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DESCRIPTION

[0001] The present invention relates to mice in which the endogenous mouse λ (lambda) light (L) chain locus and/or the λ and κ (kappa) L chain loci have been functionally silenced.

[0002] B-cells express surface immunoglobulin (Ig) either with κ (kappa) or λ L chain, a choice which is termed isotype exclusion. The proportion of antibodies containing a κ or λ L chain varies considerably in the different species but in the mouse only a few percent of antibodies express λ . L chain genes are encoded by 2 different loci, the κ or λ L chain loci, and in the mouse there is an extensive number of V(variable) κ genes upstream of 5 J(joining) κ and 1 C(constant region) κ gene. Although the κ locus is over 10-times larger than the λ locus, with more than 100 V genes, this extensive complexity is not regarded as a reason that most mouse antibodies carry a κ L chain. It may be that the mouse κ locus is simply more efficient in DNA rearrangement which is supported by the finding that in the majority of cells with rearranged V κ the λ locus is still in germline configuration whilst in most cells expressing λ L chain the κ locus is either non-productively rearranged or deleted.

[0003] Several mouse strains with silenced κ L chain locus have been described. They were generated by homologous integration of a selectable marker gene in C κ or targeted removal of C κ or J κ (see for example Zou, X. et al., 1995, Eur. J. Immunol 25(8): 2154-2162). Silencing expression of κ L chain shed light on isotype exclusion and L chain activation and it was concluded that κ and λ expression are separate and independent events. Although homozygous $\kappa^{-/-}$ mice compensate for the κ deficiency with increased λ production their splenic B-cells and μ^{+} cells in the bone marrow can be reduced compared to normal mice. This may suggest that λ L chain rearrangement and expression is perhaps a less efficient process. However, despite the lack of κ L chain these mice are healthy and can mount an efficient immune response.

[0004] During B-cell development gene segments encoding Ig H chains rearrange first by D to JH recombination at the pro B-cell stage. This is followed by VH to D-JH recombination at the pre B-1 stage and if a μ H chain can pair with a surrogate L chain, consisting of V_{preB} and $\lambda 5$ protein, this forms a surfaced expressed pre B-cell receptor (pre BCR) at the pre B-II differentiation stage. Cell surface expression of the pre BCR induces proliferation and after several divisions large pre B-II cells differentiate into small resting pre B-II cells. The pre B-II stage with a defined ratio of large and small pre B cells has been identified by surface expression of the IL-2 receptor α chain, CD25. At the transition from pre B-II to immature B cell L chain V-J rearrangement occurs where the surrogate L chain is replaced by κ or λ . At this stage the cells can leave the bone marrow for further differentiation into plasma cells or memory cells in secondary lymphoid organs such as spleen or lymph nodes.

[0005] B-cell development without L chain has not been fully elucidated in the prior art. The BCR consists of two Ig H chains each associated with one Ig L chain in conjunction with the Ig α /Ig β coreceptor. These six chains must assemble correctly in the endoplasmic reticulum (ER) to allow transport and cell surface expression of IgM to progress B-cell development. Immature B-cells without L chain are not maintained and a lack of surface IgH, Ig α or Ig β expression leads to reduced signal transducer activity which can arrest B-cell maturation. H chain, synthesised prior to L chain, is chaperoned and retained in the cytoplasm but if L chain association fails single H chains, unlike L chains, undergo rapid intracellular degradation as a result of inefficient transported from the ER to the Golgi.

[0006] The mouse lambda (λ) light chain locus is about 200 kb in size and comprises 3 variable (V) region genes and 4 joining (J) segments upstream of 4 constant (C) region genes, V2 - Vx - J2 - C2 - J4 - C4 - V1 - J3 - C3 - J1 - C1 (Fig. 1a). Silencing of the λ locus is difficult because homologous integration to delete or disable a single or even two C λ genes would not be sufficient to prohibit λ light chain rearrangement and expression. To achieve this one would have to disable 2 regions: C2 and C3-C1 which are over 100 kb apart. C4 is regarded a non-functional as no protein has been found. This means two targeting constructs have to be assembled and homologously integrated in the same allele. An advantage would be the use of integrated loxP sites to allow Cre mediated deletion of the whole locus or deletion of relevant functional genes.

