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(54) **Title**: VECTOR FOR LIVER-DIRECTED GENE THERAPY OF HEMOPHILIA AND METHODS AND USE THEREOF

(57) **Abstract**: The present invention relates to vectors containing liver-specific regulatory sequences and codon-optimized factor IX or factor VIII genes, methods employing these vectors and uses of these vectors. Expression cassettes and vectors containing these liver-specific regulatory elements and codon-optimized factor IX or factor VIII genes are also disclosed. The present invention is particularly useful for applications using gene therapy, in particular for the treatment of hemophilia A and B.

VECTORS FOR LIVER-DIRECTED GENE THERAPY OF HEMOPHILIA AND METHODS AND USE THEREOF

FIELD OF THE INVENTION

The invention relates to expression vectors for gene therapy with improved liver-specific expression capabilities, particularly for use as a gene therapy means for the treatment of hemophilia, more particularly for restoring coagulation factor IX (FIX) and/or coagulation factor VIII (FVIII) in liver-directed gene therapy of respectively, hemophilia B and hemophilia A.

BACKGROUND OF THE INVENTION

Hemophilia B is an X-linked, recessive bleeding disorder caused by deficiency of clotting factor IX (FIX). The clinical presentation for hemophilia B is characterized by episodes of spontaneous and prolonged bleeding. There are an estimated 1 in 20,000 individuals who suffer from hemophilia B. Currently, hemophilia B is treated with protein replacement therapy using either plasma-derived or recombinant FIX. Although FIX protein replacement markedly improved the life expectancy of patients suffering from hemophilia, they are still at risk for severe bleeding episodes and chronic joint damage, since prophylactic treatment is restricted by the short half-life, the limited availability and the high cost of purified FIX, which can approach 100.000$/patient/year. In addition, the use of plasma-derived factors obtained from contaminated blood sources increases the risk of viral transmission. Gene therapy offers the promise of a new method of treating hemophilia B, since the therapeutic window is relatively broad and levels slightly above 1% of normal physiologic levels are therapeutic. If successful, gene therapy could provide constant FIX synthesis which may lead to a cure for this disease. The different modalities for gene therapy of hemophilia have been extensively reviewed (Chuah et al., 2012a, 2012b, 2012c; VandenDriessche et al., 2012; High 2001, 2011; Matrai et al., 2010a, 2010b).

Hemophilia A is a serious bleeding disorder caused by a deficiency in, or complete absence of, the blood coagulation factor VIII (FVIII). The severity of hemophilia A and hemophilia B has been classified by the subcommittee on Factor VIII and Factor IX of the Scientific and Standardization Committee of the International Society on Thrombosis and Haemostasis into three forms, depending on respectively, the FVIII level and the FIX level: 1) severe form (FVIII or FIX level less than 0.01 international units (IU)/ml, i.e. less than 1% of normal FVIII or FIX level), 2) moderate form (FVIII or FIX level from 0.01 to 0.05

IU/ml, i.e. from 1 to 5% of normal FVIII or FIX level), and 3) mild from (FVIII or FIX level higher than 0.05 to 0.4 IU/ml, i.e. higher than 5 to 40% of normal FVIII or FIX level). Hemophilia A is the most common hereditary coagulation disorder with an incidence approaching approximately 1 in 5000 males.

Protein substitution therapy (PST) with purified or recombinant FVIII has significantly improved the patients' quality of life. However, PST is not curative and patients are still at risk of developing potentially life-threatening hemorrhages and crippling joint inflammation. Unfortunately, many patients suffering from hemophilia A (up to 40%) develop neutralizing antibodies to FVIII (i.e. "inhibitors") following PST. These inhibitors complicate the management of bleeding episodes and can render further PST ineffective. These limitations of PST, justify the development of gene therapy as a potential alternative for hemophilia treatment. Furthermore, only a modest increase in FVIII plasma concentration is needed for therapeutic benefit, with levels of more than 1% of normal levels able to achieve markedly reduced rates of spontaneous bleeding and long-term arthropathy.

The liver is the main physiological site of FIX and FVIII synthesis and hence, hepatocytes are well suited target cells for hemophilia gene therapy. From this location, FIX protein can easily enter into the circulation. Moreover, the hepatic niche may favor the induction of immune tolerance towards the transgene product (Annoni et al., 2007; Follenzi et al., 2004; Brown et al., 2007; Herzog et al., 1999; Matrai et al., 2011; Matsui et al., 2009). Liver-directed gene therapy for hemophilia can be accomplished with different viral vectors including retroviral (Axelrod et al., 1990; Kay et al., 1992; VandenDriessche et al., 1999, Xu et al., 2003, 2005), lentiviral (Ward et al., 2011, Brown et al., 2007, Matrai et al., 2011), adeno-associated viral (AAV) (Herzog et al., 1999) and adenoviral vectors (Brown et al., 2004)(Ehrhardt & Kay, 2002). In particular, AAV is a naturally occurring replication defective non-pathogenic virus with a single stranded DNA genome. AAV vectors have a favorable safety profile and are capable of achieving persistent transgene expression. Long-term expression is predominantly mediated by episomally retained AAV genomes. More than 90% of the stably transduced vector genomes are extra-chromosomal, mostly organized as high-molecular-weight concatamers. Therefore, the risk of insertional oncogenesis is minimal, especially in the context of hemophilia gene therapy where no selective expansion of transduced cells is expected to occur. Nevertheless, oncogenic events have been reported following AAV-based gene transfer (Donsante et al., 2007) but it has been difficult to reproduce these findings in other model systems (Li et al., 2011). The major limitation of AAV vectors is the limited packaging capacity of the vector particles (i.e. approximately 4.7 kb), constraining the size of the transgene expression

cassette to obtain functional vectors (Jiang et al., 2006). Several immunologically distinct AAV serotypes have been isolated from human and non-human primates (Gao et al., 2002, Gao et al. 2004), although most vectors for hemophilia gene therapy were initially derived from the most prevalent AAV serotype 2. The first clinical success of AAV-based gene therapy for congenital blindness underscores the potential of this gene transfer technology (Bainbridge et al., 2008).

AAV-mediated hepatic gene transfer is an attractive alternative for gene therapy of hemophilia for both liver and muscle-directed gene therapy (Herzog et al., 1997, 1999, 2002; Arruda et al., 2010; Fields et al., 2001; Buchlis et al., 2012; Jiang et al., 2006; Kay et al., 2000). Preclinical studies with the AAV vectors in murine and canine models of hemophilia or non-human primates have demonstrated persistent therapeutic expression, leading to partial or complete correction of the bleeding phenotype in the hemophilic models (Snyder et al., 1997, 1999; Wang et al., 1999, 2000; Mount et al., 2002; Nathwani et al., 2002). Particularly, hepatic transduction conveniently induces immune tolerance to FIX that required induction of regulatory T cells (Tregs) (Mingozzi et al., 2003; Dobrzynski et al., 2006). Long-term correction of the hemophilia phenotype without inhibitor development was achieved in inhibitor-prone null mutation hemophilia B dogs treated with liver-directed AAV2-FIX gene therapy (Mount et al, 2002). In order to further reduce the vector dose, more potent FIX expression cassettes have been developed. This could be accomplished by using stronger promoter/enhancer elements, codon-optimized FIX or self-complementary, double-stranded AAV vectors (scAAV) that overcome one of the limiting steps in AAV transduction (i.e. single-stranded to double-stranded AAV conversion) (McCarty, 2001, 2003; Nathwani et al, 2002, 2006, 2011; Wu et al., 2008). Alternative AAV serotypes could be used (e.g. AAV8 or AAV5) that result in increased transduction into hepatocytes, improve intra-nuclear vector import and reduce the risk of T cell activation (Gao et al., 2002; Vandenberghe et al., 2006). Liver-directed gene therapy for hemophilia B with AAV8 or AAV9 is more efficient than when lentiviral vectors are used, at least in mice, and resulted in less inflammation (VandenDriessche et al., 2007, 2002). Furthermore, recent studies indicate that mutations of the surface-exposed tyrosine residues allow the vector particles to evade phosphorylation and subsequent ubiquitination and, thus, prevent proteasome-mediated degradation, which resulted in a 10-fold increase in hepatic expression of FIX in mice (Zhong et al., 2008).

These liver-directed preclinical studies paved the way toward the use of AAV vectors for clinical gene therapy in patients suffering from severe hemophilia B. Hepatic delivery of AAV-FIX vectors resulted in transient therapeutic FIX levels (maximum 12% of normal

levels) in subjects receiving AAV-FIX by hepatic artery catheterization (Kay et al., 2000). However, the transduced hepatocytes were able to present AAV capsid-derived antigens in association with MHC class I to T cells (Manno et al., 2006, Mingozzi et al., 2007). Although antigen presentation was modest, it was sufficient to flag the transduced hepatocytes for T cell-mediated destruction. Recently, gene therapy for hemophilia made an important step forward (Nathwani et al., 2011; Commentary by VandenDriessche & Chuah, 2012). Subjects suffering from severe hemophilia B (<1% FIX) were injected intravenously with self-complementary (sc) AAV8 vectors expressing codon-optimized FIX from a liver-specific promoter. This AAV8 serotype exhibits reduced cross-reactivity with pre-existing anti-AAV2 antibodies. Interestingly, its uptake by dendritic cells may be reduced compared to conventional AAV2 vectors, resulting in reduced T cell activation (Vandenberghe et al., 2006). In mice, AAV8 allows for a substantial increase in hepatic transduction compared to AAV2, though this advantage may be lost in higher species, like dog, rhesus monkeys and man. Subjects received escalating doses of the scAAV8-FIX vector, with two participants per dose. All of the treated subjects expressed FIX above the therapeutic 1% threshold for several months after vector administration, yielding sustained variable expression levels (i.e. 2 to 11% of normal levels). The main difference with the previous liver-directed AAV trial is that for the first time sustained therapeutic FIX levels could be achieved after gene therapy. Despite this progress, T-cell mediated clearance of AAV-transduced hepatocytes remains a concern consistent with elevated liver enzyme levels in some of the patients. Transient immune suppression using a short course of glucocorticoids was used in an attempt to limit this vector-specific immune response.

One of the significant limitations in the generation of efficient viral gene delivery systems for the treatment of hemophilia A by gene therapy is the large size of the FVIII cDNA. Previous viral vector-based gene therapy studies for hemophilia A typically relied on the use of small but weak promoters, required excessively high vector doses that were not clinically relevant or resulted in severely compromised vector titers. Several other *ad hoc* strategies were explored, such as the use of split or dual vector design to overcome the packaging constraints of AAV, but these approaches were overall relatively inefficient and raised additional immunogenicity concerns (reviewed in Petrus et al., 2010). It has been found that the FVIII B domain is dispensable for procoagulant activity. Consequently, FVIII constructs in which the B domain is deleted are used for gene transfer purposes since their smaller size is more easily incorporated into vectors. Furthermore, it has been shown that deletion of the B domain leads to a 17-fold increase in mRNA and primary translation product. FVIII wherein the B domain is deleted and replaced by a short 14-amino acid

linker is currently produced as a recombinant product and marketed as Refacto® for clinical use (Wyeth Pharma) (Sandberg et al., 2001). Miao et al. (2004) added back a short B domain sequence to a B domain deleted FVIII, optimally 226 amino acids and retaining 6 sites for N-linked glycosylation, to improve secretion. McIntosh et al. (2013) replaced the 226 amino-acid spacer of Miao et al. with a 17 amino-acid peptide in which six glycosylation triplets from the B-domain were juxtaposed. Yet, production was still not sufficient for therapeutic purposes.

Non-viral vectors typically rely on a plasmid-based gene delivery system, where only the naked DNA is delivered, potentially in conjunction with physicochemical methods that facilitate transfection. Consequently, the non-viral approach maybe less immunogenic and potentially safer than viral vectors, though innate immune response may still occur. The non-viral gene transfer method is simple, but the efficiency is generally low compared to most viral vector-mediated gene transfer approaches. Efficient in vivo gene delivery of non-viral vectors remains a bottleneck. Typically, for hepatic gene delivery, plasmids are administered by hydrodynamic injection. In this case, a hydrodynamic pressure is generated by rapid injection of a large volume of DNA solution into the circulation, in order to deliver the gene of interest in the liver (Miao et al., 2000). Efforts are being made to adapt hydrodynamic injection towards a clinically relevant modality by reducing the volume of injection along with maintaining localized hydrodynamic pressure for gene transfer. Alternative approaches based on targetable nanoparticles are being explored to achieve target specific delivery of FIX into hepatocytes. Expression could be prolonged by removing bacterial backbone sequences which interfere with long term expression (i.e. mini-circle DNA) Finally, to increase the stability of FIX expression after non-viral transfection, transposons could be used that result in stable genomic transgene integration. We and others have shown that transposons could be used to obtain stable clotting factor expression following in vivo gene therapy (Yant et al., 2000; Mates, Chuah et al., 2009, VandenDriessche et al., 2009; Kren et al.,2009; Ohlfest et al., 2004).

An exemplary state of the art vector for liver-specific expression of FIX is described in WO2009/130208 and is composed of a single-stranded AAV vector that contains the TTR/Serp regulatory sequences driving a factor cDNA. A FIX first intron was included in the vector, together with a poly-adenylation signal. Using said improved vector yielded about 25-30% stable circulating factor IX.

In order to translate viral-vector based gene therapy for hemophilia to the clinic, the safety concerns associated with administering large vector doses to the liver and the need for manufacturing large amounts of clinical-grade vector must be addressed. Increasing the

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potency (efficacy per dose) of gene transfer vectors is crucial towards achieving these goals. It would allow using lower doses to obtain therapeutic benefit, thus reducing potential toxicities and immune activation associated with in vivo administration, and easing manufacturing needs.

One way to increase potency is to engineer the transgene sequence itself to maximize expression and biological activity per vector copy. We have shown that FIX transgenes optimized for codon usage and carrying an R338L amino acid substitution associated with clotting hyperactivity and thrombophilia (Simioni et al., 2009), increase the efficacy of gene therapy using lentiviral vector up to 15-fold in hemophilia B mice, without detectable adverse effects, substantially reducing the dose requirement for reaching therapeutic efficacy and thus facilitating future scale up and its clinical translation (Cantore et al., 2012).

Also codon optimization of human factor VIII cDNAs leads to high-level expression. Significantly greater levels (up to a 44-fold increase and in excess of 200% normal human levels) of active FVIII protein were detected in the plasma of neonatal hemophilia A mice transduced with lentiviral vector expressing FVIII from a codon-optimized cDNA sequence, thereby successfully correcting the disease model (Ward et al., 2011).

It is an object of the present invention to increase the efficiency and safety of liver-directed gene therapy for hemophilia A and B.

In the claims which follow and in the description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

SUMMARY OF THE INVENTION

It is an object of the present invention to increase the efficiency and safety of liver-directed gene therapy for hemophilia B. The above objective is accomplished by providing a vector, either a viral vector, in particular an AAV-based vector, or a non-viral vector, in particular a transposon-based vector, comprising a nucleic acid expression cassette with

specific regulatory elements that enhance liver-directed gene expression, while retaining tissue specificity, in conjunction with the use of a human FIX gene containing a hyper-activating mutation and/or a codon-optimized transgene.

The resulting vector and nucleic acid expression cassette results in unexpectedly high expression levels of FIX in the liver, due to its unique combination of regulatory elements and the choice of vector type and transgene. The combined effect of these elements could not have been predicted. In WO2009/130208 for example, the given AAV-based vector yielded about 25-30% stable circulating factor IX. In the current application the new vector obtained 500-600% of stable circulating factor IX levels. This represents a more than 20-

fold increase in FIX levels due to the unique combination of elements of the nucleic acid expression cassette and vector of the present invention. In particular, the inventors demonstrated in Example 7 that specific combinations of the Serpin enhancer (called "Serp" or "SerpEnh" herein) with codon-optimized hFIX transgene or the Serpin enhancer with transgene encoding hFIX containing the Padua mutation provide for synergistic effects on FIX activity. The highest hFIX activity was measured in mice hydrodynamically injected with a plasmid comprising the unique combination of the Serpin enhancer with a codon-optimized transgene encoding hFIX containing the Padua mutation. hFIX activity in these mice was up to 265-fold higher as compared to hFIX acitivity in mice injected with a corresponding hFIX plasmid without the Serpin enhancer, the codon-optimization and the Padua mutation. This increase in hFIX activity was shown to be synergistic.

It is another object of the present invention to increase the efficiency and safety of liver-directed gene therapy for hemophilia A. As shown in the experimental section, this objective is accomplished by providing a vector either a viral vector, in particular an AAV-based vector, or a non-viral vector, in particular a transposon-based vector, comprising a nucleic acid expression cassette with specific regulatory elements that enhance liver-directed gene expression, while retaining tissue specificity, in particular the Serpin enhancer, in conjunction with the use of a codon-optimized human FVIII construct, in particular a codon-optimized B domain deleted FVIII construct.

The resulting AAV-based vector and nucleic acid expression cassette resulted in unprecedented, supra-physiologic FVIII expression levels (i.e. more than 200% of normal level) using relatively low vector doses ($5x10^9$ vg/mouse). This constitutes a robust 50-fold improvement in FVIII expression levels, when compared to AAV vectors that expressed a codon-optimized B domain deleted FVIII cDNA from a truncated liver-specific promoter (McInthosh et al. 2013). This represents a significant improvement over the latest generation AAV-FVIII vectors and an important step towards clinical translation. The inventors demonstrated in Example 6 that the specific combination of the Serpin enhancer with the codon-optimized B domain deleted FVIII transgene provides for a synergistic effect on FVIII expression levels compared to expression cassettes containing either the Serpin enhancer or the codon-optimized B domain deleted FVIII transgene.

The inventors further demonstrated in Example 5 that the inclusion of the MVM intron into the nucleic acid expression cassettes disclosed herein provides for unexpectedly increased expression of the transgene operably linked thereto.

The invention therefore provides the following aspects:

Aspect 1. A vector comprising a nucleic acid expression cassette comprising a liver-specific regulatory element, a promoter, optionally a minute virus of mouse (MVM) intron, a transgene, preferably a codon-optimized transgene, and a transcriptional termination signal.

Aspect 2. The vector according to aspect 1, wherein said transgene encodes for factor VIII or factor IX.

Aspect 3. The vector according to aspect 2, wherein said coagulation factor VIII has a deletion of the B domain.

Aspect 4. The vector according to aspect 3, wherein said B domain of said FVIII is replaced by a linker having SEQ ID NO:16.

Aspect 5. The vector according to aspect 2, wherein said coagulation factor IX contains a hyper-activating mutation.

Aspect 6. The vector according to aspect 5, wherein said hyper-activating mutation in coagulation factor IX corresponds to an R338L amino acid substitution.

Aspect 7. The vector according to any one of aspects 2 to 6, wherein said transgene encoding for coagulation factor VIII or IX is codon-optimized.

Aspect 8. The vector according to any one of aspects 1 to 4, or 7, wherein said transgene encoding for coagulation factor VIII has SEQ ID NO:7.

Aspect 9. The vector according to any one of aspects 1 to 8, wherein said liver-specific regulatory element contains sequences from the serpin promoter.

Aspect 10. The vector according to any one of aspects 1 to 9, wherein said liver-specific regulatory element comprises or consists of SEQ ID NO:8, or a sequence having 95% identity to said sequence, preferably wherein said liver-specific regulatory element is the Serpin enhancer.

Aspect 11. The vector according to any one of aspects 1 to 10, wherein said promoter is derived from the transthyretin (TTR) promoter, preferably the minimal TTR promotor.

Aspect 12. The vector according to any one of aspects 1 to 11, wherein said transcriptional termination signal is derived from the bovine growth hormone polyadenylation signal or from the Simian virus 40 polyadenylation signal.

Aspect 13. The vector according to any one of aspects 1 to 12, wherein said vector is a viral vector.

Aspect 14. The vector according to aspect 13, wherein said vector is derived from an adeno-associated virus (AAV), preferably AAV serotype 9.

Aspect 15. The vector according to aspect 14, wherein said vector is a single-stranded AAV, preferably single-stranded AAV serotype 9.

Aspect 16. The vector according to any one of aspects 1 to 4, 7 to 15, having SEQ ID NO: 6, or the vector according to any one of aspects 1, 2, 5 to 7, 9 to 15, or 17, having SEQ ID NO: 1 or 2.

Aspect 17. The vector according to aspect 14, wherein said vector is a self-complementary AAV, preferably self-complementary AAV serotype 9.

Aspect 18. The vector according to any one of claims 1 to 12, wherein said vector is a non-viral vector.

Aspect 19. The vector according to aspect 18, wherein said vector is a transposon-based vector.

Aspect 20. The vector according to aspect 19, wherein said vector is a PiggyBac(PB)-based vector, such as the PB-based vector having SEQ ID NO:13, preferably a PiggyBac-based vector comprising micro inverted repeats, more preferably the PB-based vector having SEQ ID NO: 14 or 15, or a Sleeping Beauty(SB)-based vector, preferably the SB-based vector having SEQ ID NO:16.

Aspect 21. A method to obtain levels of factor VIII in plasma equal to or higher than the therapeutic threshold concentration of 10 mU/ml plasma in a subject, comprising the transduction or transfection of the vector according to any one of claims 1 to 4, 7 to 20 into a subject.

Aspect 22. The method according to aspect 21, wherein the transduction of the vector according to any one of claims 1 to 4, 7 to 17 into the subject is done at a dose lower than $2.5x10^{11}$ vg/kg.

Aspect 23. A method to obtain levels of factor IX in plasma equal to or higher than the therapeutic threshold concentration of 10mU/ml plasma in a subject, comprising the transduction or transfection of the vector according to any one of aspects 1, 2, 5 to 15, 17 to 20 into a subject.

Aspect 24. The method according to aspect 23, wherein the transduction of the vector according to any one of aspects 1, 2, 5 to 15, 17 into the subject is done at a dose lower than $2x10^{11}$ vg/kg.

Aspect 24. The method according to aspect 23, used to obtain levels of factor IX in plasma equal to or higher than the therapeutic concentration of 100 mU/ml in a subject, wherein the transduction of the vector according to any one of aspects 1, 2, 5 to 15, 17 into the subject is done at a dose lower than or equal than $6x10^{11}$ vg/kg.

Aspect 25. The method according to aspect 23, used to obtain levels of factor IX in plasma equal to or higher than the therapeutic concentration of 50 mU/ml in a subject, wherein the transduction of the vector according to any one of aspects 1, 2, 5 to 15, 17 into the subject is done at a dose lower than or equal than $6x10^{11}$ vg/kg.

Aspect 26. The method according to aspect 23, used to obtain levels of factor IX in plasma equal to or higher than the therapeutic concentration of 200 mU/ml in a subject, wherein the transduction of the vector according to any one of aspects 1, 2, 5 to 15, 17 into the subject is done at a dose lower than or equal than $2x10^{12}$ vg/kg.

Aspect 27. The method according to aspect 23, used to obtain levels of factor IX in plasma equal to or higher than the therapeutic concentration of 150 mU/ml in a subject, wherein the transduction of the vector according to any one of claims 1, 2, 5 to 15, 17 into the subject is done at a dose lower than or equal than $2x10^{12}$ vg/kg.

Aspect 28. The method according to any one of aspects 21 to 27, wherein said transduction or transfection is by intravenous administration.

Aspect 29. The method according to any one of aspects 21 or 23, wherein said transfection is by hydrodynamic transfection.

Aspect 30. The method according to any one of aspects 21, 23, 28 or 29, wherein a vector according to any one of aspects 19 or 20 is administered in combination with a vector encoding a transposase, preferably a hyperactive transposase.

Aspect 31. The method according to any one of aspects 21 to 30, wherein said subject is a mammalian subject, preferably a human subject.

Aspect 32. A method for treating hemophilia A in a mammalian subject, comprising performing the method according to any one of aspects 21, 22, 28 to 31.

Aspect 33. The use of the vector according to any one of aspects 1 to 4, 7 to 20 for the manufacture of a medicament to treat hemophilia A.

Aspect 34. The vector according to any one of aspects 1 to 4, 7 to 20 for use in the treatment of hemophilia A.

Aspect 35. A method for treating hemophilia B in a mammalian subject, comprising performing the method according to any one of aspects 23 to 31.

Aspect 36. The use of the vector according to any one of aspects 1, 2, 5 to 15, 17 to 20 for the manufacture of a medicament to treat hemophilia B.

Aspect 37. The vector according to any one of aspects 1, 2, 5 to 15, 17 to 20 for use in the treatment of hemophilia B.

Aspect 38. A pharmaceutical composition comprising a vector according to any one of aspects 1 to 4, 7 to 20 and a pharmaceutically acceptable carrier, optionally further comprising an active ingredient for treating hemophilia A.

Aspect 39. The pharmaceutical composition according to aspect 38 for use in treating hemophilia A.

Aspect 40. The pharmaceutical composition for use according to aspect 39, or the vector for use according to aspect 34, wherein said treatment results in levels of factor VIII in plasma of the treated subject that are equal to or higher than the therapeutic threshold concentration of 10 mU/ml plasma in a subject.

Aspect 41. The pharmaceutical composition for use according to any one of aspects 39 or 40, or the vector for use according to any one of aspects 34 or 40, wherein said treatment comprises the transduction of the vector according to any one of claims 1 to 4, 7 to 17 into the subject at a dose lower than or equal than $2.5x10^{11}$ vg/kg.

Aspect 42. A pharmaceutical composition comprising a vector according to any one of aspects 1, 2, 5 to 15, 17 to 20 and a pharmaceutically acceptable carrier, optionally further comprising an active ingredient for treating hemophilia B.

Aspect 43. The pharmaceutical composition according to aspect 42, for use in treating hemophilia B.

Aspect 44. The pharmaceutical composition for use according to aspect 43, or the vector for use according to aspect 37, wherein said treatment results in levels of factor IX in plasma of the treated subject that are equal to or higher than the therapeutic threshold concentration of 10 mU/ml plasma in a subject, preferably equal to or higher than the therapeutic concentration of 50 mU/ml plasma in a subject, more preferably equal to or higher than the therapeutic concentration of 100 mU/ml plasma in a subject, even more preferably equal to or higher than the therapeutic concentration of 150 mU/ml plasma in a subject and even more preferably equal to or higher than the therapeutic concentration of 200 mU/ml plasma in a subject.

Aspect 45. The pharmaceutical composition for use according to aspect 43 or 44, or the vector for use according to aspect 37 or 44, wherein said treatment comprises the transduction of the vector according to any one of aspects 1, 2, 5 to 15, 17 to 20 into the subject at a dose lower than or equal than $2x10^{12}$ vg/kg, preferably at a dose lower than or equal than $6x10^{11}$ vg/kg, more preferably at a dose lower than or equal than $2x10^{11}$vg/kg.

BRIEF DESCRIPTION OF THE FIGURES

The present invention is illustrated by the following figures which are to be considered for illustrative purposes only and in no way limit the invention to the embodiments disclosed therein:

Figure 1 A) shows a schematic diagram of the AAV9-SerpEnh-TTRm-MVM-co-hFIX construct (pdsAAVsc SerpTTRmMVMF9coptpA) with indication where the liver-specific Serpin regulatory element ("Serp" or "SerpEnh") is inserted upstream of the transthyretin minimal promoter (TTRm). Abbreviations used are: ITR: viral inverted terminal repeat; mTTR: minimal transthyretin promoter; MVM: minute virus mouse; huFIXcoptMT: codon-optimized FIX; bGHpA: polyadenylation signal of bovine growth hormone; **B)** shows the sequence of the AAV9-SerpEnh-TTRm-MVM-co-hFIX construct (SEQ ID No. 1) and **C)** shows the sequence of the AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L construct (SEQ ID No. 2).

Figure 2 shows FIX activity after intravenous injection of AAV9-SerpEnh-TTRm-MVM-co-hFIX construct (pdsAAVsc SerpTTRmMVMF9coptpA) or AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L construct in FIX-deficient hemophilia B mice. AAV vectors expressing either the human codon-optimized FIX cDNA were designated as AAV-co-hFIX or the human codon-optimized FIX-R338L cDNA as AAV-co-padua-hFIX. hFIX activity levels were determined using a chromogenic activity assay on citrated plasma. Mice were injected with different vectors dose of the cognate self-complementary AAV9 vectors (10^9 vg, $5x10^9$ vg, $2x10^{10}$ vg).

Figure 3 A) shows a schematic representation of the AAV9sc-SerpEnh-TTRm-MVM-co-hFIX-R338L vector. The expression cassette was packaged in a self-complimentary (sc) adeno-associated virus serotype 9 (AAV9), flanked by the 5' and 3' AAV inverted terminal repeats (ITR). The liver-specific minimal transthyretin (TTRm) promoter drives the codon-optimized human FIX with R338L mutation (co-hFIX-R338L) transgene. The hepatocyte-

specific regulatory elements ("Serp" or "SerpEnh") are located upstream of the TTRm promoter. The minute virus of mouse mini-intron (MVM) intron and bovine growth hormone polyadenylation site (pA) are also indicated. **B)** shows a schematic representation of a control vector AAV9-SerpEnh-TTRm-MVM-co-hFIX, which is identical to the AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L vector, but the transgene, codon-optimized hFIX, does not contain the R338L mutation. **C)** compares the R338L or Padua mutation in human FIX fragment (SEQ ID NO:23), making hFIX hyper-functional, with human FIX fragment (SEQ ID NO:24).

Figure 4. Evaluation of codon-optimized and hyper-functional FIX transgenes by AAV9 delivery in hemophilic mice. Mice were intravenously administered $1x10^9$ vg/mouse (A,B), $5x10^9$ vg/mouse (C,D) or $2x10^{10}$vg/mouse (E,F) of AAV9sc-SerpEnh-TTRm-MVM-co-hFIX-R338L (indicated as cohFIX-R338L) or AAV9sc-SerpEnh-TTRm-MVM-co-hFIX- (indicated as cohFIX) vector. hFIX activity **(A, C, E)** and hFIX protein **(B, D, F)** were measured by clotting activity using chromogenic FIX activity assays (n = 3) and by ELISA (n = 3), respectively, on plasma samples collected at the indicated times after AAV administration. **(G, H, I)** Hemophilic mice were intravenously administered $1x10^9$ vg/mouse (G), $5x10^9$ vg/mouse (H) or $2x10^{10}$vg/mouse (I) of AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L (n = 3). For each dose, hFIX expression (hFIX protein) was compared to the corresponding FIX clotting activity. **(J)** D-dimer levels and hFIX activity were determined in mice injected with AAV9sc-SerpEnh-TTRm-MVM-co-hFIX-R338L (indicated as AAV cohFIX R338L) or AAV9sc-SerpEnh-TTRm-MVM-co-hFIX (indicated as AAV cohFIX) vector at the indicated doses and compared to non-injected control mice. D-dimer levels were determined by ELISA and hFIX activity was analyzed by chromogenic assay. The D-dimer positive control is shown. Results are presented as mean±SEM. *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$ (t- test). **(K)** Analysis of immune tolerance induction in hemophilia B mice injected with $5x10^9$ vg/mouse of AAV9sc-SerpEnh-TTRm-MVM-co-hFIX-R338L (indicated as cohFIX-R338L, n=4). FIX-specific antibodies were measured by ELISA at week 2 (w2), w4, w6 and w8 after immunization with hFIX protein, as indicated. The immunizations were initiated 2 weeks after vector administration. Immunized PBS-injected hemophilia B mice (n=4) were used as control.

Figure 5. Biodistribution and transduction efficiency in different organs of mice injected with AAV9sc-SerpEnh-TTRm-MVM-co-hFIX-R338L (indicated as cohFIX-R338L, n = 3) or AAV9sc-SerpEnh-TTRm-MVM-co-hFIX (indicated as cohFIX, n = 3). **(A, B)** AAV copy number relative to 100 ng of genomic DNA was determined for both constructs at a dose

of $1x10^9$ vg/mouse (A) and $5x10^9$ vg/mouse (B). **(C, D)** Quantitative reverse transcriptase (qRT)-PCR analysis of hFIX mRNA levels in the different organs expressed relative to hFIX mRNA levels in the liver for both constructs at a dose of $1x10^9$ vg/mouse (C) and $5x10^9$ vg/mouse (D). GAPDH was used for normalization. Results are presented as mean±SEM. *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$ (t- test).

Figure 6 A) shows a schematic representation of AAVss-SerpEnh-TTRm-MVM-hFVIIIcopt-sv40pA vector. The expression cassette was packaged in a single-stranded (ss) adeno-associated virus, flanked by the 5' and 3' AAV inverted terminal repeats (ITR). The liver-specific minimal transthyretin (TTRm) promoter regulates transcription of the human codon-optimized B-domain deleted FVIII cDNA (hFVIIIcopt). The Serpin enhancer ("Serp" or "SerpEnh")is cloned upstream of the TTRm promoter. The minute virus of mouse mini-intron (MVM) and SV40 polyadenylation site (pA) are indicated. **B)** shows a schematic of the AAVss-SerpEnh-TTRm-MVM-hFVIIIcopt-sv40pA construct (AAVss-SerpTTRm-MVM-FVIIIcopt-sv40pA) with indication where the liver-specific Serpin enhancer ("Serp" or "SerpEnh") is inserted upstream of the transthyretin minimal promoter (TTRm). Abbreviations used are: ITR: viral inverted terminal repeat; MVM intron: minute virus mouse intron; FVIIIcopt: codon-optimized B domain deleted human FIX; SvpolyA: polyadenylation signal of SV40. **C)** shows the sequence of the AAVss-SerpEnh-TTRm-MVM-hFVIIIcopt -sv40pA construct (SEQ ID NO. 6). The flanking inverted terminal repeat sequences are indicated in italics, the Serpin enhancer ("Serp" or "SerpEnh") in bold (72 bp), the minimal transthyretin promoter (TTRm) is underlined (202 bp), the mTTR/5' untranslated region is boxed (21 bp), the MVM intron is in italics and underlined (92bp), the codon-optimized B domain deleted hFVIII (hFVIIIcopt) underlined and in bold (4377 bp), and the SV40 polyadenylation sequence is in italics and bold and underlined (134 bp). **D)** Nucleotide sequence of codon-optimized B domain deleted FVIII (SEQ ID NO: 7). **E)** Nucleotide sequence of the Serpin enhancer ("Serp" or "SerpEnh") (SEQ ID NO: 8). **F**) Nucleotide sequence of the minimal transthyretin promoter (TTRm) (SEQ ID NO: 9). **G)** Nucleotide sequence of the minute virus mouse (MVM) intron (SEQ ID NO: 10). **H)** Nucleotide sequence of the SV40 polyadenylation signal (SV40polyA) (SEQ ID NO: 11).

Figure 7 shows FVIII expression levels in CB17.SCID mice in function of time (days) following intravenous injection with AAVss-SerpEnh-TTRm-MVM-hFVIIIcopt-sv40pA ($5x10^9$ vg/mouse). FVIII levels were determined using a hFVIII-specific ELISA and are expressed as a percentage of normal levels (i.e. physiological level of human FVIII of 200 ng/ml or 1 IU/ml of FVIII in a normal individual) and in ng/ml plasma.

Figure 8 A) shows a schematic of the plasmid pcDNA3_mouseCO_hyPiggyBac_Transposase_MT encoding codon-optimized hyperactive PiggyBac (PB) transposase. **B)** Nucleotide sequence of the pcDNA3_mouseCO_hyPiggyBac_Transposase_MT plasmid (SEQ ID NO:12). **C)** shows a schematic of the PB_Minimal_T_(T53C-C136T)_D4Z4_TTRminSerpMVM_hFVIIIcopt_SV40pA_D4Z4 transposon. The liver-specific minimal transthyretin (TTRm) promoter is operably linked to the Serpin enhancer ("Serp" or "SerpEnh") to regulate transcription of the human codon-optimized B-domain deleted FVIII cDNA (FVIIIcopt). The minute virus of mouse mini-intron (MVM) and SV40 polyadenylation signal (SV40pA) are indicated. **D)** Nucleotide sequence of the PB_Minimal_T_(T53C-C136T)_D4Z4_TTRminSerpMVM_hFVIIIcopt_SV40pA_D4Z4 transposon (SEQ ID NO:13). **E)** schematically shows the PB_micro_T_No_ins_TTRminSerpMVM_FIXco_bghpA transposon. Codon-optimized human FIX expression is driven from the liver-specific minimal transthyretin (TTRm) promoter operably linked to the Serpin enhancer ("Serp" or "SerpEnh"). The minute virus of mouse mini-intron (MVM) and bovine growth hormone polyadenylation signal (bghpA) are indicated. **F)** Nucleotide sequence of the PB_micro_T_No_ins_TTRminSerpMVM_FIXco_bghpA transposon (SEQ ID NO:14). **G)** schematically shows the PB_micro_T_No_ins_TTRminSerpMVM_FIXco_Padua_bghpA transposon. Codon-optimized human Padua FIX expression is driven from the liver-specific minimal transthyretin (TTRm) promoter operably linked to the Serpin enhancer ("Serp" or "SerpEnh"). The minute virus of mouse mini-intron (MVM) and bovine growth hormone polyadenylation signal (bghpA) are indicated. **H)** Nucleotide sequence of the PB_micro_T_No_ins_TTRminSerpMVM_FIXco_Padua_bghpA transposon (SEQ ID NO:15). **I)** shows the Sleeping Beauty (SB) transposon pT2BH_TTRminSerpMVM_hFIXco_bghpA transposon. Codon-optimized human FIX expression is driven from the liver-specific minimal transthyretin (TTRm) promoter operably linked to the Serpin enhancer ("Serp" or "SerpEnh"). The minute virus of mouse mini-intron (MVM) and bovine growth hormone polyadenylation signal (bghpA) are indicated. **J)** shows a schematic of the plasmid pCDNA3 _CMVBGI _SBMAX_bghpA encoding the hyperactive SBmax transposase. **K)** Nucleotide sequence of the pCDNA3 _CMVBGI _SBMAX_bghpA plasmid (SEQ ID NO:17).

Figure 9. FIX expression levels in hemophilia B mice treated by liver-directed gene therapy using hyperactive PB transposon expressing either codon-optimized FIX or the

hyperactive codon-optimized FIX-R338L mutant. The amount of transposon ($IRpBAc_{micro}$) and transposase plasmid (hypBase) is indicated. Human FIX levels were determined using activity assays.

Figure 10. FVIII expression levels in SCID mice treated by liver-directed gene therapy using hyperactive PB transposon systems: 1 µg pcDNA3_mouseCO_hyPiggyBac_Transposase_MT plasmid (hyPB plasmid) + 5 µg PB_Minimal_T_(T53C-C136T)_D4Z4_TTRminSerpMVM_hFVIIIcopt_SV40pA_D4Z4 transposon **(A)**; or 1 µg hyPB plasmid + 500 ng PB_Minimal_T_(T53C-C136T)_D4Z4_TTRminSerpMVM_hFVIIIcopt_SV40pA_D4Z4 transposon **(B)**. (lines: with hyPB, broken lines: without hyPB control). Physiologic FVIII concentration (100% = 200 ng/ml plasma) is indicated. Human FVIII levels were detected by ELISA.

Figure 11. Comparison of Sleeping Beauty transposon and PiggyBac transposon for codon-optimized hFIX hepatic gene delivery. Sleeping Beauty transposon (pT2BH_TTRminSerpMVM_hFIXco_bghpA) and PiggyBac transposon (PB_micro_T_No_Ins_SerpTTrminMVM_hFIXco_BGHpA) were injected in immunodeficient (NOD SCID) mice along with plasmid encoding codon-optimized hyperactive PB transposase (pcDNA3_mouseCO_hyPiggyBac_Transposase_MT) or hyperactive SBmax transposase (pCDNA3 _CMVBGI _SBMAX_bghpA), respectively using the doses as indicated. One month post-injection FIX plasma levels were determined in plasma by ELISA.

Figure 12. Evaluation of effect of cloning MVM intron into nucleic acid constructs on *in vivo* expression of transgenes. **(A)** Schematic representation of the piggyBac transposon encoding for a wild-type hFIX (denoted as pB_hFIXIA) The expression cassette is flanked by the wild-type piggyBac transposon invert repeat (IRpBac). The liver-specific minimal transthyretin (TTRm) promoter drives the human FIX transgene comprising a truncated 1;4 kb hFIX intron A between exon 1 and the following exons 2-8. The hepatocyte-specific regulatory element (“Serp” or “SerpEnh”) is located upstream of the TTRm promoter. Bovine growth hormone polyadenylation site (pA) is also indicated. **(B)** Schematic representation of the piggyBac transposon encoding for a codon-optimized hFIX (denoted as pB_ hFIXco). The expression cassette is the same as pB_hFIXIA, except for the transgene. The hFIX transgene is codon-optimized (hFIXco) and contains no intron A. MVM intron is cloned upstream of the FIXco transgene. **(C)** Schematic representation of the mouse piggyBac transposase plasmid (denoted as mpBase). The mouse codon-

optimized native piggyBac transposase (mpB) driven by the cytomegalovirus (CMV) promoter is cloned upstream of a β-globin intron (βGI). Bovine growth hormone polyadenylation site (bghpA) is also indicated. **(D)** Schematic representation of the empty control plasmid (denoted as empty) without a transposase gene. The plasmid contains a multiple cloning site (MCS) between the CMV promoter and the bghpa polyadenylation signal. **(E, F)** Hemophilia B mice were hydrodynamically injected with 10 µg of transposon plasmids comprising wild-type hFIX transgene and truncated intron A (pB_hFIXIA, E) or codon-optimized hFIX transgene and MVM intron (pB_MVM-FIXco, F) in conjunction with 2 µg of plasmids encoding mouse piggyBac transposase (+ mpBase, full lines) or an empty control plasmid (+ empty, dashed lines) hFIX antigen expression (black squares) and hFIX clotting activity (grey squares) were measured on plasma samples collected at the indicated times by ELISA and a chromogenic hFIX activity assay, respectively. Transposon copies per diploid genome **(G)** and hFIX mRNA levels **(H)** were measured by a quantitative RT-PCR method (qRT-PCR) at the end of the experiments from total RNA extracted from liver biopsies. hFIX mRNA levels relative to FIXIA mRNA levels are shown in H. The pB hFIXco plasmid showed more than 57-fold expression of mRNA as compared to the pB FIXIA plasmid. Results were presented as mean ± standard error of the mean. n.s. indicates not significant, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$ (n = 3 mice/group).

