atggttataa aacataattc accaatgcct
4081 ggtgtttggct ggatttctta attgttgatg tttcttttgt tacttttagtg gcaaacactc
4141 ttggctactc agatcttggc ccattaaat cccttcggac actgagagct ttaagacctc
4201 taagagcctt atctagattt gaaggaatga gggctgttgt gaatgcactc ataggagcaa
4261 ttcttccat catgaatgtg ctacttgtgt gtcttatatt ctggctgata ttcagcatca
4321 tgggagtaaa tttgtttgct ggcaagttct atgagtgtat taacaccaca gatgggtcac
4381 ggtttcctgc aagtcaagtt ccaaactcgt ccgaatgttt tgccttatg aatgttagtc
4441 aaaatgtgcg atggaaaaac ctgaaagtga actttgataa tgcctgactt ggttacctat
4501 ctctgcttca agttgcaact ttttaaggat ggacgattat tatgtatgca gcagtggatt
4561 ctgttaattgt agacaagcag cccaaatatg aatatagcct ctacatgtat atttattttg
4621 tcgtctttat catcttttgg tcattcttca ctttgaactt gttcatttgt gtcacatag
4681 ataatttcaa ccaacagaaa aagaagcttg gaggtaaga catctttatg acagaagaac
4741 agaagaaata ctataatgca atgaaaaagc tggggtccaa gaagccacaa aagccaattc
4801 ctgcaccagg gaacaaaatc caaggatgta tatttgacct agtgacaaat agtgcctttg
4861 atattagtat catggttctt atctgtctca acatggtaac catgatggta gaaaaggagg
4921 gtcaaagtca acatatgact gaagttttat attggataaa tgtggttttt ataactctt
4981 tcaactggaga atgtgtgcta aaactgatct cctcagaca ctactacttc actgtaggat
5041 ggaatatttt tgattttgtg gttgtgatta tctccattgt aggtatgttt ctagtgtatt
5101 tgattgaaac gtattttgtg tccctaccc tgltccgagt gatccgtctt gccaggattg
5161 gccgaatcct acgtctagtc aaaggagcaa aggggatccg cacgtgtctc tttgctttga
5221 tgatgtcctt tctgctgtt ttaacatcg gctcctgct ctctctggtc atgttcatct
5281 acgccatctt tggaatgtcc aactttgct atgttaaaaa ggaagatgga attaatgaca
5341 tgttcaattt tgagacctt ggcaacagta tgatttgctt gttccaaatt acaacctctg
5401 ctggctggga tggattgcta gcacctatc ttaacagtaa gccacccgac tgtgacccaa
5461 aaaaagttca tcttggaggt tcagttgaag gagactgtgg taacctatct gttggaatat
5521 tctactttgt tagttatata atcatatcct tcttggttgt ggtgaacatg tacattgcag
5581 tcatactgga gaatttttagt gttgccactg aagaaagtac tgaacctctg agtgaggatg
5641 acttttagat gttctatgag gtttgggaga agtttgatcc cgatgcgacc cagtttatag