[0007] There is therefore the need to produce mice in which the λ light chain locus is deleted. It would also be desirable to produce mice lacking functional light chains for the production of heavy chain only antibodies - the exploitation of human antibody-producing mice, for example, is hampered by the problem that mouse lambda L chain associate with a large proportion of the expressed human Ig (or H chain).

[0008] WO 98/24884 is directed to transgenic non-human animals (especially mice) capable of producing heterologous antibodies.

[0009] Example 28 of WO 98/24884 is a theoretical and hypothetical example describing two possible strategies for targeted

inactivation of a mouse λ light chain locus:

[0010] In the first strategy, the deletion of the large 120 kb $\lambda 2C\lambda 2$ to $\lambda 1C\lambda 1$ segment using a replacement type targeting vector and relying on homologous recombination to insert a selectable marker such as neo would be extremely difficult if not impossible to achieve. Although the same strategy was reportedly used successfully in WO 98/24884 to achieve targeted deletion of the JH locus, the JH locus sequence to be deleted and replaced by the neo gene was only a few kilobases in size. Extrapolation of this single deletion approach for targeted deletion of the 120 kb $\lambda 2C\lambda 2$ to $\lambda 1C\lambda 1$ segment may not be technically achievable. Indeed, the inventors believe that no-one has been able to silence the mouse A light chain locus using this strategy despite several groups (of skilled persons) attempting to do so.

[0011] In the second strategy, it is suggested that two regions, viz. $\lambda 2C\lambda 2/\lambda 4C\lambda 4$ and $\lambda 3C\lambda 3/\lambda 1C\lambda 1$, could be independently deleted in the same embryonic system (ES) cell using replacement type targeting vectors. Again, the regions proposed for deletion are each fairly large and it is doubtful whether either deletion could be successfully performed. The probability of independently achieving two such deletions in the same ES cell is even lower. Again, the present inventors believe that no-one has been able to silence the mouse λ light chain locus using this strategy despite attempts having been made to do so.

[0012] WO 98/24884 does not provide sufficient and necessary information for the skilled person to perform the presently claimed invention. The present invention demonstrates, for the first time, the actual production of a mouse with a silenced λ light chain locus.

[0013] WO 94/02602 describes the production of xenogenic antibodies in a non-human host, which is preferably not capable of producing endogenous immunoglobulin heavy chain and is 'substantially incapable' of producing endogenous immunoglobulin light chains. Thus the antibodies of WO 94/02602 will retain some endogenous light chain activity, as the methods used to produce them are only 'substantially incapable' of producing endogenous immunoglobulin light chains. In contrast, the antibodies of the present invention are produced by a method that does not produce endogenous immunoglobulin light chains, rather than just being 'substantially incapable' of doing so. Furthermore, the general methods for producing inactivated endogenous immunoglobulin loci are wholly insufficient in describing the detailed steps necessary to produce antibodies of the present invention. WO 94/02602 discusses in the most general terms two broad strategies for the production of such antibodies. As discussed above the present invention was not susceptible to such routine techniques and the successful deletion of the relevant loci represented a significant technical challenge. WO 94/02602 does not provide sufficient and necessary information for the skilled person to produce antibodies according to the present invention.

[0014] WO 96/33735 features the use of a mouse in which the endogenous heavy and light chains are disrupted for the production of human antibodies. This document refers to WO 94/02602 for provision of a mouse incapable of producing endogenous heavy or light immunoglobulin chains (the so-called 'XenoMouse'). For the same reasons set out above this document does not provide sufficient and necessary information for the skilled person to perform the presently claimed invention.

[0015] According to a first aspect of the present invention, there is provided a mouse in which the endogenous mouse λ light chain locus is functionally silenced characterised in that the mouse has a deletion of λ light chain genes selected from the following part of the λ locus region :

1. (a) C2 and C3-C1; or
2. (b) C2-C1 (i.e. C2-C4-C3-C1).