Figure 13. Comparison of nucleic acid expression cassettes comprising hFVIII transgene. **(A,B)** Predicted (a,b) and measured (c,d) hFVIII levels in mice hydrodynamically injected with, from left to right, (a) AAV9ss-TTRm-MVM-hFVIII-SV40pA plasmid, (b) AAV9ss-SerpEnh-TTRm-MVM-hFVIII-SV40pA plasmid, (c) AAV9ss-TTRm-MVM-hFVIIIcopt-SV40pA plasmid, or (d) AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA plasmid, at 2 µg DNA (A) or 5 µg DNA (B). **(C,D)** Bars showing from left to right, predicted hFVIII levels in mice hydrodynamically injected with (b) AAV9ss-SerpEnh-TTRm-MVM-hFVIII-SV40pA plasmid; measured hFVIII levels in mice injected with (c) AAV9ss-TTRm-MVM-hFVIIIcopt-SV40pA plasmid; sum of hFVIII levels predicted in mice injected with (b) and hFVIII levels measured in mice injected with (c); and hFVIII levels measured in mice transfected with (d) AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA plasmid. (C) shows the data for mice that were injected with 2 µg DNA, (D) shows the data for mice that were injected with 5 µg DNA.

Figure 14. Comparison of nucleic acid expression cassettes comprising hFIX transgene. **(A,B)** Bars showing from left to right, hFIX activity in mice hydrodynamically injected with (a) AAVsc-TTRm-MVM-hFIX-SV40pA plasmid; (b) AAVsc-SerpEnh-TTRm-MVM-hFIX-SV40pA plasmid; (c) AAVsc-TTRm-MVM-hFIXco-SV40pA plasmid; (b) and (c) calculated as the sum of hFIX activity measured in mice injected with (b) and (c); and (d) AAVsc-SerpEnh-TTRm-MVM-hFIXco-SV40pA plasmid at day 2 (A) and day 6 (B) post-injection. **(C,D)** Bars showing from left to right, hFIX activity in mice hydrodynamically injected with (c) AAVsc-TTRm-MVM-hFIXco-SV40pA plasmid; (d) AAVsc-SerpEnh-TTRm-MVM-hFIXco-SV40pA plasmid; (e) AAVsc-TTRm-MVM-hFIXcoPadua-SV40pA plasmid; (d) and (e) calculated as the sum of hFIX activity measured in mice injected with (d) and (e); and (f) AAVsc-SerpEnh-TTRm-MVM-hFIXcoPadua-SV40pA plasmid at day 2 (C) and day 6 (D) post-injection.

Figure 15. (A) Schematic representation of the piggyBac transposon pB_hFIXco/IR_{mut16}. wherein the expression cassette is flanked by a wild-type piggyBac transposon inverted repeat (IRwt) and a piggybac transposon inverted repeat containing the indicated point mutations (IRmut16). The liver-specific minimal transthyretin (TTRmin) promoter drives a codon-optimized hFIX (hFIXco). Minute virus of mouse (MVM) intron is cloned upstream of the FIXco transgene. The Serpin enhancer (denoted as HSH8) is located upstream of the TTRmin promoter. Bovine growth hormone polyadenylation site (pA) is also indicated. **(B)** Schematic representation of the piggybac transposon pB_hFIXco/IR_{micro}. The transposon is the same as pB_hFIXco/IR_{mut16}, except for the inverted repeats, which are micro inverted repeats (IRmicro). **(C)** Schematic representation of the piggybac transposon pB_hFIXco-R338L. The transposon is the same as pB_hFIXco/IR_{micro}, except for the transgene which is codon-optimized human FIX containing the Padua mutation (hFIXco-R338L). **(D)** Schematic representation of the hyperactive piggyBac transposase (hyPBase) plasmid. The hyperactive piggyBac transposase (hyPBase) driven by the cytomegalovirus (CMV) promoter is cloned upstream of a β-globin intron (βGI). The hyperacting mutations are indicated. Bovine growth hormone polyadenylation site (bghpA) is also indicated. **(E)** Three months after transfection with pB transposons pB_hFIXIA, pB_hFIXco, or pB_hFIXco-R338L, mice were subjected to immunization with recombinant hFIX antigen and adjuvant. Anti-hFIX specific antibodies were measured by ELISA at week 2 (black) and week 4 (grey) post-immunization (p.i). PBS-injected hemophilia B mice that were immunized with recombinant hFIX and adjuvant were used as positive control. Results are presented as mean ± standard error of the mean. n.s.

indicates not significant, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$ (n = 3 mice/group). **(F,G,H,I,J,K)** CB17/IcrTac/Prkdc^{scid} mice were hydrodynamically transfected with 500 ng (F,H,J) or 50 ng (G,I,K) of *pB-hFIXco* (F-K), *pB-hFIXco/IR$_{micro}$* (H,I; triangle) or *pB-hFIXco/IR $_{mut16}$* (J,K; triangle) transposon plasmids along with 1000 ng (F,H,J) or 100 ng (G,I,K) mPB (triangle F,G) or hyPB-expressing plasmid (F,G; square and H-K) or empty control plasmid (hatched lines). hFIX expression was measured on plasma samples collected at the indicated times by a specific ELISA assay. Results were presented as mean ± standard error of the mean. n.s. indicates not significant, *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$ (n = 3 mice/group).

DETAILED DESCRIPTION OF THE INVENTION

The present invention will be described with respect to particular embodiments and with reference to certain drawings but the invention is not limited thereto but only by the claims. Any reference signs in the claims shall not be construed as limiting the scope. The drawings described are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes.

Where the term "comprising" is used in the present description and claims, it does not exclude other elements or steps. The term “comprising” also encompasses the more specific embodiments defined as “consisting of” and “consisting essentially of”.

Where an indefinite or definite article is used when referring to a singular noun e.g. "a" or "an", "the", this includes a plural of that noun unless something else is specifically stated. Furthermore, the terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order.

It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

The following terms or definitions are provided to aid in the understanding of the invention. Unless specifically defined herein, all terms used herein have the same meaning as they would to one skilled in the art of the present invention. Practitioners are particularly directed to Sambrook et al., Molecular Cloning: A Laboratory Manual, 2nd ed., Cold Spring Harbor Press, Plainsview, New York (1989); and Ausubel et al., Current Protocols

in Molecular Biology (Supplement 47), John Wiley & Sons, New York (1999), for definitions and terms of the art.

The definitions provided herein should not be construed to have a scope less than understood by a person of ordinary skill in the art.

The term “coagulation factor IX” has the meaning as known in the art. Synonyms of coagulation factor IX are “FIX” or “Christmas factor” or “F9” and can be used interchangeably. In particular, the term “coagulation factor IX” encompasses the human protein encoded by the mRNA sequence as defined in Genbank accession number NM_000133.

Preferably, said FIX is a mutated FIX, which is hyperactive or hyper-functional as compared to the wild type FIX. Modifying functional activity of human coagulation factor can be done by bioengineering e.g. by introduction of point mutations. By this approach a hyperactive R338A variant was reported, which showed a 3 fold increased clotting activity compared to the wild type human FIX in an *in vitro* activated partial thromboplastin time assay (APPT) (Chang et al., 1998) and a 2 to 6-fold higher specific activity in hemophilia B mice transduced with the mutant FIX gene (Schuettrumpf et al., 2005). Further exemplary FIX point-mutants or domain exchange mutants with even higher clotting activities have been described: FIX, with the EGF-1 domain replaced with the EGF-1 domain from FVII, alone or in combination with a R338A point mutation (Brunetti-Pierri et al., 2009), the V86A/E277A/R338A triple mutant (Lin et al., 2010), the Y259F, K265T, and/or Y345T single, double or triple mutants (Milanov, et al., 2012), and the G190V point mutant (Kao et al., 2010), all incorporated herein by reference. In a particularly preferred embodiment, the FIX mutant is the one described by Simioni et al., in 2009 and denominated as the “factor IX Padua” mutant, causing X-linked thrombophilia. Said mutant factor IX is hyperactive and carries an R338L amino acid substitution. In a preferred embodiment of the present invention, the FIX transgene used in expression vector encodes the human FIX protein, most preferably the FIX transgene encodes for the Padua mutant of the human FIX protein.

The term “coagulation factor VIII” has the meaning as known in the art. Synonyms of coagulation factor VIII are “FVIII” or “anti-hemophilic factor” or “AHF” and can be used interchangeably herein. The term “coagulation factor VIII” encompasses, for example, the human protein having the amino acid sequence as defined in Uniprot accession number P00451.

In embodiments, said FVIII is a FVIII wherein the B domain is deleted (i.e. B domain deleted FVIII, also referred to as BDD FVIII or FVIIIΔB herein). The term "B domain deleted FVIII" encompasses for example, but without limitation, FVIII mutants wherein whole or a part of the B domain is deleted and FVIII mutants wherein the B domain is replaced by a linker. Non-limiting examples of B domain deleted FVIII are described in Ward et al. (2011) and WO 2011/005968, which are specifically incorporated by reference herein.

In preferred embodiments, said FVIII is B domain deleted FVIII wherein the B domain is replaced by a linker having the following sequence: SFSQNPPVLTRHQR (SEQ ID NO: 16) (i.e. SQ FVIII as defined in Ward et al. (2011)). In particularly preferred embodiments, said FVIII has SEQ ID NO:7 (i.e. codon-optimized B domain deleted human FVIII or hFVIIIcopt), as disclosed also in WO 2011/0059.

A "regulatory element" as used herein refers to transcriptional control elements, in particular non-coding cis-acting transcriptional control elements, capable of regulating and/or controlling transcription of a gene, in particular tissue-specific transcription of a gene. Regulatory elements comprise at least one transcription factor binding site (TFBS), more in particular at least one binding site for a tissue-specific transcription factor, most particularly at least one binding site for a liver-specific transcription factor. Typically, regulatory elements as used herein increase or enhance promoter-driven gene expression when compared to the transcription of the gene from the promoter alone, without the regulatory elements. Thus, regulatory elements particularly comprise enhancer sequences, although it is to be understood that the regulatory elements enhancing transcription are not limited to typical far upstream enhancer sequences, but may occur at any distance of the gene they regulate. Indeed, it is known in the art that sequences regulating transcription may be situated either upstream (e.g. in the promoter region) or downstream (e.g. in the 3'UTR) of the gene they regulate in vivo, and may be located in the immediate vicinity of the gene or further away. Of note, although regulatory elements as disclosed herein typically are naturally occurring sequences, combinations of (parts of) such regulatory elements or several copies of a regulatory element, i.e. non-naturally occurring sequences, are themselves also envisaged as regulatory element. Regulatory elements as used herein may be part of a larger sequence involved in transcriptional control, e.g. part of a promoter sequence. However, regulatory elements alone are typically not sufficient to initiate transcription, but require a promoter to this end.

The regulatory elements contained in the nucleic acid expression cassettes and vectors disclosed herein are preferably liver-specific. Non-limiting examples of liver-specific

regulatory elements are disclosed in WO 2009/130208, which is specifically incorporated by reference herein.

In preferred embodiments, the regulatory element in the nucleic acid expression cassettes and vectors disclosed herein is a liver-specific regulatory element derived from the serpin gene promotor. Siad regulatory element comprises the sequence as defined in SEQ ID NO:8, a sequence having at least 85%, preferably at least 90%, more preferably at least 95%, such as 96%, 97%, 98% or 99%, identity to said sequence, or a functional fragment thereof. Said regulatory element is herein referred to as “the Serpin enhancer”, “SerpEnh”, or “Serp”.

In further embodiments, the regulatory element in the nucleic acid expression cassettes and vectors disclosed herein consists of the sequence defined by SEQ ID NO:8 (i.e. the Serpin enhancer, also called “SerpEnh”, or “Serp” herein).

'Liver-specific expression', as used in the application, refers to the preferential or predominant expression of a (trans)gene (as RNA and/or polypeptide) in the liver as compared to other tissues. According to particular embodiments, at least 50% of the (trans)gene expression occurs within the liver. According to more particular embodiments, at least 60%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, at least 97%, at least 99% or 100% of the (trans)gene expression occurs within the liver. According to a particular embodiment, liver-specific expression entails that there is no 'leakage' of expressed gene product to other organs, such as spleen, muscle, heart and/or lung. The same applies mutatis mutandis for hepatocyte-specific expression, which may be considered as a particular form of liver-specific expression. Throughout the application, where liver-specific is mentioned in the context of expression, hepatocyte-specific expression is also explicitly envisaged. Similarly, where tissue-specific expression is used in the application, cell-type specific expression of the cell type(s) predominantly making up the tissue is also envisaged.

The term “functional fragment” as used in the application refers to fragments of the sequences disclosed herein that retain the capability of regulating liver-specific expression, i.e. they still confer tissue specificity and they are capable of regulating expression of a (trans)gene in the same way (although possibly not to the same extent) as the sequence from which they are derived. Fragments comprise at least 10 contiguous nucleotides from the sequence from which they are derived. In further particular embodiments, fragments comprise at least 15, at least 20, at least 25, at least 30, at least 35 or at least 40 contiguous nucleotides from the sequence from which they are derived.

As used herein, the term “nucleic acid expression cassette” refers to nucleic acid molecules that include one or more transcriptional control elements (such as, but not limited to promoters, enhancers and/or regulatory elements, polyadenylation sequences, and introns) that direct (trans)gene expression in one or more desired cell types, tissues or organs. Typically, they will also contain the FIX transgene or the FVIII transgene as defined herein.

The term “operably linked” as used herein refers to the arrangement of various nucleic acid molecule elements relative to each such that the elements are functionally connected and are able to interact with each other. Such elements may include, without limitation, a promoter, an enhancer and/or a regulatory element, a polyadenylation sequence, one or more introns and/or exons, and a coding sequence of a gene of interest to be expressed (i.e., the transgene). The nucleic acid sequence elements, when properly oriented or operably linked, act together to modulate the activity of one another, and ultimately may affect the level of expression of the transgene. By modulate is meant increasing, decreasing, or maintaining the level of activity of a particular element. The position of each element relative to other elements may be expressed in terms of the 5' terminus and the 3' terminus of each element, and the distance between any particular elements may be referenced by the number of intervening nucleotides, or base pairs, between the elements.

As used in the application, the term “promoter” refers to nucleic acid sequences that regulate, either directly or indirectly, the transcription of corresponding nucleic acid coding sequences to which they are operably linked (e.g. a transgene or endogenous gene). A promoter may function alone to regulate transcription or may act in concert with one or more other regulatory sequences (e.g. enhancers or silencers). In the context of the present application, a promoter is typically operably linked to regulatory elements to regulate transcription of a transgene.

When a regulatory element as described herein is operably linked to both a promoter and a transgene, the regulatory element can (1) confer a significant degree of liver specific expression in vivo (and/or in hepatocytes/ hepatic cell lines in vitro) of the transgene, and/or (2) can increase the level of expression of the transgene in the liver (and/or in hepatocytes/hepatocyte cell lines in vitro).

According to a particular embodiment, the promoter contained in the nucleic acid expression cassettes and vectors disclosed herein is a liver-specific promoter. According to a further particular embodiment, the liver-specific promoter is from the transthyretin (TTR) gene. According to yet a further particular embodiment, the TTR promoter is a

minimal promoter (also referred to as TTRm, mTTR or TRRmin herein), most particularly the minimal TTR promoter as defined in SEQ ID NO: 9.

According to another particular embodiment, the promoter in the nucleic acid expression cassettes and vectors disclosed herein is a minimal promoter.

A 'minimal promoter' as used herein is part of a full-size promoter still capable of driving expression, but lacking at least part of the sequence that contributes to regulating (e.g. tissue-specific) expression. This definition covers both promoters from which (tissue-specific) regulatory elements have been deleted- that are capable of driving expression of a gene but have lost their ability to express that gene in a tissue-specific fashion and promoters from which (tissue-specific) regulatory elements have been deleted that are capable of driving (possibly decreased) expression of a gene but have not necessarily lost their ability to express that gene in a tissue-specific fashion. Minimal promoters have been extensively documented in the art, a non-limiting list of minimal promoters is provided in the specification.

Typically, the nucleic acid expression cassette in the expression vector according to the invention comprises a plasmid origin, a promotor and/or enhancer, a (trans)gene, a transcription terminator, and a selection gene.

In embodiments, the nucleic acid expression cassette in the expression vector according to the invention comprises the following elements:

- a plasmid origin such as the f1 origin,
- an Inverted Terminal Repeat sequence (ITR), sometimes mutated,
- an enhancer, preferably the Serpin enhancer (“Serp” or “SerpEnh”),
- a promoter, preferably the minimal TTR promoter (TTRm),
- the MVM intron,
- a (trans)gene, preferably a codon-optimized transgene
- a transcription terminator, preferably a polyadenylation signal such as the bGHpA,
- an Inverted Terminal Repeat sequence (ITR),
- a selection gene (e.g. an antibiotic resistance gene such as an ampicilin resistance gene), and
- a plasmid origin such as the pBR322 origin.

The cloning of the MVM intron into a nucleic acid expression cassette described herein was shown to unexpectedly high expression levels of the transgene operably linked thereto.

In a typical embodiment of the present invention, said nucleic acid expression cassette in the expression vector comprises the following elements (cf. Figure 1):

- an plasmid origin such as the f1 origin,
- an Inverted Terminal Repeat sequence (ITR), sometimes mutated,
- an enhancer, preferably the Serpin enhancer ("Serp" or "SerpEnh"),
- a promoter, preferably the minimal TTR promoter (TTRm),
- an intron sequence, preferably the MVM intron,
- a (trans)gene, preferably the FIX encoding gene, or its Padua mutant form,
- a transcription terminator, preferably a polyadenylation signal such as the bGHpA,
- an Inverted Terminal Repeat sequence (ITR),
- a selection gene (e.g. an antibiotic resistance gene such as an ampicilin resistance gene), and
- a plasmid origin such as the pBR322 origin.

The combination of said elements results in an unexpectedly high expression level of FIX and in particular of the Padua mutant thereof in the liver of subjects. Preferably, the vector is an adeno-associated virus-derived vector, in combination with the Padua-mutant FIX gene.

In another typical embodiment of the present invention, said nucleic acid expression cassette in the vector comprises the following elements:

- a plasmid origin, such as the f1 Origin,
- an Inverted Terminal Repeat sequence (ITR), optionally mutated,
- a liver-specific regulatory element, preferably the Serpin enhancer,
- a promoter, preferably the minimal TTR promoter,
- an intron sequence, preferably the MVM intron,
- a (trans)gene, preferably codon-optimized factor VIII cDNA, even more preferably codon-optimized B domain deleted factor VIII cDNA,

- a transcription terminator, preferably a polyadenylation signal such as the Simian vacuolating virus 40 or Simian virus 40 (SV40) polyadenylation signal,

- an Inverted Terminal Repeat sequence (ITR),

- a selection gene (e.g. an antibiotic resistance gene such as an ampicilin resistance gene), and

- a plasmid origin, such as the pBR322 origin.

The combination of said elements results in an unexpectedly high expression level of FVIII specifically in the liver of subjects. Preferably, the vector is an adeno-associated virus(AAV)-derived vector in combination with codon-optimized B domain deleted FVIII cDNA.

In typical embodiment of the invention, said nucleic acid expression cassette in the vectors disclosed herein comprises:

- a liver-specific regulatory element, preferably the Serpin enhancer,

- a promoter, preferably the minimal TTR promoter,

- the MVM intron

- a (trans)gene, preferably a codon-optimized transgene

- a transcription terminator, preferably a polyadenylation signal such as the bovine growth hormone polyadenylation signal.

In another typical embodiment of the present invention, said nucleic acid expression cassette in the vectors disclosed herein comprises:

- a liver-specific regulatory element, preferably the Serpin enhancer,

- a promoter, preferably the minimal TTR promoter,

- an intron sequence, preferably the MVM intron,

- a (trans)gene, preferably codon-optimized factor IX cDNA, even more preferably codon-optimized factor IX Padua cDNA,

- a transcription terminator, preferably a polyadenylation signal such as the bovine growth hormone polyadenylation signal,

In yet another typical embodiment of the present invention, said nucleic acid expression cassette in the vectors disclosed herein comprises:

- a liver-specific regulatory element, preferably the Serpin enhancer,

- a promoter, preferably the minimal TTR promoter,

- an intron sequence, preferably the MVM intron,

- a (trans)gene, preferably codon-optimized factor VIII cDNA, even more preferably codon-optimized B domain deleted factor VIII cDNA,

- a transcription terminator, preferably a polyadenylation signal such as the Simian vacuolating virus 40 or Simian virus 40 (SV40) polyadenylation signal,

The term “transgene” or “(trans)gene” as used herein refers to particular nucleic acid sequences encoding a polypeptide or a portion of a polypeptide to be expressed in a cell into which the nucleic acid sequence is inserted. However, it is also possible that transgenes are expressed as RNA, typically to lower the amount of a particular polypeptide in a cell into which the nucleic acid sequence is inserted. These RNA molecules include but are not limited to molecules that exert their function through RNA interference (shRNA, RNAi), micro-RNA regulation (miR), catalytic RNA, antisense RNA, RNA aptamers, etc. How the nucleic acid sequence is introduced into a cell is not essential to the invention, it may for instance be through integration in the genome or as an episomal plasmid. Of note, expression of the transgene may be restricted to a subset of the cells into which the nucleic acid sequence is inserted. The term 'transgene' is meant to include (1) a nucleic acid sequence that is not naturally found in the cell (i.e., a heterologous nucleic acid sequence); (2) a nucleic acid sequence that is a mutant form of a nucleic acid sequence naturally found in the cell into which it has been introduced ; (3) a nucleic acid sequence that serves to add additional copies of the same (i.e., homologous) or a similar nucleic acid sequence naturally occurring in the cell into which it has been introduced ; or (4) a silent naturally occurring or homologous nucleic acid sequence whose expression is induced in the cell into which it has been introduced. By 'mutant form' is meant a nucleic acid sequence that contains one or more nucleotides that are different from the wild-type or naturally occurring sequence, i.e., the mutant nucleic acid sequence contains one or more nucleotide substitutions, deletions, and/or insertions. In some cases, the transgene may also include a sequence encoding a leader peptide or signal sequence such that the transgene product will be secreted from the cell.

The term 'vector' as used in the application refers to nucleic acid molecules, usually double- stranded DNA, which may have inserted into it another nucleic acid molecule (the insert nucleic acid molecule) such as, but not limited to, a cDNA molecule. The vector is used to transport the insert nucleic acid molecule into a suitable host cell. A vector may contain the necessary elements that permit transcribing the insert nucleic acid molecule,

and, optionally, translating the transcript into a polypeptide. The insert nucleic acid molecule may be derived from the host cell, or may be derived from a different cell or organism. Once in the host cell, the vector can replicate independently of, or coincidental with, the host chromosomal DNA, and several copies of the vector and its inserted nucleic acid molecule may be generated.

The term “vector” may thus also be defined as a gene delivery vehicle that facilitates gene transfer into a target cell. This definition includes both non-viral and viral vectors. Non-viral vectors include but are not limited to cationic lipids, liposomes, nanoparticles, PEG, PEI, etc. Viral vectors are derived from viruses including but not limited to: retrovirus, lentivirus, adeno- associated virus, adenovirus, herpesvirus, hepatitis virus or the like. Typically, but not necessarily, viral vectors are replication-deficient as they have lost the ability to propagate in a given cell since viral genes essential for replication have been eliminated from the viral vector. However, some viral vectors can also be adapted to replicate specifically in a given cell, such as e.g. a cancer cell, and are typiclly used to trigger the (cancer) cell-specific (onco)lysis.

Preferred vectors are derived from adeno-associated virus, adenovirus, retroviruses and Antiviruses. Alternatively, gene delivery systems can be used to combine viral and non-viral components, such as nanoparticles or virosomes (Yamada et al., 2003). Retroviruses and Antiviruses are RNA viruses that have the ability to insert their genes into host cell chromosomes after infection. Retroviral and lentiviral vectors have been developed that lack the genes encoding viral proteins, but retain the ability to infect cells and insert their genes into the chromosomes of the target cell (Miller, 1990; Naldini et al., 1996, VandenDriessche et al., 1999). The difference between a lentiviral and a classical Moloney-murine leukemia-virus (MLV) based retroviral vector is that lentiviral vectors can transduce both dividing and non-dividing cells whereas MLV-based retroviral vectors can only transduce dividing cells.

Adenoviral vectors are designed to be administered directly to a living subject. Unlike retroviral vectors, most of the adenoviral vector genomes do not integrate into the chromosome of the host cell. Instead, genes introduced into cells using adenoviral vectors are maintained in the nucleus as an extrachromosomal element (episome) that persists for an extended period of time. Adenoviral vectors will transduce dividing and nondividing cells in many different tissues in vivo including airway epithelial cells, endothelial cells, hepatocytes and various tumors (Trapnell, 1993; Chuah et al., 2003). Another viral vector is derived from the herpes simplex virus, a large, double-stranded DNA virus.

Recombinant forms of the vaccinia virus, another dsDNA virus, can accommodate large inserts and are generated by homologous recombination.

Adeno-associated virus (AAV) is a small ssDNA virus which infects humans and some other primate species, not known to cause disease and consequently causing only a very mild immune response. AAV can infect both dividing and non-dividing cells and may incorporate its genome into that of the host cell. These features make AAV a very attractive candidate for creating viral vectors for gene therapy, although the cloning capacity of the vector is relatively limited. In a preferred embodiment of the invention, the vector used is therefore derived from adeno-associated virus (i.e. AAV vector).

Different serotypes of AAVs have been isolated and characterized, such as, for example AAV serotype 2, AAV serotype 5, AAV serotype 8, and AAV serotype 9, and all AAV serotypes are contemplated herein. In a preferred embodiment, the vector used is AAV serotype 9.

The AAV vectors disclosed herein may be single-stranded (i.e. ssAAV vectors) or self-complementary (i.e. scAAV vectors). In particular, AAV vectors that comprise a FIX transgene as disclosed herein are preferably self-complementary, and AAV vectors that comprise a FVIII transgene as disclosed herein are preferably single-stranded. With the term “self-complementary AAV” is meant herein a recombinant AAV-derived vector wherein the coding region has been designed to form an intra-molecular double-stranded DNA template.

Gene therapy with adeno-associated viral vectors disclosed herein was shown to induce immune tolerance towards the transgene comprised in the vector.

In another aspect, the vector is a transposon-based vector. Preferably, said transposon-based vectors are preferably derived from Sleeping Beauty (SB) or PiggyBac (PB). A preferred SB transposon has been described in Ivics et al. (1997).

In preferred embodiments, said transposon-based vectors comprise the nucleic acid expression cassettes disclosed herein.

In embodiments, said transposon-based vectors are PiggyBac-based transposons. Such vectors are safe in that they do no enhance the tumorigenic risk. Furthermore, liver-directed gene therapy with these vectors was shown to induce immune tolerance towards the transgene, in particular hFIX, comprised in the vector.

In further embodiments, said PiggyBac-based vectors comprise micro inverted repeats, preferably inverted repeats having SEQ ID NO:29 and SEQ ID NO:30. With “micro

inverted repeats" is meant herein inverted repeats wherein the majority of the native sequence has been removed. Exemplary micro inverted repeats have been described in Meir et al. (2011. BMC Biotechnology 11:28) and are characterized by the sequences ttaaccctagaaagataatcatattgtgacgtacgttaaagataatcatgcgtaaaattgacgcatg (SEQ ID NO:29) and gcatgcgtcaattttacgcagactatctttctagggttaa (SEQ ID NO:30). Such micro inverted repeats advantageously increase the expression level of the transgene comprised in the vector.

In a particularly preferred embodiment, said transposon-based vector is a PiggyBac-based transposon comprising the Serpin enhancer, the minimal transthyretin promoter, the minute virus of mouse intron, the codon-optimized human FIX Padua mutant, and the bovine growth hormone polyadenylation signal, such as, e.g., the transposon defined by SEQ ID NO:15. In further embodiments, said transposon-based vector comprises micro inverted repeats.

In another particularly preferred embodiment, said transposon-based vector is a PiggyBac-based transposon comprising the Serpin enhancer, the minimal transthyretin promoter, the minute virus of mouse intron, codon-optimized human FIX cDNA, and the bovine growth hormone polyadenylation signal, such as, e.g., the transposon defined by SEQ ID NO:14. In further embodiments, said transposon-based vector comprises micro inverted repeats.

In another particularly preferred embodiment, said transposon-based vector is a PiggyBac-based transposon comprising the Serpin enhancer, the minimal transthyretin promoter, the minute virus of mouse intron, a codon-optimized human B domain deleted FVIII cDNA, and the SV40 polyadenylation signal, such as, e.g., the transposon defined by SEQ ID NO:13. In further embodiments, said transposon-based vector comprises micro inverted repeats.

In yet another particularly preferred embodiment, said transposon-based vector is a Sleeping Beauty-based transposon comprising the Serpin enhancer, the minimal transthyretin promoter, the minute virus of mouse intron, codon-optimized human FIX cDNA, and the bovine growth hormone polyadenylation signal (Fig. 8I).

The transposon-based vectors disclosed herein are preferably administered in combination with a vector encoding a transposase for gene therapy. For example, the PiggyBac-derived transposon-based vector can be administered with wild-type PiggyBac transposase (Pbase) or mouse codon-optimized PiggyBac transposase (mPBase) Preferably, said transposases are hyperactive transposases, such as, for example,

SBmax transposase and hyperactive PB (hyPB) transposase containing seven amino acid substitutions (I30V, S103P, G165S, M282V, S509G, N538K, N570S) as described in Yusa et al. (2011), which is specifically incorporated by reference herein.

Transposon/transposase constructs can be delivered by hydrodynamic injection or using non-viral nanoparticles to transfect hepatocytes.

In a further particular aspect, the nucleic acid regulatory elements, the nucleic acid expression cassettes and the vectors described herein can be used in gene therapy. Gene therapy protocols, intended to achieve therapeutic gene product expression in target cells, in vitro, but also particularly *in vivo*, have been extensively described in the art. These include, but are not limited to, intramuscular injection of plasmid DNA (naked or in liposomes), interstitial injection, instillation in airways, application to endothelium, intra-hepatic parenchyme, and intravenous or intra-arterial administration (e.g. intra-hepatic artery, intra-hepatic vein). Various devices have been developed for enhancing the availability of DNA to the target cell. A simple approach is to contact the target cell physically with catheters or implantable materials containing DNA. Another approach is to utilize needle-free, jet injection devices which project a column of liquid directly into the target tissue under high pressure. These delivery paradigms can also be used to deliver viral vectors. Another approach to targeted gene delivery is the use of molecular conjugates, which consist of protein or synthetic ligands to which a nucleic acid-or DNA-binding agent has been attached for the specific targeting of nucleic acids to cells (Cristiano et al., 1993).

According to a particular embodiment, the use of the nucleic acid regulatory elements, nucleic acid expression cassettes or vectors as described herein is envisaged for gene therapy of liver cells. According to a further particular embodiment, the use of the regulatory elements, expression cassettes or vectors is for gene therapy *in vivo*. According to yet a further particular embodiment, the use is for a method of gene therapy to treat hemophilia, in particular to treat hemophilia B or hemophilia A.

Gene transfer into mammalian hepatocytes has been performed using both *ex vivo* and *in vivo* procedures. The *ex vivo* approach requires harvesting of the liver cells, *in vitro* transduction with long-term expression vectors, and reintroduction of the transduced hepatocytes into the portal circulation (Kay et al., 1992; Chowdhury et al., 1991). *In vivo* targeting has been done by injecting DNA or viral vectors into the liver parenchyma, hepatic artery, or portal vein, as well as via transcriptional targeting (Kuriyama et al., 1991; Kistner et al., 1996). Recent methods also include intraportal delivery of naked DNA

(Budker et al., 1996) and hydrodynamic tail vein transfection (Liu et al., 1999; Zhang et al., 1999).

According to a further aspect, methods for expressing a protein in liver cells are provided, comprising the steps of introducing in liver cells the nucleic acid expression cassette (or a vector) as described herein and expressing the transgene protein product in the liver cells. These methods may be performed both in vitro and in vivo.

Methods of gene therapy for a subject in need thereof are also provided, comprising the steps of introducing in the liver of the subject a nucleic acid expression cassette containing a transgene encoding a therapeutic protein, and expressing a therapeutic amount of the therapeutic protein in the liver. According to a further embodiment, the method comprises the steps of introducing in the liver of the subject a vector comprising the nucleic acid expression cassette containing a transgene encoding a therapeutic protein, and expressing a therapeutic amount of the therapeutic protein in the liver. According to a very specific embodiment, the therapeutic protein encoded by the transgene in the nucleic acid expression cassette is factor IX, and the method is a method for treating hemophilia B. By expressing factor IX in the liver via gene therapy, hemophilia B can be treated (Snyder et al., 1999).

According to another very specific embodiment, the therapeutic protein encoded by the transgene in the nucleic acid expression cassette is factor VIII, and the method is a method for treating hemophilia A.

Except when noted differently, the terms "subject" or "patient" are used interchangeably and refer to animals, preferably vertebrates, more preferably mammals, and specifically includes human patients and non-human mammals. "mammalian" subjects include, but are not limited to, humans, domestic animals, commercial animals, farm animals, zoo animals, sport animals, pet and experimental animals such as dogs, cats, guinea pigs, rabbits, rats, mice, horses, cattle, cows; primates such as apes, monkeys, orang-utans, and chimpanzees; canids such as dogs and wolves; felids such as cats, lions, and tigers; equids such as horses, donkeys, and zebras; food animals such as cows, pigs, and sheep; ungulates such as deer and giraffes; rodents such as mice, rats, hamsters and guinea pigs; and so on. Accordingly, "subject" or "patient" as used herein means any mammalian patient or subject to which the compositions of the invention can be administered. Preferred patients or subjects are human subjects.

As used herein, the terms "treat" or "treatment" refer to both therapeutic treatment and prophylactic or preventative measures, wherein the object is to prevent or slow down

(lessen) an undesired physiological change or disorder, such as the development or spread of proliferative disease, e.g., cancer. Beneficial or desired clinical results include, but are not limited to, alleviation of symptoms, diminishment of extent of disease, stabilised (i.e., not worsening) state of disease, delay or slowing of disease progression, amelioration or palliation of the disease state, and remission (whether partial or total), whether detectable or undetectable. "Treatment" can also mean prolonging survival as compared to expected survival if not receiving treatment.

As used herein, a phrase such as "a subject in need of treatment" includes subjects, such as mammalian subjects, that would benefit from treatment of a given condition, such as, hemophilia B. Such subjects will typically include, without limitation, those that have been diagnosed with the condition, those prone to have or develop the said condition and/or those in whom the condition is to be prevented.

The term "therapeutically effective amount" refers to an amount of a compound or pharmaceutical composition of the invention effective to treat a disease or disorder in a subject, i.e., to obtain a desired local or systemic effect and performance. In a particular embodiment, the term implies that levels of factor IX in plasma equal to or higher than the therapeutic threshold concentration of 10mU/ml (milli-units per milliliter) plasma, 50mU/ml plasma, 100mU/ml plasma, 150mU/ml or 200mU/ml plasma in a subject can be obtained by transduction or transfection of the vector according to any one the embodiments described herein into a subject. Due to the very high efficiency of the vector and nucleic acid expression cassette of the present invention, this high physiological level of factor IX in the subject can be obtained even by administering relatively low doses of vector. In another particular embodiment, the term implies that levels of factor VIII in plasma equal to or higher than the therapeutic threshold concentration of 10mU/ml (milli-units per milliliter) plasma, 50mU/ml plasma, 100mU/ml plasma, 150mU/ml plasma, 200mU/ml plasma or higher can be obtained by transduction or transfection of any of the vectors disclosed herein into a subject. Due to the very high efficiency of the vectors and nucleic acid expression cassettes disclosed herein, these high physiological levels of factor VIII in the subject can be obtained even by administering relatively low doses of vector. The term thus refers to the quantity of compound or pharmaceutical composition that elicits the biological or medicinal response in a tissue, system, animal, or human that is being sought by a researcher, veterinarian, medical doctor or other clinician, which includes alleviation of the symptoms of the hemophilia being treated. In particular, these terms refer to the quantity of compound or pharmaceutical composition according to the invention which is necessary to prevent, cure, ameliorate, or at least minimize the clinical impairment,

symptoms, or complications associated with hemophilia, in particular hemophilia B or hemophila A, in either a single or multiple dose.

In particular, the transduction of the vector according to any one of the embodiments defined herein into the subject can be done at a dose lower than $2x10^{11}$ vg/kg (viral genomes per kilogram) to obtain a physiological factor IX level of 10mU/ml plasma or of 50mU/ml plasma in a subject.

Alternatively, if a level of factor IX of 100 mU/ml plasma needs to be reached in a subject, the transduction of the vector according to any one of the embodiments defined herein into the subject can be done at a dose lower than or equal to $6x10^{11}$ vg/kg.

Further, if a level of factor IX equal to 150 mU/ml plasma or higher needs to be reached, the transduction of the vector according to any one of the embodiments defined herein into the subject can be done at a dose lower than or equal than $2x10^{12}$ vg/kg. In a preferred embodiment, a level of factor IX of 200 mU/ml plasma or higher can be reached in a subject, when the transduction of the vector according to any one of the embodiments defined herein into the subject is done at a dose lower than or equal to $2x10^{12}$ vg/kg.

In particular, the transduction of the vector according to any one of the embodiments defined herein into the subject can be done at a dose lower than or equal to $2x10^{12}$ vg/kg (viral genomes per kilogram), such as lower than or equal to $1x10^{12}$ vg/kg, $5x10^{11}$ vg/kg, $2.5x10^{11}$ vg/kg, $1x10^{11}$ vg/kg, $5x10^{10}$ vg/kg, $1x10^{10}$ vg/kg, $5x10^{9}$ vg/kg, or $1x10^{9}$ vg/kg preferably at a dose lower than or equal to $2.5x10^{11}$ vg/kg, to obtain a physiological factor VIII level of 10 mU/ml plasma, 50 mU/ml plasma, 100 mU/ml plasma, 150 mU/ml plasma, 200 mU/ml plasma, or higher in a subject.

For hemophilia therapy, efficacy of the treatment can, for example, be measured by assessing the hemophilia-caused bleeding in the subject. In vitro tests such as, but not limited to the in vitro actived partial thromboplastin time assay (APPT), test factor IX chromogenic activity assays, blood clotting times, factor IX or human factor VIII-specific ELISAs are also available. Any other tests for assessing the efficacy of the treatment known in the art can of course be used.

The compound or the pharmaceutical composition of the invention may be used alone or in combination with any of the know hemophilia therapies, such as the administration of recombinant or purified clotting factors. The compound or the pharmaceutical composition of the invention can thus be administered alone or in combination with one or more active compounds. The latter can be administered before, after or simultaneously with the administration of the said agent(s).

A further object of the invention are pharmaceutical preparations which comprise a therapeutically effective amount of the expression vector of the invention as defined herein, and a pharmaceutically acceptable carrier, i.e., one or more pharmaceutically acceptable carrier substances and/or additives, e.g., buffers, carriers, excipients, stabilisers, etc. The term "pharmaceutically acceptable" as used herein is consistent with the art and means compatible with the other ingredients of a pharmaceutical composition and not deleterious to the recipient thereof. The term "pharmaceutically acceptable salts" as used herein means an inorganic acid addition salt such as hydrochloride, sulfate, and phosphate, or an organic acid addition salt such as acetate, maleate, fumarate, tartrate, and citrate. Examples of pharmaceutically acceptable metal salts are alkali metal salts such as sodium salt and potassium salt, alkaline earth metal salts such as magnesium salt and calcium salt, aluminum salt, and zinc salt. Examples of pharmaceutically acceptable ammonium salts are ammonium salt and tetramethylammonium salt. Examples of pharmaceutically acceptable organic amine addition salts are salts with morpholine and piperidine. Examples of pharmaceutically acceptable amino acid addition salts are salts with lysine, glycine, and phenylalanine. The pharmaceutical composition according to the invention can be administered orally, for example in the form of pills, tablets, lacquered tablets, sugar-coated tablets, granules, hard and soft gelatin capsules, aqueous, alcoholic or oily solutions, syrups, emulsions or suspensions, or rectally, for example in the form of suppositories. Administration can also be carried out parenterally, for example subcutaneously, intramuscularly or intravenously in the form of solutions for injection or infusion. Other suitable administration forms are, for example, percutaneous or topical administration, for example in the form of ointments, tinctures, sprays or transdermal therapeutic systems, or the inhalative administration in the form of nasal sprays or aerosol mixtures, or, for example, microcapsules, implants or rods. The pharmaceutical composition can be prepared in a manner known per se to one of skill in the art. For this purpose, the expression vector according to the invention as defined herein, one or more solid or liquid pharmaceutically acceptable excipients and, if desired, in combination with other pharmaceutical active compounds, are brought into a suitable administration form or dosage form which can then be used as a pharmaceutical in human medicine or veterinary medicine.

According to another aspect, a pharmaceutical composition is provided comprising a nucleic acid expression cassette containing a transgene encoding a therapeutic protein, and a pharmaceutically acceptable carrier. According to another embodiment, the pharmaceutical composition comprises a vector containing the nucleic acid expression

cassette containing a transgene encoding a therapeutic protein, and a pharmaceutically acceptable carrier. According to further particular embodiments, the transgene encodes factor IX and the pharmaceutical composition is for treating hemophilia B or the transgene encodes factor VIII and the pharmaceutical composition is for treating hemophilia A.

The use of the nucleic acid expression cassette, its regulatory elements and the vector components as disclosed herein for the manufacture of these pharmaceutical compositions for use in treating hemophilia, preferably hemophilia B or hemophilia A, is also envisaged.

It is to be understood that although particular embodiments, specific constructions and configurations, as well as materials, have been discussed herein for methods and applications according to the present invention, various changes or modifications in form and detail may be made without departing from the scope and spirit of this invention.

The following examples are provided to better illustrate particular embodiments, and they should not be considered limiting the application. The application is limited only by the claims.

EXAMPLES

Example 1: In vivo validation of liver-specific regulatory enhancer sequences expressing hyper-active FIX via AAV vector gene delivery.

Materials and methods

Vector construction

AAV-based vectors were constructed that express either the codon-optimized factor IX or the codon-optimized factor IX with the Padua R338L mutation from the TTRm promoter operably linked to the Serpin regulatory sequence. The Serpin regulatory sequence has been identified and described under patent application WO2009/130208.