5701 agttctctaa actctctgat tttgcagctg ccttggatcc tctcttctc atagcaaaac
5761 ccaacaaagt ccagctcatt gccatggatc tgcctatggg tagtggtgac cggatccatt
5821 gtcttgacat ctattttgct tttacaaagc gtgttttggg tgagagtggg gagattgatt
5881 ctcttctgtt acagatggaa gaaaggttca tgtctgcaaa tcttccaaa tcttctatg
5941 aacctatcac aaccacacta aaacggaaac aagaggatgt gtctgtact gtcattcagc
6001 gtgcttatag acgttaccgc ttaaggcaaa atgtcaaaaa tatatcaagt atatacataa
6061 aagatggaga cagagatgat gatttactca ataaaaaaga tatggctttt gataatgtta
6121 atgagaactc aagtcagaa aaaacagatg ccacttcac caccacctct ccaccttcat
6181 atgatagtgt aacaaagcca gacaaagaga aatatgaaca agacagaaca gaaaagggaag
6241 acaaagggaa agacagcaag gaaagcaaaa aatagagctt catttttgat atattgttta
6301 cagcctgtga aagtgtattt tttgtgttaa taaaactctt ttgaggaagt ctatgccaaa
6361 atccttttta tcaaaatatt ctogaaggca gtgcagtcac taactctgat ttctaagaa
6421 aggtgggcag cattagcaga tggttatttt tgcactgatg attctttaag aatcgtaaga
6481 gaactctgta ggaattattg attatagcat acaaaagtga ttcagttttt tggtttttaa
6541 taaatcagaa gacctgttag aaaactttta catctgcctt gtcactttt cacaggattg
6601 taattagtct tgtttcccat gtaataaaac aacacacgca tacagaaaaa tctattattt
6661 atctattatt tggaaatcaa caaagtatt tgccttggct ttgcaatgaa atgcttgata
6721 gaagtaattg acattagtta tgaatgttta gttaaaatgc attattagg agcttgactt
6781 tttatcaatg tacagagggt attctatatt ttgaggtgct taaatttatt ctacattgca
6841 tcagaaccaa tttatatgtg cctataaaat gccatgggat taaaaatata tgtaggctat
6901 tcattttctac aaatgttttt cattcatctt gactcacatg ccaacaagga taagacttac

```

Figure 31 Cont.

```

6961 ctttagagta ttgtgtttca tagcctttct tctttcatat ccttttttgt tcatagaata
7021 accacagAAC ttgaaaaatt attctaagta catattacac tctcAAAAA aaacaaagat
7081 aactgagaaa aaagttattg acagaagttc tatttgctat tatttacata gcctaacatt
7141 tgactgtgct gcccaaaata ctgataatag tctcttaaAC tcttttgtca aattttcctg
7201 ctttcttatg cagtattgtt tagtcatcct ttcgctgtaa gcaaagttga tgaaatcctt
7261 cctgatatgc agttagttgt ttgaccacgg tacatacttg agcagataat aacttgggca
7321 cagtatttat tgcatcactt gtatacaatc ccgtgtttgg caagctttca aatcatgtaa