A transgenic mouse according to the invention has been produced for the first time by the present inventors. Uses of such a mouse are described below.

[0016] The exemplified procedure of rendering the endogenous mouse lambda light chain locus non-functional used two strategies of silencing all constant region genes: 1. integration of a selectable marker gene to disable individual constant region genes and 2. gene and locus deletion. As described further in the Experimental section below, this produced two lambda KO strains, $\lambda 1.3.2^{-/-}\kappa^{-/-}$ and $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice, with essentially the same features of a silent lambda locus. Silencing of the mouse lambda light chains verified gene/locus organisation and showed that no additional L chain-like genes participate in B-cell development.

[0017] In a further embodiment of the invention, the κ light chain locus of the mouse may be functionally silenced. Mice with complete L chain knock-out (KO), i.e. kappa and lambda locus silenced by gene targeting, showed a block in B-cell development at the stage when L chain expression should have been completed. These mice still produce or express μ H chain. Indeed it is expected that they produce a heavy chain antibody repertoire. There is extensive commercial interest in such mice because 1)

they are the first mouse strain with silenced lambda locus and 2) by crossing with existing strains they would allow to produce mice that do not express any form of mouse H or L chain.

[0018] In a further embodiment of the invention, the heavy chain locus of the mouse may be silenced by a method of gene targeting (knock-out).

[0019] The λ , κ and heavy chain loci of the mouse may be knocked out or silenced.

[0020] In yet a further embodiment, the mouse may carry at least one transgene which comprises one or more heavy genes or loci and/or a light chain genes or loci from a heterologous species. The mouse may produce heavy chain only antibodies of the heterologous species. The heterologous species may be human.

[0021] In a further aspect of the invention, there is provided the use of a mouse as defined above to produce antibodies. The antibodies may be produced through immunisation procedures. In a preferred embodiment, the antibodies are human.

[0022] Also provided is a method of producing a mouse as defined above in which the λ light chain locus is functionally silenced, comprising the step of deleting at least the constant region genes C1, C2 and C3 of the λ light chain locus. The C2-C4 loci and C3-C1 loci may be deleted simultaneously or sequentially. In one embodiment of the disclosure, the targeting constructs shown in Fig. 1 are used.

[0023] The invention will be further described in the Experimental section below with reference to the accompanying figures, of which:

Figure 1 Shows targeted integration and deletion of the mouse λ L chain locus. a, The locus is ~200 kb with 2 sets of J-C genes (J2-C2 J4-C4 and J3-C3-J1-C1) separated ~110 kb. Two V genes, V2 and Vx, are located ~75 kb and ~56 kb upstream of C2, respectively, and V1 is located ~20 kb upstream of C3. Targeted integration of C3-C1 inserts $^{tk}Neo-loxP$ into C1 and $loxP$ 3' of J3, this allows deletion of C3, J1 and 5'CI. The C2-C4 targeting construct inserts $loxP.^{tk}Neo$ into C2. Both targeting constructs disable all functional C genes. Upon Cre mediated deletion the region between C2 and C1 is removed. b, Analysis of targeted integration and Cre-mediated deletion. Southern blot of normal mouse DNA (NM), ES cell DNA from clones with homologous integration in C3-C1 (ES3.1) and C2-C4 (ES2.4), and deletion of C3-C1 (ES3.1 $\Delta^{+/-}$ and 3.1 $\Delta^{-/-}$) with digests and probes (A, B, C, D) indicated. PCR analysis of tail DNA identified the configuration of the Ig λ locus before and after Cre deletion. Oligonucleotides (1 - 6; see below) are indicated by arrows and resulting PCR bands are the product of used oligo combinations indicated by shading. Restriction sites used for the analysis are B, BamHI; H, HindIII; R, EcoRI; S, SacI; X, XhoI; Xb, XbaI;