An intron and poly-A sequence were also provided. The full sequence of the construct containing the codon-optimized factor IX is given in SEQ ID No.1 (Fig. 1B) and the construct containing the codon-optimized factor IX with the Padua R338L mutation in SEQ ID No.2 (Fig. 1C). The vectors were constructed by conventional cloning and DNA synthesis. A schematic overview of the AAV vector containing the codon-optimized huFIX

is shown in Fig. 1A. The vector with the Padua R338L is identical except for the specific R338L mutation that results in FIX hyper-activity.

Cell lines and culture conditions

293T cells were cultured in Dulbecco's modified Eagle's medium (DMEM) supplemented with 2 mM L-glutamine (Gln), 100 IU/ml penicillin, 100 µg/ml streptomycin and 10% heat-inactivated fetal bovine serum (FBS, Invitrogen, Merelbeke, Belgium).

AAV vector production

As an example, the AAV serotype 9 viral vector was chosen to package the construct, known to be a promising vector for gene therapy (Vandendriessche et al. 2007). AAV vectors expressing human FIX were produced at high-titer by calcium phosphate transfection according to the manufacturer's instruction (Calcium phosphate transfection kit, Invitrogen) of 293 cells with AAV2-vector DNA (26 µg/10 cm dish), an adenoviral helper plasmid (52 µg/10 cm dish)and AAV helper plasmids expressing Rep2 and Cap9 (26 µg/10 cm dish) for production of AAV9 serotypes, as described in Gao et al. (2002), Mingozzi et al. (2003) and Gehrke (2003).

Two days post-transfection, cells were lysed by successive freeze-thaw cycles and sonication. Lysates were treated with benzonase (Merck) and deoxycholate (Sigma-Aldrich) and subsequently subjected to three successive rounds of cesium chloride density ultracentrifugation. The fractions containing the AAV particles were concentrated using an Amicon filter (Millipore) and washed with PBS 1mM MgCl2. Vector genome titers were determined by quantitative polymerase chain reaction (qPCR) using TaqMan® probes and primers specific for the polyadenylation signal (forward primer: 5'GCCTTCTAGTTGCCAGCCAT (SEQ ID No.3), probe: 5'TGTTTGCCCCTCCCCCGTGC (SEQ ID No.4), reverse primer : 5'GGCACCTTCCAGGGTCAAG (SEQ ID No.5)).

Animal studies

Animal procedures were approved by the animal Ethical Commission of the VUB. Animals were housed under Biosafety Level II conditions. Mice were injected with the AAV9 vectors as described in Vandendriessche et al. (2007). Briefly, 10^9 vg, $5x10^9$ vg, $2x10^{10}$ vg

(vector genomes = vg) were injected (i.v.) into the tail vein of adult hemophilia B mice (3 mice/group). Blood was collected by retro-orbital bleeds under general anesthesia. Human FIX expression was determined in citrated mouse plasma using a chromogenic FIX activity assay, according to the manufacturer (Hyphen Biomed, Neuville-sur-Oise, France) using serially diluted hFIX standards for calibration.

Results

AAV vectors expressing either the human codon-optimized FIX cDNA (designated as AAV-co-hFIX in Fig. 2) or the human codon-optimized FIX-R338L cDNA (designated as AAV-co-padua-hFIX in Fig. 2) from a chimeric liver-specific promoter (SerpEnh/TTRm) were injected into FIX-deficient hemophilic mice that suffered from hemophilia B. A dose-response was observed and the AAV vector expressing the codon-optimized FIX-R338L yielded significantly higher FIX activity than the codon-optimzed FIX control without the hyper-activating mutation. Remarkably, the AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L vector reached therapeutic FIX levels at a relatively low dose (>50% of normal FIX levels at $1x10^9$ gc/mouse, >250% of normal FIX levels at $5x10^9$ gc/mouse and >700% of normal FIX levels at $2x10^{10}$ gc/mouse after 5 days), which underscores its potency. These levels typically increase more than 2-fold to stable levels in subsequent weeks, reaching respectively approximately >100%, >500% and >1400% FIX at doses of respectively, $1x10^9$ gc/mouse, $5x10^9$ gc/mouse and $2x10^{10}$ gc/mouse. These levels were still increasing in subsequent days following vector injection. Hence, this new vector produced unprecedented, high levels of human IX and can be used at much lower doses than described in the art to cure hemophilia B in a clinically relevant animal model.

Example 2: Enhanced, liver-specific expression of FIX via AAV vector gene delivery.

Materials and methods

Vector constructs

A FIX construct comprising human FIX cDNA (hFIX), was cloned downstream of a liver-specific minimal transthyretin (TTRm) promoter in an adeno-associated viral vector 9 (AAV9) backbone. This vector was further improved to AAV9-SerpEnh-TTRm-hFIX, which comprised an additional hepatocyte-specific regulatory element, namely the Serpin regulatory sequence (“Serp” or “SerpEnh”), upstream of the TTRm promoter. To improve the function of this vector, a minute virus of mice (MVM) intron was cloned in between the

TTRm promoter and the hFIX transgene (AAV9-SerpEnh-TTRm-MVM-hFIX). Next, the hFIX transgene was codon-optimized in order to augment the expression of the protein (AAV9-SerpEnh-TTRm-MVM-co-hFIX). A further improvement encompassed a mutation, namely the R338L, Padua mutation (Fig. 3C), of the co-hFIX fragment (AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L).

Vectors:

-AAV9-TTRm-hFIX

-AAV9-SerpEnh-TTRm-hFIX

-AAV9-SerpEnh-TTRm-MVM-hFIX

-AAV9-SerpEnh-TTRm-MVM-co-hFIX (Fig. 3B)

-AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L (Fig. 3A,C)

Vector production and purification

Calcium phosphate (Invitrogen Corp, Carlsbad, CA, USA) co-transfection of AAV-293 cells with the AAV plasmid of interest, a chimeric packaging construct and an adenoviral helper plasmid, were used to produce AAV vectors as described in VandenDriessche T et al. (2007, VandenDriessche T., Thorrez L, Acosta-Sanchez, Petrus I, Wang L, Ma L, De Waele L, Iwasaki Y, Giillijns V, Wilson JM, Collen D, Chuah MK; Efficacy and safety of adeno-associated viral vectors based on serotype 8 and 9 vs. lentiviral vectors for hemophilia B gene therapy. J Thromb Haemost, 2007. 5(1): p. 16-24), which is specifically incorporated by reference herein. Cells were harvested two days after transfection and lysed by freeze/thaw cycles and sonication, followed by bezonase (Novagen, Madison, WI, USA) and deoxycholic acid (Sigma-Aldrich, St Louis, MO, USA) treatments and 3 consecutive rounds of cesium chloride (Invitrogen Corp, Carlsbad, CA, USA) density gradient ultracentrifugation. AAV vector containing fractions were collected and concentrated in Dulbecco's phosphate buffered saline (PBS) (Gibco, BRL) containing 1 mM $MgCl_2$.

Quantitative real-time PCR with SYBR® Green and primers for the bovine growth hormone polyadenylation sequence (bGHpolyA) was used to determine vector titers. The forward primer sequence was 5'-GCCTTCTAGTTGCCAGCCAT-3' (SEQ ID NO:3). The reverse primer used was 5'-GGCACCTTCCAGGGTCAAG-3' (SEQ ID NO:5). To generate standard curves, known copy numbers (10^2–10^7) of the corresponding vector plasmids were used.

Animal experiments and clotting assays

Vector administration was carried out by tail vein injection on adult hemophilia B mice at doses of $1x10^9$vg/mouse, $5x10^9$vg/mouse and $2x10^{10}$vg/mouse. Whole blood was collected into buffered citrate by phlebotomy of the retro-orbital plexus. Human FIX antigen concentration in citrated plasma was determined by enzyme-linked immunosorbent assay (ELISA) specific for hFIX antigen (Diagnostica Stago, France) using manufacturer's protocol. FIX activity was assessed using BIOPHEN Factor IX chromogenic assay (Hyphen BioMed, Neuville-sur-Oise, France) according to the manufacturer's protocol. For both assays, serially diluted hFIX standards were used for calibration.

D-dimer levels were determined by ELISA, according to the manufacturers instructions (Hyphen Biomed, Neuville-sur-Oise, France).

Tail-clipping assay was performed. Mice were anesthetized and tail was placed in pre-warmed 37°C normal saline solution for 2 minutes and subsequently cut at 2-3 mm diameter. Tail was then immediately placed in 37°C normal saline solution and monitored for bleeding and survival.

Immunizations and detection of anti-FIX antibodies

Immunizations were carried out by subcutaneous injection of 5 µg of recombinant human (rh)FIX protein (BeneFix, Pfizer, Italy) in incomplete Freund's adjuvant (IFA) (Sigma-Aldrich, USA). Briefly, 96-well microtiter plates were coated with hFIX (1µg/ml) and serially diluted standards made of purified mouse IgG (Invitrogen, Europe). The plate was incubated overnight at 4° C. On day 2, the samples of mouse plasma were diluted in dilution buffer, loaded on the pre-coated plates and incubated overnight at 4°C. Experimental plasma samples were obtained from mice injected with AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L. Plasma from phosphate-buffered saline (PBS)-injected mice immunized with rhFIX was used as control. The plate was then incubated with horseradish peroxidase (HRP)-goat anti-mouse IgG (Invitrogen, Europe) secondary antibody. Anti-hFIX antibody levels were measured following incubation with detection buffer constituting 12ml 0.01M sodium citrate, 12mg o-phenylenediamine and 2.5 µl hydrogen peroxide (Invitrogen, Europe). The chromogenic reaction was monitored by determining the absorbance at 450 nm.

Vector DNA and mRNA quantification

Genomic DNA was extracted from different tissues using the DNeasy Blood & Tissue Kit (Qiagen, Chatsworth, CA, USA). 100ng DNA was analyzed using qPCR ABI Prism 7900HT (Applied Biosystems, Foster City/CA, USA) with bGHPolyA specific primers 5'-GCCTTCTAGTTGCCAGCCAT-3' (SEQ ID NO:3) (forward) and 5'-GGCACCTTCCAGGGTCAAG-3' (SEQ ID NO:4) (Reverse). To generate standard curves, known copy numbers of the corresponding vector plasmid was used.

The mRNA was isolated from different organs using a NucleoSpin RNA extraction kit (Machery-Nagel, Germany). Using a cDNA synthesis kit (Invitrogen corp, Carlsbad, CA, USA), RNA from each organ was reverse transcribed to cDNA. cDNA was then analyzed by qPCR ABI Prism 7900HT (Applied Biosystems, Foster City/CA, USA) using bGHPolyA specific primers 5'-GCCTTCTAGTTGCCAGCCAT-3' (SEQ ID NO:3) (forward) and 5'-GGCACCTTCCAGGGTCAAG-3' (SEQ ID NO:4) (Reverse). To expression levels were normalized to glyceraldehyde-3-phosphate dehydrogenase (GAPDH) mRNA expression, obtained by using the forward primer 5'-GAAGGTGAAGGTCGGAGTC-3' (SEQ ID NO:18) and reverse primer 5'-GAAGATGGTGATGGGATTTC-3' (SEQ ID NO:19).

Statistics

Data were analyzed using Microsoft Excel Statistics package. Values shown in the figures are the mean + SEM. Specific values were obtained by comparison using t-test.

Results

Figure 4 shows that administration of the AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L vector to hemophilia B mice provides for significantly higher FIX levels and activity compared to the AAV9-SerpEnh-TTRm-MVM-co-hFIX vector. The FIX response was dose-dependent. Therapeutic FIX levels could be attained at relatively low vector doses of $1x10^9$ vgc/mouse, $5x10^9$ vgc/mouse, and $2x10^{10}$ vgc/mouse. Furthermore, these vector doses are safe as no thrombolysis was observed (Fig. 4J). Figure 5 shows that FIX was specifically expressed in the liver (Fig. 5 C-D), despite transduction of the vector in other organs (Fig. 5 A-B).

To further assess the clinical relevance of the AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L vector, a tail-clipping assay was performed on hemophilia B mice treated with $1x10^9$ vg/mouse of the vector (n=5). Wild-type (C57BL6) (n=4) and untreated hemophilia B (HemoB) mice (n=4) were used as controls. Survival rate for each cohort was monitored and the FIX clotting activity were analyzed. The results are summarized in Table 1 and show that administration of the AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L vector allows for correcting the bleeding phenotype.

Table 1: Tail-clipping assay

	Survival	FIX activity
Wild-type mice	4/4	-
untreated HemoB mice	0/4	0.0013%
treated HemoB mice	5/5	33%

To assess the immune consequences of expressing the hyper-functional FIX Padua at high levels, the anti-FIX antibody response before and after active immunization with wild-type FIX protein and adjuvant was analyzed. The results show that immune tolerance could be achieved since none of the mice treated with the AAV9-SerpEnh-TTRm-MVM-co-hFIX-R338L vectors developed anti-FIX antibodies, in contrast to the controls that were not treated with this vector (Fig.4K).

Example 3: Liver-specific expression of FVIII via AAV vector gene delivery.

Materials and methods

Vector construction

AAV-based vectors were constructed that express a codon-optimized B domain-deleted human coagulation factor VIII (hFVIIIcopt) cDNA (Ward et al., 2011) from the minimal TTR (TTRm) promoter operably linked to the nucleic acid regulatory element Serpin enhancer ("Serp" or "SerpEnh") described in WO 2009/130208, which is specifically incorporated by reference herein. The codon-optimized B domain-deleted human FVIII cDNA was PCR amplified and subcloned into a pGEM-T easy plasmid (Promega, Belgium) and after restriction with SpeI-BamHI, the FVIII cDNA was cloned into the NheI-BglII restricted pAAV-SerpEnh-TTRm vector to generate AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA (also indicated as AAVss-SerpTTRm-MVM-FVIIIcopt-sv40pA herein). This vector also contained a small intron from minute virus of mouse (MVM) to boost FVIII expression levels.

Vector production

For titration of the AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA vector, primers binding the SV40 polyA region were used, including 5'-TGATGCTATTGCTTTATTTGTAACC-3' (SEQ ID NO:20) as forward primer, 5'-

CCTGAACCTGAAACATAAAATGA-3' (SEQ ID NO:21) as reverse primer and 5'-FAM-AGCTGCAATAAACAAGTTAACAACAACAATTGCA-TAMRA-3' (SEQ ID NO:22)as probe. Titers were achieved in the normal range of 2–5x10^{12} vg/ml. Briefly, reactions were performed in TaqMan® Universal PCR Master Mix (Applied Biosystems, Foster City,CA,USA), on an ABI 7500 Real-Time PCR System (Applied Biosystems, Foster City,CA,USA). Known copy numbers (10^2–10^7) of the vector plasmid used to generate the AAV vector were used to generate the standard curves.

Animal studies

The AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA vectors were injected intravenously into adult male SCID mice (CB17/IcrTac/Prkdc scid) at a dose of 5x10^9 vg/mouse or 2.5x 10^{11}vg/kg.

FVIII expression analysis

Human (h) FVIII antigen levels were assayed in citrated mouse plasma using a hFVIII-specific enzyme-linked immunosorbent assay (ELISA) (Asserachrom® VIII:Ag, Diagnostica Stago, France), as per the manufacturer's instructions. Samples were diluted in sample diluent provided and analyzed in triplicate. Standard curves in percentage FVIII antigen activity were constructed by diluting normal control plasma. In brief, 200 ml diluted samples and standards were pipetted into the wells of the strips pre-coated with mouse monoclonal anti-human FVIII Fab fragments and incubated for 2 hours at room temperature for antigen immobilization. The wells were then washed with the wash buffer for 5 times before adding 200 ml mouse monoclonal anti-hFVIII antibody coupled with peroxidase for immobilization of immunoconjugate. After incubation for 2 hr at room temperature and washing, 200 ml of TMB substrate was added to the wells for color development. This mixture was incubated at room temperature for exactly 5 minutes. The reaction was then stopped by 50ml 1M H_2SO_4 and then read at 450 nm within 1h.

Results

High-titer AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA vectors expressing a codon-optimized B-domain deleted human FVIII cDNA (hFVIIIcopt) from a liver-specific promoter (TTRm) operably linked to a regulatory element ("Serp" or "SerpEnh") could be produced with a total insert size of 4913 bp (excluding ITR) (Fig. 6). Intravenous injection of a very low vector dose (5x10^9 vg/mouse) resulted in therapeutic FVIII levels approximating 421.8 ± 4.9 ng/ml (i.e. 210.9 ± 3.1% of normal levels) (Fig. 7). To our knowledge, AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA vector is the most robust AAV-FVIII vector design to date.

Example 4: Enhanced, liver-specific expression of FVIII and FIX via transposon-based gene delivery.

Materials and methods

The codon-optimized hyperactive PB transposase (huPB) was cloned into pcDNA3 and expressed from the CAG promoter (Fig. 8A,B). The hyperactive SBmax transposase was cloned into pcDNA3 and expressed from the CAG promoter (Fig. 8K,L). A codon-optimized B-domain deleted FVIII (hFVIIIcopt), described as SQ FVIII (co) in Ward et al. (2011) was cloned by conventional cloning techniques into a PB transposon to generate the PB_Minimal_T_(T53C-C136T)_D4Z4_TTRminSerpMVM_hFVIIIcopt_SV40pA-D4Z4 (Fig. 8C,D). The human codon-optimized FIX cDNA and the codon-optimized FIX cDNA with the hyperactivating Padua mutation were cloned by conventional cloning techniques into a PB transposon to generate the PB_micro_T_No_Ins_TTRminSerpMVM_hFIXco_bghpA (Fig. 8E,F) and PB_micro_T_No_Ins_TTRminSerpMVM_hFIXco_Padua_bghpA (Fig. 8G,H), respectively. The human codon-optimized FIX cDNA was cloned by conventional cloning techniques into an SB-based vector to generate pT2BH_TTRminSerpMVM_hFIXco_bghpA (Fig. 8I,J).

The transgenes were expressed from a liver-specific minimal transthyretin (TTRm) promoter along with the Serpin enhancer ("Serp" or "SerpEnh"). The contructs also contained a mouse mini-intron (MVM) and a polyadenylation site. The recombinant clones were verified by restriction analysis and sequencing.

The different FVIII-transposons and matching plasmids encoding the cognate hyperactive transposases (i.e. hyPB and SBmax, respectively) were purified by ion exchange chromatography and transfected by hydrodynamic transfection at varying transposon/transposase ratios and concentrations into adult mice. Controls without transposase were employed. The FIX expression was monitored by ELISA or using chromogenic activity assays in hemophilia B mice. FVIII expression in SCID mice was assessed using a human FVIII-specific ELISA.

Results

Incorporation of the Serpin enhancer into the PB transposons resulted in robust, stable gene transfer efficiencies in hepatocytes yielding high unprecedented activity of the codon-optimized FIX Padua (hFIXco-R338L), when the hyperactive hyPB transposase was employed (Fig. 9A). Conversely, in the absence of the hyperactive hyPB transposase,

expression declined gradually to basal levels, consistent with our previous observations that transposition is required for stable gene expression in the liver. Molecular analysis, performed 1 year post-transfection, confirmed stable genomic integration of the FIX-transposons. Moreover, side-by-side comparisons revealed a nearly 100-fold increase in FIX expression with this optimized FIX transposon compared to early-generation transposon design.

Fig. 10 demonstrates that the use of the liver-specific Serpin enhancer ("Serp" or "SerpEnh") in conjunction with codon-optimized B-domain deleted FVIII (hFVIIIcopt), and the hyperactive hyPB system resulted in robust, stable gene transfer efficiencies in hepatocytes, yielding high unprecedented expression levels of FVIII. Conversely, in the absence of the hyperactive hyPB transposase, expression declined gradually to basal levels. This confirms that stable genomic integration by transposition is required for stable hepatic FVIII gene expression.

Sleeping Beauty (SB) transposon (pT2BH_TTRminSerpMVM_hFIXco_bghpa) was compared side by side with the PiggyBac (PB) transposon (PB_micro_T_No_Ins_SerpTTrminMVM_hFIXco_BGHpA)) in immunodeficient NOD SCID mice using two different doses as indicated (Fig. 11). One month post-injection of the transposon and transposase plasmids, blood was collected. FIX ELISA was performed to determine the amount of FIX expression. About 1500-2000 ng/ml of FIX antigen was detected in both, SB and PB, transposons. These data show that the SB and PB vectors are equally potent and can induce high therapeutic level of FIX expression amounting to about 30-40 % of normal FIX.

No adverse events were noted in the different mouse models with any of the transposons, regardless of the transgene, that could be ascribed to the transposition or to the transient transposase expression.

To further ascertain the safety of the PB transposons we administered the transposons by hydrodynamic transfection into a tumor prone mouse model. In this model, mice were injected repeatedly with the carcinogen N,N-diethylnitrosamine (DEN) and developed hepatocellular carcinoma. The tumor burden was assessed 36 weeks post-DEN injection. We did not observe any statistically significant difference in tumor mass or number of tumor nodules in mice treated with the transposons vs. controls without transposition. These data indicate that PB transposition in itself does not significantly increase tumorigenicity, even in an HCC tumor-prone mouse model, which supports its safety.

Example 5: Enhanced expression of FVIII and FIX by cloning the MVM intron into the nucleic acid expression cassette.

Materials and methods

A piggyBac transposon plasmid was constructed that comprises human FIX cDNA cloned downstream of a liver-specific minimal transthyretin (TTRmin) promoter operably linked to the Serpin regulatory sequence ("Serp" or "SerpEnh" or "HSH8"). The bovine growth hormone poly A (bghpA) was provided as a transcription termination signal. Human FIX cDNA comprises a truncated 1.4 kb intron A between exons 1 and the following exons 2-8. A schematic representation of said transposon, denoted as pB_hFIXIA, is shown in Figure 12A.

A piggyBac transposon plasmid was constructed that contains a synthetic codon-optimized human FIX cDNA without intron A. Said codon-optimized hFIX cDNA was cloned downstream of a liver-specific minimal transthyretin (TTRmin) promoter operably linked to the Serpin regulatory sequence ("Serp" or "SerpEnh" or "HSH8"). A minute virus of mice (MVM) intron was cloned between the TTRmin promoter and the hFIXco transgene. The bovine growth hormone poly A (bghpA) was provided as a transcription termination signal. A schematic representation of said transposon, denoted as pB_hFIXco, is shown in Figure 12B.The plasmids were constructed by conventional cloning and DNA synthesis.

Hemophilia B mice were hydrodynamically injected with 10 µg transposon plasmid and 2 µg of mouse transposase plasmid mpBase (Fig. 12C) or empty control plasmid (Fig. 12D) diluted in 2 ml of PBS into the tail vein. Typically, the injection took less than 10 s for each mouse. Determination of hFIX levels and activity occurred as described in Example 2.

Transposon genome copy number quantification

Genomic DNA was extracted from frozen liver samples according to DNeasy Blood & Tissue Kit protocol (Qiagen, Chatsworth, CA, USA). RNase A (Qiagen, Chatsworth, CA, USA) treatment was carried out to eliminate carry-over RNA. Transposon copy numbers were quantified by qPCR using a primer set against a specific region common to both transposon constructs using forward primer 5'- AACAGGGGCTAAGTCCACAC -3' (SEQ ID NO: 25) and reverse primer 5'- GAGCGAGTGTTCCGATACTCT -3' (SEQ ID NO: 26). Briefly, 50 ng of genomic DNA from each sample was subjected to qPCR in triplicate

using an ABI Prism 7500 Fast Real-Time PCR System (Applied Biosystems, Foster City/CA, USA) and Power SYBR® Green PCR Master Mix (Applied Biosystems, Foster City/CA, USA). Copy number was determined comparing the amplification signal with a standard curve consisting of serial dilutions over a 6 log range of the corresponding linearized plasmid spiked with 50 ng of liver genomic DNA from saline-injected mouse (slope ≈ -3,3, intercept ≈ 35, efficiency % ≈ 100). Average copies per diploid genome were calculated taking into account that one murine diploid genome = 5,92 pg.

hFIX mRNA expression analysis

Total RNA was extracted from frozen liver samples using a miRCURY™ RNA isolation kit (Exiqon, Denmark). DNase (Thermo Scientific, USA) treatment was carried out. The reverse transcription reaction was performed starting from 1 μg of total RNA from each sample using the SuperScript® III First Strand cDNA Synthesis Kit (Life Technologies, USA). Next, a cDNA amount corresponding to 10 ng of total RNA from each sample was analyzed in triplicate by quantitative (q)PCR using an ABI Prism 7500 Fast Real-Time PCR System (Applied Biosystems, Foster City/CA, USA) and Power SYBR® Green PCR Master Mix (Applied Biosystems, Foster City/CA, USA). The following primer set was used: forward primer 5'-GCCTTCTAGTTGCCAGCCAT-3' (SEQ ID NO:3), reverse primer 5'- GGCACCTTCCAGGGTCAAG-3' (SEQ ID NO:4). The hFIX mRNA levels were normalized using a primer set against the mRNA of the housekeeping gene glyceraldehyde-3-phosphate dehydrogenase (mGAPDH) which is uniformly and constantly expressed in all samples (i.e. forward primer 5'-ATCAAGAAGGTGGTGAAGCAGGCA -3' (SEQ ID NO:27) and reverse primer 5'-TGGAAGAGTGGGAGTTGCTGTTGA -3' (SEQ ID NO:28)). RNA samples were amplified with and without reverse transcriptase to exclude genomic DNA amplification. The $2^{-\Delta\Delta Ct}$ relative quantification method was used to determine the relative changes in hFIX mRNA expression level. The ΔCt was calculated by subtracting the Ct of mGAPDH mRNA from the Ct of the hFIX mRNA (Ct_{hFIX} - Ct_{GAPDH}). The ΔΔCt was calculated by subtracting the ΔCt of the reference sample (highest Ct) from the ΔCt of each sample (ΔCt_{sample} - $\Delta Ct_{reference}$). Fold-change was determined by using the equation $2^{-\Delta\Delta Ct}$.

Results

As shown in Figures 12E and F, hFIX expression and activity is transient and gradually declines to basal levels in mice that were co-injected with the empty control plasmid (Fig. 12E: pB_hFIXIA + empty plasmid: 46 ± 13 ng/ml hFIX, 0,87 ± 0,2% normal clotting activity

and Fig. 12F: pB_hFIXco + empty plasmid: 48 ± 22 ng/ml hFIX, 0,97 ± 0,49% normal clotting activity). These results indicate that stable transposition is necessary for sustained expression, but the non-integrated pB-hFIXIA or pB-hFIXco plasmids may have contributed to the initial surge in hFIX expression

The transposon plasmid comprising the MVM intron yielded significantly higher hFIX levels and activity as compared to the plasmid without MVM intron when co-delivered with the mouse transposase plasmid (Fig. 12E,F). Liver-directed hydrodynamic co-transfection of the pB-hFIXIA transposon without MVM intron (10 µg) along with 2 µg mPB plasmid, resulted in stable therapeutic hFIX antigen and activity levels for at least up to 12 months in hemophilic FIX-deficient mice (Fig. 12E, 1168 ± 218 ng/ml hFIX and 32 ± 6% normal clotting activity). Similarly, liver-directed co-transfection of the pB_hFIXco transposon with MVM intron and mPB plasmid resulted in a significant ≈12-fold higher ($p<0.001$) hFIX protein and activity level that stabilized in the supra-physiologic range (Fig. 12F: 13290 ± 990 ng/ml hFIX and 313 ± 7% normal clotting activity). The increase in hFIX protein levels was consistent with a more than 57-fold increase in hFIX mRNA levels when comparing the transposon with and without the MVM intron (Fig. 12 H), although the transposon copies per genome content were similar in the liver of mice that were injected with pB hFIXIA and pB hFIXco (Fig. 12G).

Example 6: Comparison of expression cassettes comprising a FVIII transgene.

Material and methods

The AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA plasmid of Example 3 was compared to:

(a) AAV9ss-TTRm-MVM-hFVIII-SV40pA,

(b) AAV9ss-SerpEnh-TTRm-MVM-hFVIII-SV40pA, and

(c) AAV9ss-TTRm-MVM-hFVIIIcopt-SV40pA.

AAV9ss-TTRm-MVM-hFVIIIcopt-SV40pA plasmid (c) was constructed by excising the Serpin enhancer from AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA plasmid.

Mice were hydrodynamically injected with 2 µg or 5 µg of the plasmid DNA diluted in 2 ml of phosphate buffered saline (PBS) and injected into the tail vein. Typically, the injection took less than 10 s for each mouse. FVIII expression analysis was carried out as described in Example 3.

Results

The AAV9ss-TTRm-MVM-hFVIIIcopt-SV40pA (c) and AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA (d) constructs were hydrodynamically injected in mice at 2 µg and 5 µg DNA, and human FVIII levels were measured 1, 2 and 6 days post-transfection.

The effect of cloning the Serpin enhancer into the expression cassette on hFVIII levels can be calculated by dividing the hFVIII levels measured in mice injected with construct (d) by the levels measured in mice injected with construct (c). 3- to 6-fold higher hFVIII levels can be obtained by cloning the Serpin enhancer into the expression cassette (Table 2).

The codon-optimized B domain-deleted human coagulation factor VIII (hFVIIIcopt) cDNA was reported to achieve 29- to 44-fold increase in expression (Ward et al. 2011). We used the average increase in expression of 36.5 to predict the hFVIII levels in mice that are transfected with AAV9ss-SerpEnh-TTRm-MVM-hFVIII-SV40pA construct (b), namely by dividing the hFVIII levels measured in mice transfected with construct (d) by 36.5.

Based on said predicted hFVIII levels in mice that are hydrodynamically injected with AAV9ss-SerpEnh-TTRm-MVM-hFVIII-SV40pA construct (b), we can further predict the hFVIII levels in mice that are hydrodynamically injected with AAV9ss-TTRm-MVM-hFVIII-SV40pA construct (a) by dividing said predicted hFVIII levels by the calculated effect of cloning the Serpin enhancer into the expression cassette on hFVIII levels.

The measured and predicted hFVIII levels in mice hydrodynamically injected with the different constructs a-d are summarized in Table 3 and Figures 13A and 13B.

Table 3: hFVIII levels in mice hydrodynamically injected with 2 or 5 µg of plasmids (a) AAV9ss-TTRm-MVM-hFVIII-SV40pA, (b) AAV9ss-SerpEnh-TTRm-MVM-hFVIII-SV40pA, (c) AAV9ss-TTRm-MVM-hFVIIIcopt-SV40pA, and (d) AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA.

	(a) AAVss-TTRm-MVM-hFVIII	**(b) AAVss-SERP-TTRm-hFVIII**	**(c) AAVss-TTR-MVM-hFVIIIcopt**	**(d) AAVss-SERP-TTR-MVM-hFVIIIcopt**
	Predicted level: (a) = (b) : [(d):(c)]	Predicted level: (b) = (d) : 36,5x	Measured level	Measured level
	no SERP, no codon-optimization	*SERP*	*codon-optimization*	*SERP + codon-optimization*
Day 1	2 µg = 11/4 = **3 ng/ml**	2 µg = **11 ng/ml**	2 µg = **102 ng/ml**	2 µg = **412 ng/ml**
	5 µg = 20/3,3 = **6 ng/ml**	5 µg = **20 ng/ml**	5 µg = **227 ng/ml**	5 µg = **751 ng/ml**
Day 2	2 µg = 4,1/1,9 = **2 ng/ml**	2 µg = **4,1 ng/ml**	2 µg = **77 ng/ml**	2 µg = **150 ng/ml**
	5 µg = 11,7/3,3 = **3,5 ng/ml**	5 µg = **11,7 ng/ml**	5 µg = **129 ng/ml**	5 µg = **429 ng/ml**
Day 6	2 µg = 1/3,5 = **0,28 ng/ml**	2 µg = **1 ng/ml**	2 µg = **11 ng/ml**	2 µg = **39 ng/ml**
	5 µg = 6,4/5,9 = **1 ng/ml**	5 µg = **6,4 ng/ml**	5 µg = **39 ng/ml**	5 µg = **233 ng/ml**

The data shows that expression cassettes comprising the specific combination of the codon-optimized B domain-deleted human coagulation factor VIII (hFVIIIcopt) cDNA described in Ward et al. (2011) and the Serpin enhancer can induce hFVIII levels that are significantly higher as compared to the sum of the hFVIII levels that are obtained by expression cassettes comprising each of these elements alone (Table 4, Figures 13C and 13D). In other words, said specific combination of hFVIIIcopt cDNA and the Serpin enhancer provides for a synergistic effect on hFVIII levels.

Table 4: Comparison of hFVIII levels induced by AAV9ss-SerpEnh-TTRm-MVM-hFVIIIcopt-SV40pA construct (d) as compared to the levels induced by (b) AAV9ss-SerpEnh-TTRm-MVM-hFVIII-SV40pA construct and (c) AAV9ss-TTRm-MVM-hFVIIIcopt-SV40pA construct, and as compared to the levels induced by (a) AAV9ss-TTRm-MVM-hFVIII-SV40pA construct.

	(b) + (c)	(d) / [(b)+(c)]	(d) / (a)
Day 1	2 µg = 11 + 102 = **113 ng/ml**	2 µg = 412 / 113 = **3,6x** >>>	2 µg = 412 / 3 = **137x** >>>
	5 µg = 20 + 227 = **247 ng/ml**	5 µg = 751 / 247 = **3x** >>>	5 µg = 751 / 6 = **125x** >>>
Day 2	2 µg = 77 + 4 = **81 ng/ml**	2 µg = 150 / 81 = **1,8x** >>>	2 µg = 150 / 2 = **75x** >>>
	5 µg = 11 + 129 = **140 ng/ml**	5 µg = 429 / 140 = **3x** >>>	5 µg = 429 / 3,5 = **122x** >>>
Day 6	2 µg = 11 + 1 = **12 ng/ml**	2 µg = 39 / 12 = **3,25x** >>>	2 µg = 39 / 0,28 = **139x** >>>
	5 µg = 39 + 6,4 = **45,4 ng/ml**	5 µg = 233 / 45,4 = **5,1x** >>>	5 µg = 233 / 1 = **223x** >>>

Example 7: Comparison of expression cassettes comprising a FIX transgene.

Material and methods

AAV-based plasmids comprising a FIX transgene were constructed as described in Example 2.

FIX knockout mice were hydrodynamically injected with 2 µg of each of the following FIX plasmids diluted in 2 ml of phosphate buffered saline (PBS) into the tail vein:

(a): AAVsc-TTRm-MVM-hFIX-pA;

(b): AAVsc-SerpEnh-TTRm-MVM-hFIX-pA;

(c): AAVsc-TTRm-MVM-hFIXco-pA

(d): AAVsc-SerpEnh-TTRm-MVM-hFIXco-pA

(e): AAVsc-TTRm-MVM-hFIXcoPadua-pA

(f): AAVsc-SerpEnh-TTRm-MVM-hFIXcoPadua-pA

Blood was collected from these mice at day 2 and day 6 post-injection. FIX activity was determined as described in Example 2.

Results

FIX activity as measured in the different mice is summarized in Table 5.

Table 5: hFIX activity at days 2 and 6 post-injection in mice hydrodynamically injected with 2 µg of (a) AAVsc-TTRm-MVM-hFIX-pA plasmid, (b) AAVsc-SerpEnh-TTRm-MVM-hFIX-pA plasmid, (c) AAVsc-TTRm-MVM-hFIXco-pA plasmid, (d) AAVsc-SerpEnh-TTRm-MVM-hFIXco-pA plasmid, (e) AAVsc-TTRm-MVM-hFIXcoPadua-pA plasmid, and (f) AAVsc-SerpEnh-TTRm-MVM-hFIXcoPadua-pA plasmid.

	(a) AAVsc-TTRm-MVM-hFIX-pA	(b) AAVsc-SerpEnh-TTRm-MVM-hFIX-pA	(c) AAVsc-TTRm-MVM-hFIXco-pA	(d) AAVsc-SerpEnh-TTRm-MVM-hFIXco-pA	(e) AAVsc-TTRm-MVM-hFIXcoPadua-pA	(f) AAVsc-SerpEnh-TTRm-MVM-hFIXcoPadua-pA
	no SERP, no codon-optimization, no Padua	SERP	codon-optimization	SERP + codon-optimization	codon-optimization + Padua	SERP + codon-optimization + Padua
Day 2	5.92%	42.99%	6.36%	74.25%	75.09%	289.34%
Day 6	1.00%	12.90%	0.23%	34.32%	18.48%	265.71%

The data shows that the specific combination of codon-optimized human coagulation factor IX (hFIXco) cDNA and the Serpin enhancer results in hFIX activity that is higher than would have been predicted based on the sum of the hFIX activity determined in mice hydrodynamiclly injected with plasmids (b) and (c) comprising either a Serpin enhancer (b) or a codon-optimized hFIX transgene (c) (Table 6, Figures 14A and 14B). In other words, said specific combination of hFIXco cDNA and the Serpin enhancer provides for a synergistic effect on hFIX activity.

To evaluate the combination of the Serpin enhancer and the Padua mutation on hFIX activity, hFIX activity in mice hydrodynamically injected with (f) AAVsc-SerpEnh-TTRm-MVM-hFIXcoPadua-pA plasmid was compared versus hFIX activity in mice hydrodynamically injected with (d) AAVsc-SerpEnh-TTRm-MVM-hFIXco-pA plasmid and (e) AAVsc-TTRm-MVM-hFIXcoPadua-pA plasmid (Table 6, Figures 14C and 14D). The

combination of the Serpin enhancer and the Padua mutation provides for a synergistic effect on hFIX activity.

Also the combination of the Serpin enhancer with codon-optimized transgene encoding hFIX containing the Padua mutation shows synergy on hFIX activity, as revealed by comparing hFIX activity in mice injected with (f) AAVsc-SerpEnh-TTRm-MVM-hFIXcoPadua-pA plasmid versus hFIX activity in mice injected with (b) AAVsc-SerpEnh-TTRm-MVM-hFIX-pA plasmid, and (e) AAVsc-TTRm-MVM-hFIXcoPadua-pA plasmid.

Table 6: Comparison of hFIX activity induced by the different FIX plasmids: (a) AAVsc-TTRm-MVM-hFIX-pA plasmid, (b) AAVsc-SerpEnh-TTRm-MVM-hFIX-pA plasmid, (c) AAVsc-TTRm-MVM-hFIXco-pA plasmid, (d) AAVsc-SerpEnh-TTRm-MVM-hFIXco-pA plasmid, (e) AAVsc-TTRm-MVM-hFIXcoPadua-pA plasmid, and (f) AAVsc-SerpEnh-TTRm-MVM-hFIXcoPadua-pA plasmid.

(b) + (c)	(d) / (b) + (c)	(d) + (e)	(f) / (d) + (e)	(b) + (e)	(f) / (b) + (e)	(d) / (a)	(f) / (a)
	SERP + codon-optimization		SERP + Padua		SERP + codon-optimization + Padua		
42,99 + 6,36 = 49,35%	74,25 / 49,35 = 1,5x ↑	74,25 + 75,09 = 149,34%	289,34 / 149,34 = 1,9x ↑	42,99 + 75,09 = 118,08%	289,34 / 118,08 = 2,5x↑	74,25 / 5,92 = 12,5x	289,34 / 5,92 = 48,9x
12,90 + 0,23 = 13,13%	34,32 / 13,13 = 2,6x ↑	34,32 + 18,48 = 52,80%	265,71 / 52,80 = 5,0x ↑	12,90 + 18,48 = 31,38%	265,71 / 31,38 = 8,5x↑	34,32 / 1 = 34,32x	265,71 / 1 = 265,71x

Example 8: Evaluation of the piggyBac transposon system.

Materials and methods *Transposon constructs*

pB_hFIXIA (Fig. 12A) and pB_hFIXco (Fig. 12B) plasmids were constructed as described in Example 5.

A terminal inverted repeat of pB_hFIXco (IR_{wt}) was replaced by a terminal inverted repeat containing T53C and C136T point mutation (IR_{mut16}) to generate pB_hFIXco/IR_{mut16} (Fig. 15A).

The terminal inverted repeats of pB_hFIXco were replaced by micro terminal inverted repeats as described in Meir et al. (2011) (IRmicro) to yield pB_hFIXco/IR_{micro} (Fig. 15B).

pB_hFIX-R338L plasmid (Fig. 15C) containing hyper-functional, codon-optimized hFIX transgene with Padua mutation was constructed by site-directed mutagenesis using pB_hFIXco/IR_{micro} as template.

Hydrodynamic injection, analysis of hFIX levels and activity and anti-hFIX antibodies

Plasmids were diluted in 2 ml of Dulbecco's PBS and hydrodynamically delivered to adult mice (6-7-week-old) by rapid tail vein injection. At different time intervals, we collected whole blood (≈ 200µl) by phlebotomy of the retro-orbital plexus in eppendorf tubes pre-filled with 20% citrate buffer that were centrifuged at 14000 r.p.m. for 5 min at 4°C. The citrated plasma was stored at -80°C for future analysis.

hFIX antigen levels and activity and antibodies directed against hFIX were analyzed as described in Example 2.

Tail clipping assay

A tail-clipping assay was used on hemophilic mice to assess phenotypic correction of the bleeding phenotype. Briefly, the tails of mice were transected (1 cm from the end) and mice were monitored for clotting and survival. Tail clip was performed on immobilized mice, allowing continuous blood collection at room temperature and total blood volume, bleeding time and survival rate were monitored.

Results

To assess the immune consequences of treating hemophilia B mice with piggyBac transposons expressing hFIXIA, hFIXco or hFIXco-R338L, the anti-FIX antibody response was analyzed after active immunization with recombinant hFIX antigen and adjuvant. None of the hemophilia B mice treated with the *PB* transposons expressing hFIXIA, hFIXco or hFIXco-R338L (Padua) developed an anti-hFIX specific antibody response (Fig.15E). This indicates that liver-directed gene therapy using the various PB transposons encoding either hFIXIA, hFIXco or hFIXco-R338L (Padua) induced immune tolerance to the hFIX protein.

A tail-clip assay showed that the bleeding diathesis of hemophilia B mice transfected with pB-hFIXIA or pB-hFIXco and plasmid encoding mPBase was phenotypically corrected 1 year post-transfection (Table 7). Bleeding time and volume were lower in mice transfected with plasmid comprising codon-optimized hFIX transgene and MVM intron compared to mice transfected with wild-type hFIX transgene.