7381 tatgacagac ttacacaga tatgtgttta gtatgaataa aaaagcattg aaatagggat
7441 tcttgccaac ttgctctctt gccaccaact tactttccta aattatggaa gtaatctttt
7501 ttggatatac ttcaatgtat acaatgagga agatgtcacc ttctccttaa aattctatga
7561 tgtgaaatat attttgcttc aatcaacaca gtaccatggg ctctcaattt atcaagcaca
7621 tattcatttt gcattagctg tagacatcta gttttttgaa aacacctatt aatagtaatt
7681 tgaaaagaaa taaccataat gctttttttc gtgagtttat ttcaggaata tgagatcttt
7741 cttctataaa gttattcatg cacaggcaaa aattgagcta cacaggtaga atgtagtttt
7801 acttagaaga tttttgtggg aggttttgaa gcaaataat aaaacaactt tcaataattt
7861 gctttccata tttaaaaaat aataaattac atttatataa taaatgttta aagcacatat
7921 tttttgttgt tctggcaatt taaaaagaaa gaggatttaa acgtacctat agaaacaaag
7981 atttatgggt aaagaatgag atcagaagtc tagaatgttt ttaaattgtg atatatttta
8041 caacatccgt tattactttg agacatttgt cctaactcac gtataaaact caatctaggg
8101 ctaaagattc tttataccat cttaggttca ttcacttag gctatttgaa ccacttttta
8161 atttaatatg aaagacacca tgcagtgttt tccgagacta catagatcat tttatcacat
8221 acctaccaag cctgttgga ataggttttg ataatttaag tagggaccta taaaaatat
8281 attacattta tcagattttt aaatacatte aattaagaat ttaacatcac cttaaatttg
8341 aattcaatct accgttattt caaactcaca aatataactg cattatgaat acttacataa
8401 tgtagtgaag caagatgttt gacaggttcg tgtgtaattt tctattaatg tttttacatt
8461 gccttgtttt tatgtaaaat aaaaaatatg ggcaactggg ttgttaacaa cacaattttt
8521 tcttagcatt tcaaaaatat atataaagtt gttctttttc ctatttcatg aactatgttt
8581 ttttttaaaa taacatgggt aagttttata tatatttacg tttgtttcag gaatgtctac
8641 ttgtgacttt ttatcaatta aaaataatat ttggaagaaa gagcttatta agtataagct
8701 tgaaagtaaa ttagacctct ctttccatgt agattactgt ttgtactgat ggtttcaccc
8761 ttcagaaggc actgtcatat taatatttaa attttataat cgtgaactt attacacca
8821 acaatacaga aaggcagtta cactgaagaa cttaacttag aataaaatgg aagcaaacag
8881 gttttctaaa aactttttta agtgaccagg tctcgctctg tcaccaggc tagagtgcAA
8941 tggcatgac atagctctct gcagcctcaa ctctgggctc aagcaaccct cctgcctcag
9001 cctcccaagt agctaagact acaggtacat gccaccatgc ctggctaata tttaaatttt