Figure 2 Shows flow cytometry analysis of a, bone marrow and b, splenic B-cell populations from normal (NM), $\kappa^{-/-}$, $\lambda 1^{-/-}\kappa^{-/-}$, $\lambda 1.3^{-/-}\kappa^{-/-}$, $\lambda 1.3.2^{-/-}\kappa^{-/-}$ and $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice. The profiles are representative for results obtained for at least 5 mice per group and show staining of gated bone marrow lymphocytes with PE-conjugated c-*kit*, biotin-conjugated anti-mouse CD43, biotin-conjugated anti-mouse CD25 or biotin-conjugated anti-IgM in combination with PE- or APC-conjugated anti-B220. Spleen cells were stained with biotin-conjugated anti-IgM, FITC-conjugated anti-IgD, biotin-or FITC-conjugated anti- λ and/or PE-conjugated anti- κ and APC-conjugated anti-B220 for setting the B-lymphocyte gate;

Figure 3 Shows cytoplasmic and surface staining of CD25⁺ bone marrow B-cells from $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ and normal (NM) mice. a, cytoplasmic and, separately, surface staining with FITC-coupled anti- μ . b, separation of B-cells according to their size;

Figure 4 Shows flow cytometry analysis of B- and T-cells in the peritoneum of $\kappa^{-/-}$ and $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice. Cells were stained with PE-conjugated anti-CD5 and APC-conjugated anti-B220; and

Figure 5 Shows gel separation of cytoplasmic and serum antibodies from $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ (L KO) and normal (NM) mice captured with anti- μ .

Experimental

[0024] Here we show that mice with silenced L chain loci are immunodeficient. They do not produce B-1 or B-2 cells in the periphery and B-cell development is compromised at the immature B-cell stage with a complete block at the stage of

differentiation when L chain rearrangement should have been completed.

[0025] To analyse the importance of light (L) chain expression for antibody development mutant mice with targeted deletion of the Igλ locus were generated and crossed with mice carrying a non-functional Igκ locus. Successive silencing of Cλ genes in a κ^{-/-} background showed a reduction in mature B-cell levels and animals with silenced L chain genes, i.e. λ^{-/-}κ^{-/-} mice, do not express Ig polypeptides. Their spleens are devoid of B-cells and neither peritoneal B-1 nor B-2 cells are present whilst T-cell numbers remain normal. Bone marrow pro and pre B-cells are only slightly reduced and levels of CD25⁺ large and small pre B-II cells are largely retained. In λ^{-/-}κ^{-/-} mice B-cell development appears to be essentially uncompromised up to the immature stage. However, a complete block is apparent when L chain rearrangement, resulting in surface IgM expression, should be completed. The lack of L chain prevents BCR association and L chain function cannot be substituted (e.g. by surrogate light chain). It was unexpected that the lack of L chain had no profound effect on precursor cell development, such as accumulation of pre B-II cells at the pre B-to immature B-cell transition stage.

Materials and Methods

[0026] *Targeting constructs.* A phage λ library derived from ES cell DNA, a kind gift from A. Smith and T. Rabbitts (Laboratory of Molecular Biology, MRC, Cambridge, UK), was hybridised with a Vλ and Cλ probe (clone #505 kindly provided by M. Neuberger, MRC, UK) which identified several clones containing Vλ and, separately, Cλ genes. Part of the C2-C4 and C3-C1 regions were subcloned in pUC19 to assemble the constructs and to obtain gene probes. This allowed blunt end insertion of loxP from pGEM-30 (Gu, H. et al., 1993, Cell 73: 1155-1164) in the HindIII site 3' of J3, loxP insertion in ^{tk}Neo (Stratagene, La Jolla, CA) and blunt end insertion of ^{tk}Neo-loxP into Cλ1, and loxP-^{tk}Neo, derived from pGH-1 (pGEM-30 and pGH-1 were a kind gift from H. Gu, Institute for Genetics, University of Cologne, Germany), into Cλ2 (see Fig. 1a). The -14 kb C3-C1 targeting construct was obtained by XhoI and HindIII digest and the -13 kb C2-C4 targeting construct was obtained by XhoI excision in the internal and polylinker site. Restriction sites for integration of ^{tk}Neo (SacI and BamHI) or loxP (HindIII) in the targeting constructs were not maintained.