Table 7: Phenotypic correction of murine hemophilia B following tail clipping 48 weeks after gene transfer. 2 µg plasmid encoding mPBase was co-delivered with the indicated transposon plasmids via hydrodynamic injection. hFIX concentration (ng/ml) at the time of tail clipping is indicated. Bleeding time and volume were assayed following clipping of a section of tail 1 cm in length. Values represent means ± SEM

Group	Transposon plasmid	hFIX (ng/ml)	Bleeding time (min)	Bleeding volume (µl)	Survival
C57BL/6	none	0	30±5	146±31	3/3
$FIX^{-/-}$	none	0	294±50	1433±57	0/3
$FIX^{-/-}$	pB_hFIXIA	1168±218	109±10	677±52	3/3
$FIX^{-/-}$	pB_hFIXco	13290±990	57±12	500±45	3/3

The efficiency of the piggyBac platform could be improved by using the hyperactive PB transposase (hyPBase) described in Yusa et al. (2011) (Fig. 15D), allowing the use of lower transposon/transposase doses. This hyPBase contained several mutated residues compared to the mouse codon-usage optimized mPBase (compare Fig. 15D with 12C). Liver-directed hydrodynamic transfection of immune deficient SCID mice with 500 ng of *pB-hFIXco* transposon along with 1000 ng hyPB resulted in stable supra-physiologic hFIX levels corresponding to 200% of normal hFIX levels (Fig. 15F). These FIX levels were significantly higher ($p<0.001$) than what could be achieved with the original mPB transposase. Similarly, liver-directed transfection of SCID mice with 50 ng of *pB-hFIXco* transposon plasmid along with 100 ng hyPB resulted in a dose-dependent effect yielding therapeutic hFIX levels corresponding to 20% of normal levels. This represented a significant 20-fold increase ($p<0.001$) in FIX levels compared to when the mPB transposase was used (Fig 15G).

To evaluate the effect of the terminal repeats IR_{micro} and IR_{mut16} on the *in vivo* potency of the PB transposons, mice were hydrodynamically injected with *pB-hFIXco* (Fig.12B), *pB-hFIXco/*$IR_{mut16.}$ (Fig. 15A) or *B-hFIXco/*IR_{micro} (Fig. 15B) along with hyPBase. A significant 1.5-fold increase in hFIX expression was apparent when the IR_{micro} was used compared to its wild-type counterpart (Fig. 15 H-I). Liver-directed transfection of the *PB-hFIXco/*IR_{micro} transposon (500 ng) along with 1000 ng hyPB transposase-encoding plasmid resulted in stable FIX levels reaching approximately 300% of normal hFIX levels (Fig. 15H). Similarly, at 10-fold lower *PB-hFIXco/*IR_{micro} and hyPB doses a dose-dependent decrease in hFIX expression was apparent, yielding 30% of normal hFIX levels (Fig. 15I). In contrast, FIX

expression was not or only slighly increased when the IR_{mut16} was used compared to the IR_{wt}. (Fig. 15 J-K).

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CLAIMS:

1. A vector comprising a nucleic acid expression cassette comprising a Serpin enhancer defined by SEQ ID NO:8 or a sequence having at least 95% identity to SEQ ID NO:8, a promoter, a minute virus of mice (MVM) intron, a codon-optimized transgene encoding for coagulation factor IX (FIX) containing a hyper-activating mutation or a codon-optimized transgene encoding for coagulation factor VIII (FVIII) having a deletion of the B-domain, and a transcriptional termination signal.

2. The vector according to claim 1, wherein the B domain of said FVIII is replaced by a linker having SEQ ID NO:16.

3. The vector according to any one of claims 1 or 2, wherein said transgene encoding for coagulation factor VIII has SEQ ID NO:7.

4. The vector according to any one of claims 1 to 3, having SEQ ID NO: 6.

5. The vector according to claim 1, wherein said hyper-activating mutation corresponds to an R338L amino acid substitution.

6. The vector according to any one of claims 1 to 5, having SEQ ID NO: 1 or 2.

7. The vector according to any one of claims 1 to 6, wherein the promoter is derived from the transthyretin (TTR) promoter, preferably the minimal TTR promotor.

8. The vector according to any one of claims 1 to 7, wherein said transcriptional termination signal is derived from the Simian virus 40 polyadenylation signal or the bovine growth hormone polyadenylation signal.

9. The vector according to any one of claims 1 to 8, wherein said vector is a viral vector.

10. The vector according to claim 9, wherein said vector is derived from an adeno-associated virus (AAV).

11. The vector according to any one of claims 1 to 10, wherein said vector is a single-stranded AAV.

12. The vector according to claim 10, wherein said vector is a self-complementary AAV.

13. The vector according to any one of claims 1 to 3, 5, 7, or 8, wherein said vector is a non-viral vector.

14. The vector according to claim 13, wherein said vector is a transposon-based vector.

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15. The vector according to any one of claims 13 or 14, wherein said vector is a PiggyBac-based vector, preferably a PiggyBac-based vector comprising micro inverted repeats, or a Sleeping Beauty-based vector.

16. The use of the vector according to any one of claims 1 to 4, and 7 to 15 for the manufacture of a medicament to treat hemophilia A.

17. The use of the vector according to any one of claims 1, 5, 6, and 7 to 15 for the manufacture of a medicament to treat hemophilia B.

18. A method to obtain levels of factor VIII in plasma equal to or higher than the therapeutic threshold concentration of 10 mU/ml plasma in a subject, comprising the transduction or transfection of the vector according to any one of claims 1 to 4, and 7 to 15 into a subject.

19. A method to obtain levels of factor IX in plasma equal to or higher than the therapeutic threshold concentration of 10mU/ml plasma in a subject, comprising the transduction or transfection of the vector according to any one of claims 1, 5, 6, and 7 to 15 into a subject.

20. The method according to claim 18 or 19, wherein said transduction or transfection is by intravenous administration.

21. The method according to claim 18 or 19, wherein said transfection is by hydrodynamic transfection.

22. The method according to any one of claims 18, 19 or 21, wherein a vector according to any one of claims 14 or 15 is administered in combination with a vector encoding a transposase, preferably a hyperactive transposase.

23. The method according to any one of claims 18 to 22, wherein said subject is a mammalian subject.

24. The method according to claim 23, wherein said subject is a human subject.

25. A method for treating hemophilia A in a mammalian subject, comprising performing the method according to any one of claims 18, or 20 to 24.

26. A method for treating hemophilia B in a mammalian subject, comprising performing the method according to any one of claims 19 to 24.

27. The vector according to any one of claims 1 to 4, and 7 to 15 for use in the treatment of hemophilia A.

28. The vector according to any one of claims 1, 5, 6, and 7 to 15 for use in the treatment of hemophilia B.

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29. A pharmaceutical composition comprising a vector according to any one of claims 1 to 4, and 7-15 and a pharmaceutically acceptable carrier, optionally further comprising an active ingredient for treating hemophilia A.

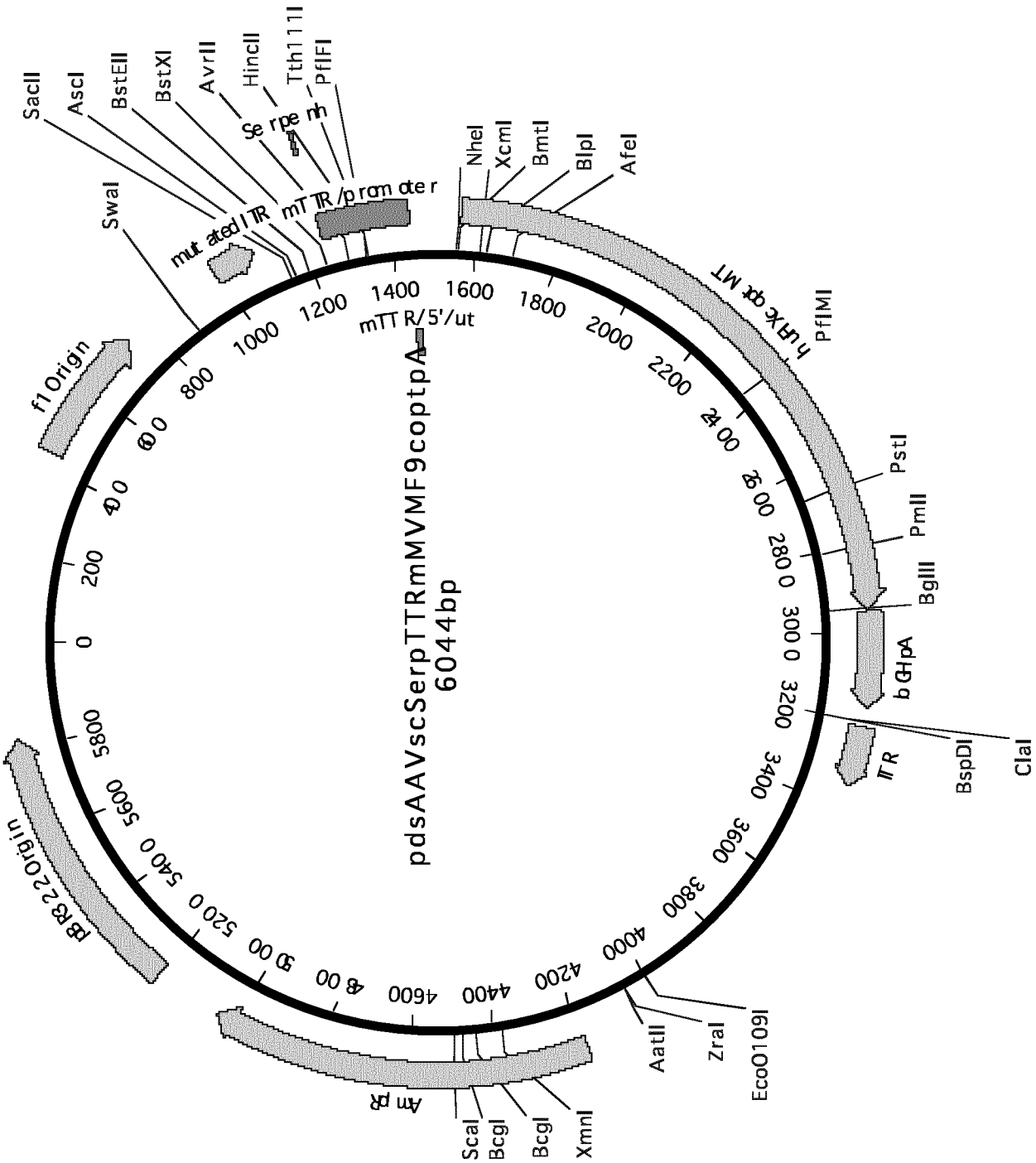
30. The pharmaceutical composition according to claim 29, for use in treating hemophilia A.

31. The pharmaceutical composition for use according to claim 30, or the vector for use according to claim 27, wherein said treatment results in levels of factor VIII in plasma of the treated subject that are equal to or higher than the therapeutic threshold concentration of 10 mU/ml plasma in a subject.

32. A pharmaceutical composition comprising a vector according to any one of claims 1, 5, 6, and 7 to 15 and a pharmaceutically acceptable carrier, optionally further comprising an active ingredient for treating hemophilia B.

33. The pharmaceutical composition according to claim 32, for use in treating hemophilia B.

34. The pharmaceutical composition for use according to claim 33, or the vector for use according to claim 28, wherein said treatment results in levels of factor IX in plasma of the treated subject that are equal to or higher than the therapeutic threshold concentration of 10 mU/ml plasma in a subject, preferably equal to or higher than the therapeutic concentration of 50 mU/ml plasma in a subject.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BstEII
BstXI
AvrII
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mTTR/5'ut
NheI
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PstI
PmlII
BglII
bGHpA
ITR
BspDI
ClaI
f1Origin
pBR322Origin
AmpR
ScaI
BcgI
BcgI
XmnI
AatII
ZraI
EcoO109I

Figure 1A

Figure 1B: SEQ ID 1

```
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GTCGTCGACCGCATTATCGCTTCTCCGGGCGTGGCTAGCGGGAAGGGTTG

         60         70         80         90        100
AGTTGCGCAGCCTGAATGGCGAATGGAATTCCAGACGATTGAGCGTCAAA
TCAACGCGTCGGACTTACCGCTTACCTTAAGGTCTGCTAACTCGCAGTTT

        110        120        130        140        150
ATGTAGGTATTTCCATGAGCGTTTTTCCTGTTGCAATGGCTGGCGGTAAT
TACATCCATAAAGGTACTCGCAAAAAGGACAACGTTACCGACCGCCATTA

        160        170        180        190        200
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        210        220        230        240        250
GGCAAGTGATGTTATTACTAATCAAAGAAGTATTGCGACAACGGTTAATT
CCGTTCACTACAATAATGATTAGTTTCTTCATAACGCTGTTGCCAATTAA

        260        270        280        290        300
TGCGTGATGGACAGACTCTTTTACTCGGTGGCCTCACTGATTATAAAAAC
ACGCACTACCTGTCTGAGAAAATGAGCCACCGGAGTGACTAATATTTTTG

        310        320        330        340        350
ACTTCTCAGGATTCTGGCGTACCGTTCCTGTCTAAAATCCCTTTAATCGG
TGAAGAGTCCTAAGACCGCATGGCAAGGACAGATTTTAGGGAAATTAGCC

        360        370        380        390        400
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GGAGGACAAATCGAGGGCGAGACTAAGATTGCTCCTTTCGTGCAATATGC

        410        420        430        440        450
TGCTCGTCAAAGCAACCATAGTACGCGCCCTGTAGCGGCGCATTAAGCGC
ACGAGCAGTTTCGTTGGTATCATGCGCGGGACATCGCCGCGTAATTCGCG
                                              ___________>

        460        470        480        490        500
GGCGGGTGTGGTGGTTACGCGCAGCGTGACCGCTACACTTGCCAGCGCCC
CCGCCCACACCACCAATGCGCGTCGCACTGGCGATGTGAACGGTCGCGGG
__________________F1 ORIGIN__________________>

        510        520        530        540        550
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__________________F1 ORIGIN__________________>

        560        570        580        590        600
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__________________F1 ORIGIN__________________>

        610        620        630        640        650
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TAGTGCTTTACGGCACCTCGACCCCAAAAAACTTGATTAGGGTGATGGTT
ATCACGAAATGCCGTGGAGCTGGGGTTTTTTGAACTAATCCCACTACCAA
_____________________F1 ORIGIN_____________________>

       660       670       680       690       700
CACGTAGTGGGCCATCGCCCTGATAGACGGTTTTTCGCCCTTTGACGTTG
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_____________________F1 ORIGIN_____________________>

       710       720       730       740       750
GAGTCCACGTTCTTTAATAGTGGACTCTTGTTCCAAACTGGAACAACACT
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____________________F1 ORIGIN____________________>

       760       770       780       790       800
CAACCCTATCTCGGTCTATTCTTTTGATTTATAAGGGATTTTGCCGATTT
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       810       820       830       840       850
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       860       870       880       890       900
TTTAACAAAATATTAACGTTTACAATTTAAATATTTGCTTATACAATCTT
AAATTGTTTTATAATTGCAAATGTTAAATTTATAAACGAATATGTTAGAA

       910       920       930       940       950
CCTGTTTTTGGGGCTTTTCTGATTATCAACCGGGGTACATATGATTGACA
GGACAAAAACCCCGAAAAGACTAATAGTTGGCCCCATGTATACTAACTGT

       960       970       980       990      1000
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                                  ___MUTATEDITR____>

      1010      1020      1030      1040      1050
CACTGAGGCCGCCCGGGCAAAGCCCGGGCGTCGGGCGACCTTTGGTCGCC
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_____________________MUTATEDITR_____________________>

      1060      1070      1080      1090      1100
CGGCCTCAGTGAGCGAGCGAGCGCGCAGAGAGGGAGTGGAATTCACGCGT
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_________________MUTATEDITR_________________>

      1110      1120      1130      1140      1150
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      1160      1170      1180      1190      1200
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                            >Serp_enh   >mTTR/promoter
                                   |     |
```

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      1210      1220      1230     |1240 |    1250
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      1260      1270      1280      1290      1300
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GTGTAAAGCATCTCGCTCACAAGGCTATGAGATTAGAGGGATCCGTTCCA

      1310      1320      1330      1340      1350
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      1360      1370      1380      1390      1400
CAGAATCAGCAGGTTTGGAGTCAGCTTGGCAGGGATCAGCAGCCTGGGTT
GTCTTAGTCGTCCAAACCTCAGTCGAACCGTCCCTAGTCGTCGGACCCAA

                                          >mTTR/5'/ut
                                                 |
      1410      1420      1430      1440      |  1450
GGAAGGAGGGGGTATAAAAGCCCCTTCACCAGGAGAAGCCGTCACACAGA
CCTTCCTCCCCCATATTTTCGGGGAAGTGGTCCTCTTCGGCAGTGTGTCT

           >MVMint
              |
      1460    | 1470      1480      1490      1500
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      1510      1520      1530      1540      1550
GTATTAATGTTTAATTACCTGGAGCACCTGCCTGAAATCACTTTTTTTCA
CATAATTACAAATTAATGGACCTCGTGGACGGACTTTAGTGAAAAAAAGT

      1560      1570      1580      1590      1600
GGTTGGCTAGCATGCAGCGCGTGAACATGATCATGGCCGAGAGCCCCGGC
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           _____________HUFIXCOPTMT_____________>

      1610      1620      1630      1640      1650
CTGATCACCATCTGCCTGCTGGGCTACCTGCTGAGCGCCGAGTGCACCGT
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_____________________HUFIXCOPTMT_____________________>

      1660      1670      1680      1690      1700
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_____________________HUFIXCOPTMT_____________________>

      1710      1720      1730      1740      1750
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TGTTGTCGCCGTTCGACCTCCTCAAGCACGTCCCGTTGGACCTCGCGCTC
_____________________HUFIXCOPTMT_____________________>

      1760      1770      1780      1790      1800
TGCATGGAGGAGAAGTGCAGCTTCGAGGAGGCCCGCGAGGTGTTCGAGAA
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_____________________HUFIXCOPTMT_____________________>

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_____________________HUFIXCOPTMT_____________________>

      1860      1870      1880      1890      1900
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_____________________HUFIXCOPTMT_____________________>

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_____________________HUFIXCOPTMT_____________________>

      1960      1970      1980      1990      2000
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_____________________HUFIXCOPTMT_____________________>

      2010      2020      2030      2040      2050
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_____________________HUFIXCOPTMT_____________________>

      2060      2070      2080      2090      2100
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_____________________HUFIXCOPTMT_____________________>

      2110      2120      2130      2140      2150
CGTGAGCGTGAGCCAGACCAGCAAGCTGACCCGCGCCGAGGCCGTGTTCC
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_____________________HUFIXCOPTMT_____________________>

      2160      2170      2180      2190      2200
CCGACGTGGACTACGTGAACAGCACCGAGGCCGAGACCATCCTGGACAAC
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_____________________HUFIXCOPTMT_____________________>

      2210      2220      2230      2240      2250
ATCACCCAGAGCACCCAGAGCTTCAACGACTTCACCCGCGTGGTGGGCGG
TAGTGGGTCTCGTGGGTCTCGAAGTTGCTGAAGTGGGCGCACCACCCGCC
_____________________HUFIXCOPTMT_____________________>

      2260      2270      2280      2290      2300
CGAGGACGCCAAGCCCGGCCAGTTCCCCTGGCAGGTGGTGCTGAACGGCA
GCTCCTGCGGTTCGGGCCGGTCAAGGGGACCGTCCACCACGACTTGCCGT
_____________________HUFIXCOPTMT_____________________>

      2310      2320      2330      2340      2350
AGGTGGACGCCTTCTGCGGCGGCAGCATCGTGAACGAGAAGTGGATCGTG
TCCACCTGCGGAAGACGCCGCCGTCGTAGCACTTGCTCTTCACCTAGCAC
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_____________________HUFIXCOPTMT_____________________>

      2360      2370      2380      2390      2400
ACCGCCGCCCACTGCGTGGAGACCGGCGTGAAGATCACCGTGGTGGCCGG
TGGCGGCGGGTGACGCACCTCTGGCCGCACTTCTAGTGGCACCACCGGCC
_____________________HUFIXCOPTMT_____________________>

      2410      2420      2430      2440      2450
CGAGCACAACATCGAGGAGACCGAGCACACCGAGCAGAAGCGCAACGTGA
GCTCGTGTTGTAGCTCCTCTGGCTCGTGTGGCTCGTCTTCGCGTTGCACT
_____________________HUFIXCOPTMT_____________________>

      2460      2470      2480      2490      2500
TCCGCATCATCCCCCACCACAACTACAACGCCGCCATCAACAAGTACAAC
AGGCGTAGTAGGGGGTGGTGTTGATGTTGCGGCGGTAGTTGTTCATGTTG
_____________________HUFIXCOPTMT_____________________>

      2510      2520      2530      2540      2550
CACGACATCGCCCTGCTGGAGCTGGACGAGCCCCTGGTGCTGAACAGCTA
GTGCTGTAGCGGGACGACCTCGACCTGCTCGGGGACCACGACTTGTCGAT
_____________________HUFIXCOPTMT_____________________>

      2560      2570      2580      2590      2600
CGTGACCCCCATCTGCATCGCCGACAAGGAGTACACCAACATCTTCCTGA
GCACTGGGGGTAGACGTAGCGGCTGTTCCTCATGTGGTTGTAGAAGGACT
_____________________HUFIXCOPTMT_____________________>

      2610      2620      2630      2640      2650
AGTTCGGCAGCGGCTACGTGAGCGGCTGGGGCCGCGTGTTCCACAAGGGC
TCAAGCCGTCGCCGATGCACTCGCCGACCCCGGCGCACAAGGTGTTCCCG
_____________________HUFIXCOPTMT_____________________>

      2660      2670      2680      2690      2700
CGCAGCGCCCTGGTGCTGCAGTACCTGCGCGTGCCCCTGGTGGACCGCGC
GCGTCGCGGGACCACGACGTCATGGACGCGCACGGGGACCACCTGGCGCG
_____________________HUFIXCOPTMT_____________________>

      2710      2720      2730      2740      2750
CACCTGCCTGCGCAGCACCAAGTTCACCATCTACAACAACATGTTCTGCG
GTGGACGGACGCGTCGTGGTTCAAGTGGTAGATGTTGTTGTACAAGACGC
_____________________HUFIXCOPTMT_____________________>

      2760      2770      2780      2790      2800
CCGGCTTCCACGAGGGCGGCCGCGACAGCTGCCAGGGCGACAGCGGCGGC
GGCCGAAGGTGCTCCCGCCGGCGCTGTCGACGGTCCCGCTGTCGCCGCCG
_____________________HUFIXCOPTMT_____________________>

      2810      2820      2830      2840      2850
CCCCACGTGACCGAGGTGGAGGGCACCAGCTTCCTGACCGGCATCATCAG
GGGGTGCACTGGCTCCACCTCCCGTGGTCGAAGGACTGGCCGTAGTAGTC
_____________________HUFIXCOPTMT_____________________>

      2860      2870      2880      2890      2900
CTGGGGCGAGGAGTGCGCCATGAAGGGCAAGTACGGCATCTACACCAAGG
GACCCCGCTCCTCACGCGGTACTTCCCGTTCATGCCGTAGATGTGGTTCC
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_____________________HUFIXCOPTMT____________________>

      2910      2920      2930      2940      2950
TGAGCCGCTACGTGAACTGGATCAAGGAGAAGACCAAGCTGACCTGGAGA
ACTCGGCGATGCACTTGACCTAGTTCCTCTTCTGGTTCGACTGGACCTCT
____________________HUFIXCOPTMT____________________>

      2960      2970      2980      2990      3000
TCTGATCAGCCTCGACTGTGCCTTCTAGTTGCCAGCCATCTGTTGTTTGC
AGACTAGTCGGAGCTGACACGGAAGATCAACGGTCGGTAGACAACAAACG
   ____________________BGHPA ____________________>

      3010      3020      3030      3040      3050
CCCTCCCCCGTGCCTTCCTTGACCCTGGAAGGTGCCACTCCCACTGTCCT
GGGAGGGGGCACGGAAGGAACTGGGACCTTCCACGGTGAGGGTGACAGGA
____________________BGHPA ____________________>

      3060      3070      3080      3090      3100
TTCCTAATAAAATGAGGAAATTGCATCGCATTGTCTGAGTAGGTGTCATT
AAGGATTATTTTACTCCTTTAACGTAGCGTAACAGACTCATCCACAGTAA
____________________BGHPA ____________________>

      3110      3120      3130      3140      3150
CTATTCTGGGGGGTGGGGTGGGGCAGGACAGCAAGGGGGAGGATTGGGAA
GATAAGACCCCCCACCCCACCCCGTCCTGTCGTTCCCCCTCCTAACCCTT
____________________BGHPA ____________________>

      3160      3170      3180      3190      3200
GACAATAGCAGGCATGCTGGGGATCTGATAGCAGGCATGCTGGGGAGAGA
CTGTTATCGTCCGTACGACCCCTAGACTATCGTCCGTACGACCCCTCTCT
_________BGHPA __________>

      3210      3220      3230      3240      3250
TCGATCTAGGAACCCCTAGTGATGGAGTTGGCCACTCCCTCTCTGCGCGC
AGCTAGATCCTTGGGGATCACTACCTCAACCGGTGAGGGAGAGACGCGCG
       ____________________ITR____________________>

      3260      3270      3280      3290      3300
TCGCTCGCTCACTGAGGCCGCCCGGGCAAAGCCCGGGCGTCGGGCGACCT
AGCGAGCGAGTGACTCCGGCGGGCCCGTTTCGGGCCCGCAGCCCGCTGGA
____________________ITR____________________>

      3310      3320      3330      3340      3350
TTGGTCGCCCGGCCTCAGTGAGCGAGCGAGCGCGCAGAGAGGGAGTGGCC
AACCAGCGGGCCGGAGTCACTCGCTCGCTCGCGCGTCTCTCCCTCACCGG
____________________ITR____________________>

      3360      3370      3380      3390      3400
AACCCCCCCCCCCCCCCCCCTGCATGCAGGCGATTCTCTTGTTTGCTCCA
TTGGGGGGGGGGGGGGGGGGACGTACGTCCGCTAAGAGAACAAACGAGGT
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      3410      3420      3430      3440      3450
GACTCTCAGGCAATGACCTGATAGCCTTTGTAGAGACCTCTCAAAAATAG
CTGAGAGTCCGTTACTGGACTATCGGAAACATCTCTGGAGAGTTTTTATC
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      3460       3470       3480       3490       3500
CTACCCTCTCCGGCATGAATTTATCAGCTAGAACGGTTGAATATCATATT
GATGGGAGAGGCCGTACTTAAATAGTCGATCTTGCCAACTTATAGTATAA

      3510       3520       3530       3540       3550
GATGGTGATTTGACTGTCTCCGGCCTTTCTCACCCGTTTGAATCTTTACC
CTACCACTAAACTGACAGAGGCCGGAAAGAGTGGGCAAACTTAGAAATGG

      3560       3570       3580       3590       3600
TACACATTACTCAGGCATTGCATTTAAAATATATGAGGGTTCTAAAAATT
ATGTGTAATGAGTCCGTAACGTAAATTTTATATACTCCCAAGATTTTTAA

      3610       3620       3630       3640       3650
TTTATCCTTGCGTTGAAATAAAGGCTTCTCCCGCAAAAGTATTACAGGGT
AAATAGGAACGCAACTTTATTTCCGAAGAGGGCGTTTTCATAATGTCCCA

      3660       3670       3680       3690       3700
CATAATGTTTTTGGTACAACCGATTTAGCTTTATGCTCTGAGGCTTTATT
GTATTACAAAAACCATGTTGGCTAAATCGAAATACGAGACTCCGAAATAA

      3710       3720       3730       3740       3750
GCTTAATTTTGCTAATTCTTTGCCTTGCCTGTATGATTTATTGGATGTTG
CGAATTAAAACGATTAAGAAACGGAACGGACATACTAAATAACCTACAAC

      3760       3770       3780       3790       3800
GAATTCCTGATGCGGTATTTTCTCCTTACGCATCTGTGCGGTATTTCACA
CTTAAGGACTACGCCATAAAAGAGGAATGCGTAGACACGCCATAAAGTGT

      3810       3820       3830       3840       3850
CCGCATATGGTGCACTCTCAGTACAATCTGCTCTGATGCCGCATAGTTAA
GGCGTATACCACGTGAGAGTCATGTTAGACGAGACTACGGCGTATCAATT

      3860       3870       3880       3890       3900
GCCAGCCCCGACACCCGCCAACACCCGCTGACGCGCCCTGACGGGCTTGT
CGGTCGGGGCTGTGGGCGGTTGTGGGCGACTGCGCGGGACTGCCCGAACA

      3910       3920       3930       3940       3950
CTGCTCCCGGCATCCGCTTACAGACAAGCTGTGACCGTCTCCGGGAGCTG
GACGAGGGCCGTAGGCGAATGTCTGTTCGACACTGGCAGAGGCCCTCGAC

      3960       3970       3980       3990       4000
CATGTGTCAGAGGTTTTCACCGTCATCACCGAAACGCGCGAGACGAAAGG
GTACACAGTCTCCAAAAGTGGCAGTAGTGGCTTTGCGCGCTCTGCTTTCC

      4010       4020       4030       4040       4050
GCCTCGTGATACGCCTATTTTTATAGGTTAATGTCATGATAATAATGGTT
CGGAGCACTATGCGGATAAAAATATCCAATTACAGTACTATTATTACCAA

      4060       4070       4080       4090       4100
TCTTAGACGTCAGGTGGCACTTTTCGGGGAAATGTGCGCGGAACCCCTAT
AGAATCTGCAGTCCACCGTGAAAAGCCCCTTTACACGCGCCTTGGGGATA

      4110       4120       4130       4140       4150
TTGTTTATTTTTCTAAATACATTCAAATATGTATCCGCTCATGAGACAAT
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AACAAATAAAAAGATTTATGTAAGTTTATACATAGGCGAGTACTCTGTTA

      4160      4170      4180      4190      4200
AACCCTGATAAATGCTTCAATAATATTGAAAAAGGAAGAGTATGAGTATT
TTGGGACTATTTACGAAGTTATTATAACTTTTTCCTTCTCATACTCATAA
                                                _____>

      4210      4220      4230      4240      4250
CAACATTTCCGTGTCGCCCTTATTCCCTTTTTTGCGGCATTTTGCCTTCC
GTTGTAAAGGCACAGCGGGAATAAGGGAAAAAACGCCGTAAAACGGAAGG
_____________________AMPR_____________________>

      4260      4270      4280      4290      4300
TGTTTTTGCTCACCCAGAAACGCTGGTGAAAGTAAAAGATGCTGAAGATC
ACAAAAACGAGTGGGTCTTTGCGACCACTTTCATTTTCTACGACTTCTAG
_____________________AMPR_____________________>

      4310      4320      4330      4340      4350
AGTTGGGTGCACGAGTGGGTTACATCGAACTGGATCTCAACAGCGGTAAG
TCAACCCACGTGCTCACCCAATGTAGCTTGACCTAGAGTTGTCGCCATTC
_____________________AMPR_____________________>

      4360      4370      4380      4390      4400
ATCCTTGAGAGTTTTCGCCCCGAAGAACGTTTTCCAATGATGAGCACTTT
TAGGAACTCTCAAAAGCGGGGCTTCTTGCAAAAGGTTACTACTCGTGAAA
_____________________AMPR_____________________>

      4410      4420      4430      4440      4450
TAAAGTTCTGCTATGTGGCGCGGTATTATCCCGTATTGACGCCGGGCAAG
ATTTCAAGACGATACACCGCGCCATAATAGGGCATAACTGCGGCCCGTTC
_____________________AMPR_____________________>

      4460      4470      4480      4490      4500
AGCAACTCGGTCGCCGCATACACTATTCTCAGAATGACTTGGTTGAGTAC
TCGTTGAGCCAGCGGCGTATGTGATAAGAGTCTTACTGAACCAACTCATG
_____________________AMPR_____________________>

      4510      4520      4530      4540      4550
TCACCAGTCACAGAAAAGCATCTTACGGATGGCATGACAGTAAGAGAATT
AGTGGTCAGTGTCTTTTCGTAGAATGCCTACCGTACTGTCATTCTCTTAA
_____________________AMPR_____________________>

      4560      4570      4580      4590      4600
ATGCAGTGCTGCCATAACCATGAGTGATAACACTGCGGCCAACTTACTTC
TACGTCACGACGGTATTGGTACTCACTATTGTGACGCCGGTTGAATGAAG
_____________________AMPR_____________________>

      4610      4620      4630      4640      4650
TGACAACGATCGGAGGACCGAAGGAGCTAACCGCTTTTTTGCACAACATG
ACTGTTGCTAGCCTCCTGGCTTCCTCGATTGGCGAAAAAACGTGTTGTAC
_____________________AMPR_____________________>

      4660      4670      4680      4690      4700
GGGGATCATGTAACTCGCCTTGATCGTTGGGAACCGGAGCTGAATGAAGC
CCCCTAGTACATTGAGCGGAACTAGCAACCCTTGGCCTCGACTTACTTCG
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_____________________AMPR_____________________>

      4710      4720      4730      4740      4750
CATACCAAACGACGAGCGTGACACCACGATGCCTGTAGCAATGGCAACAA
GTATGGTTTGCTGCTCGCACTGTGGTGCTACGGACATCGTTACCGTTGTT
_____________________AMPR_____________________>

      4760      4770      4780      4790      4800
CGTTGCGCAAACTATTAACTGGCGAACTACTTACTCTAGCTTCCCGGCAA
GCAACGCGTTTGATAATTGACCGCTTGATGAATGAGATCGAAGGGCCGTT
_____________________AMPR_____________________>

      4810      4820      4830      4840      4850
CAATTAATAGACTGGATGGAGGCGGATAAAGTTGCAGGACCACTTCTGCG
GTTAATTATCTGACCTACCTCCGCCTATTTCAACGTCCTGGTGAAGACGC
_____________________AMPR_____________________>

      4860      4870      4880      4890      4900
CTCGGCCCTTCCGGCTGGCTGGTTTATTGCTGATAAATCTGGAGCCGGTG
GAGCCGGGAAGGCCGACCGACCAAATAACGACTATTTAGACCTCGGCCAC
_____________________AMPR_____________________>

      4910      4920      4930      4940      4950
AGCGTGGGTCTCGCGGTATCATTGCAGCACTGGGGCCAGATGGTAAGCCC
TCGCACCCAGAGCGCCATAGTAACGTCGTGACCCCGGTCTACCATTCGGG
_____________________AMPR_____________________>

      4960      4970      4980      4990      5000
TCCCGTATCGTAGTTATCTACACGACGGGGAGTCAGGCAACTATGGATGA
AGGGCATAGCATCAATAGATGTGCTGCCCCTCAGTCCGTTGATACCTACT
_____________________AMPR_____________________>

      5010      5020      5030      5040      5050
ACGAAATAGACAGATCGCTGAGATAGGTGCCTCACTGATTAAGCATTGGT
TGCTTTATCTGTCTAGCGACTCTATCCACGGAGTGACTAATTCGTAACCA
_____________________AMPR_____________________>

      5060      5070      5080      5090      5100
AACTGTCAGACCAAGTTTACTCATATATACTTTAGATTGATTTAAAACTT
TTGACAGTCTGGTTCAAATGAGTATATATGAAATCTAACTAAATTTTGAA
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      5110      5120      5130      5140      5150
CATTTTTAATTTAAAAGGATCTAGGTGAAGATCCTTTTTGATAATCTCAT
GTAAAAATTAAATTTTCCTAGATCCACTTCTAGGAAAAACTATTAGAGTA

      5160      5170      5180      5190      5200
GACCAAAATCCCTTAACGTGAGTTTTCGTTCCACTGAGCGTCAGACCCCG
CTGGTTTTAGGGAATTGCACTCAAAAGCAAGGTGACTCGCAGTCTGGGGC

      5210      5220      5230      5240      5250
TAGAAAAGATCAAAGGATCTTCTTGAGATCCTTTTTTTCTGCGCGTAATC
ATCTTTTCTAGTTTCCTAGAAGAACTCTAGGAAAAAAAGACGCGCATTAG
      _________________PBR322 ORIGIN_________________>
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      5260      5270      5280      5290      5300
TGCTGCTTGCAAACAAAAAAACCACCGCTACCAGCGGTGGTTTGTTTGCC
ACGACGAACGTTTGTTTTTTTGGTGGCGATGGTCGCCACCAAACAAACGG
_____________________PBR322 ORIGIN_____________________>

      5310      5320      5330      5340      5350
GGATCAAGAGCTACCAACTCTTTTTCCGAAGGTAACTGGCTTCAGCAGAG
CCTAGTTCTCGATGGTTGAGAAAAAGGCTTCCATTGACCGAAGTCGTCTC
_____________________PBR322 ORIGIN_____________________>

      5360      5370      5380      5390      5400
CGCAGATACCAAATACTGTCCTTCTAGTGTAGCCGTAGTTAGGCCACCAC
GCGTCTATGGTTTATGACAGGAAGATCACATCGGCATCAATCCGGTGGTG
_____________________PBR322 ORIGIN_____________________>

      5410      5420      5430      5440      5450
TTCAAGAACTCTGTAGCACCGCCTACATACCTCGCTCTGCTAATCCTGTT
AAGTTCTTGAGACATCGTGGCGGATGTATGGAGCGAGACGATTAGGACAA
_____________________PBR322 ORIGIN_____________________>

      5460      5470      5480      5490      5500
ACCAGTGGCTGCTGCCAGTGGCGATAAGTCGTGTCTTACCGGGTTGGACT
TGGTCACCGACGACGGTCACCGCTATTCAGCACAGAATGGCCCAACCTGA
_____________________PBR322 ORIGIN_____________________>

      5510      5520      5530      5540      5550
CAAGACGATAGTTACCGGATAAGGCGCAGCGGTCGGGCTGAACGGGGGGT
GTTCTGCTATCAATGGCCTATTCCGCGTCGCCAGCCCGACTTGCCCCCCA
_____________________PBR322 ORIGIN_____________________>

      5560      5570      5580      5590      5600
TCGTGCACACAGCCCAGCTTGGAGCGAACGACCTACACCGAACTGAGATA
AGCACGTGTGTCGGGTCGAACCTCGCTTGCTGGATGTGGCTTGACTCTAT
_____________________PBR322 ORIGIN_____________________>

      5610      5620      5630      5640      5650
CCTACAGCGTGAGCTATGAGAAAGCGCCACGCTTCCCGAAGGGAGAAAGG
GGATGTCGCACTCGATACTCTTTCGCGGTGCGAAGGGCTTCCCTCTTTCC
_____________________PBR322 ORIGIN_____________________>

      5660      5670      5680      5690      5700
CGGACAGGTATCCGGTAAGCGGCAGGGTCGGAACAGGAGAGCGCACGAGG
GCCTGTCCATAGGCCATTCGCCGTCCCAGCCTTGTCCTCTCGCGTGCTCC
_____________________PBR322 ORIGIN_____________________>

      5710      5720      5730      5740      5750
GAGCTTCCAGGGGGAAACGCCTGGTATCTTTATAGTCCTGTCGGGTTTCG
CTCGAAGGTCCCCCTTTGCGGACCATAGAAATATCAGGACAGCCCAAAGC
_____________________PBR322 ORIGIN_____________________>

      5760      5770      5780      5790      5800
CCACCTCTGACTTGAGCGTCGATTTTTGTGATGCTCGTCAGGGGGGCGGA
GGTGGAGACTGAACTCGCAGCTAAAAACACTACGAGCAGTCCCCCCGCCT
_____________________PBR322 ORIGIN_____________________>
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      5810      5820      5830      5840      5850
GCCTATGGAAAAACGCCAGCAACGCGGCCTTTTTACGGTTCCTGGCCTTT
CGGATACCTTTTTGCGGTCGTTGCGCCGGAAAAATGCCAAGGACCGGAAA
______PBR322 ORIGIN_______>

      5860      5870      5880      5890      5900
TGCTGGCCTTTTGCTCACATGTTCTTTCCTGCGTTATCCCCTGATTCTGT
ACGACCGGAAAACGAGTGTACAAGAAAGGACGCAATAGGGGACTAAGACA

      5910      5920      5930      5940      5950
GGATAACCGTATTACCGCCTTTGAGTGAGCTGATACCGCTCGCCGCAGCC
CCTATTGGCATAATGGCGGAAACTCACTCGACTATGGCGAGCGGCGTCGG

      5960      5970      5980      5990      6000
GAACGACCGAGCGCAGCGAGTCAGTGAGCGAGGAAGCGGAAGAGCGCCCA
CTTGCTGGCTCGCGTCGCTCAGTCACTCGCTCCTTCGCCTTCTCGCGGGT

      6010      6020      6030      6040
ATACGCAAACCGCCTCTCCCCGCGCGTTGGCCGATTCATTAATG
TATGCGTTTGGCGGAGAGGGGCGCGCAACCGGCTAAGTAATTAC
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Figure 1C: SEQ ID 2

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        10         20         30         40         50
CAGCAGCTGGCGTAATAGCGAAGAGGCCCGCACCGATCGCCCTTCCCAAC
GTCGTCGACCGCATTATCGCTTCTCCGGGCGTGGCTAGCGGGAAGGGTTG

        60         70         80         90        100
AGTTGCGCAGCCTGAATGGCGAATGGAATTCCAGACGATTGAGCGTCAAA
TCAACGCGTCGGACTTACCGCTTACCTTAAGGTCTGCTAACTCGCAGTTT

       110        120        130        140        150
ATGTAGGTATTTCCATGAGCGTTTTTCCTGTTGCAATGGCTGGCGGTAAT
TACATCCATAAAGGTACTCGCAAAAAGGACAACGTTACCGACCGCCATTA

       160        170        180        190        200
ATTGTTCTGGATATTACCAGCAAGGCCGATAGTTTGAGTTCTTCTACTCA
TAACAAGACCTATAATGGTCGTTCCGGCTATCAAACTCAAGAAGATGAGT

       210        220        230        240        250
GGCAAGTGATGTTATTACTAATCAAAGAAGTATTGCGACAACGGTTAATT
CCGTTCACTACAATAATGATTAGTTTCTTCATAACGCTGTTGCCAATTAA

       260        270        280        290        300
TGCGTGATGGACAGACTCTTTTACTCGGTGGCCTCACTGATTATAAAAAC
ACGCACTACCTGTCTGAGAAAATGAGCCACCGGAGTGACTAATATTTTTG