9061 tgtagataag ggtcttgct atgttgccca ggctagtctc aaactcctgg cttaagtgt
9121 tctactgtc atgacctgcc aacatgctgg ggttacaggc atgagccacc atgccccaaa
9181 caggtttgaa cacaatctt tcggatgaaa attagagaac ctaatttttag ctttttgata
9241 gttacctagt ttgcaaaaga tttgggtgac ttgtgagctg tttttaaatg ctgattgttg
9301 aacatcacia cccaaaatac ttagcatgat tttatagagt tttgatagct ttattaaaaa
9361 gagtgaaaat aaaatgcata tgtaaataaa gcagttctaa atagctattt cagagaaatg
9421 ttaatagaag tgctgaaaga agggccaact aaattaggat ggccaggga ttggcctggg
9481 tttaggacct atgtatgaag gccaccaatt ttttaaaaa atctgtgggt tattatgtta
9541 ttatcttctt gaggaaaaca atcaagaatt gtttcatgaa aataaataaa tagccatgaa
9601 tatcataaag ctgtttacat aggattcttt acaaatttca tagatctatg aatgctcaaa
9661 atgtttgagt ttgccataaa ttatatgtta gttatatgtt agttatactt gagactgaca
9721 cattgtaata taatctaaga ataaaagtta taaaaataa aaaaaaaaaa a

```

Figure 31 Cont.



Figure 32a

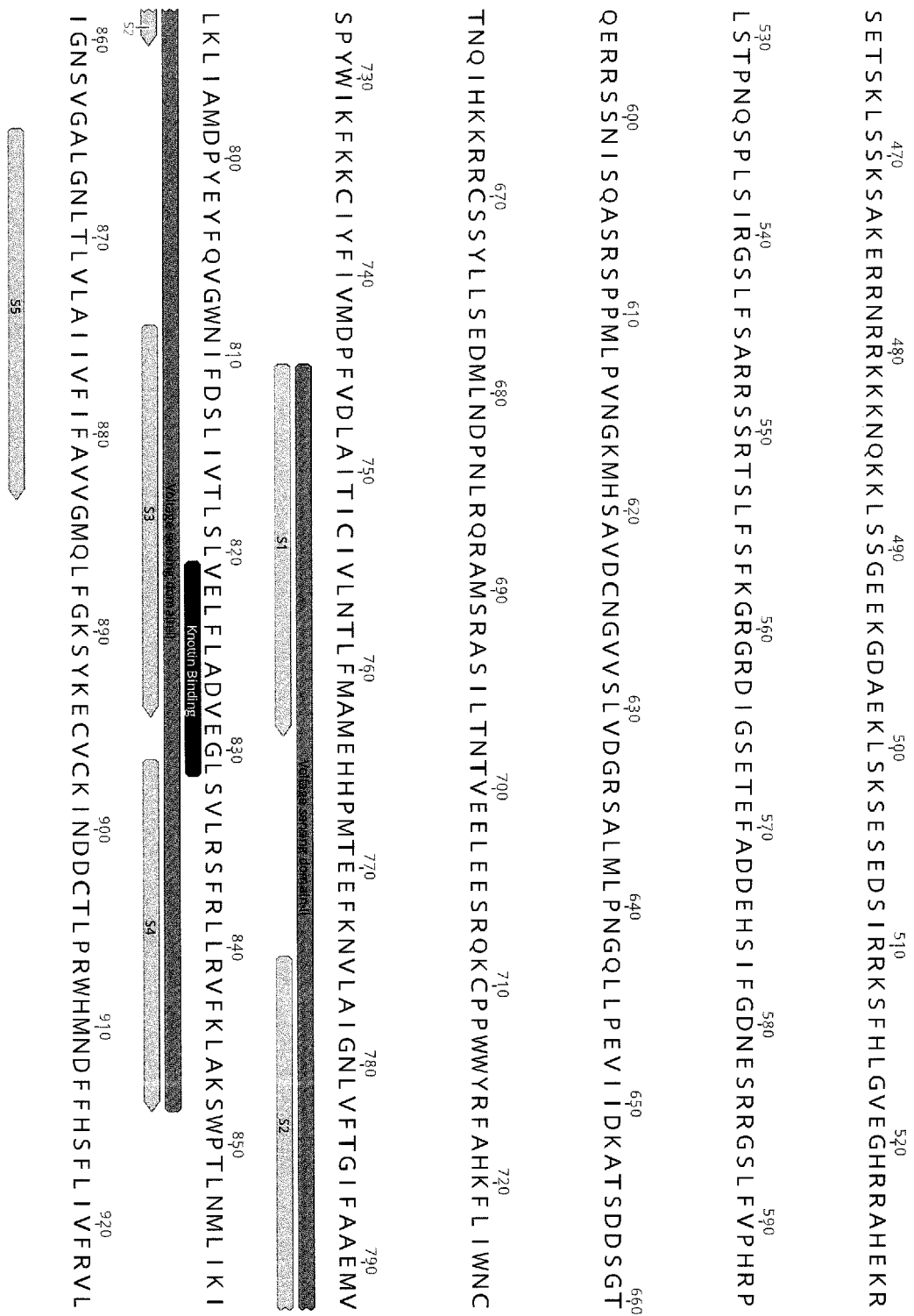


Figure 32b



Figure 32c



Figure 32d

1,850 1,860 1,870 1,880 1,890 1,900 1,910
VLGESGEMDSLRSQMEERFMSANPSKVSYPEITTTLLKRKQEDVSATVIQRAYRRYRLRQNVKNIS
1,920 1,930 1,940 1,950 1,960 1,970 1,980
IYIKDGD RDDL LNKKDMAFDNVNENSSPEKTDATSS TSPSPSYDSVTKPDKEKYEQDRTEKEDKG
1,988
KDSKESKK

Figure 32e

(A)

Nav1.7 DII S3-S4	E L F L A D V E G L
Nav1.1 DII S3-S4	· · G · · N · · · ·
Nav1.2 DII S3-S4	· · G · · N · · · ·
Nav1.3 DII S3-S4	· · G · S N · · · ·
Nav1.6 DII S3-S4	· · S · · · · · · ·

(B)

Nav1.7 DII S1-S2	E H H P M T E E F K N V
Nav1.1 DII S1-S2	· · Y · · · D H · N · ·
Nav1.2 DII S1-S2	· · Y · · · · Q · S S ·
Nav1.3 DII S1-S2	· · Y · · · · Q · S S ·
Nav1.6 DII S1-S2	· · · · · P Q · E H ·

Figure 33

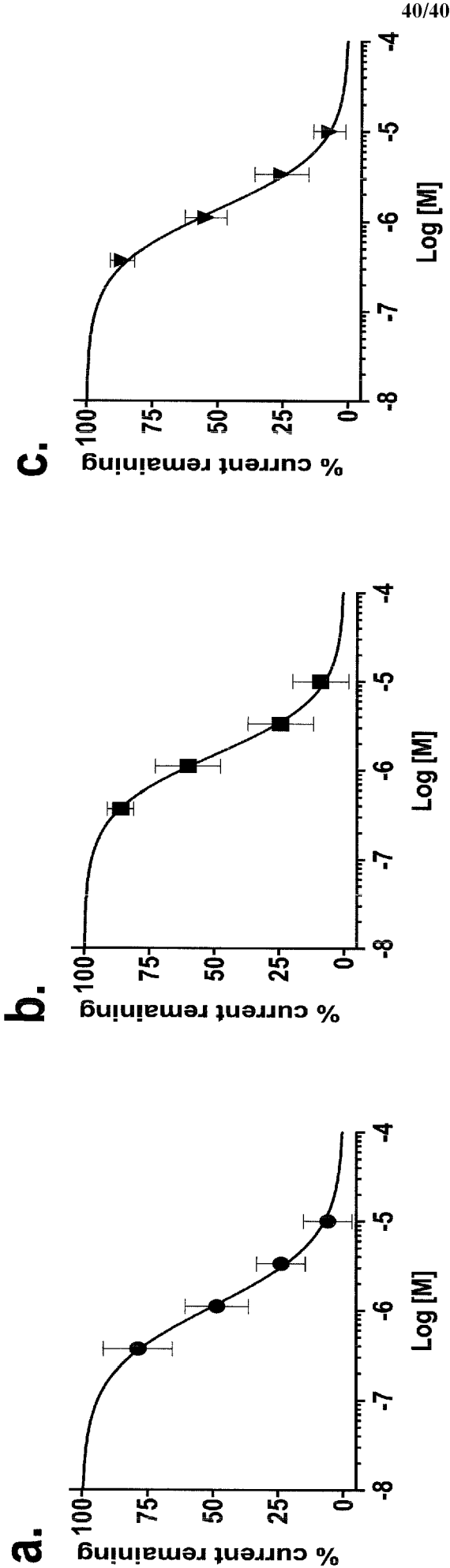


Figure 34

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/068855

A. CLASSIFICATION OF SUBJECT MATTER