[0027] *Analysis of homologous integration.* Methods used for electroporation of targeting constructs and ES cell selection have been described (Zou, X. et al., 1995, *supra*). The C3-C1 construct was integrated in HM-1 (Selfridge, J. et al., 1992, Somat. Cell. Mol. Genet. 18: 325-336) and C2-C4 was integrated in λES3.1Δ-5 ES cells. Targeting of C3-C1 was identified with a 0.4 kb HindIII fragment (probe A, all probes are marked in Fig. 1a) and SacI digest of ES cell DNA, and verified with a 2 kb XbaI-HindIII fragment (probe B) and SacI, HindIII and BamHI digests which also allowed identification of C3-C1 Cre-loxP deletion. Homologous integration in C2-C4 was identified with a 0.7 kb HindIII-XbaI fragment (probe C, the XbaI site is immediately 5' of SacI) and a 1.2 kb HindIII-BamHI fragment (probe D), and HindIII and BamHI digests of ES cell DNA. To obtain deletion of the λ locus the Cre plasmid pBS185 (GIBCO, #10347-011) was transiently integrated by electroporation (Zou, X. et al., 1995, *supra*). Clones were tested by PCR using the following oligonucleotides (arrow 1-6 in Fig. 1a):

C1rev 5'-GCCTTTCCCATGCTCTTGCTGTCAGGG-3' (SEQ ID NO: 1) (< 1);

C1for 5'-CCAAGTCTTCGCCATCAGTCACCC-3' (SEQ ID NO: 2) (2>);

3'J3for 5'-CCCAGGTGCTTGCCCCACAGGTTTAGG-3' (SEQ ID NO: 3) (3>);

5'C2for 5'-GGAGATCAGGAATGAGGGACAAAC-3' (SEQ ID NO: 4) (4>);

3' ^{tk}Neorev 5'-CTCGACGGATCCGTCGAGGAATTCC-3' (SEQ ID NO: 5) (<5 neo); and

^{tk}Neofor 5'-ATGGCCGATCCCATATTGGCTGCAGGG-3' (SEQ ID NO: 6) (neo 6>).

Oligos 1-2 and separately, 4-5 identified construct integration whilst the combination of oligos 1-3 and 1-4 identified partial or complete C gene deletion. PCR reactions were performed under the following conditions: two initial cycles of 45 sec at 97°C, 30 sec at 60°C and 60 sec at 72°C followed by 30 cycles with 30 sec at 94°C, 30 sec at 60°C and 60 sec at 72°C, and 10 min at 72°C to complete the reaction.

[0028] *Derivation of mice.* Chimeric mice and germline transmission was obtained as described (Hogan, B. et al., 1994a, In: Manipulating the mouse embryo, a laboratory manual, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, p253-289). λ1.3 mice, in a 129/Ola x Balb/c background, were mated with 129/Ola mice for 5 generations and crossed with Cre mice and each other to obtain homozygous λ1.3^{-/-} mice. For the derivation of ES cells, blastocysts were collected and cultured on mitomycin-C

treated feeder cells (Hogan, B. et al., 1994b, In: *Manipulating the mouse embryo, a laboratory manual*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, p217-251). Several ES cell lines were obtained and λES3.1Δ-5, a female line, was used for integration of the C2-C4 targeting construct.

[0029] For the derivation of transgenic mice expressing Cre-protein ubiquitously, the Cre plasmid pBS185 was linearised with *ScaI* and purified using a DNA purification kit (Qiagen #28304). DNA was microinjected into the male pronucleus of F1 embryos (CBA x C57B1/6) according to standard methods (Hogan, B. et al., 1994b, *supra*) and several founders were produced, two of which showed a high gene/locus deletion rate when crossed with *loxP* mice.