       310        320        330        340        350
ACTTCTCAGGATTCTGGCGTACCGTTCCTGTCTAAAATCCCTTTAATCGG
TGAAGAGTCCTAAGACCGCATGGCAAGGACAGATTTTAGGGAAATTAGCC

       360        370        380        390        400
CCTCCTGTTTAGCTCCCGCTCTGATTCTAACGAGGAAAGCACGTTATACG
GGAGGACAAATCGAGGGCGAGACTAAGATTGCTCCTTTCGTGCAATATGC

       410        420        430        440        450
TGCTCGTCAAAGCAACCATAGTACGCGCCCTGTAGCGGCGCATTAAGCGC
ACGAGCAGTTTCGTTGGTATCATGCGCGGGACATCGCCGCGTAATTCGCG
                                              _________>

       460        470        480        490        500
GGCGGGTGTGGTGGTTACGCGCAGCGTGACCGCTACACTTGCCAGCGCCC
CCGCCCACACCACCAATGCGCGTCGCACTGGCGATGTGAACGGTCGCGGG
_____________________F1 ORIGIN_____________________>

       510        520        530        540        550
TAGCGCCCGCTCCTTTCGCTTTCTTCCCTTCCTTTCTCGCCACGTTCGCC
ATCGCGGGCGAGGAAAGCGAAAGAAGGGAAGGAAAGAGCGGTGCAAGCGG
_____________________F1 ORIGIN_____________________>

       560        570        580        590        600
GGCTTTCCCCGTCAAGCTCTAAATCGGGGGCTCCCTTTAGGGTTCCGATT
CCGAAAGGGGCAGTTCGAGATTTAGCCCCCGAGGGAAATCCCAAGGCTAA
_____________________F1 ORIGIN_____________________>
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       610        620        630        640        650
TAGTGCTTTACGGCACCTCGACCCCAAAAAACTTGATTAGGGTGATGGTT
ATCACGAAATGCCGTGGAGCTGGGGTTTTTTGAACTAATCCCACTACCAA
_____________________F1 ORIGIN_____________________>

       660        670        680        690        700
CACGTAGTGGGCCATCGCCCTGATAGACGGTTTTTCGCCCTTTGACGTTG
GTGCATCACCCGGTAGCGGGACTATCTGCCAAAAAGCGGGAAACTGCAAC
_____________________F1 ORIGIN_____________________>

       710        720        730        740        750
GAGTCCACGTTCTTTAATAGTGGACTCTTGTTCCAAACTGGAACAACACT
CTCAGGTGCAAGAAATTATCACCTGAGAACAAGGTTTGACCTTGTTGTGA
___________________F1 ORIGIN___________________>

       760        770        780        790        800
CAACCCTATCTCGGTCTATTCTTTTGATTTATAAGGGATTTTGCCGATTT
GTTGGGATAGAGCCAGATAAGAAAACTAAATATTCCCTAAAACGGCTAAA

       810        820        830        840        850
CGGCCTATTGGTTAAAAAATGAGCTGATTTAACAAAAATTTAACGCGAAT
GCCGGATAACCAATTTTTTACTCGACTAAATTGTTTTTAAATTGCGCTTA

       860        870        880        890        900
TTTAACAAAATATTAACGTTTACAATTTAAATATTTGCTTATACAATCTT
AAATTGTTTTATAATTGCAAATGTTAAATTTATAAACGAATATGTTAGAA

       910        920        930        940        950
CCTGTTTTTGGGGCTTTTCTGATTATCAACCGGGGTACATATGATTGACA
GGACAAAAACCCCGAAAAGACTAATAGTTGGCCCCATGTATACTAACTGT

       960        970        980        990       1000
TGCTAGTTTTACGATTACCGTTCATCGCCTGCACTGCGCGCTCGCTCGCT
ACGATCAAAATGCTAATGGCAAGTAGCGGACGTGACGCGCGAGCGAGCGA
                                  ___MUTATEDITR____>

      1010       1020       1030       1040       1050
CACTGAGGCCGCCCGGGCAAAGCCCGGGCGTCGGGCGACCTTTGGTCGCC
GTGACTCCGGCGGGCCCGTTTCGGGCCCGCAGCCCGCTGGAAACCAGCGG
_____________________MUTATEDITR_____________________>

      1060       1070       1080       1090       1100
CGGCCTCAGTGAGCGAGCGAGCGCGCAGAGAGGGAGTGGAATTCACGCGT
GCCGGAGTCACTCGCTCGCTCGCGCGTCTCTCCCTCACCTTAAGTGCGCA
_________________MUTATEDITR_________________>

      1110       1120       1130       1140       1150
GGTACGATCTGAATTCGGTACAATTCACGCGTGGTACGGCCGCGGTACCG
CCATGCTAGACTTAAGCCATGTTAAGTGCGCACCATGCCGGCGCCATGGC

      1160       1170       1180       1190       1200
GCGCGCCGGGGGAGGCTGCTGGTGAATATTAACCAAGGTCACCCCAGTTA
CGCGCGGCCCCCTCCGACGACCACTTATAATTGGTTCCAGTGGGGTCAAT

                              >Serp_enh    >mTTR/promoter
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                                      |     |
      1210      1220      1230      |1240 |    1250
TCGGAGGAGCAAACAGGGGCTAAGTCCACACGCGTGGTACCGTCTGTCTG
AGCCTCCTCGTTTGTCCCCGATTCAGGTGTGCGCACCATGGCAGACAGAC

      1260      1270      1280      1290      1300
CACATTTCGTAGAGCGAGTGTTCCGATACTCTAATCTCCCTAGGCAAGGT
GTGTAAAGCATCTCGCTCACAAGGCTATGAGATTAGAGGGATCCGTTCCA

      1310      1320      1330      1340      1350
TCATATTTGTGTAGGTTACTTATTCTCCTTTTGTTGACTAAGTCAATAAT
AGTATAAACACATCCAATGAATAAGAGGAAAACAACTGATTCAGTTATTA

      1360      1370      1380      1390      1400
CAGAATCAGCAGGTTTGGAGTCAGCTTGGCAGGGATCAGCAGCCTGGGTT
GTCTTAGTCGTCCAAACCTCAGTCGAACCGTCCCTAGTCGTCGGACCCAA

                                        >mTTR/5'/ut
                                                |
      1410      1420      1430      1440      |  1450
GGAAGGAGGGGGTATAAAAGCCCCTTCACCAGGAGAAGCCGTCACACAGA
CCTTCCTCCCCCATATTTTCGGGGAAGTGGTCCTCTTCGGCAGTGTGTCT

           >MVMint
              |
      1460    | 1470      1480      1490      1500
TCCACAAGCTCCTGAAGAGGTAAGGGTTTAAGGGATGGTTGGTTGGTGGG
AGGTGTTCGAGGACTTCTCCATTCCCAAATTCCCTACCAACCAACCACCC

      1510      1520      1530      1540      1550
GTATTAATGTTTAATTACCTGGAGCACCTGCCTGAAATCACTTTTTTTCA
CATAATTACAAATTAATGGACCTCGTGGACGGACTTTAGTGAAAAAAAGT

      1560      1570      1580      1590      1600
GGTTGGCTAGCATGCAGCGCGTGAACATGATCATGGCCGAGAGCCCCGGC
CCAACCGATCGTACGTCGCGCACTTGTACTAGTACCGGCTCTCGGGGCCG
            _____________HUFIXCOPTMT_____________>

      1610      1620      1630      1640      1650
CTGATCACCATCTGCCTGCTGGGCTACCTGCTGAGCGCCGAGTGCACCGT
GACTAGTGGTAGACGGACGACCCGATGGACGACTCGCGGCTCACGTGGCA
____________________HUFIXCOPTMT____________________>

      1660      1670      1680      1690      1700
GTTCCTGGACCACGAGAACGCCAACAAGATCCTGAACCGCCCCAAGCGCT
CAAGGACCTGGTGCTCTTGCGGTTGTTCTAGGACTTGGCGGGGTTCGCGA
____________________HUFIXCOPTMT____________________>

      1710      1720      1730      1740      1750
ACAACAGCGGCAAGCTGGAGGAGTTCGTGCAGGGCAACCTGGAGCGCGAG
TGTTGTCGCCGTTCGACCTCCTCAAGCACGTCCCGTTGGACCTCGCGCTC
____________________HUFIXCOPTMT____________________>