INV. C07K16/28 A61K39/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C07K A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, BIOSIS, EMBASE, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Mccafferty: "Scaffolds within scaffolds: Generating ion channel blocking antibodies by fusing knottin to peripheral CDR loops", May 2015 (2015-05), XP055510774, Retrieved from the Internet: URL: http://sophion.com/wp-content/uploads/2017/05/PEGS2017_KB-poster_final.pdf [retrieved on 2018-09-27] figure all; example all ----- -/-	2,7,8, 14-18, 24-31



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

29 November 2018

Date of mailing of the international search report

18/12/2018

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Fellows, Edward

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2018/068855

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Karatt-Vellatt et al.: "Scaffolds within scaffolds: generating ion channel blocking antibodies by fusing knottin to peripheral CDR loops", sophion.com 5 April 2017 (2017-04-05), XP002785172, Retrieved from the Internet: URL: http://sophion.com/wp-content/uploads/2017/05/PEGS2017_KB-poster_final.pdf [retrieved on 2018-09-27] 2nd search result	1-54
X	Aneesh Karatt Vellatt: "KnotBodiesTM: creating ion channel blocking antibodies by fusing Knottins into peripheral CDR loops", 1 March 2017 (2017-03-01), XP055510794, Retrieved from the Internet: URL: http://www.aurorabiomed.com/wp-content/uploads/2015/03/Aneesh-Karatt-Vellatt.pdf [retrieved on 2018-09-27]	1,3-6, 9-13, 19-23, 32-54
Y	figure all; example all	2,7,8, 14-18, 24-31
A	WO 2015/166272 A2 (IONTAS LTD [GB]) 5 November 2015 (2015-11-05) figure all; example all; table all	1-54

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2018/068855

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2015166272 A2	05-11-2015	AU 2015255013 A1	17-11-2016
		BR 112016025352 A2	17-10-2017
		CA 2947513 A1	05-11-2015
		CN 106574264 A	19-04-2017
		EA 201691990 A1	31-05-2017
		EP 3137602 A2	08-03-2017
		JP 2017518362 A	06-07-2017
		SG 11201609123R A	29-11-2016
		US 2017073664 A1	16-03-2017
		WO 2015166272 A2	05-11-2015