[0030] *Flow cytometry analysis.* For the analysis of B cell populations by flow cytometry cells from the different tissues were prepared and stained with various combinations of differently labelled antibodies against cell surface markers (see Fig. 2): these were for bone marrow cells PE-conjugated anti-mouse *c-kit* (CD117) (09995B; PharMingen), Phycoerythrin (PE)- or allophycocyanin (APC)-conjugated anti-mouse CD45R (B220) (01125A, 01129A; PharMingen, San Diego, CA), Biotin-conjugated anti-mouse CD25 (01092A; PharMingen), FITC-conjugated monoclonal rat anti-mouse IgM (μ chain specific, 04-6811; Zymed) and/or Biotin-conjugated anti-mouse CD43 (01602D; PharMingen); for spleen cells PE- or APC-conjugated anti-mouse CD45R (B220) (01125A, 01129A; PharMingen), Biotin-conjugated anti-mouse IgM (μ chain specific, 02082D; PharMingen), FITC-conjugated anti-mouse IgD (02214D; PharMingen), Biotin or FITC conjugated anti-mouse Igλ (02172D, 02174D; PharMingen) and/or PE-conjugated anti-mouse Igk (559940, PharMingen); and for peritoneal cells PE-conjugated anti-mouse CD5 (Ly-1) (01035A; PharMingen) and APC-conjugated anti-mouse CD45R (B220) (01125A, 01129A; PharMingen).

[0031] For cytoplasmic staining bone marrow B-cells were pre-treated using a fix and perm cell permeabilization kit (GSA-004, Caltag) and then stained with FITC-conjugated monoclonal rat anti-mouse IgM (μ chain specific, 04-6811; Zymed), PE-conjugated anti-mouse CD45R (B220) (01125A, 01129A; PharMingen) and Biotin-conjugated anti-mouse CD25 (01092A; PharMingen) according to the manufacturer's protocol. Binding of biotinylated antibody was developed with streptavidin-Quantum Red (S2899; Sigma) or streptavidin-Tri-color (SA1006, Caltag, Burlingame).

[0032] *Protein analysis.* Serum antibodies were identified by ELISA as described (Zou, X. et al., 1995, *supra*). For separation on acrylamide gels digitonin lysates of bone marrow cells (Bell, S.E. et al., 1994, EMBO J. 13(4): 816-26) and, separately, serum was incubated for 1 h at 4°C with anti-mouse IgM (μ chain specific, The Binding Site, Birmingham, UK) coupled to CNBr-activated Sepharose 4B (Pharmacia LKB, Uppsala, Sweden) as described (March, S.C et al., 1974, Anal. Biochem. 60: 149-152). Samples were fractionated on 4-15% precast gels (161-1104, Bio-Rad, Hemel Hempstead, UK) and, after transfer to nitrocellulose membranes, incubated with biotinylated anti-mouse μ (B-9265, Sigma) for 1h at RT and then placed in streptavidin biotinylated horseradish peroxidase (HRP) solution (RPN 1051, Amersham) for 30 minutes on a rocker. Bands were visualised with SuperSignal West Pico chemiluminescent substrate (34080, Pierce, Illinois).