      1760      1770      1780      1790      1800
TGCATGGAGGAGAAGTGCAGCTTCGAGGAGGCCCGCGAGGTGTTCGAGAA
```

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ACGTACCTCCTCTTCACGTCGAAGCTCCTCCGGGCGCTCCACAAGCTCTT
_____________________HUFIXCOPTMT_____________________>

      1810      1820      1830      1840      1850
CACCGAGCGCACCACCGAGTTCTGGAAGCAGTACGTGGACGGCGACCAGT
GTGGCTCGCGTGGTGGCTCAAGACCTTCGTCATGCACCTGCCGCTGGTCA
_____________________HUFIXCOPTMT_____________________>

      1860      1870      1880      1890      1900
GCGAGAGCAACCCCTGCCTGAACGGCGGCAGCTGCAAGGACGACATCAAC
CGCTCTCGTTGGGGACGGACTTGCCGCCGTCGACGTTCCTGCTGTAGTTG
_____________________HUFIXCOPTMT_____________________>

      1910      1920      1930      1940      1950
AGCTACGAGTGCTGGTGCCCCTTCGGCTTCGAGGGCAAGAACTGCGAGCT
TCGATGCTCACGACCACGGGGAAGCCGAAGCTCCCGTTCTTGACGCTCGA
_____________________HUFIXCOPTMT_____________________>

      1960      1970      1980      1990      2000
GGACGTGACCTGCAACATCAAGAACGGCCGCTGCGAGCAGTTCTGCAAGA
CCTGCACTGGACGTTGTAGTTCTTGCCGGCGACGCTCGTCAAGACGTTCT
_____________________HUFIXCOPTMT_____________________>

      2010      2020      2030      2040      2050
ACAGCGCCGACAACAAGGTGGTGTGCAGCTGCACCGAGGGCTACCGCCTG
TGTCGCGGCTGTTGTTCCACCACACGTCGACGTGGCTCCCGATGGCGGAC
_____________________HUFIXCOPTMT_____________________>

      2060      2070      2080      2090      2100
GCCGAGAACCAGAAGAGCTGCGAGCCCGCCGTGCCCTTCCCCTGCGGCCG
CGGCTCTTGGTCTTCTCGACGCTCGGGCGGCACGGGAAGGGGACGCCGGC
_____________________HUFIXCOPTMT_____________________>

      2110      2120      2130      2140      2150
CGTGAGCGTGAGCCAGACCAGCAAGCTGACCCGCGCCGAGGCCGTGTTCC
GCACTCGCACTCGGTCTGGTCGTTCGACTGGGCGCGGCTCCGGCACAAGG
_____________________HUFIXCOPTMT_____________________>

      2160      2170      2180      2190      2200
CCGACGTGGACTACGTGAACAGCACCGAGGCCGAGACCATCCTGGACAAC
GGCTGCACCTGATGCACTTGTCGTGGCTCCGGCTCTGGTAGGACCTGTTG
_____________________HUFIXCOPTMT_____________________>

      2210      2220      2230      2240      2250
ATCACCCAGAGCACCCAGAGCTTCAACGACTTCACCCGCGTGGTGGGCGG
TAGTGGGTCTCGTGGGTCTCGAAGTTGCTGAAGTGGGCGCACCACCCGCC
_____________________HUFIXCOPTMT_____________________>

      2260      2270      2280      2290      2300
CGAGGACGCCAAGCCCGGCCAGTTCCCCTGGCAGGTGGTGCTGAACGGCA
GCTCCTGCGGTTCGGGCCGGTCAAGGGGACCGTCCACCACGACTTGCCGT
_____________________HUFIXCOPTMT_____________________>

      2310      2320      2330      2340      2350
AGGTGGACGCCTTCTGCGGCGGCAGCATCGTGAACGAGAAGTGGATCGTG
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TCCACCTGCGGAAGACGCCGCCGTCGTAGCACTTGCTCTTCACCTAGCAC
_____________________HUFIXCOPTMT_____________________>

      2360      2370      2380      2390      2400
ACCGCCGCCCACTGCGTGGAGACCGGCGTGAAGATCACCGTGGTGGCCGG
TGGCGGCGGGTGACGCACCTCTGGCCGCACTTCTAGTGGCACCACCGGCC
_____________________HUFIXCOPTMT_____________________>

      2410      2420      2430      2440      2450
CGAGCACAACATCGAGGAGACCGAGCACACCGAGCAGAAGCGCAACGTGA
GCTCGTGTTGTAGCTCCTCTGGCTCGTGTGGCTCGTCTTCGCGTTGCACT
_____________________HUFIXCOPTMT_____________________>

      2460      2470      2480      2490      2500
TCCGCATCATCCCCCACCACAACTACAACGCCGCCATCAACAAGTACAAC
AGGCGTAGTAGGGGGTGGTGTTGATGTTGCGGCGGTAGTTGTTCATGTTG
_____________________HUFIXCOPTMT_____________________>

      2510      2520      2530      2540      2550
CACGACATCGCCCTGCTGGAGCTGGACGAGCCCCTGGTGCTGAACAGCTA
GTGCTGTAGCGGGACGACCTCGACCTGCTCGGGGACCACGACTTGTCGAT
_____________________HUFIXCOPTMT_____________________>

      2560      2570      2580      2590      2600
CGTGACCCCCATCTGCATCGCCGACAAGGAGTACACCAACATCTTCCTGA
GCACTGGGGGTAGACGTAGCGGCTGTTCCTCATGTGGTTGTAGAAGGACT
_____________________HUFIXCOPTMT_____________________>

      2610      2620      2630      2640      2650
AGTTCGGCAGCGGCTACGTGAGCGGCTGGGGCCGCGTGTTCCACAAGGGC
TCAAGCCGTCGCCGATGCACTCGCCGACCCCGGCGCACAAGGTGTTCCCG
_____________________HUFIXCOPTMT_____________________>

      2660      2670      2680      2690      2700
CGCAGCGCCCTGGTGCTGCAGTACCTGCGCGTGCCCCTGGTGGACCGCGC
GCGTCGCGGGACCACGACGTCATGGACGCGCACGGGGACCACCTGGCGCG
_____________________HUFIXCOPTMT_____________________>

      2710      2720      2730      2740      2750
CACCTGCCTGCTGAGCACCAAGTTCACCATCTACAACAACATGTTCTGCG
GTGGACGGACGACGTCGTGGTTCAAGTGGTAGATGTTGTTGTACAAGACGC
_____________________HUFIXCOPTMT_____________________>

      2760      2770      2780      2790      2800
CCGGCTTCCACGAGGGCGGCCGCGACAGCTGCCAGGGCGACAGCGGCGGC
GGCCGAAGGTGCTCCCGCCGGCGCTGTCGACGGTCCCGCTGTCGCCGCCG
_____________________HUFIXCOPTMT_____________________>

      2810      2820      2830      2840      2850
CCCCACGTGACCGAGGTGGAGGGCACCAGCTTCCTGACCGGCATCATCAG
GGGGTGCACTGGCTCCACCTCCCGTGGTCGAAGGACTGGCCGTAGTAGTC
_____________________HUFIXCOPTMT_____________________>

      2860      2870      2880      2890      2900
CTGGGGCGAGGAGTGCGCCATGAAGGGCAAGTACGGCATCTACACCAAGG
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GACCCCGCTCCTCACGCGGTACTTCCCGTTCATGCCGTAGATGTGGTTCC
_____________________HUFIXCOPTMT____________________>

      2910       2920       2930       2940       2950
TGAGCCGCTACGTGAACTGGATCAAGGAGAAGACCAAGCTGACCTGGAGA
ACTCGGCGATGCACTTGACCTAGTTCCTCTTCTGGTTCGACTGGACCTCT
____________________HUFIXCOPTMT____________________>

      2960       2970       2980       2990       3000
TCTGATCAGCCTCGACTGTGCCTTCTAGTTGCCAGCCATCTGTTGTTTGC
AGACTAGTCGGAGCTGACACGGAAGATCAACGGTCGGTAGACAACAAACG
   ____________________BGHPA ____________________>

      3010       3020       3030       3040       3050
CCCTCCCCCGTGCCTTCCTTGACCCTGGAAGGTGCCACTCCCACTGTCCT
GGGAGGGGGCACGGAAGGAACTGGGACCTTCCACGGTGAGGGTGACAGGA
____________________BGHPA ____________________>

      3060       3070       3080       3090       3100
TTCCTAATAAAATGAGGAAATTGCATCGCATTGTCTGAGTAGGTGTCATT
AAGGATTATTTTACTCCTTTAACGTAGCGTAACAGACTCATCCACAGTAA
____________________BGHPA ____________________>

      3110       3120       3130       3140       3150
CTATTCTGGGGGGTGGGGTGGGGCAGGACAGCAAGGGGGAGGATTGGGAA
GATAAGACCCCCCACCCCACCCCGTCCTGTCGTTCCCCCTCCTAACCCTT
____________________BGHPA ____________________>

      3160       3170       3180       3190       3200
GACAATAGCAGGCATGCTGGGGATCTGATAGCAGGCATGCTGGGGAGAGA
CTGTTATCGTCCGTACGACCCCTAGACTATCGTCCGTACGACCCCTCTCT
________BGHPA _________>

      3210       3220       3230       3240       3250
TCGATCTAGGAACCCCTAGTGATGGAGTTGGCCACTCCCTCTCTGCGCGC
AGCTAGATCCTTGGGGATCACTACCTCAACCGGTGAGGGAGAGACGCGCG
       ____________________ITR____________________>

      3260       3270       3280       3290       3300
TCGCTCGCTCACTGAGGCCGCCCGGGCAAAGCCCGGGCGTCGGGCGACCT
AGCGAGCGAGTGACTCCGGCGGGCCCGTTTCGGGCCCGCAGCCCGCTGGA
____________________ITR____________________>

      3310       3320       3330       3340       3350
TTGGTCGCCCGGCCTCAGTGAGCGAGCGAGCGCGCAGAGAGGGAGTGGCC
AACCAGCGGGCCGGAGTCACTCGCTCGCTCGCGCGTCTCTCCCTCACCGG
____________________ITR____________________>

      3360       3370       3380       3390       3400
AACCCCCCCCCCCCCCCCCCTGCATGCAGGCGATTCTCTTGTTTGCTCCA
TTGGGGGGGGGGGGGGGGGGACGTACGTCCGCTAAGAGAACAAACGAGGT
__>

      3410       3420       3430       3440       3450
GACTCTCAGGCAATGACCTGATAGCCTTTGTAGAGACCTCTCAAAAATAG
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CTGAGAGTCCGTTACTGGACTATCGGAAACATCTCTGGAGAGTTTTTATC

      3460      3470      3480      3490      3500
CTACCCTCTCCGGCATGAATTTATCAGCTAGAACGGTTGAATATCATATT
GATGGGAGAGGCCGTACTTAAATAGTCGATCTTGCCAACTTATAGTATAA

      3510      3520      3530      3540      3550
GATGGTGATTTGACTGTCTCCGGCCTTTCTCACCCGTTTGAATCTTTACC
CTACCACTAAACTGACAGAGGCCGGAAAGAGTGGGCAAACTTAGAAATGG

      3560      3570      3580      3590      3600
TACACATTACTCAGGCATTGCATTTAAAATATATGAGGGTTCTAAAAATT
ATGTGTAATGAGTCCGTAACGTAAATTTTATATACTCCCAAGATTTTTAA

      3610      3620      3630      3640      3650
TTTATCCTTGCGTTGAAATAAAGGCTTCTCCCGCAAAAGTATTACAGGGT
AAATAGGAACGCAACTTTATTTCCGAAGAGGGCGTTTTCATAATGTCCCA

      3660      3670      3680      3690      3700
CATAATGTTTTTGGTACAACCGATTTAGCTTTATGCTCTGAGGCTTTATT
GTATTACAAAAACCATGTTGGCTAAATCGAAATACGAGACTCCGAAATAA

      3710      3720      3730      3740      3750
GCTTAATTTTGCTAATTCTTTGCCTTGCCTGTATGATTTATTGGATGTTG
CGAATTAAAACGATTAAGAAACGGAACGGACATACTAAATAACCTACAAC

      3760      3770      3780      3790      3800
GAATTCCTGATGCGGTATTTTCTCCTTACGCATCTGTGCGGTATTTCACA
CTTAAGGACTACGCCATAAAAGAGGAATGCGTAGACACGCCATAAAGTGT

      3810      3820      3830      3840      3850
CCGCATATGGTGCACTCTCAGTACAATCTGCTCTGATGCCGCATAGTTAA
GGCGTATACCACGTGAGAGTCATGTTAGACGAGACTACGGCGTATCAATT

      3860      3870      3880      3890      3900
GCCAGCCCCGACACCCGCCAACACCCGCTGACGCGCCCTGACGGGCTTGT
CGGTCGGGGCTGTGGGCGGTTGTGGGCGACTGCGCGGGACTGCCCGAACA

      3910      3920      3930      3940      3950
CTGCTCCCGGCATCCGCTTACAGACAAGCTGTGACCGTCTCCGGGAGCTG
GACGAGGGCCGTAGGCGAATGTCTGTTCGACACTGGCAGAGGCCCTCGAC

      3960      3970      3980      3990      4000
CATGTGTCAGAGGTTTTCACCGTCATCACCGAAACGCGCGAGACGAAAGG
GTACACAGTCTCCAAAAGTGGCAGTAGTGGCTTTGCGCGCTCTGCTTTCC

      4010      4020      4030      4040      4050
GCCTCGTGATACGCCTATTTTTATAGGTTAATGTCATGATAATAATGGTT
CGGAGCACTATGCGGATAAAAATATCCAATTACAGTACTATTATTACCAA

      4060      4070      4080      4090      4100
TCTTAGACGTCAGGTGGCACTTTTCGGGGAAATGTGCGCGGAACCCCTAT
AGAATCTGCAGTCCACCGTGAAAAGCCCCTTTACACGCGCCTTGGGGATA

      4110      4120      4130      4140      4150
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TTGTTTATTTTTCTAAATACATTCAAATATGTATCCGCTCATGAGACAAT
AACAAATAAAAAGATTTATGTAAGTTTATACATAGGCGAGTACTCTGTTA

      4160      4170      4180      4190      4200
AACCCTGATAAATGCTTCAATAATATTGAAAAAGGAAGAGTATGAGTATT
TTGGGACTATTTACGAAGTTATTATAACTTTTTCCTTCTCATACTCATAA
                                                _____>

      4210      4220      4230      4240      4250
CAACATTTCCGTGTCGCCCTTATTCCCTTTTTTGCGGCATTTTGCCTTCC
GTTGTAAAGGCACAGCGGGAATAAGGGAAAAAACGCCGTAAAACGGAAGG
_____________________AMPR_____________________>

      4260      4270      4280      4290      4300
TGTTTTTGCTCACCCAGAAACGCTGGTGAAAGTAAAAGATGCTGAAGATC
ACAAAAACGAGTGGGTCTTTGCGACCACTTTCATTTTCTACGACTTCTAG
_____________________AMPR_____________________>

      4310      4320      4330      4340      4350
AGTTGGGTGCACGAGTGGGTTACATCGAACTGGATCTCAACAGCGGTAAG
TCAACCCACGTGCTCACCCAATGTAGCTTGACCTAGAGTTGTCGCCATTC
_____________________AMPR_____________________>

      4360      4370      4380      4390      4400
ATCCTTGAGAGTTTTCGCCCCGAAGAACGTTTTCCAATGATGAGCACTTT
TAGGAACTCTCAAAAGCGGGGCTTCTTGCAAAAGGTTACTACTCGTGAAA
_____________________AMPR_____________________>

      4410      4420      4430      4440      4450
TAAAGTTCTGCTATGTGGCGCGGTATTATCCCGTATTGACGCCGGGCAAG
ATTTCAAGACGATACACCGCGCCATAATAGGGCATAACTGCGGCCCGTTC
_____________________AMPR_____________________>

      4460      4470      4480      4490      4500
AGCAACTCGGTCGCCGCATACACTATTCTCAGAATGACTTGGTTGAGTAC
TCGTTGAGCCAGCGGCGTATGTGATAAGAGTCTTACTGAACCAACTCATG
_____________________AMPR_____________________>

      4510      4520      4530      4540      4550
TCACCAGTCACAGAAAAGCATCTTACGGATGGCATGACAGTAAGAGAATT
AGTGGTCAGTGTCTTTTCGTAGAATGCCTACCGTACTGTCATTCTCTTAA
_____________________AMPR_____________________>

      4560      4570      4580      4590      4600
ATGCAGTGCTGCCATAACCATGAGTGATAACACTGCGGCCAACTTACTTC
TACGTCACGACGGTATTGGTACTCACTATTGTGACGCCGGTTGAATGAAG
_____________________AMPR_____________________>

      4610      4620      4630      4640      4650
TGACAACGATCGGAGGACCGAAGGAGCTAACCGCTTTTTTGCACAACATG
ACTGTTGCTAGCCTCCTGGCTTCCTCGATTGGCGAAAAAACGTGTTGTAC
_____________________AMPR_____________________>

      4660      4670      4680      4690      4700
GGGGATCATGTAACTCGCCTTGATCGTTGGGAACCGGAGCTGAATGAAGC
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CCCCTAGTACATTGAGCGGAACTAGCAACCCTTGGCCTCGACTTACTTCG
_____________________AMPR_____________________>

      4710      4720      4730      4740      4750
CATACCAAACGACGAGCGTGACACCACGATGCCTGTAGCAATGGCAACAA
GTATGGTTTGCTGCTCGCACTGTGGTGCTACGGACATCGTTACCGTTGTT
_____________________AMPR_____________________>

      4760      4770      4780      4790      4800
CGTTGCGCAAACTATTAACTGGCGAACTACTTACTCTAGCTTCCCGGCAA
GCAACGCGTTTGATAATTGACCGCTTGATGAATGAGATCGAAGGGCCGTT
_____________________AMPR_____________________>

      4810      4820      4830      4840      4850