Results

[0033] *Silencing of the mouse λ L chain locus.* To investigate B-cell development without L chain we produced mice with a deleted Igλ locus. The λ^{-/-} mice were crossed with animals carrying a non-functional Igk locus, κ^{-/-} mice, also obtained by gene targeting (Zou, X. et al., 1995, *supra*). The mouse λ L chain locus contains 3 V (variable) region genes, 4 J (joining) segments and 4 C (constant) region genes which can independently rearrange and express 3 different λ L chains. C4 has not found to be expressed. Silencing of the λ locus was carried out in 4 successive steps by introduction of 3 *loxP* sequences and targeting of C 1 and C2 (Fig. 1a). Introduction of the C3-C1 targeting construct silenced C1 and germline transmission mice were produced which, upon mating with ubiquitous Cre expressers, had C3-C1 deleted on both alleles. Such mice, bred into the 129/Ola background, were used for the derivation of embryonic stem (ES) cells which allowed homologous integration and silencing of C2. Germline transmission mice were obtained and bred with the Cre expressers and each other which resulted in homozygous animals with a C2 to C1 deletion of ~120 kb. Analysis of ES cells and mice by Southern blot and PCR, with representative examples shown in Fig. 1b, identified homologous integration and locus deletion and resulted in separate animals with the following genes silenced: a) λC1^{-/-} (mouse 130 = ES1.3), b) λC1^{-/-} and λC3^{-/-} (mouse 1.3 = ES1.3Δ), c) λC1^{-/-}, λC2^{-/-} and λC3^{-/-} (mouse 50 = ES2.4) and c) deletion of λC1^{-/-}, λC2^{-/-}, λC3^{-/-} and λC4^{-/-} (mouse 1.3-2.4Δ). These mouse strains were crossed into the κ^{-/-} background and termed according to their silenced or deleted (Δ) C genes: λ1^{-/-}κ^{-/-}, λ1.3^{-/-}κ^{-/-}, λ1.3.2^{-/-}κ^{-/-} and λ1-2Δ^{-/-}κ^{-/-}. Deletion of the λ locus was verified by sequencing of the 686 bp PCR fragment shown in Fig. 1b which contained the 3'J2 and 3' C1 region separated by *loxP*.

[0034] *B-cell reduction upon Cλ gene removal.* Mice with individually silenced Cλ genes in the κ^{-/-} background showed

significantly reduced numbers of mature IgM⁺ B-cells compared to normal mice kept in the same pathogen-free conditions (Table 1). Serum antibodies in $\lambda 1^{-/-}\kappa^{-/-}$ and $\lambda 1.3^{-/-}\kappa^{-/-}$ were also reduced but comparable to those in $\kappa^{-/-}$ mice (Zou, X. *et al.*, 1995, *supra*). Unexpectedly $\lambda 1.3.2^{-/-}\kappa^{-/-}$ and $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice derived from heterozygous females or foster mothers had significant antibody titers in serum still detectable by ELISA 6 weeks after weaning. However, serum analyses from such mice older than 3 months showed that no antibodies remain (data not shown). The lack of serum Ig in $\lambda 1.3.2^{-/-}\kappa^{-/-}$ mice confirms that CA4 must be a pseudogene and that the remaining V λ genes cannot be expressed using an as yet unknown C gene. The reduction of B-cell levels in bone marrow and spleen at each successive silencing step is shown in Fig. 2 and Table 1. In the bone marrow pro and pre B-cell development appears to be little affected by the loss of L chain expression and the levels of c-*kit*⁺, CD43⁺ and CD25⁺ B-cells are quite similar in the KO strains and compared to normal mice (Fig. 2a). However, at the stage when L chain rearrangement should have been completed normal development is blocked and immature B-cells fail to express surface IgM. Interestingly, a reduction in the number of cells expressing surface IgM is clearly visible and, compared to the 12% of IgM⁺ B220⁺ lymphocytes in normal mouse bone marrow, 4% are found in $\kappa^{-/-}$ mice, 2% in $\lambda 1^{-/-}\kappa^{-/-}$, 1% in $\lambda 1.3^{-/-}\kappa^{-/-}$ and essentially none in $\lambda 1.3.2^{-/-}\kappa^{-/-}$ and $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice. In the spleen the levels of Ig⁺ B-cells in $\lambda 1^{-/-}\kappa^{-/-}$ and $\lambda 1.3^{-/-}\kappa^{-/-}$ mice are similar to those in $\kappa^{-/-}$ mice whilst in $\lambda 1.3.2^{-/-}\kappa^{-/-}$ and $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice only background staining remains (Fig. 2b).