CAATTAATAGACTGGATGGAGGCGGATAAAGTTGCAGGACCACTTCTGCG
GTTAATTATCTGACCTACCTCCGCCTATTTCAACGTCCTGGTGAAGACGC
_____________________AMPR_____________________>

      4860      4870      4880      4890      4900
CTCGGCCCTTCCGGCTGGCTGGTTTATTGCTGATAAATCTGGAGCCGGTG
GAGCCGGGAAGGCCGACCGACCAAATAACGACTATTTAGACCTCGGCCAC
_____________________AMPR_____________________>

      4910      4920      4930      4940      4950
AGCGTGGGTCTCGCGGTATCATTGCAGCACTGGGGCCAGATGGTAAGCCC
TCGCACCCAGAGCGCCATAGTAACGTCGTGACCCCGGTCTACCATTCGGG
_____________________AMPR_____________________>

      4960      4970      4980      4990      5000
TCCCGTATCGTAGTTATCTACACGACGGGGAGTCAGGCAACTATGGATGA
AGGGCATAGCATCAATAGATGTGCTGCCCCTCAGTCCGTTGATACCTACT
_____________________AMPR_____________________>

      5010      5020      5030      5040      5050
ACGAAATAGACAGATCGCTGAGATAGGTGCCTCACTGATTAAGCATTGGT
TGCTTTATCTGTCTAGCGACTCTATCCACGGAGTGACTAATTCGTAACCA
_____________________AMPR_____________________>

      5060      5070      5080      5090      5100
AACTGTCAGACCAAGTTTACTCATATATACTTTAGATTGATTTAAAACTT
TTGACAGTCTGGTTCAAATGAGTATATATGAAATCTAACTAAATTTTGAA
__>

      5110      5120      5130      5140      5150
CATTTTTAATTTAAAAGGATCTAGGTGAAGATCCTTTTTGATAATCTCAT
GTAAAAATTAAATTTTCCTAGATCCACTTCTAGGAAAAACTATTAGAGTA

      5160      5170      5180      5190      5200
GACCAAAATCCCTTAACGTGAGTTTTCGTTCCACTGAGCGTCAGACCCCG
CTGGTTTTAGGGAATTGCACTCAAAAGCAAGGTGACTCGCAGTCTGGGGC

      5210      5220      5230      5240      5250
TAGAAAAGATCAAAGGATCTTCTTGAGATCCTTTTTTTCTGCGCGTAATC
ATCTTTTCTAGTTTCCTAGAAGAACTCTAGGAAAAAAAGACGCGCATTAG
      _________________PBR322 ORIGIN_________________>
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      5260      5270      5280      5290      5300
TGCTGCTTGCAAACAAAAAAACCACCGCTACCAGCGGTGGTTTGTTTGCC
ACGACGAACGTTTGTTTTTTTGGTGGCGATGGTCGCCACCAAACAAACGG
_____________________PBR322 ORIGIN_____________________>

      5310      5320      5330      5340      5350
GGATCAAGAGCTACCAACTCTTTTTCCGAAGGTAACTGGCTTCAGCAGAG
CCTAGTTCTCGATGGTTGAGAAAAAGGCTTCCATTGACCGAAGTCGTCTC
_____________________PBR322 ORIGIN_____________________>

      5360      5370      5380      5390      5400
CGCAGATACCAAATACTGTCCTTCTAGTGTAGCCGTAGTTAGGCCACCAC
GCGTCTATGGTTTATGACAGGAAGATCACATCGGCATCAATCCGGTGGTG
_____________________PBR322 ORIGIN_____________________>

      5410      5420      5430      5440      5450
TTCAAGAACTCTGTAGCACCGCCTACATACCTCGCTCTGCTAATCCTGTT
AAGTTCTTGAGACATCGTGGCGGATGTATGGAGCGAGACGATTAGGACAA
_____________________PBR322 ORIGIN_____________________>

      5460      5470      5480      5490      5500
ACCAGTGGCTGCTGCCAGTGGCGATAAGTCGTGTCTTACCGGGTTGGACT
TGGTCACCGACGACGGTCACCGCTATTCAGCACAGAATGGCCCAACCTGA
_____________________PBR322 ORIGIN_____________________>

      5510      5520      5530      5540      5550
CAAGACGATAGTTACCGGATAAGGCGCAGCGGTCGGGCTGAACGGGGGGT
GTTCTGCTATCAATGGCCTATTCCGCGTCGCCAGCCCGACTTGCCCCCCA
_____________________PBR322 ORIGIN_____________________>

      5560      5570      5580      5590      5600
TCGTGCACACAGCCCAGCTTGGAGCGAACGACCTACACCGAACTGAGATA
AGCACGTGTGTCGGGTCGAACCTCGCTTGCTGGATGTGGCTTGACTCTAT
_____________________PBR322 ORIGIN_____________________>

      5610      5620      5630      5640      5650
CCTACAGCGTGAGCTATGAGAAAGCGCCACGCTTCCCGAAGGGAGAAAGG
GGATGTCGCACTCGATACTCTTTCGCGGTGCGAAGGGCTTCCCTCTTTCC
_____________________PBR322 ORIGIN_____________________>

      5660      5670      5680      5690      5700
CGGACAGGTATCCGGTAAGCGGCAGGGTCGGAACAGGAGAGCGCACGAGG
GCCTGTCCATAGGCCATTCGCCGTCCCAGCCTTGTCCTCTCGCGTGCTCC
_____________________PBR322 ORIGIN_____________________>

      5710      5720      5730      5740      5750
GAGCTTCCAGGGGGAAACGCCTGGTATCTTTATAGTCCTGTCGGGTTTCG
CTCGAAGGTCCCCCTTTGCGGACCATAGAAATATCAGGACAGCCCAAAGC
_____________________PBR322 ORIGIN_____________________>

      5760      5770      5780      5790      5800
CCACCTCTGACTTGAGCGTCGATTTTTGTGATGCTCGTCAGGGGGGCGGA
GGTGGAGACTGAACTCGCAGCTAAAAACACTACGAGCAGTCCCCCCGCCT
_____________________PBR322 ORIGIN_____________________>
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      5810      5820      5830      5840      5850
GCCTATGGAAAAACGCCAGCAACGCGGCCTTTTTACGGTTCCTGGCCTTT
CGGATACCTTTTTGCGGTCGTTGCGCCGGAAAAATGCCAAGGACCGGAAA
______PBR322 ORIGIN_______>

      5860      5870      5880      5890      5900
TGCTGGCCTTTTGCTCACATGTTCTTTCCTGCGTTATCCCCTGATTCTGT
ACGACCGGAAAACGAGTGTACAAGAAAGGACGCAATAGGGGACTAAGACA

      5910      5920      5930      5940      5950
GGATAACCGTATTACCGCCTTTGAGTGAGCTGATACCGCTCGCCGCAGCC
CCTATTGGCATAATGGCGGAAACTCACTCGACTATGGCGAGCGGCGTCGG

      5960      5970      5980      5990      6000
GAACGACCGAGCGCAGCGAGTCAGTGAGCGAGGAAGCGGAAGAGCGCCCA
CTTGCTGGCTCGCGTCGCTCAGTCACTCGCTCCTTCGCCTTCTCGCGGGT

      6010      6020      6030      6040
ATACGCAAACCGCCTCTCCCCGCGCGTTGGCCGATTCATTAATG
TATGCGTTTGGCGGAGAGGGGCGCGCAACCGGCTAAGTAATTAC
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Fig. 2

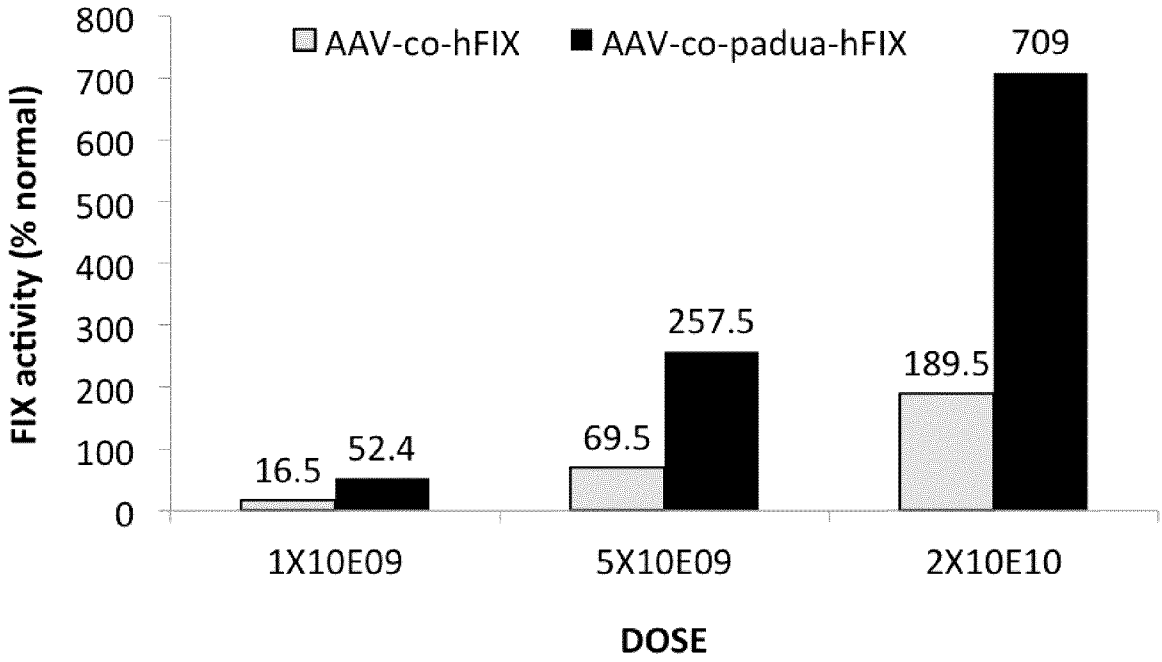
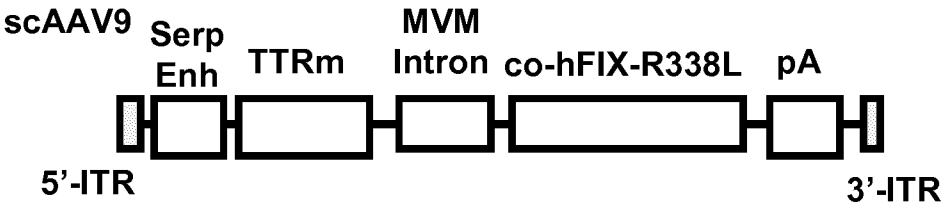

800
700
600
500
400
300
200
100
0
FIX activity (% normal)
AAV-co-hFIX
AAV-co-padua-hFIX
16.5
52.4
69.5
257.5
189.5
709
1X10E09
5X10E09
2X10E10
DOSE

Fig. 3

A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MVM Intron
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pA
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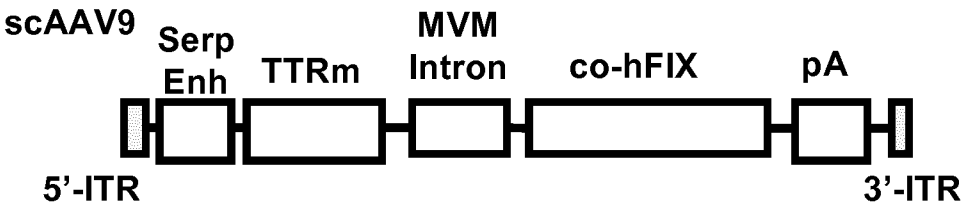
B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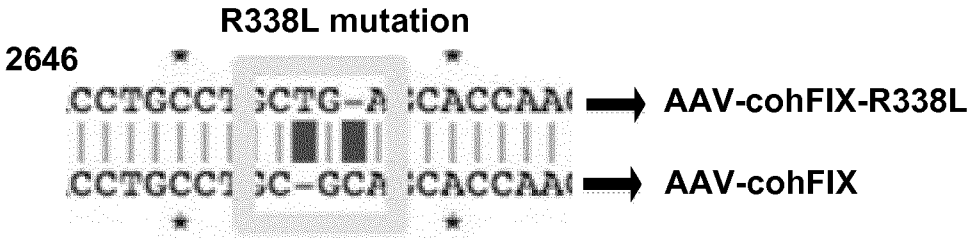
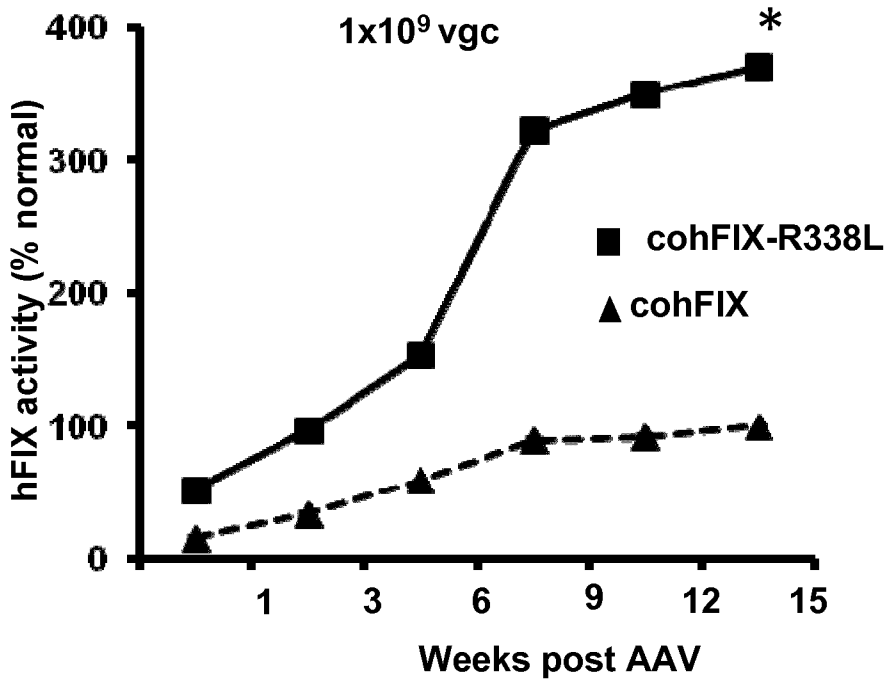

R338L mutation
2646
AAV-cohFIX-R338L
AAV-cohFIX

Fig. 4

A


1x10⁹ vgc
*
400
300
200
100
0
hFIX activity (% normal)
cohFIX-R338L
cohFIX
1
3
6
9
12
15
Weeks post AAV

B

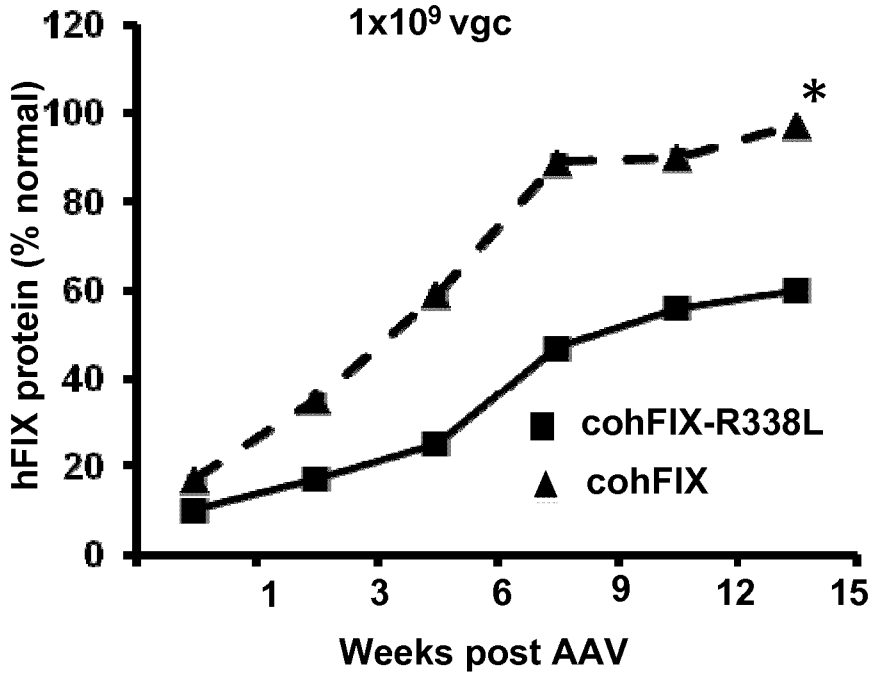
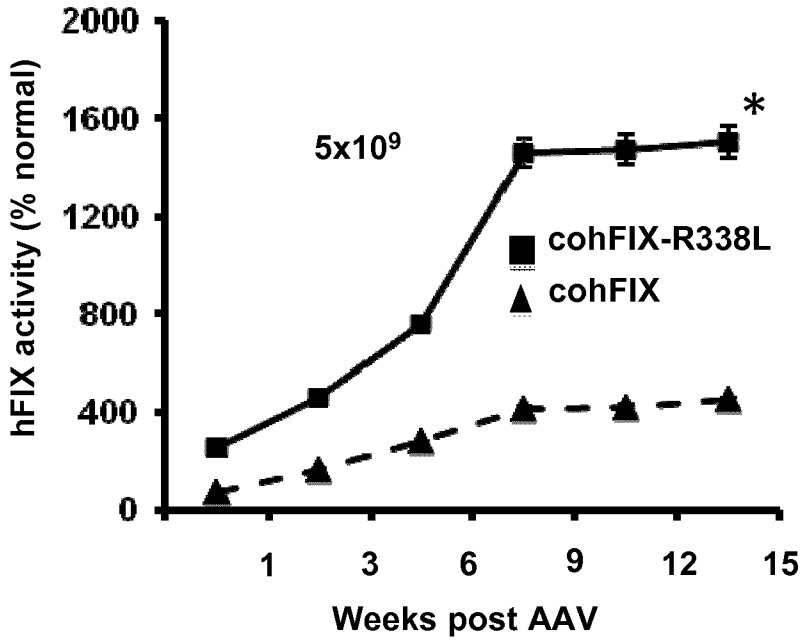
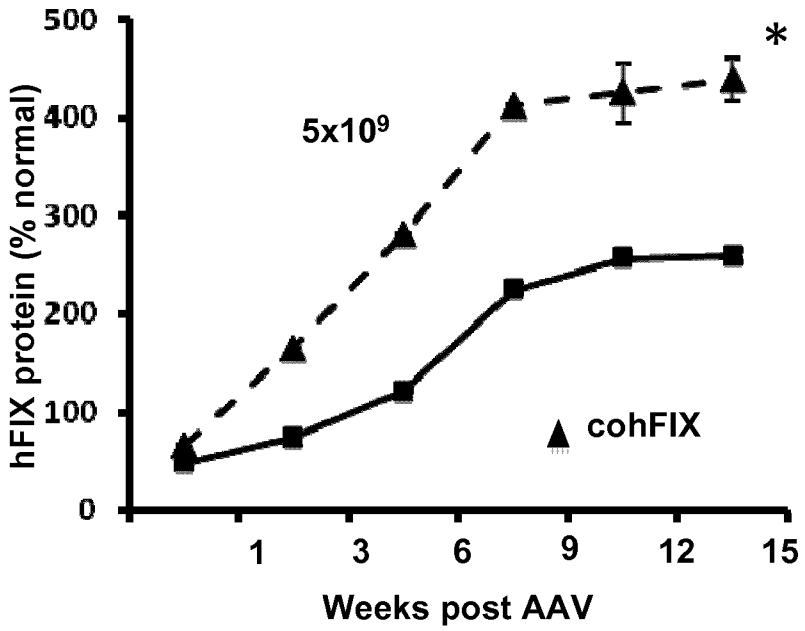

1x10⁹ vgc
*
120
100
80
60
40
20
0
hFIX protein (% normal)
cohFIX-R338L
cohFIX
1
3
6
9
12
15
Weeks post AAV

Fig. 4

C


2000
1600
1200
800
400
0
hFIX activity (% normal)
5x10⁹
*
cohFIX-R338L
cohFIX
1
3
6
9
12
15
Weeks post AAV

D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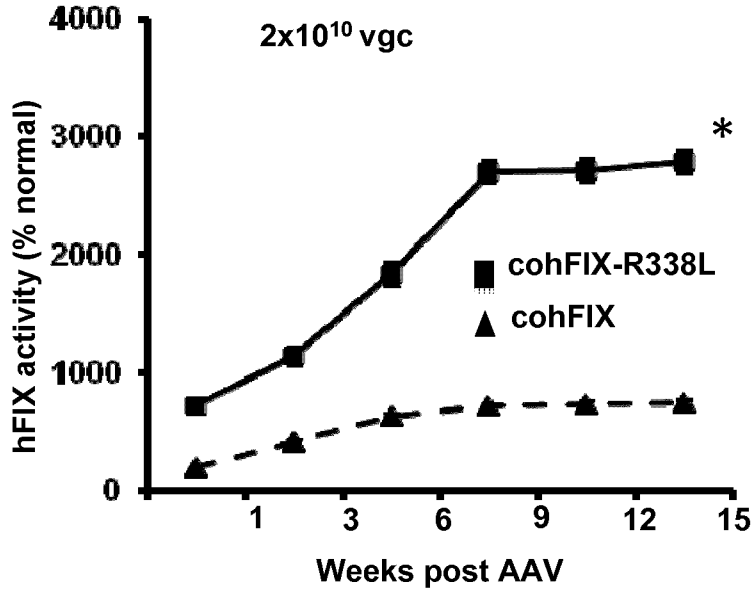
400
300
200
100
0
hFIX protein (% normal)
5x10⁹
*
cohFIX
1
3
6
9
12
15
Weeks post AAV

Fig. 4

E


4000
3000
2000
1000
0
2x10^10 vgc
*
hFIX activity (% normal)
cohFIX-R338L
cohFIX
1
3
6
9
12
15
Weeks post AAV

F

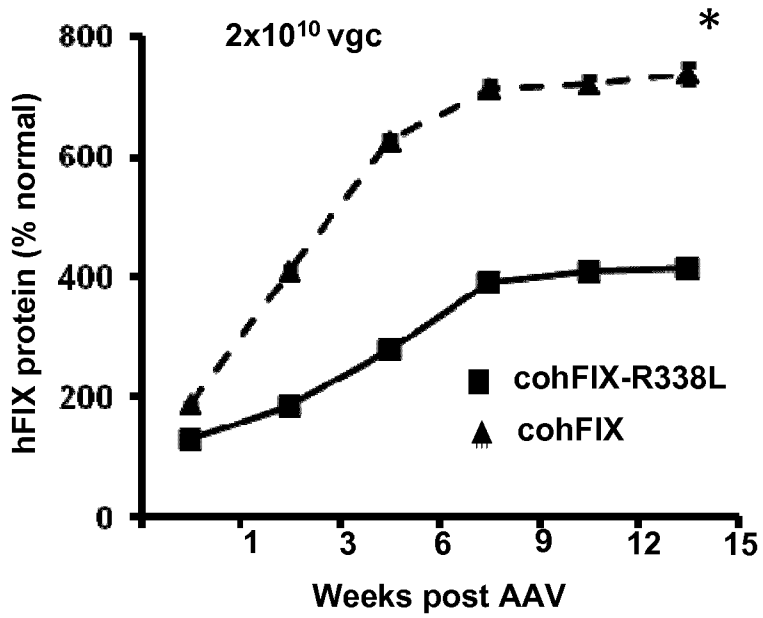
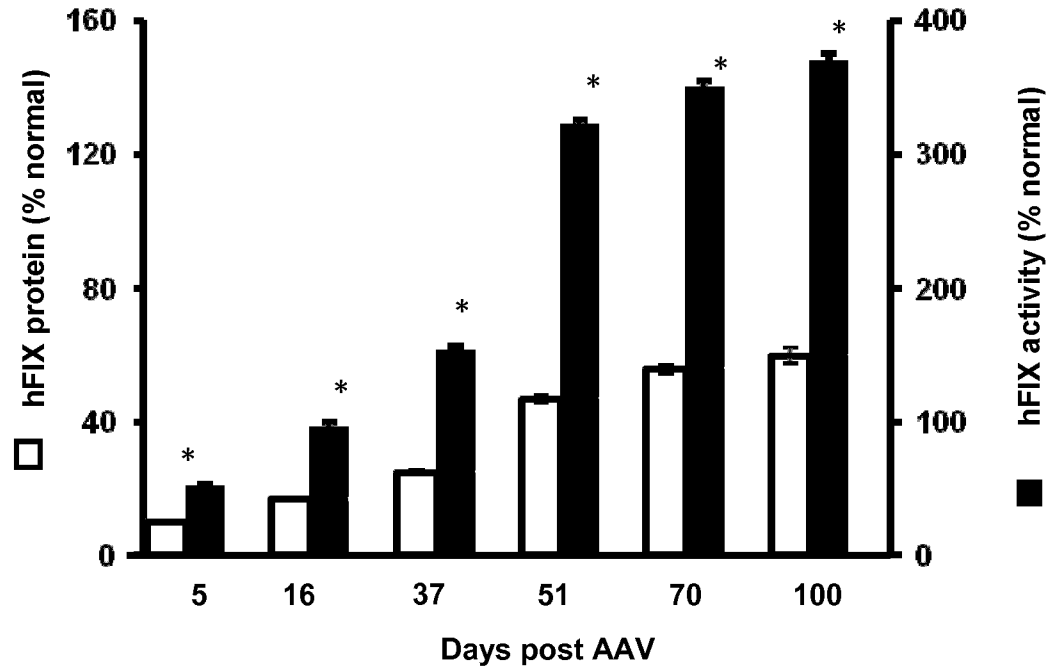

800
600
400
200
0
2x10^10 vgc
*
hFIX protein (% normal)
cohFIX-R338L
cohFIX
1
3
6
9
12
15
Weeks post AAV

Fig. 4

G


hFIX protein (% normal)
hFIX activity (% normal)
160
120
80
40
0
400
300
200
100
0
5
16
37
51
70
100
Days post AAV

H

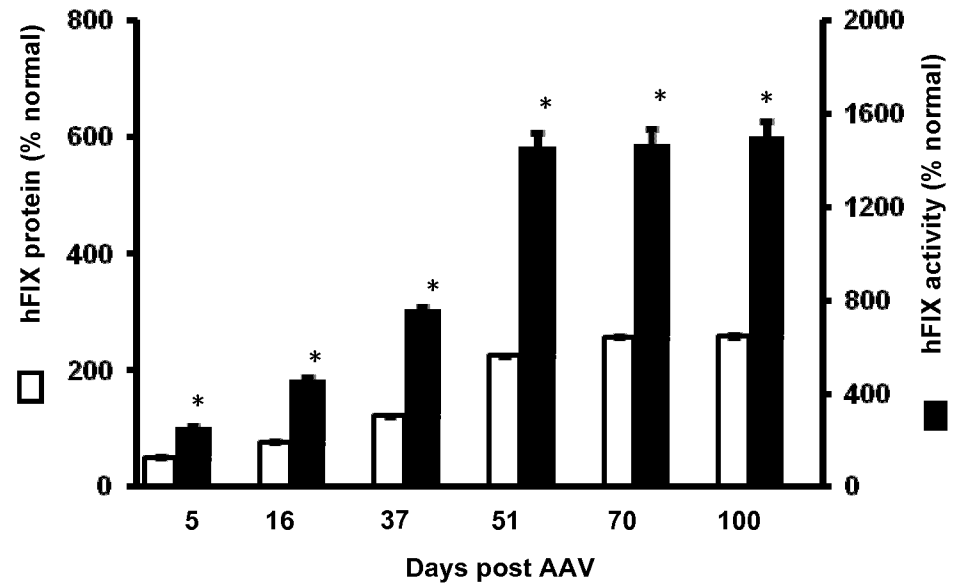

hFIX protein (% normal)
hFIX activity (% normal)
800
600
400
200
0
2000
1600
1200
800
400
0
5
16
37
51
70
100
Days post AAV

Fig. 4

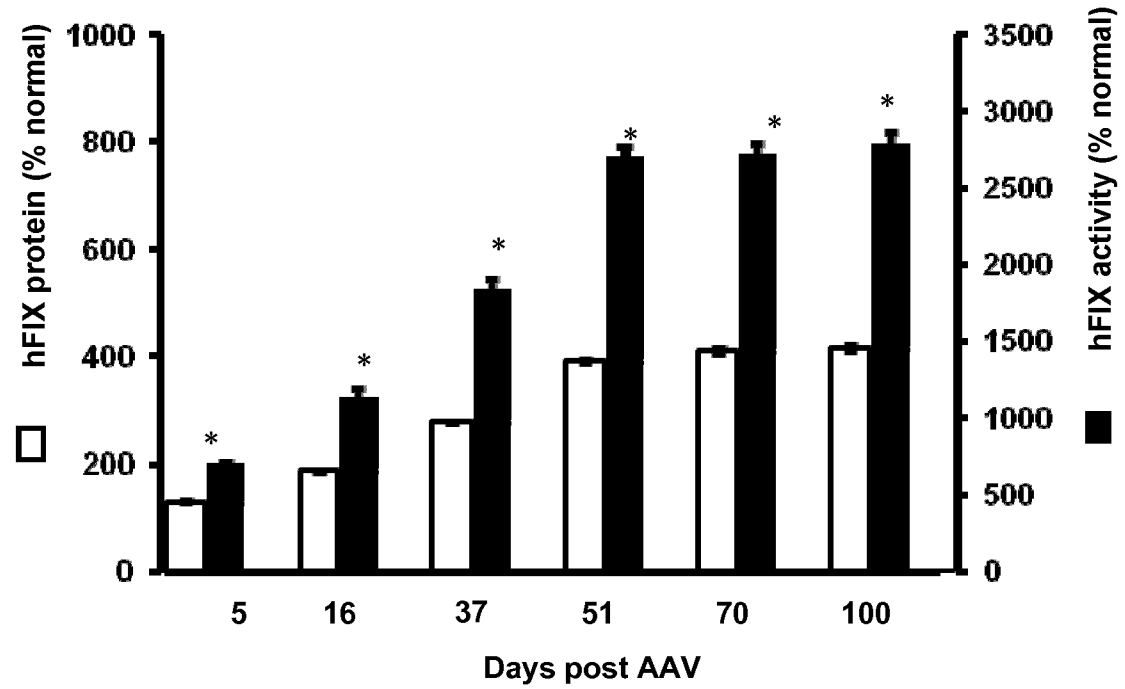
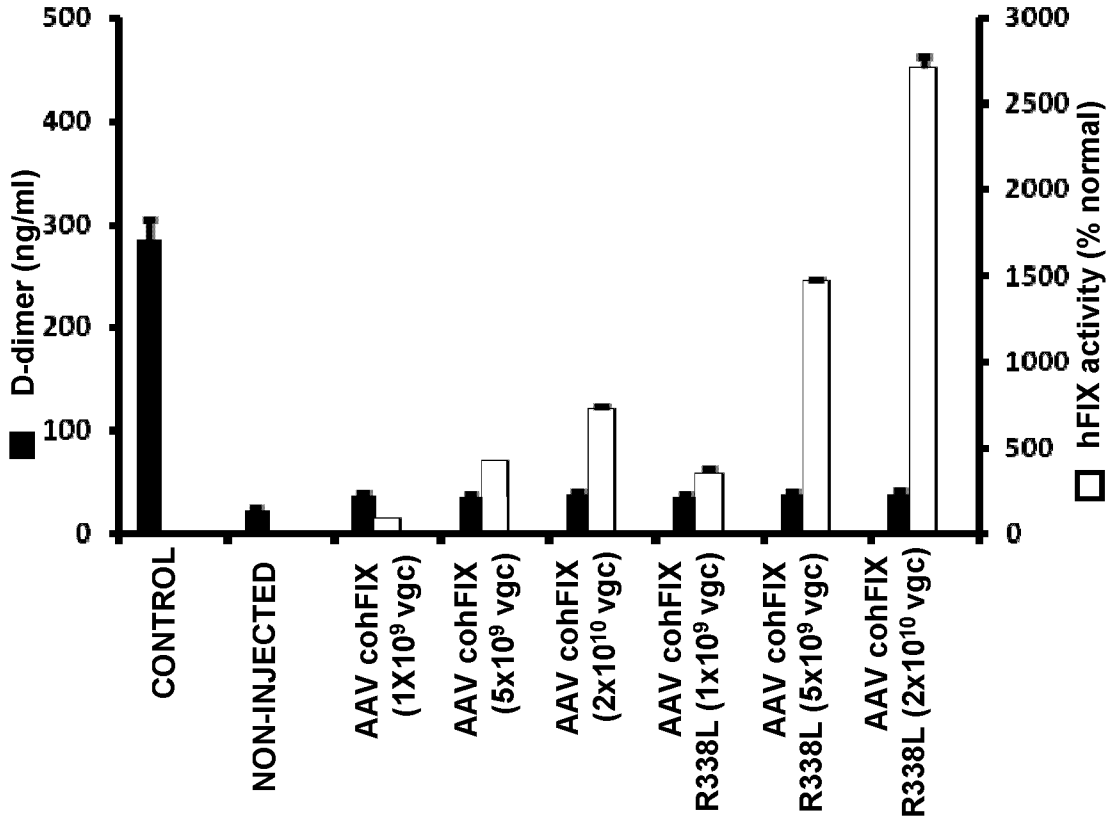

hFIX protein (% normal)
1000
800
600
400
200
0
3500
3000
2500
2000
1500
1000
500
0
hFIX activity (% normal)
*
5
16
37
51
70
100
Days post AAV

Fig.4

J


D-dimer (ng/ml)
hFIX activity (% normal)
500
400
300
200
100
0
3000
2500
2000
1500
1000
500
0
CONTROL
NON-INJECTED
AAV cohFIX (1X10⁹ vgc)
AAV cohFIX (5x10⁹ vgc)
AAV cohFIX (2x10¹⁰ vgc)
AAV cohFIX R338L (1x10⁹ vgc)
AAV cohFIX R338L (5x10⁹ vgc)
AAV cohFIX R338L (2x10¹⁰ vgc)

K

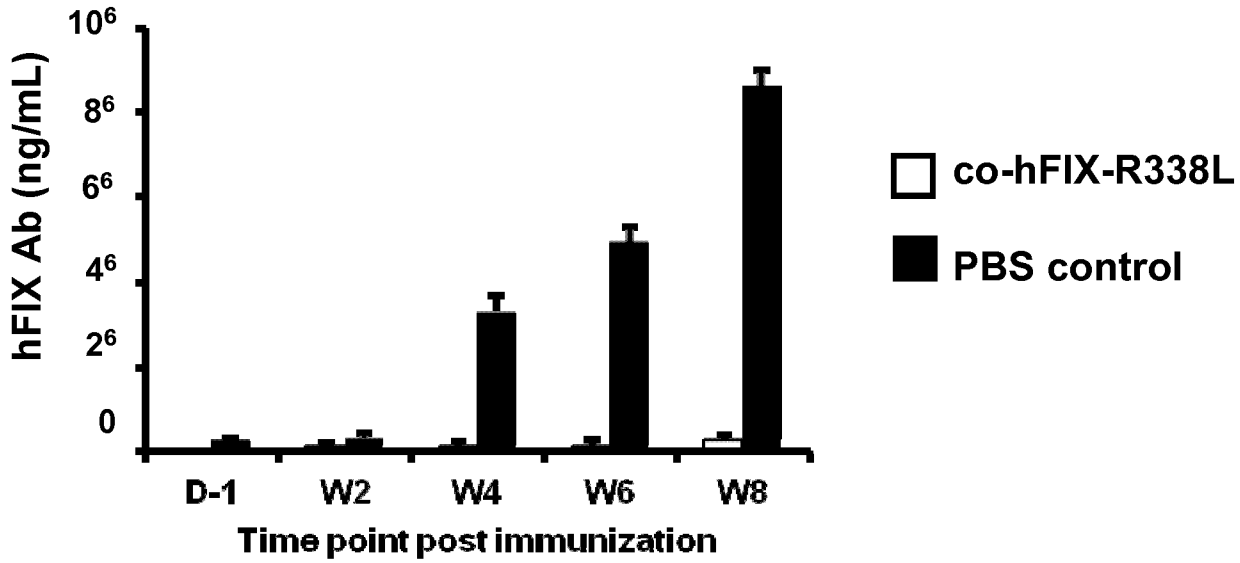
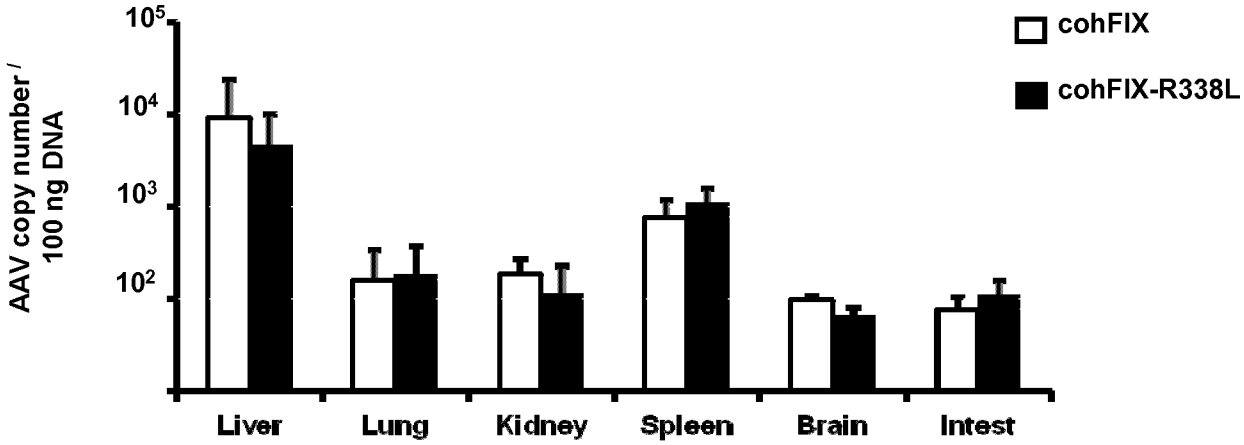

hFIX Ab (ng/mL)
10⁶
8⁶
6⁶
4⁶
2⁶
0
D-1
W2
W4
W6
W8
Time point post immunization
co-hFIX-R338L
PBS control

Fig.5

A


AAV copy number / 100 ng DNA
10^5
10^4
10^3
10^2
Liver
Lung
Kidney
Spleen
Brain
Intest
cohFIX
cohFIX-R338L

B

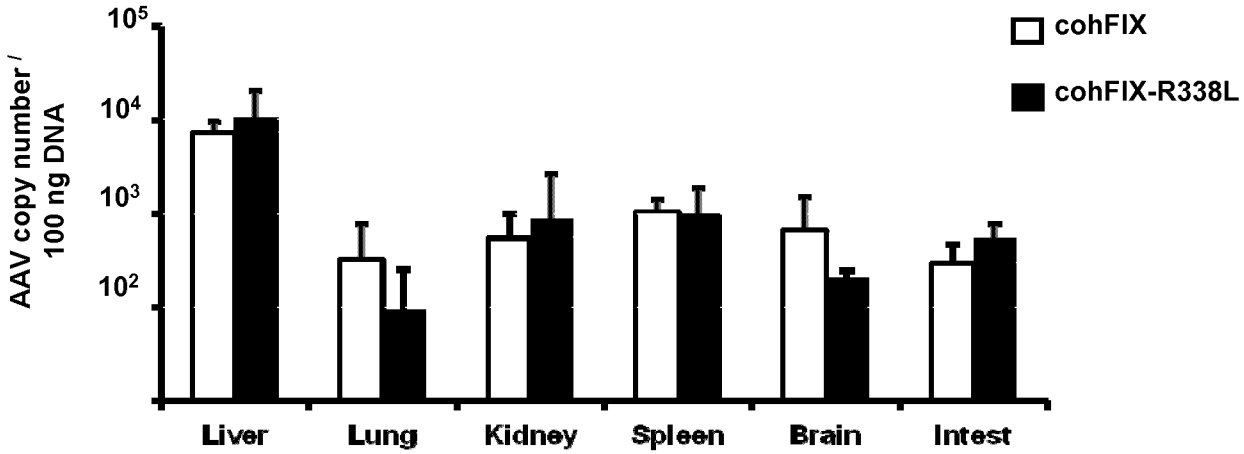
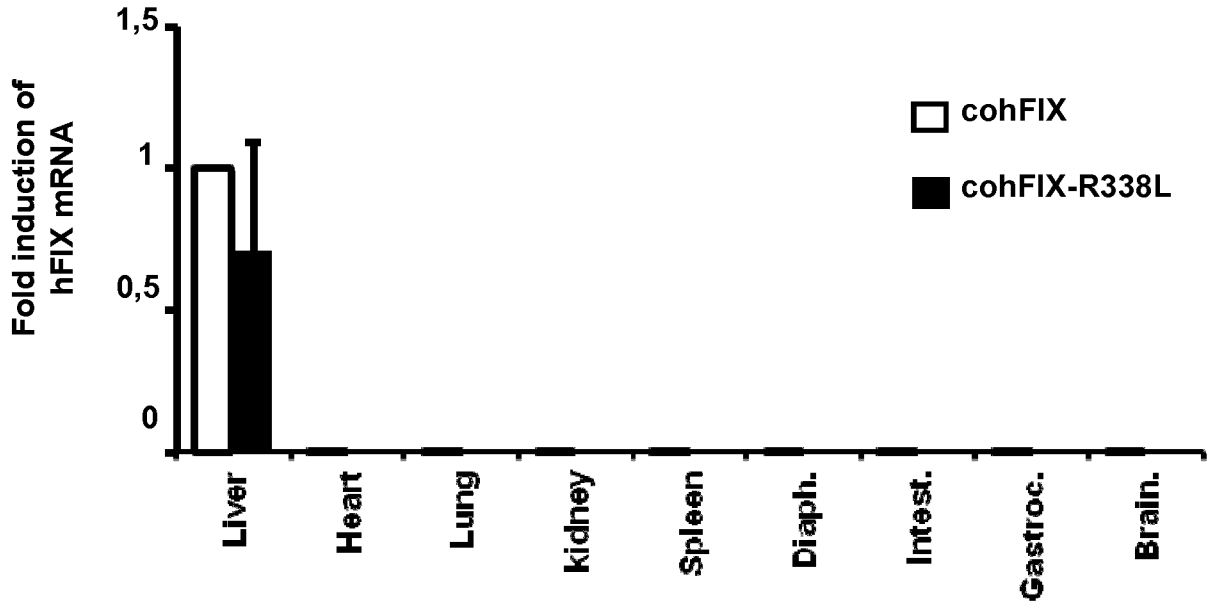

AAV copy number / 100 ng DNA
10^5
10^4
10^3
10^2
Liver
Lung
Kidney
Spleen
Brain
Intest
cohFIX
cohFIX-R338L

Fig. 5

C


1,5
1
0,5
0
Fold induction of hFIX mRNA
cohFIX
cohFIX-R338L
Liver
Heart
Lung
kidney
Spleen
Diaph.
Intest.
Gastroc.
Brain.

D

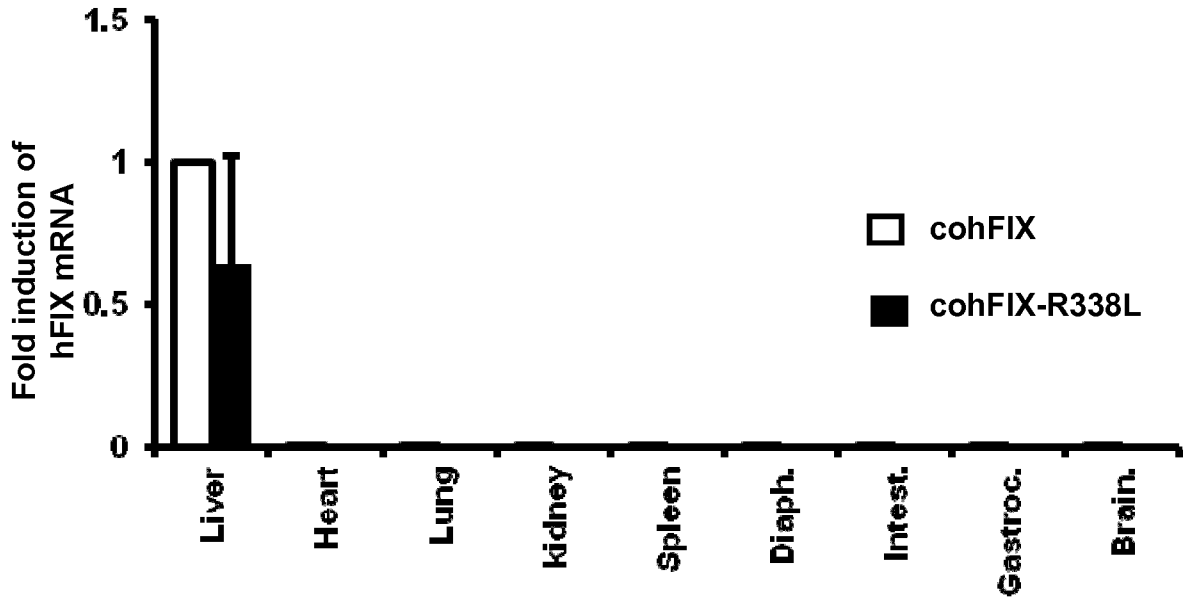
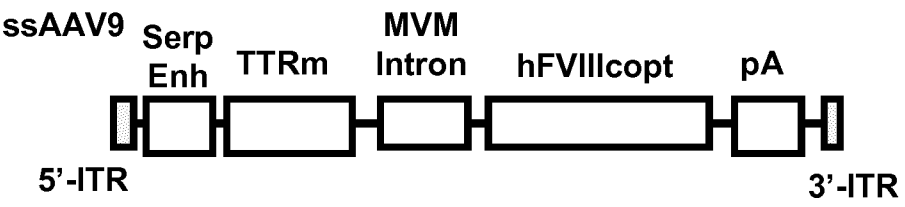

1.5
1
0.5
0
Fold induction of hFIX mRNA
cohFIX
cohFIX-R338L
Liver
Heart
Lung
kidney
Spleen
Diaph.
Intest.
Gastroc.
Brain.

Fig. 6

A


ssAAV9
Serp Enh
TTRm
MVM Intron
hFVIIIcopt
pA
5'-ITR
3'-ITR

B

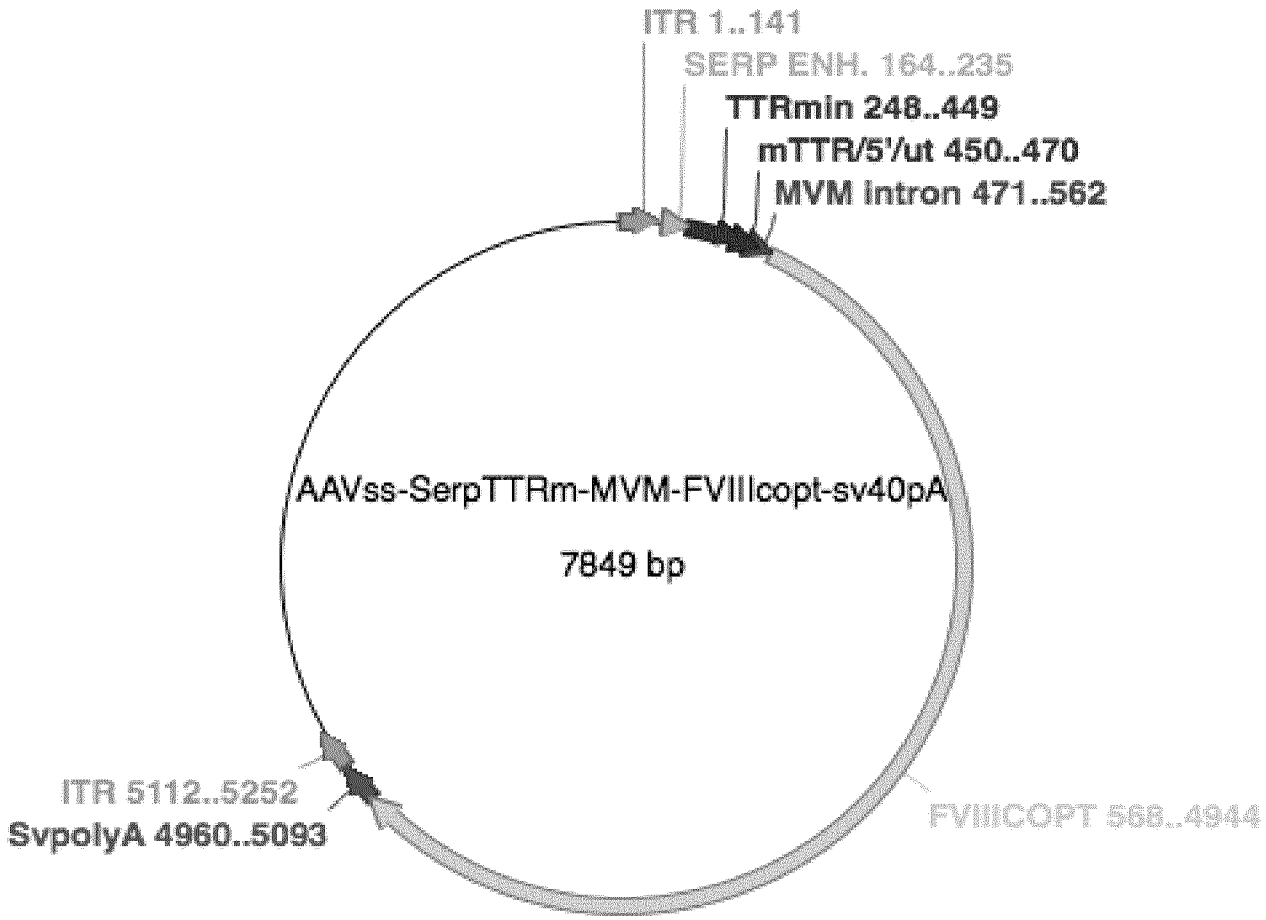

ITR 1..141
SERP ENH. 164..235
TTRmin 248..449
mTTR/5'/ut 450..470
MVM intron 471..562
AAVss-SerpTTRm-MVM-FVIIIcopt-sv40pA
7849 bp
ITR 5112..5252
SvpolyA 4960..5093
FVIIICOPT 568..4944

Fig. 6

C

SEQ ID NO: 6

CCTGCAGGCAGCTGCGCGCTCGCTCGCTCACTGAGGCCGCCCGGGCAAAGCCCG
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*GAGGGAGTGGCCAACTCCATCACTAGGGGTTCCT*GCGGCCGCGGTACCGGCGC
GCC**GGGGGAGGCTGCTGGTGAATATTAACCAAGGTCACCCCAGTTATCG**
GAGGAGCAAACAGGGGCTAAGTCCACACGCGTGGTACCGTCTGTCTGCAC
ATTTCGTAGAGCGAGTGTTCCGATACTCTAATCTCCCTAGGCAAGGTTCATAT
TTGTGTAGGTTACTTATTCTCCTTTTGTTGACTAAGTCAATAATCAGAATCAG
CAGGTTTGGAGTCAGCTTGGCAGGGATCAGCAGCCTGGGTTGGAAGGAGGGG
GTATAAAAGCCCCTTCACCAGGAGAAGCCGTCACACAGATCCACAAGCTCCT
G*AAGAGGTAAGGGTTTAAGGGATGGTTGGTTGGTGGGGNATTAATGTTTAATTACC*
*TGGAGCACCTGCCTGAAATCACTTTTTTTCAGGTTGG*CTAGT**ATGCAGATCGAG**
CTGTCCACCTGCTTTTTTCTGTGCCTGCTGCGGTTCTGCTTCAGCGCCAC
CCGGCGGTACTACCTGGGCGCCGTGGAGCTGTCCTGGGACTACATGCAG
AGCGACCTGGGCGAGCTGCCCGTGGACGCCCGGTTCCCCCCCAGAGTG
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GAACAGCCTGATGCAGGACCGGGACGCCGCCTCTGCCAGAGCCTGGCC
CAAGATGCACACCGTGAACGGCTACGTGAACAGAAGCCTGCCCGGCCTG
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TTCGACGACGACAACAGCCCCAGCTTCATCCAGATCAGAAGCGTGGCCA
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GCTGCCCAAGGGCGTGAAGCACCTGAAGGACTTCCCCATCCTGCCCGGC
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GCACCAGATCGCCCTCAGGATGGAAGTCCTGGGATGTGAGGCCCAGGAT
CTGTACTGATGAGGATCTAGGCTCGAC***ATGCTTTATTTGTGAAATTTGTGATG***
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*GGCTTTGCCCGGGCGGCCTCAGTGAGCGAGCGAGCGCGCAGCTGCCTGCAGG*G
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Fig. 6
D

SEQ ID NO: 7

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CCCCACCATCCAGGCCGAGGTGTACGACACCGTGGTGATCACCCTGAAGAACATG
GCCAGCCACCCCGTGAGCCTGCACGCCGTGGGCGTGAGCTACTGGAAGGCCAGC
GAGGGCGCCGAGTACGACGACCAGACCAGCCAGCGGGAGAAAGAAGATGACAAG
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GGTGAAGGACCTGAACAGCGGCCTGATCGGCGCTCTGCTCGTCTGCCGGGAGGG
CAGCCTGGCCAAAGAGAAAACCCAGACCCTGCACAAGTTCATCCTGCTGTTCGCC
GTGTTCGACGAGGGCAAGAGCTGGCACAGCGAGACAAAGAACAGCCTGATGCAGG
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Fig. 6

E

SEQ ID NO: 8

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F

SEQ ID NO: 9

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G

SEQ ID NO: 10

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H

SEQ ID NO: 11

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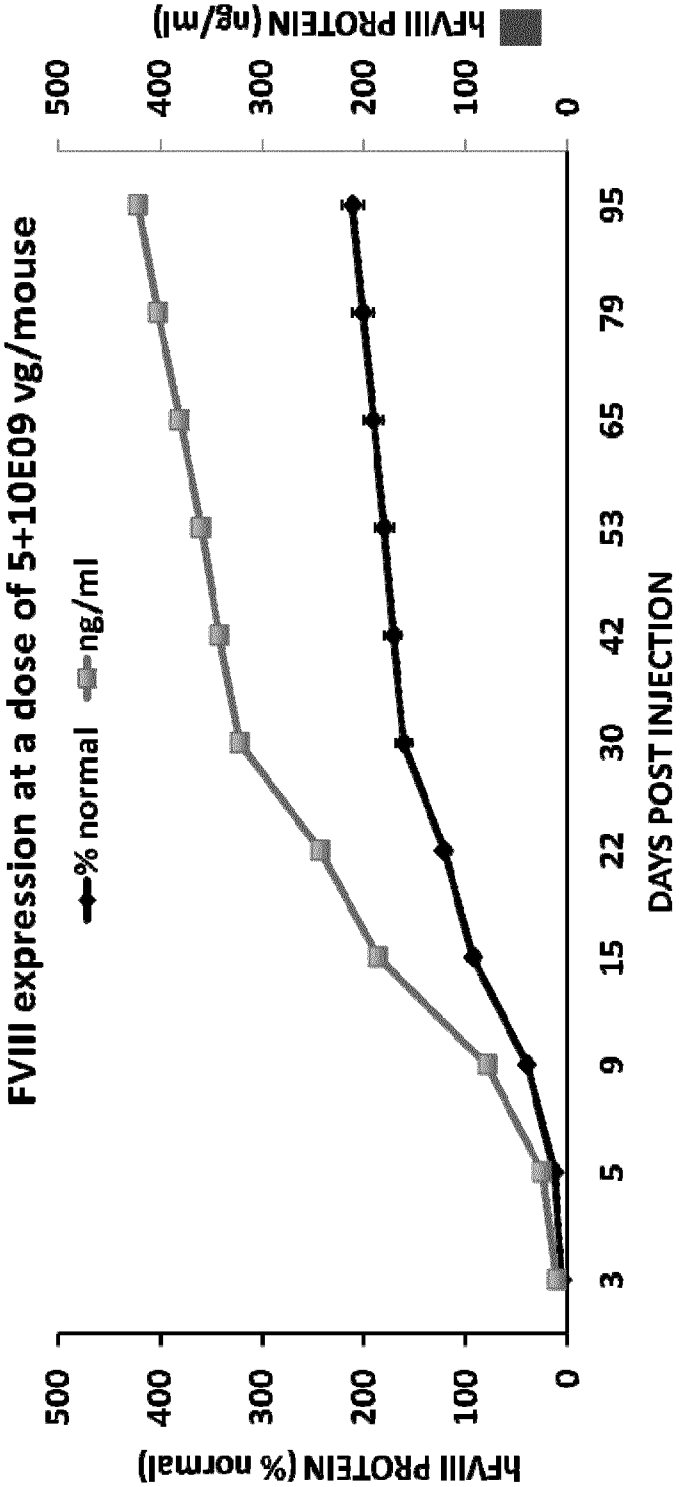
Fig. 7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% normal
ng/ml
hFVIII PROTEIN (% normal)
hFVIII PROTEIN (ng/ml)
DAYS POST INJECTION
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400
500
3
5
9
15
22
30
42
53
65
79
95

Fig. 8

A.

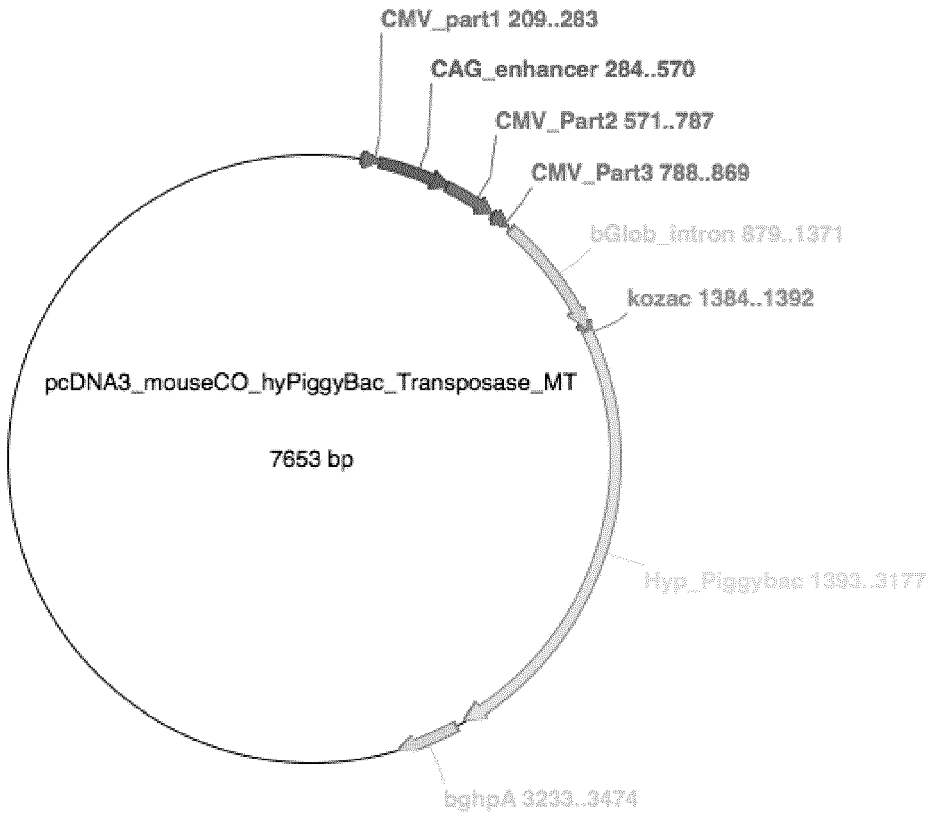
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Fig. 8

B.

SEQ ID NO: 12

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Fig. 8

C.

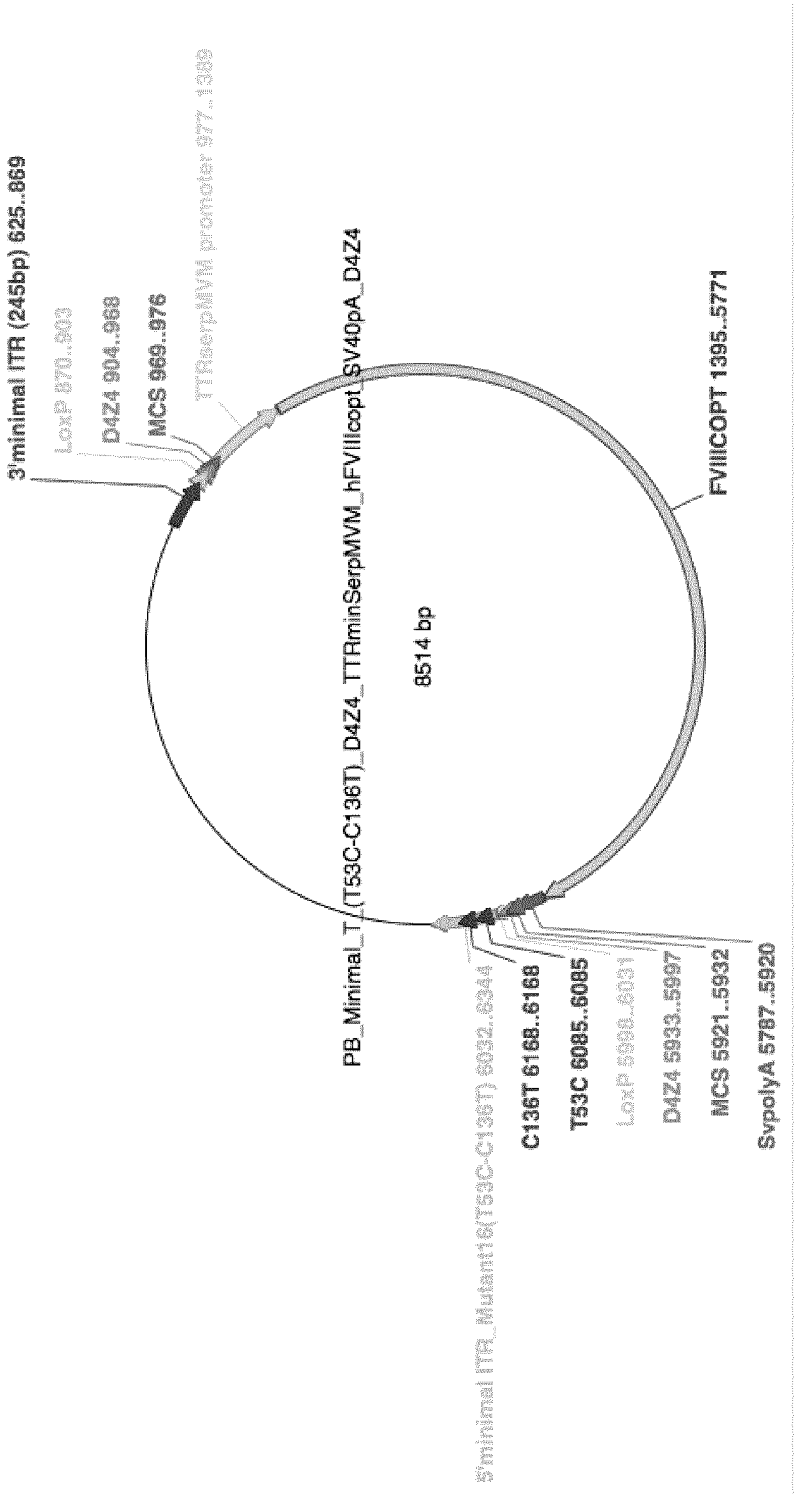
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Fig.8

D

SEQ ID NO: 13

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Fig.8

E

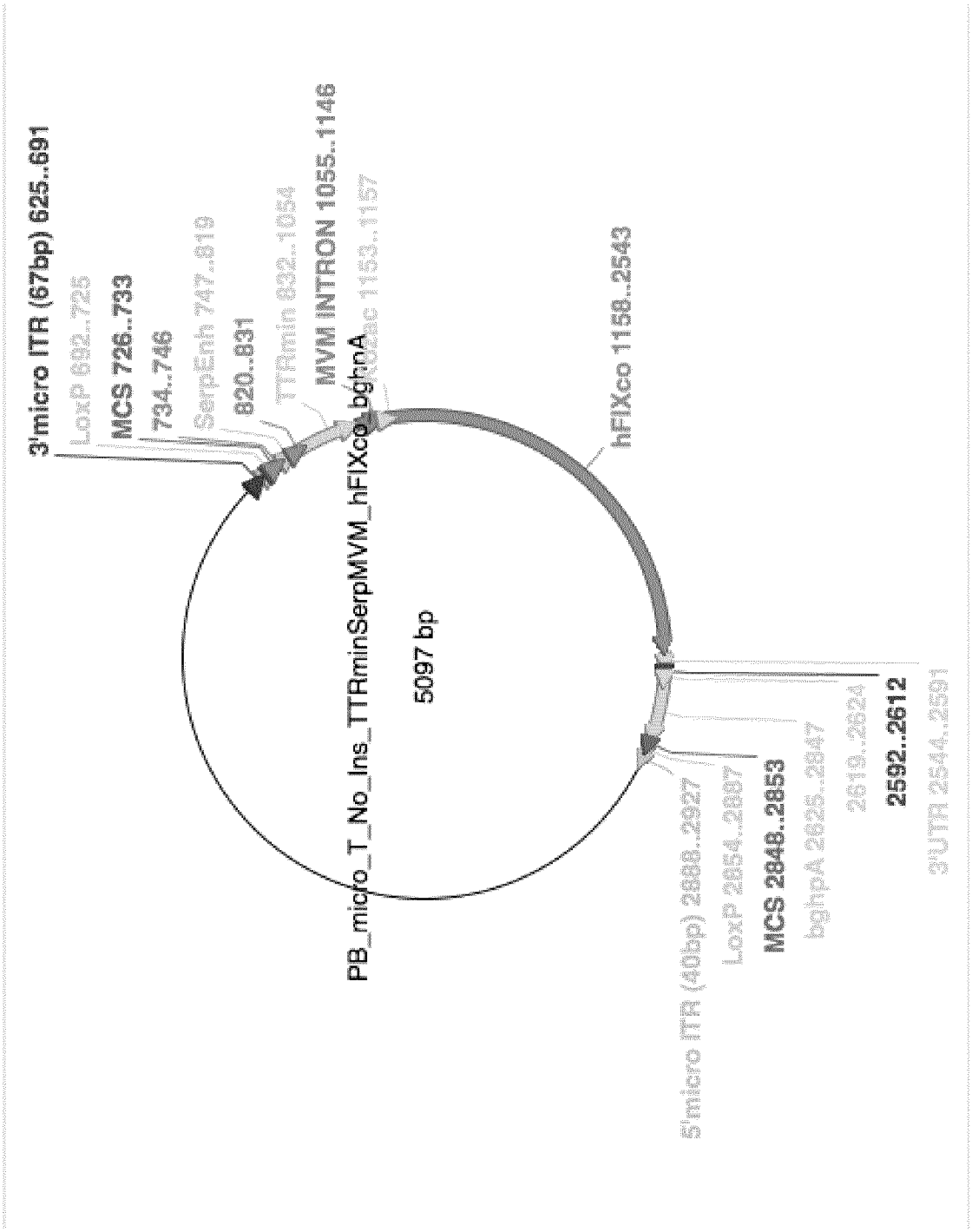
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Fig. 8

F

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Fig. 8

G

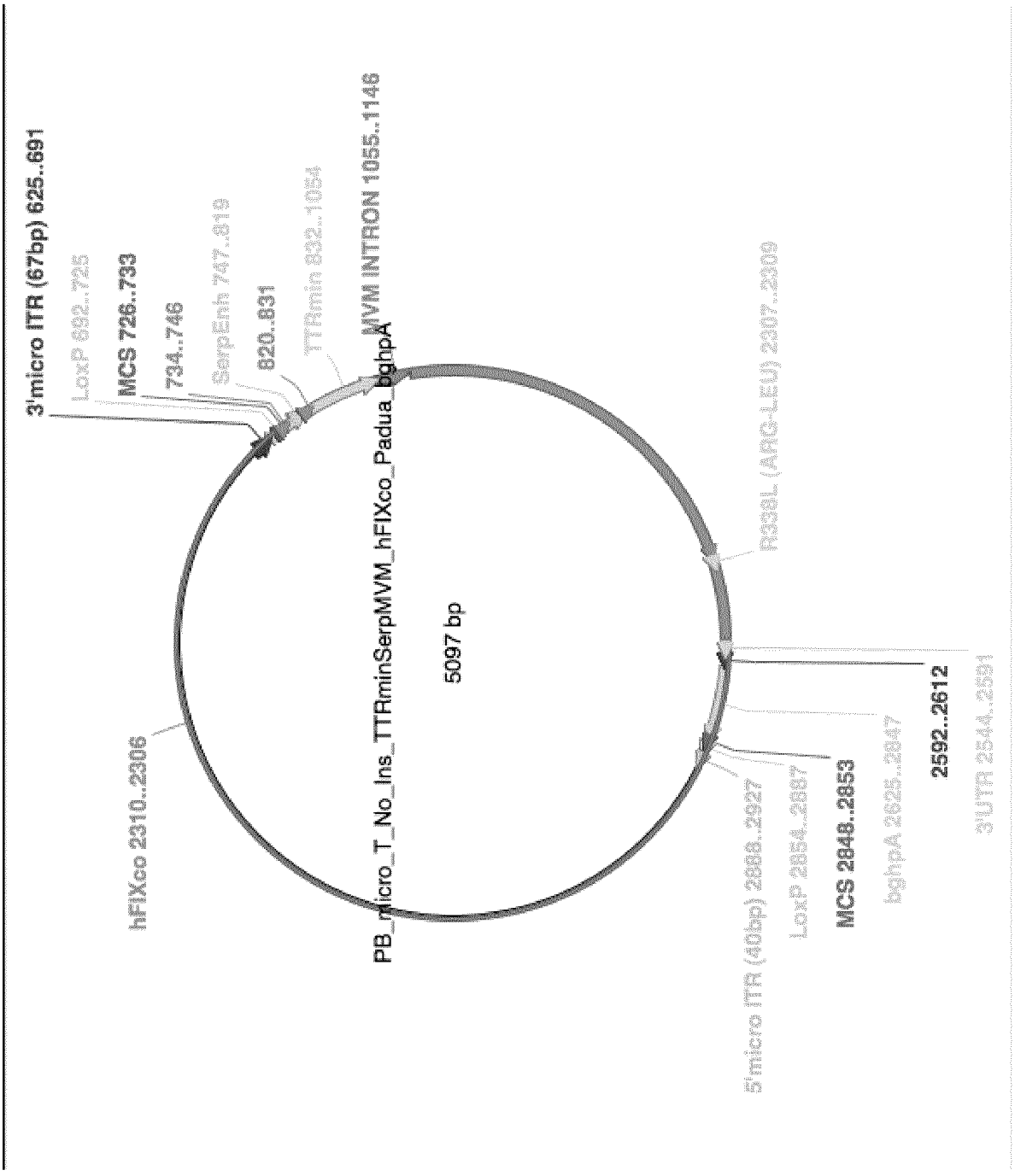
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Fig. 8

H

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Fig. 8
I

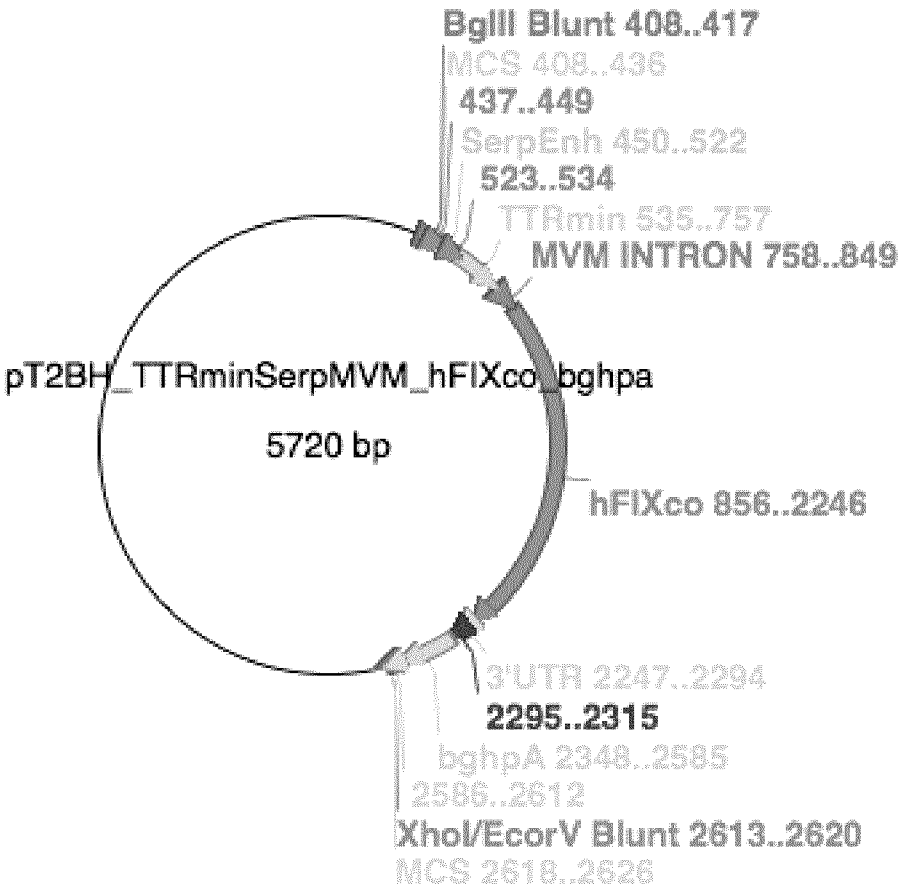
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Fig. 8
J

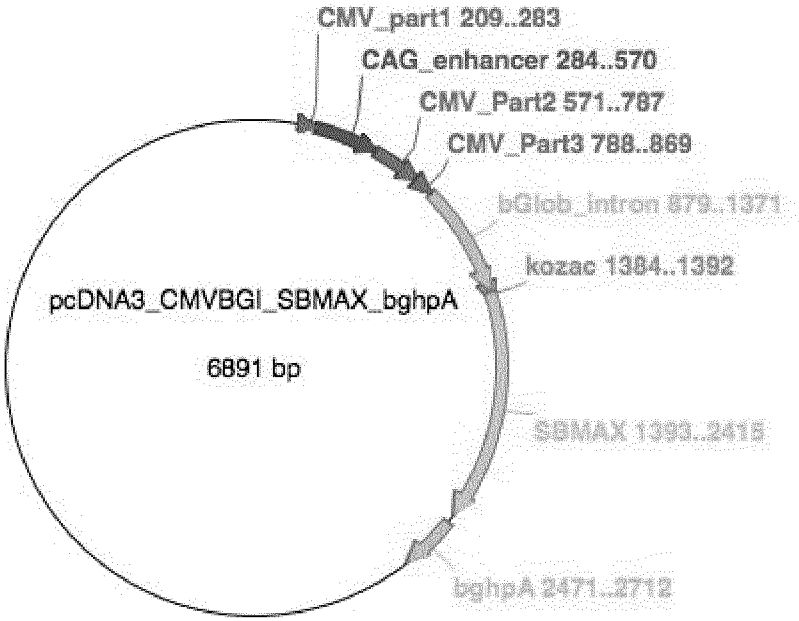
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Fig. 8
K

SEQ ID NO: 17

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AGGCGTTTTGCGCTGCTTCGCGCGTGGAGCTAGTTATTAATAGTAATCAATTACGGGGTCATT
AGTTCATAGCCCATATATGGAGTTCCGCGTTACATAACTTACGGTAAATGGCCCGCCTGGCTG
ACCGCCCAACGACCCCCGCCCATTGACGTCAATAATGACGTATGTTCCCATAGTAACGTCAAT
AGGGACTTTCCATTGACGTCAATGGGTGGAGTATTTACGGTAAACTGCCCACTTGGCAGTACA
TCAAGTGTATCATATGCCAAGTACGCCCCCTATTGACGTCAATGACGGTAAATGGCCCGCCTG
GCATTATGCCCAGTACATGACCTTATGGGACTTTCCTACTTGGCAGTACATCTACGTATTAGTC
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TCACGGGGATTTCCAAGTCTCCACCCCATTGACGTCAATGGGAGTTTGTTTTGGCACCAAAAT
CAACGGGACTTTCCAAAATGTCGTAACAACTCCGCCCCATTGACGCAAATGGGCGGTAGGCGT
GTACGGTGGGAGGTCTATATAAGCAGAGCTCGTTTAGTGAACCGTCAGATCGCCTGGAGACG
CCATCCACGCTGTTTTGACCTCCATAGAAGACACCGGGACCGATCCAGCCTCCGCGGATTCGA
ATCCCGGCCGGGAACGGTGCATTGGAACGCGGATTCCCCGTGCCAAGAGTGACGTAAGTACC
GCCTATAGAGTCTATAGGCCCACAAAAAATGCTTTCTTCTTTTAATATACTTTTTTGTTTATCTT
ATTTCTAATACTTTCCCTAATCTCTTTCTTTCAGGGCAATAATGATACAATGTATCATGCCTCTT
TGCACCATTCTAAAGAATAACAGTGATAATTTCTGGGTTAAGGCAATAGCAATATTTCTGCAT
ATAAATATTTCTGCATATAAATTGTAACTGATGTAAGAGGTTTCATATTGCTAATAGCAGCTA
CAATCCAGCTACCATTCTGCTTTTATTTTATGGTTGGGATAAGGCTGGATTATTCTGAGTCCAA
GCTAGGCCCTTTTGCTAATCATGTTCATACCTCTTATCTTCCTCCCACAGCTCCTGGGCAACGT
GCTGGTCTGTGTGCTGGCCCATCACTTTGGCAAAGAATTGGGATTCGAACATCGATGCCGCCA
CCATGGGAAAATCAAAAGAAATCAGCCAAGACCTCAGAAAAAGAATTGTAGACCTCCACAAG
TCTGGTTCATCCTTGGGAGCAATTTCCCGACGCCTGGCGGTACCACGTTCATCTGTACAAACA
ATAGTACGCAAGTATAAACACCATGGGACCACGCAGCCGTCATACCGCTCAGGAAGGAGACG
CGTTCTGTCTCCTAGAGATGAACGTACTTTGGTGCGAAAAGTGCAAATCAATCCCAGAACAAC
AGCAAAGGACCTTGTGAAGATGCTGGAGGAAACAGGTACAAAAGTATCTATATCCACAGTAA
AACGAGTCCTATATCGACATAACCTGAAAGGCCACTCAGCAAGGAAGAAGCCACTGCTCCAA
AACCGACATAAGAAAGCCAGACTACGGTTTGCAACTGCACATGGGGACAAAGATCTAACTTT
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TTATGTTTGGAGGAAGAAGGGGGAGGCTTGCAAGCCGAAGAACACCATCCCAACCGTGAAGC
ACGGGGGTGGCAGCATCATGTTGTGGGGGTGCTTTGCTGCAGGAGGGACTGGTAAACTTGTCC
GAATAGAAGGCATCATGGACGCGGTGCAGTATGTGGATATATTGAAGCAACATCTCAAGACA
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ACTTCCAAAGTTGTGGCAAAATGGCTTAAGGACAACAAAGTCAAGGTATTGGACTGGCCATC
ACAAAGCCCTGACCTCAATCCTATAGAAAATTTGTGGGCAGAACTGAAAAAGCGTGTGCGAG
CAAGGAGGCCTACAAACCTGACTCAGTTACACCAGCTCTGTCAGGAGGAATGGGCCAAAATT
CACCCAAATTATTGTGGGAAGCTTGTGGAAGGCTACCCGAAACGTTTGACCCAAGTTAAACAA
TTTAAAGGCAATGCTACCAAATACTAGCTCGAGCATGCATCTAGAGGGCCCTATTCTATAGTG
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GTTTGCCCCTCCCCCGTGCCTTCCTTGACCCTGGAAGGTGCCACTCCCACTGTCCTTTCCTAAT
AAAATGAGGAAATTGCATCGCATTGTCTGAGTAGGTGTCATTCTATTCTGGGGGGTGGGGTGG
GGCAGGACAGCAAGGGGGAGGATTGGGAAGACAATAGCAGGCATGCTGGGGATGCGGTGGG
CTCTATGGCTTCTGAGGCGGAAAGAACCAGCTGGGGCTCTAGGGGGTATCCCCACGCGCCCTG
TAGCGGCGCATTAAGCGCGGCGGGTGTGGTGGTTACGCGCAGCGTGACCGCTACACTTGCCA
GCGCCCTAGCGCCCGCTCCTTTCGCTTTCTTCCCTTCCTTTCTCGCCACGTTCGCCGGCTTTCCC
CGTCAAGCTCTAAATCGGGGCATCCCTTTAGGGTTCCGATTTAGTGCTTTACGGCACCTCGACC
CCAAAAAACTTGATTAGGGTGATGGTTCACGTAGTGGGCCATCGCCCTGATAGACGGTTTTTC

GCCCTTTGACGTTGGAGTCCACGTTCTTTAATAGTGGACTCTTGTTCCAAACTGGAACAACACT
CAACCCTATCTCGGTCTATTCTTTTGATTTATAAGGGATTTTGGGGATTTCGGCCTATTGGTTA
AAAAATGAGCTGATTTAACAAAAATTTAACGCGAATTAATTCTGTGGAATGTGTGTCAGTTAG
GGTGTGGAAAGTCCCCAGGCTCCCCAGGCAGGCAGAAGTATGCAAAGCATGCATCTCAATTA
GTCAGCAACCAGGTGTGGAAAGTCCCCAGGCTCCCCAGCAGGCAGAAGTATGCAAAGCATGC
ATCTCAATTAGTCAGCAACCATAGTCCCGCCCCTAACTCCGCCCATCCCGCCCCTAACTCCGCC
CAGTTCCGCCCATTCTCCGCCCCATGGCTGACTAATTTTTTTTATTTATGCAGAGGCCGAGGCC
GCCTCTGCCTCTGAGCTATTCCAGAAGTAGTGAGGAGGCTTTTTTGGAGGCCTAGGCTTTTGC
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TTTCGCATGATTGAACAAGATGGATTGCACGCAGGTTCTCCGGCCGCTTGGGTGGAGAGGCTA
TTCGGCTATGACTGGGCACAACAGACAATCGGCTGCTCTGATGCCGCCGTGTTCCGGCTGTCA
GCGCAGGGGCGCCCGGTTCTTTTTGTCAAGACCGACCTGTCCGGTGCCCTGAATGAACTGCAG
GACGAGGCAGCGCGGCTATCGTGGCTGGCCACGACGGGCGTTCCTTGCGCAGCTGTGCTCGAC
GTTGTCACTGAAGCGGGAAGGGACTGGCTGCTATTGGGCGAAGTGCCGGGGCAGGATCTCCT
GTCATCTCACCTTGCTCCTGCCGAGAAAGTATCCATCATGGCTGATGCAATGCGGCGGCTGCA
TACGCTTGATCCGGCTACCTGCCCATTCGACCACCAAGCGAAACATCGCATCGAGCGAGCACG
TACTCGGATGGAAGCCGGTCTTGTCGATCAGGATGATCTGGACGAAGAGCATCAGGGGCTCG
CGCCAGCCGAACTGTTCGCCAGGCTCAAGGCGCGCATGCCCGACGGCGAGGATCTCGTCGTG
ACCCATGGCGATGCCTGCTTGCCGAATATCATGGTGGAAAATGGCCGCTTTTCTGGATTCATC
GACTGTGGCCGGCTGGGTGTGGCGGACCGCTATCAGGACATAGCGTTGGCTACCCGTGATATT
GCTGAAGAGCTTGGCGGCGAATGGGCTGACCGCTTCCTCGTGCTTTACGGTATCGCCGCTCCC
GATTCGCAGCGCATCGCCTTCTATCGCCTTCTTGACGAGTTCTTCTGAGCGGGACTCTGGGGTT
CGAAATGACCGACCAAGCGACGCCCAACCTGCCATCACGAGATTTCGATTCCACCGCCGCCTT
CTATGAAAGGTTGGGCTTCGGAATCGTTTTCCGGGACGCCGGCTGGATGATCCTCCAGCGCGG
GGATCTCATGCTGGAGTTCTTCGCCCACCCCAACTTGTTTATTGCAGCTTATAATGGTTACAAA
TAAAGCAATAGCATCACAAATTTCACAAATAAAGCATTTTTTTCACTGCATTCTAGTTGTGGTT
TGTCCAAACTCATCAATGTATCTTATCATGTCTGTATACCGTCGACCTCTAGCTAGAGCTTGGC
GTAATCATGGTCATAGCTGTTTCCTGTGTGAAATTGTTATCCGCTCACAATTCCACACAACATA
CGAGCCGGAAGCATAAAGTGTAAAGCCTGGGGTGCCTAATGAGTGAGCTAACTCACATTAAT
TGCGTTGCGCTCACTGCCCGCTTTCCAGTCGGGAAACCTGTCGTGCCAGCTGCATTAATGAAT
CGGCCAACGCGCGGGGAGAGGCGGTTTGCGTATTGGGCGCTCTTCCGCTTCCTCGCTCACTGA
CTCGCTGCGCTCGGTCGTTCGGCTGCGGCGAGCGGTATCAGCTCACTCAAAGGCGGTAATACG
GTTATCCACAGAATCAGGGGATAACGCAGGAAAGAACATGTGAGCAAAAGGCCAGCAAAAG
GCCAGGAACCGTAAAAAGGCCGCGTTGCTGGCGTTTTTCCATAGGCTCCGCCCCCCTGACGAG
CATCACAAAAATCGACGCTCAAGTCAGAGGTGGCGAAACCCGACAGGACTATAAAGATACCA
GGCGTTTCCCCCTGGAAGCTCCCTCGTGCGCTCTCCTGTTCCGACCCTGCCGCTTACCGGATAC
CTGTCCGCCTTTCTCCCTTCGGGAAGCGTGGCGCTTTCTCAATGCTCACGCTGTAGGTATCTCA
GTTCGGTGTAGGTCGTTCGCTCCAAGCTGGGCTGTGTGCACGAACCCCCCGTTCAGCCCGACC
GCTGCGCCTTATCCGGTAACTATCGTCTTGAGTCCAACCCGGTAAGACACGACTTATCGCCAC
TGGCAGCAGCCACTGGTAACAGGATTAGCAGAGCGAGGTATGTAGGCGGTGCTACAGAGTTC
TTGAAGTGGTGGCCTAACTACGGCTACACTAGAAGGACAGTATTTGGTATCTGCGCTCTGCTG
AAGCCAGTTACCTTCGGAAAAAGAGTTGGTAGCTCTTGATCCGGCAAACAAACCACCGCTGGT
AGCGGTGGTTTTTTTGTTTGCAAGCAGCAGATTACGCGCAGAAAAAAAGGATCTCAAGAAGA
TCCTTTGATCTTTTCTACGGGGTCTGACGCTCAGTGGAACGAAAACTCACGTTAAGGGATTTTG
GTCATGAGATTATCAAAAAGGATCTTCACCTAGATCCTTTTAAATTAAAAATGAAGTTTTAAA
TCAATCTAAAGTATATATGAGTAAACTTGGTCTGACAGTTACCAATGCTTAATCAGTGAGGCA
CCTATCTCAGCGATCTGTCTATTTCGTTCATCCATAGTTGCCTGACTCCCCGTCGTGTAGATAA
CTACGATACGGGAGGGCTTACCATCTGGCCCCAGTGCTGCAATGATACCGCGAGACCCACGCT
CACCGGCTCCAGATTTATCAGCAATAAACCAGCCAGCCGGAAGGGCCGAGCGCAGAAGTGGT
CCTGCAACTTTATCCGCCTCCATCCAGTCTATTAATTGTTGCCGGGAAGCTAGAGTAAGTAGTT
CGCCAGTTAATAGTTTGCGCAACGTTGTTGCCATTGCTACAGGCATCGTGGTGTCACGCTCGTC
GTTTGGTATGGCTTCATTCAGCTCCGGTTCCCAACGATCAAGGCGAGTTACATGATCCCCCAT
GTTGTGCAAAAAAGCGGTTAGCTCCTTCGGTCCTCCGATCGTTGTCAGAAGTAAGTTGGCCGC
AGTGTTATCACTCATGGTTATGGCAGCACTGCATAATTCTCTTACTGTCATGCCATCCGTAAGA

TGCTTTTCTGTGACTGGTGAGTACTCAACCAAGTCATTCTGAGAATAGTGTATGCGGCGACCG
AGTTGCTCTTGCCCGGCGTCAATACGGGATAATACCGCGCCACATAGCAGAACTTTAAAAGTG
CTCATCATTGGAAAACGTTCTTCGGGGCGAAAACTCTCAAGGATCTTACCGCTGTTGAGATCC
AGTTCGATGTAACCCACTCGTGCACCCAACTGATCTTCAGCATCTTTTACTTTCACCAGCGTTT
CTGGGTGAGCAAAAACAGGAAGGCAAAATGCCGCAAAAAAGGGAATAAGGGCGACACGGAA
ATGTTGAATACTCATACTCTTCCTTTTTCAATATTATTGAAGCATTTATCAGGGTTATTGTCTCA
TGAGCGGATACATATTTGAATGTATTTAGAAAAATAAACAAATAGGGGTTCCGCGCACATTTC
CCCGAAAAGTGCCACCTGACGTC

Fig. 9

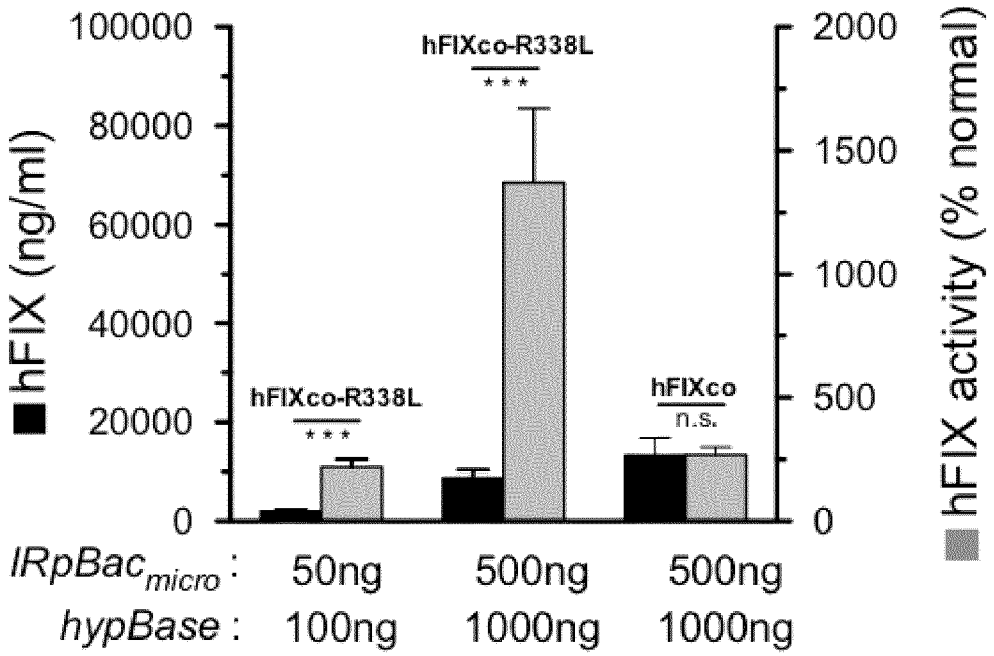

100000
80000
60000
40000
20000
0
hFIX (ng/ml)
2000
1500
1000
500
0
hFIX activity (% normal)
hFIXco-R338L
***
hFIXco-R338L
***
hFIXco
n.s.
lRpBac micro : 50ng 500ng 500ng
hypBase : 100ng 1000ng 1000ng

Fig. 10

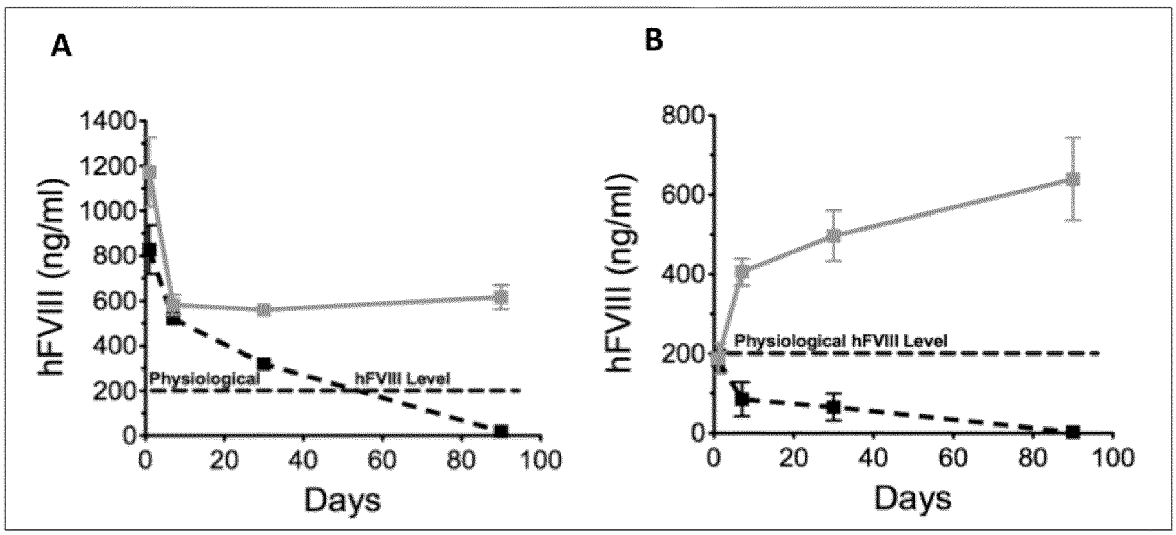

A
1400
1200
1000
800
600
400
200
0
hFVIII (ng/ml)
Physiological
hFVIII Level
0 20 40 60 80 100
Days
B
800
600
400
200
0
hFVIII (ng/ml)
Physiological hFVIII Level
0 20 40 60 80 100
Days

Fig. 11

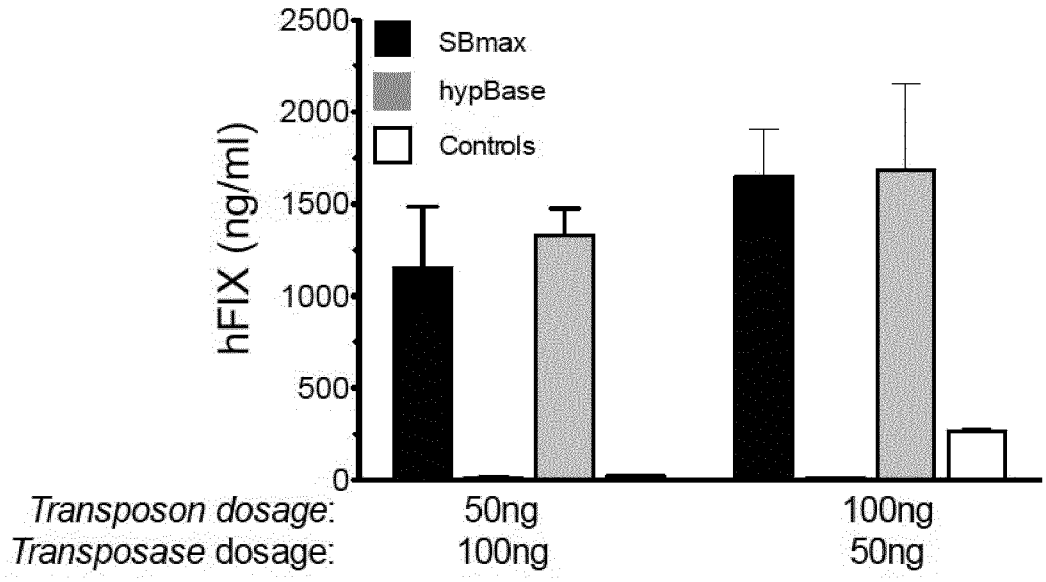
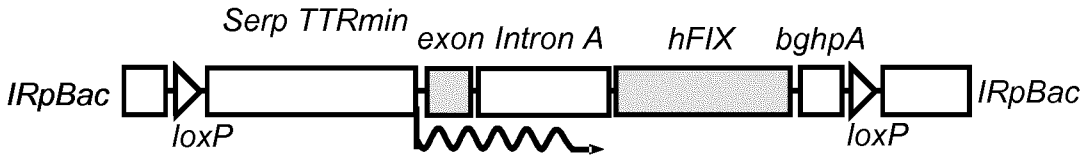
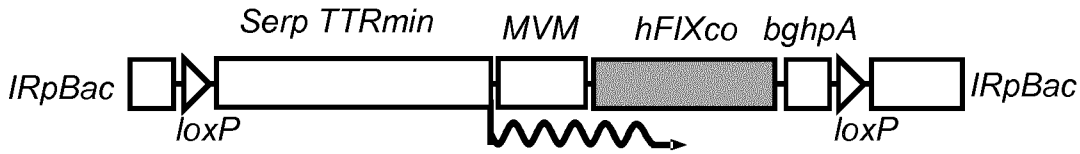

2500
2000
1500
1000
500
0
hFIX (ng/ml)
SBmax
hypBase
Controls
Transposon dosage:
Transposase dosage:
50ng
100ng
100ng
50ng

Fig. 12

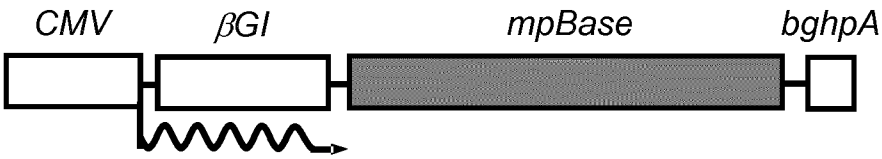
A.


Serp TTRmin
exon Intron A
hFIX
bghpA
IRpBac
loxP
loxP
IRpBac

B


Serp TTRmin
MVM
hFIXco
bghpA
IRpBac
loxP
loxP
IRpBac

C


CMV
βGI
mpBase
bghpA

D

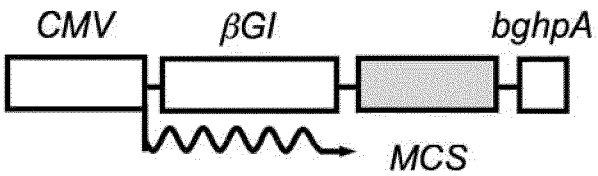
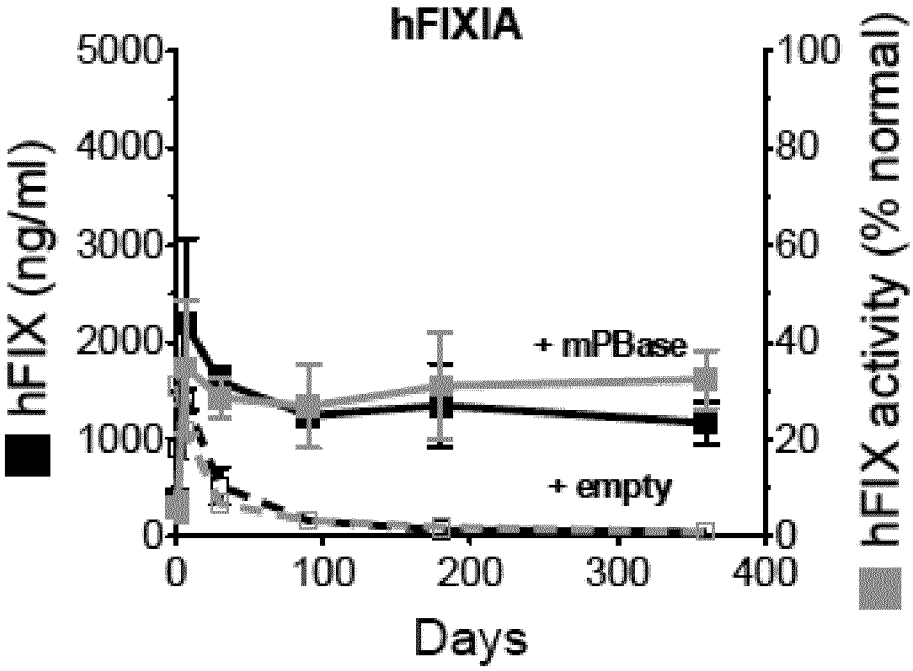

CMV
βGI
bghpA
MCS

Fig. 12

E.


hFIXIA
hFIX (ng/ml)
hFIX activity (% normal)
+ mPBase
+ empty
Days
0
1000
2000
3000
4000
5000
0
20
40
60
80
100
0
100
200
300
400

F.

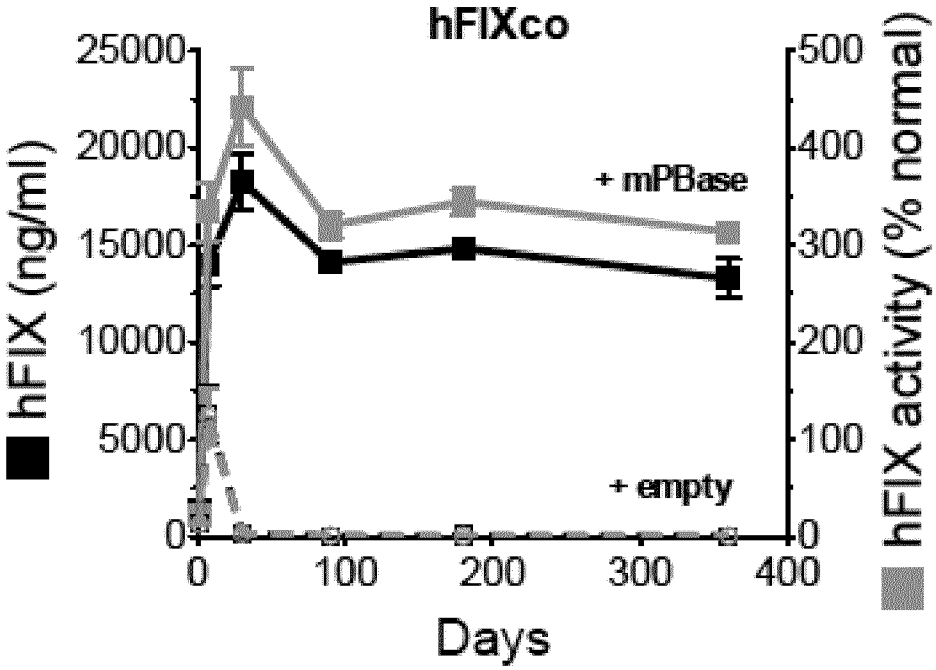
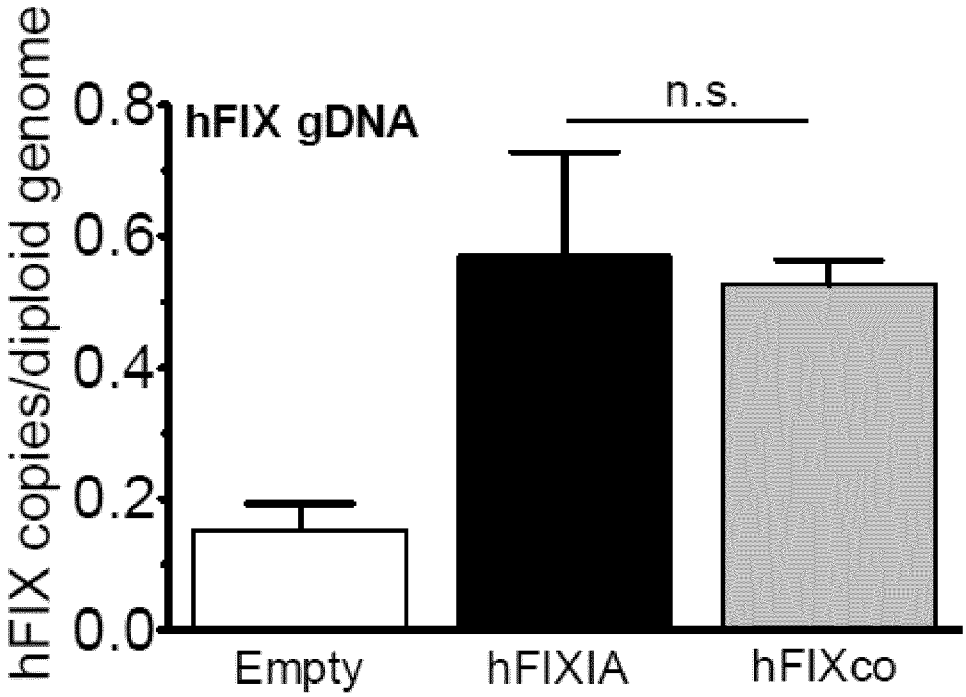

hFIXco
hFIX (ng/ml)
hFIX activity (% normal)
+ mPBase
+ empty
Days
0
5000
10000
15000
20000
25000
0
100
200
300
400
500
0
100
200
300
400

Fig. 12

G.


hFIX copies/diploid genome
0.8
0.6
0.4
0.2
0.0
hFIX gDNA
n.s.
Empty
hFIXIA
hFIXco

H.

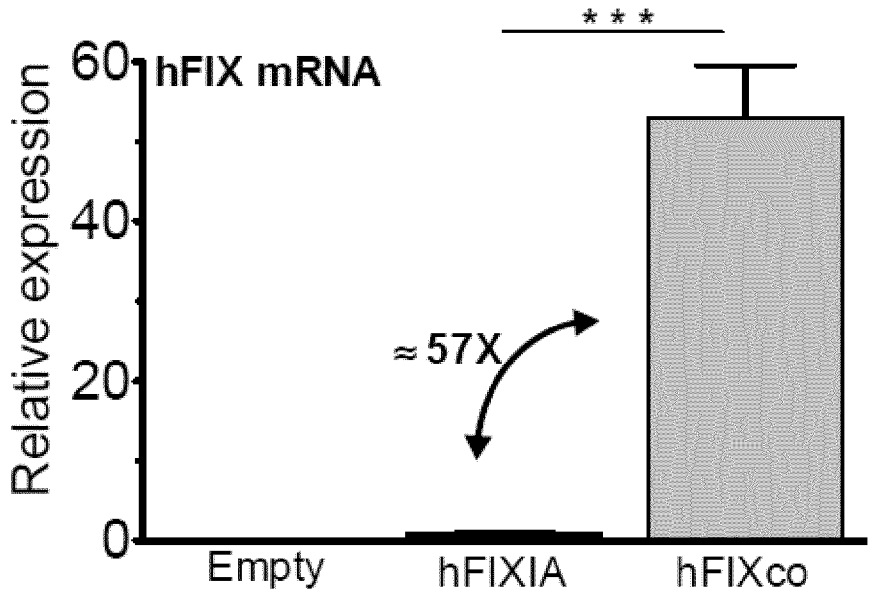
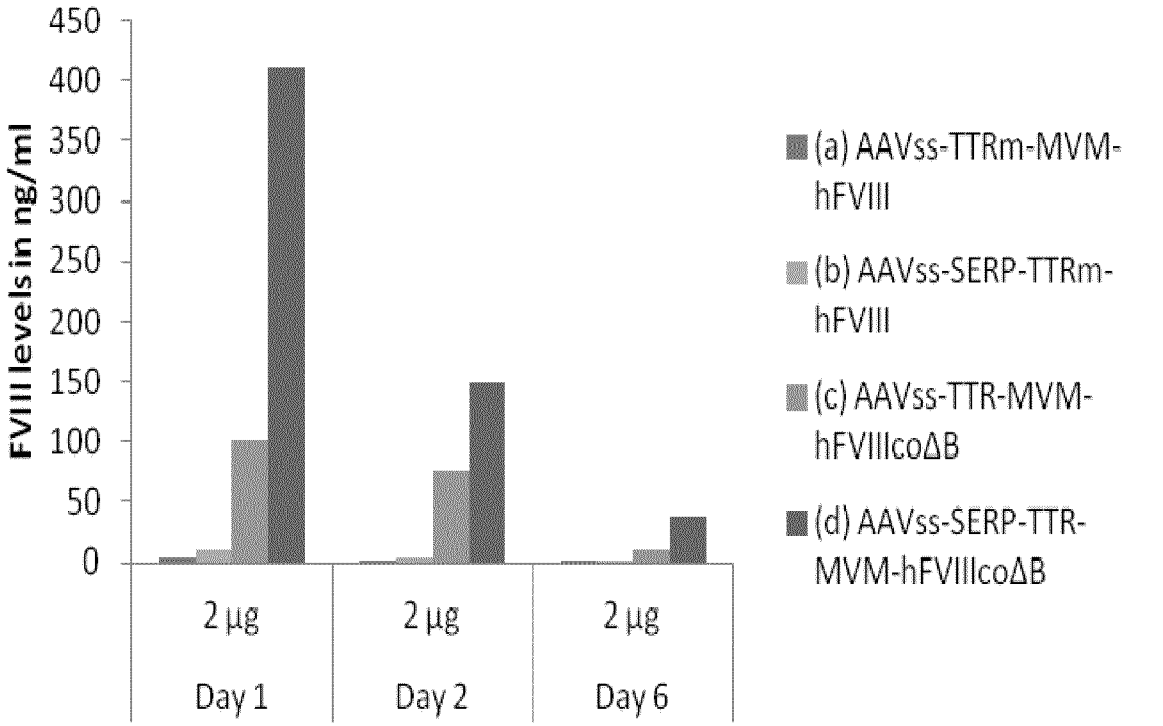

Relative expression
60
40
20
0
hFIX mRNA
* * *
≈ 57X
Empty
hFIXIA
hFIXco

Fig. 13

A.


FVIII levels in ng/ml
450
400
350
300
250
200
150
100
50
0
2 µg
Day 1
2 µg
Day 2
2 µg
Day 6
(a) AAVss-TTRm-MVM-hFVIII
(b) AAVss-SERP-TTRm-hFVIII
(c) AAVss-TTR-MVM-hFVIIIcoΔB
(d) AAVss-SERP-TTR-MVM-hFVIIIcoΔB

B.

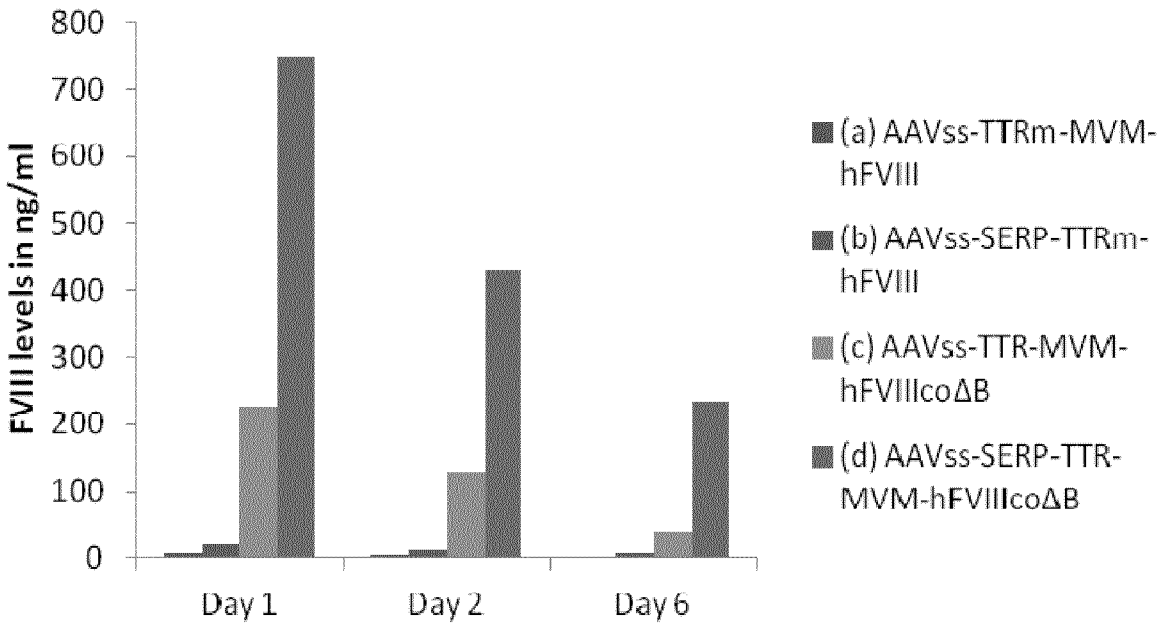
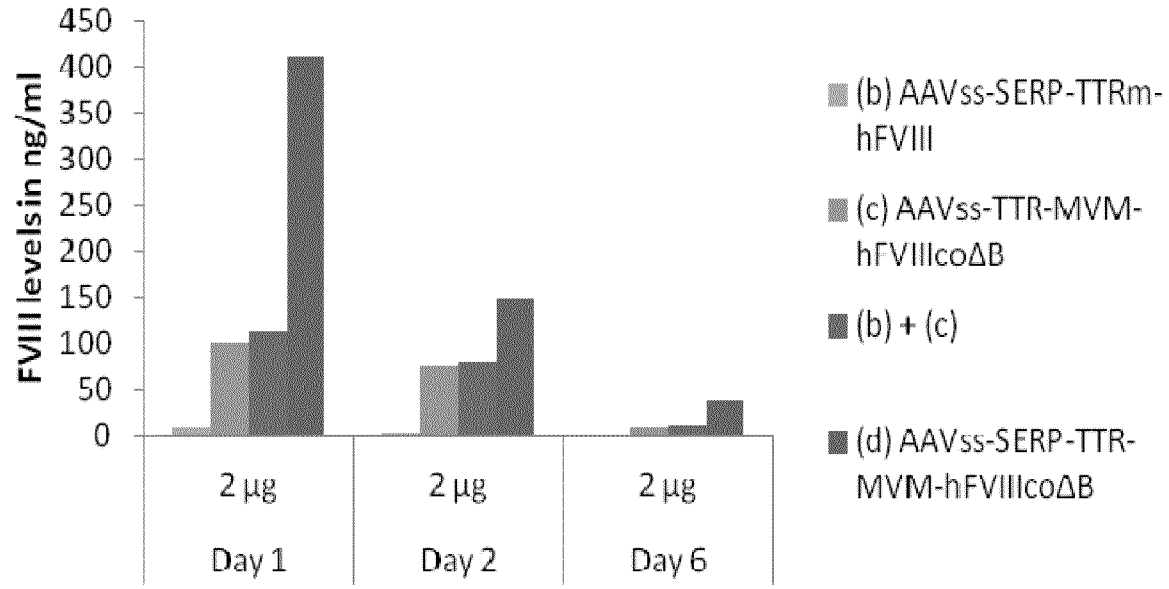

FVIII levels in ng/ml
800
700
600
500
400
300
200
100
0
Day 1
Day 2
Day 6
(a) AAVss-TTRm-MVM-hFVIII
(b) AAVss-SERP-TTRm-hFVIII
(c) AAVss-TTR-MVM-hFVIIIcoΔB
(d) AAVss-SERP-TTR-MVM-hFVIIIcoΔB

Fig. 13

C.


FVIII levels in ng/ml
450
400
350
300
250
200
150
100
50
0
2 µg
Day 1
2 µg
Day 2
2 µg
Day 6
(b) AAVss-SERP-TTRm-hFVIII
(c) AAVss-TTR-MVM-hFVIIIcoΔB
(b) + (c)
(d) AAVss-SERP-TTR-MVM-hFVIIIcoΔB

D.

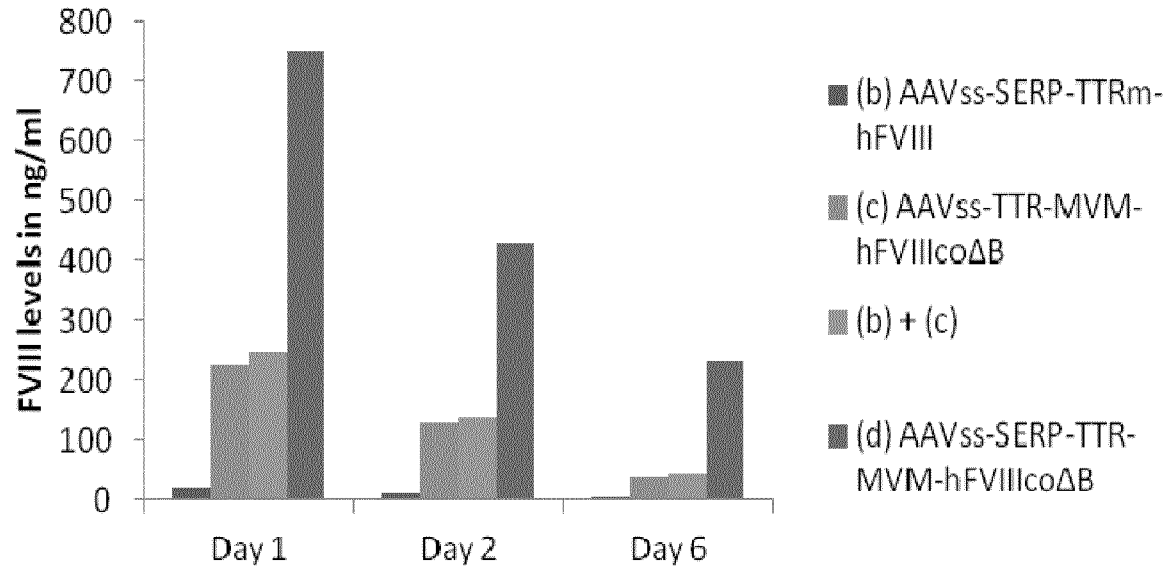
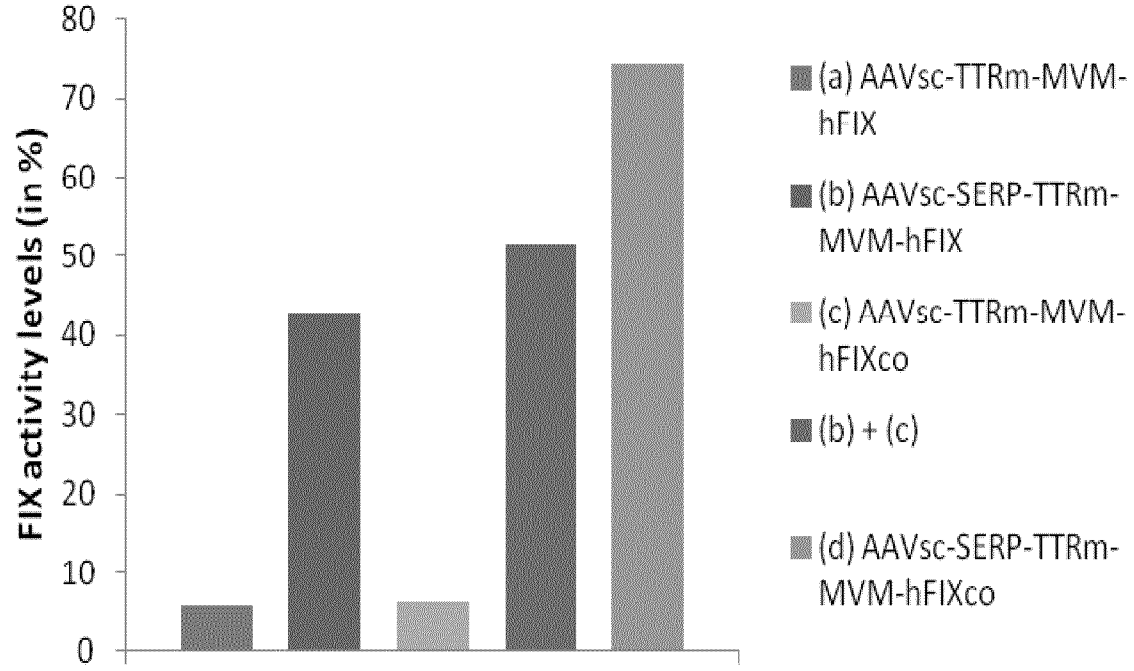

FVIII levels in ng/ml
800
700
600
500
400
300
200
100
0
Day 1
Day 2
Day 6
(b) AAVss-SERP-TTRm-hFVIII
(c) AAVss-TTR-MVM-hFVIIIcoΔB
(b) + (c)
(d) AAVss-SERP-TTR-MVM-hFVIIIcoΔB

Fig. 14

A.


FIX activity levels (in %)
80
70
60
50
40
30
20
10
0
(a) AAVsc-TTRm-MVM-hFIX
(b) AAVsc-SERP-TTRm-MVM-hFIX
(c) AAVsc-TTRm-MVM-hFIXco
(b) + (c)
(d) AAVsc-SERP-TTRm-MVM-hFIXco

B.

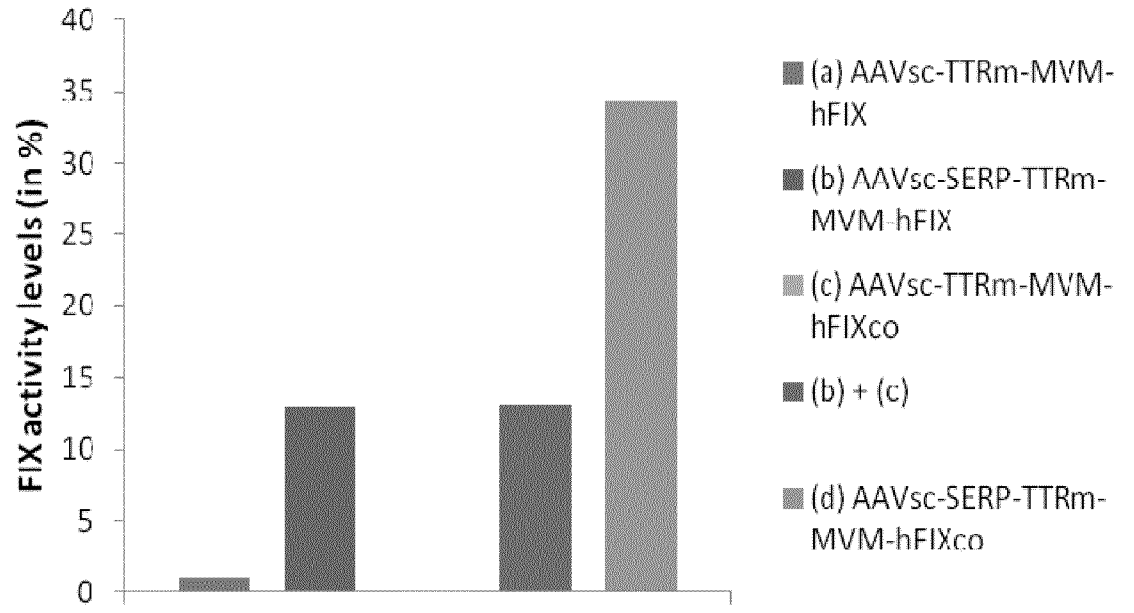
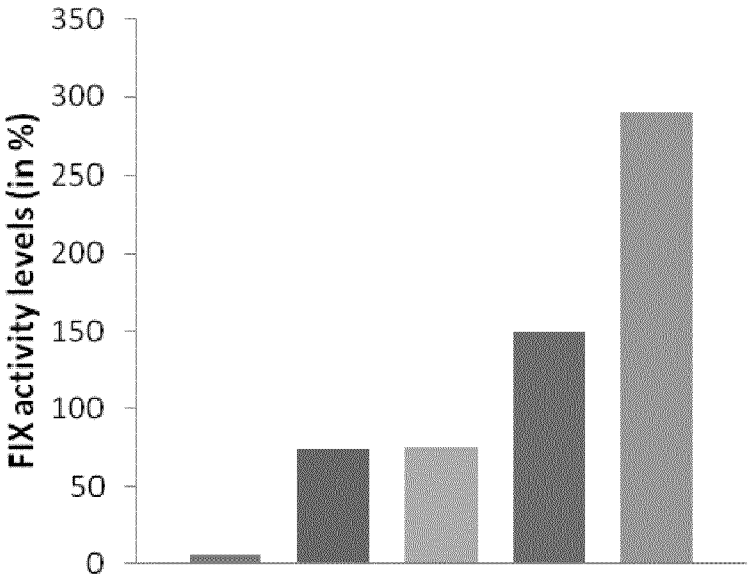

FIX activity levels (in %)
40
35
30
25
20
15
10
5
0
(a) AAVsc-TTRm-MVM-hFIX
(b) AAVsc-SERP-TTRm-MVM-hFIX
(c) AAVsc-TTRm-MVM-hFIXco
(b) + (c)
(d) AAVsc-SERP-TTRm-MVM-hFIXco

Fig. 14

C.


FIX activity levels (in %)
350
300
250
200
150
100
50
0

D.

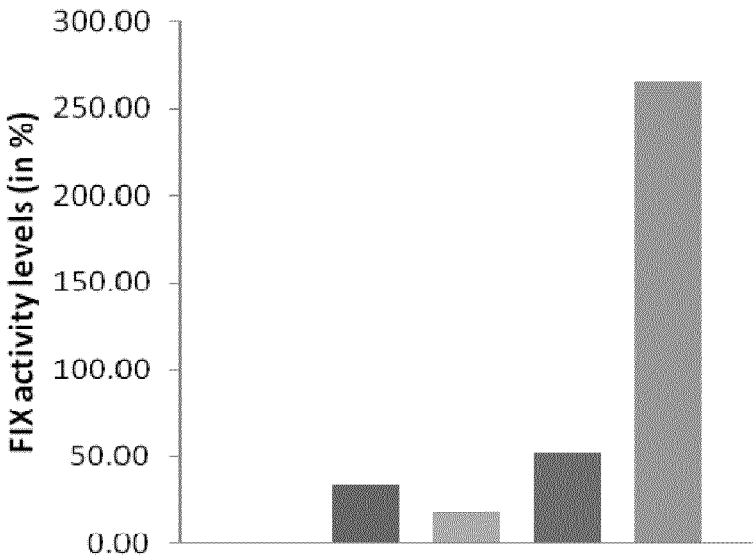
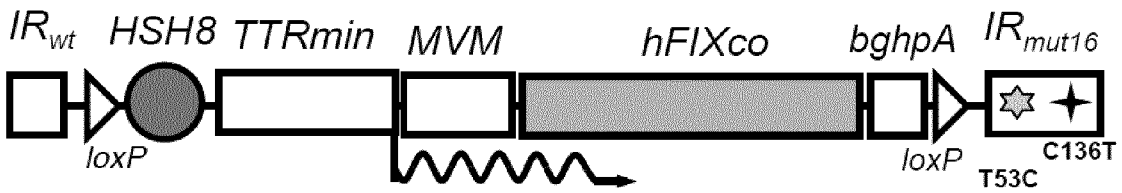
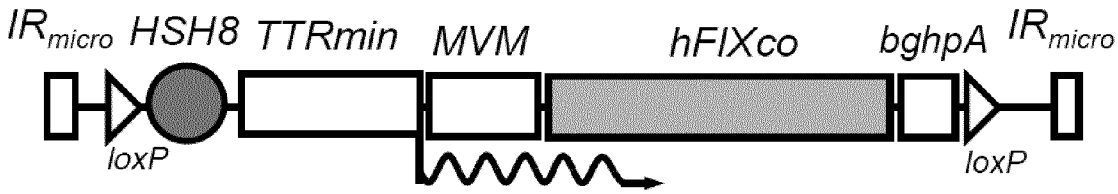

FIX activity levels (in %)
300.00
250.00
200.00
150.00
100.00
50.00
0.00

Fig. 15

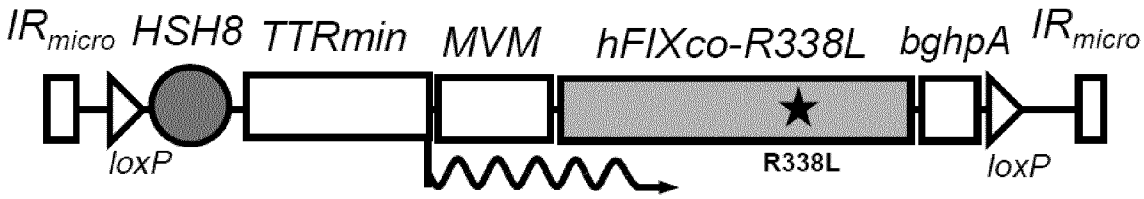
A


IRwt
HSH8
TTRmin
MVM
hFIXco
bghpA
IRmut16
loxP
loxP
C136T
T53C

B


IRmicro
HSH8
TTRmin
MVM
hFIXco
bghpA
IRmicro
loxP
loxP

C


IRmicro
HSH8
TTRmin
MVM
hFIXco-R338L
bghpA
IRmicro
loxP
R338L
loxP

D

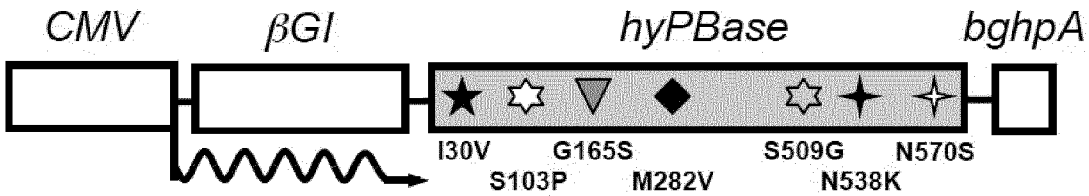

CMV
βGI
hyPBase
bghpA
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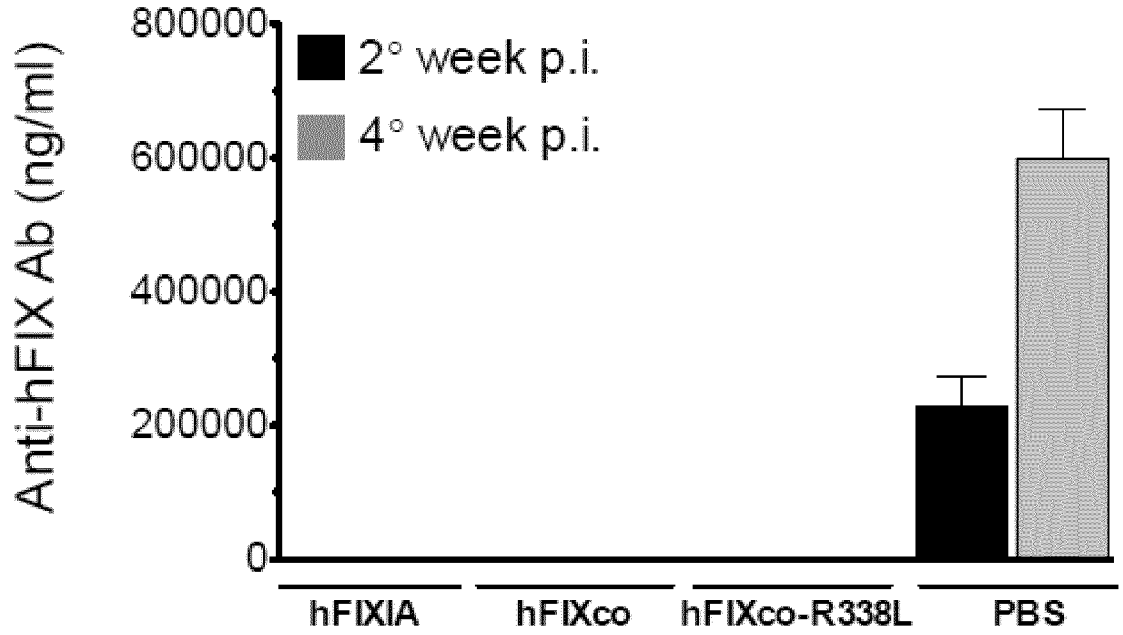
Fig. 15

E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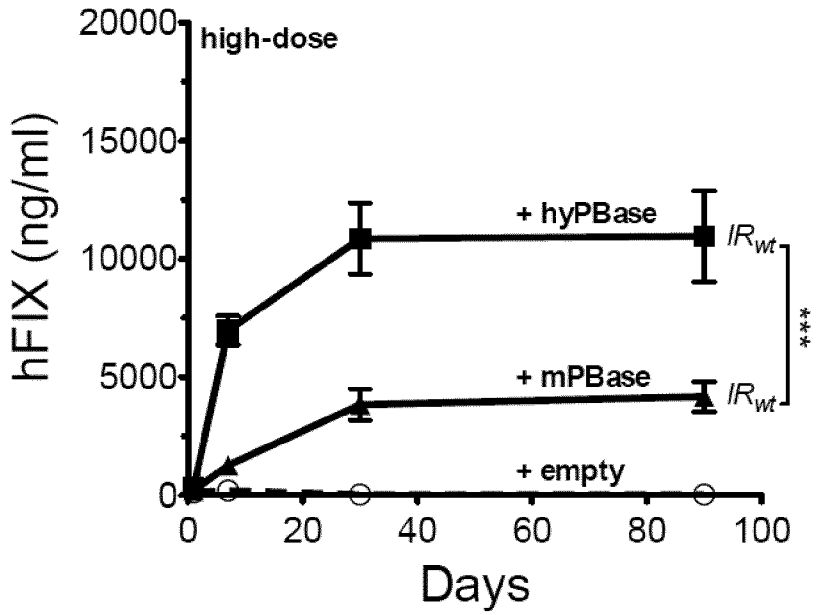
PBS

Fig. 15

F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15000
10000
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0
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IRwt
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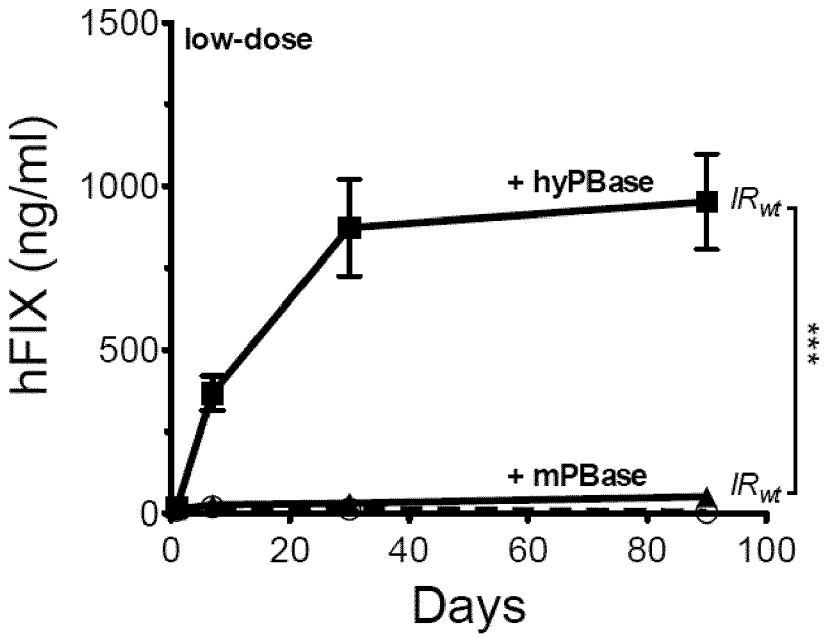
0
20
40
60
80
100
Days

G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hFIX (ng/ml)
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1000
500
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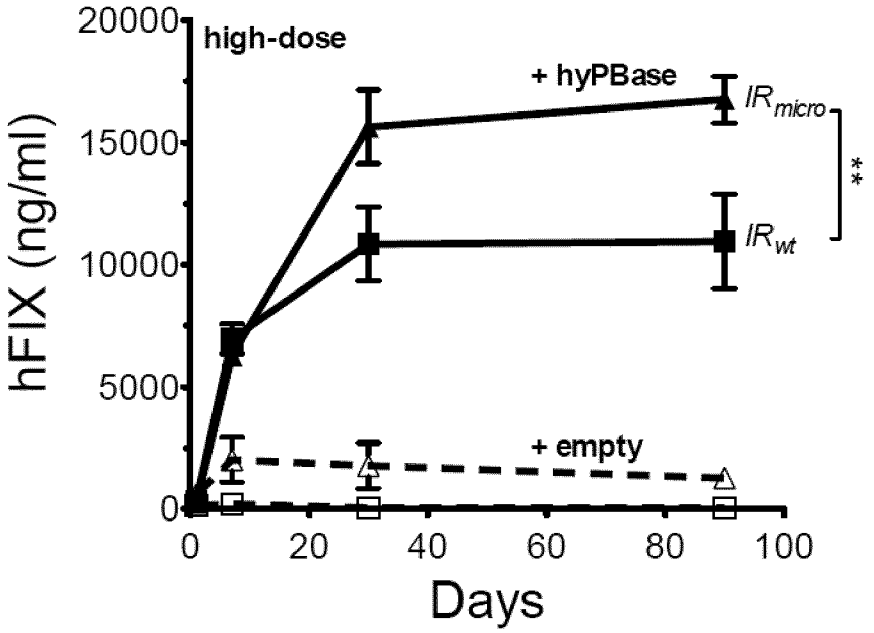
IRwt
***
+ mPBase
IRwt
0
20
40
60
80
100
Days

Fig. 15

H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+ hyPBase
IR_{micro}
IR_{wt}
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+ empty
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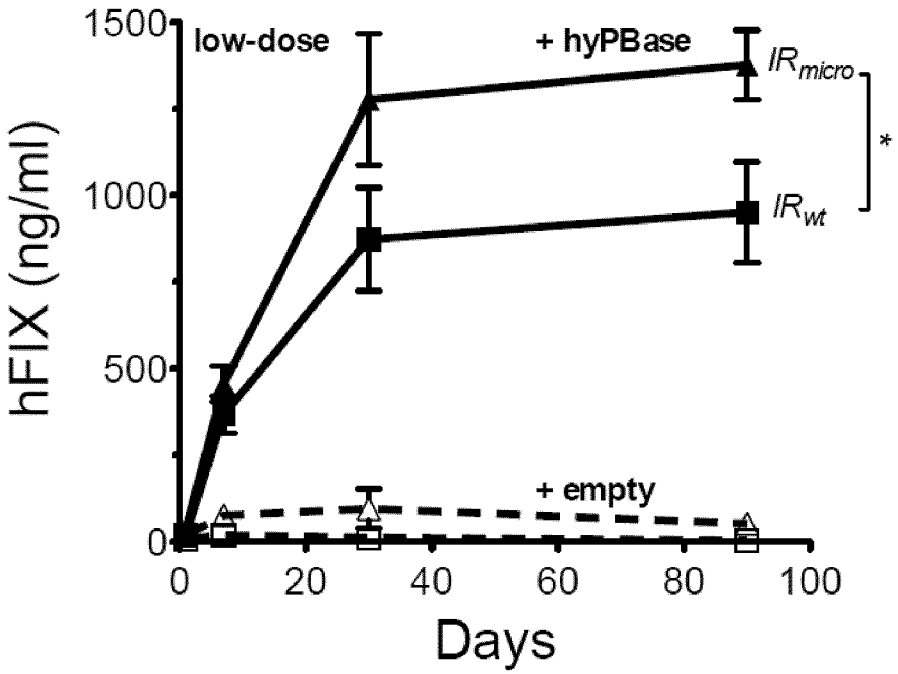
15000
10000
5000
0
0
20
40
60
80
100
Days

I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+ hyPBase
IR_{micro}
IR_{wt}
*
+ empty
hFIX (ng/ml)
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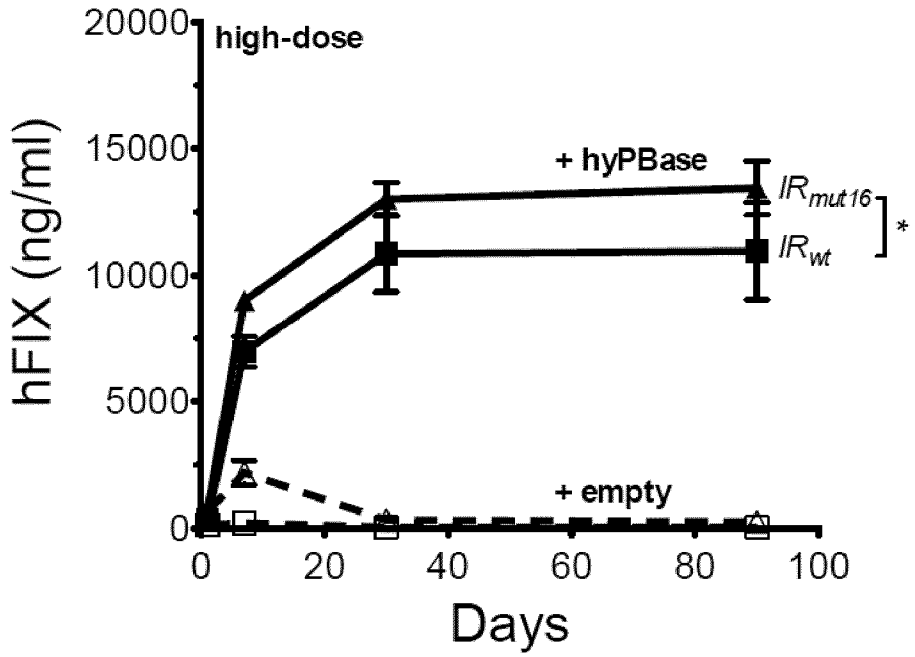
1000
500
0
0
20
40
60
80
100
Days

Fig. 15

J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IR_{wt}
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+ empty
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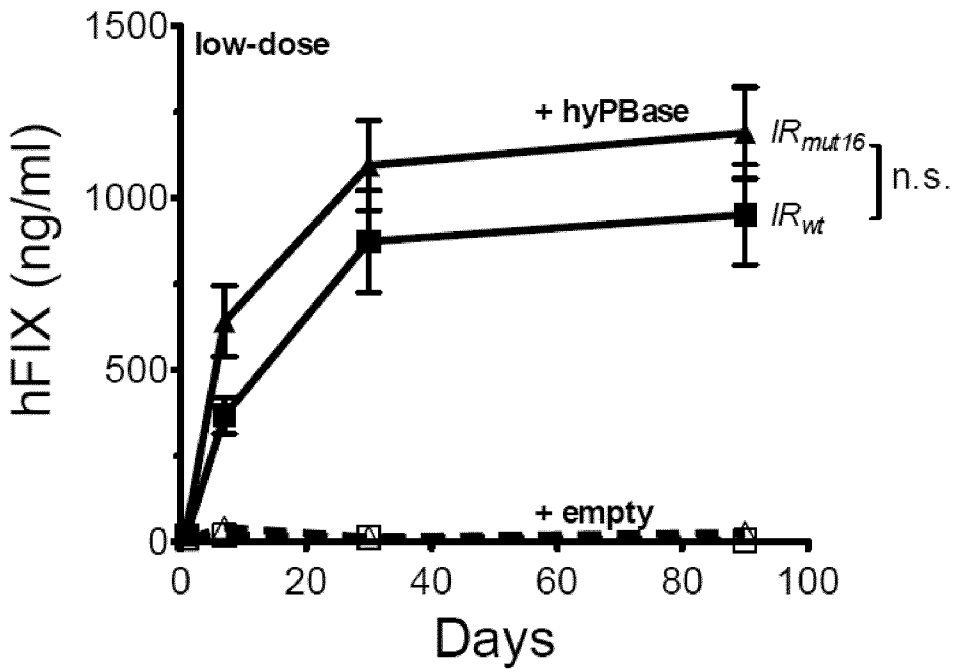
40
60
80
100
Days

K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<120> Vectors for liver-directed gene therapy of hemophilia and methods and use thereof

<130> VUB-057-PCT2

<150> PCT/EP2012/071297
<151> 2012-10-26

<150> PCT/EP2013/064054
<151> 2013-07-03

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