To evaluate if B220⁺ B-cells in the bone marrow do accumulate μ H chain in the cytoplasm and if these cells migrate to secondary lymphoid organs we stained for cytoplasmic IsM. As shown in figure 3a CD25⁺ bone marrow B-cells from $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice do indeed stain for cytoplasmic μ H chain but show no staining for surface IgM. Indeed the levels of CD25⁺ B-cells and their size distribution is very similar in normal and L KO mice (Fig. 3b). However, migration of these cells to, for example, the peritoneum is not taking place and Fig. 4 shows that essentially no B-cells exist in secondary lymphoid organs. We wondered if the identified μ H chain in the cytoplasm of B-cells from $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice is of the same size or molecular weight as conventional μ H chain. Cell lysis using digitonin and capturing bound or unbound μ H chain, analysed on polyacrylamide gels (Fig. 5), showed no size difference of the μ H chain produced in the cytoplasm of normal or L chain silenced mice. However, as also shown in Fig. 5 serum Ig is not produced by these mice. This re-emphasises that B-cell development and μ H chain expression up to the stage when L chains are expressed appears to be largely unaffected in L chain KO mice. Furthermore, the lack of L chain prevents the release of μ H chain from the cell which prevents Ig secretion.

[0035] *Block in development at the immature B-cell stage.* Silencing of the λ L chain genes in a $\kappa^{-/-}$ background showed that no surface or secreted Ig is produced and that the resulting block in B-cell development is established at the pre B-II to immature transition phase. At this stage CD25 expression is revoked, the pre BCR is replaced by the BCR, surrogate L chain is no longer expressed and κ or λ L chain rearrangement is completed with successful expression that allows μ H chain association. After several divisions large CD25⁺ pre B-II cells differentiate into small CD25⁺ resting pre B-II cells which are in the process of rearranging their L chain genes. As can be seen in Fig. 2a the number of CD25⁺B220⁺ cells at the stage immediately before the developmental block is by and large very similar. As successful L chain rearrangement is prevented or impaired in the mutant mice we wondered if this block in development alters the ratio of large and small CD25⁺ cells. In Fig. 3b the number of CD25⁺ gated bone marrow cells from age-matched normal, $\kappa^{-/-}$ and $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice is plotted against cell size. The comparison shows slight variations as expected but no major differences in the large and small pre B-II cell populations. This concludes that the failure to express L chain initiates a complete block in development at the immature B-cell stage when surface IgM should be expressed. In addition no immature B-cells accumulate before the event.

[0036] This block in development with no apparent recovery impedes surface IgM expression and subsequent cell migration. As shown in Table 1 the number of spleen cells in $\lambda 1.3.2^{-/-}\kappa^{-/-}$ and $\lambda 1-2\Delta^{-/-}\kappa^{-/-}$ mice is significantly reduced. A complete lack of mature B-cells is also found in the peritoneal cavity with no B220⁺ and B220⁺CD5⁺ cells (Fig. 4). This lack of B-1 and B-2 cells appears to have no effect on T-cell levels which are maintained.

Discussion

[0037] Our experiments show that B-cell development is aborted in L chain deletion mice at the pre B-II to immature B-cell transition stage when surface receptor expression should have been accomplished. This complete block in development prevents B-cell maturation and the mouse is immunodeficient regarding antibody expressing B-cells. The surrogate L chain encoded by VpreB and $\lambda 5$ does not sustain B-cell development and with the failure to express L chain polypeptides B-cell differentiation ceases exactly at the stage when L chain rearrangement should have been completed. This re-emphasises the importance of L chain for immune development and that, at least in the mouse, there is no gene or rescue event that can compensate L chain

deficiency.

[0038] B-cell development in the mouse has been extensively studied by gene targeting and in one of the early experiments a μ transmembrane exon was rendered non-functional which prevented surface IgM expression. This μ MT KO caused a block in development, leading to the accumulation of pre B-I and the disappearance of pre B-II cells. With the lack of surface IgM expression no proliferation or differentiation into immature or mature B-cells was obtained, however, DNA rearrangement was maintained. Indeed the μ MT mice do rearrange H and L chain genes whilst H chain KO mice without J segments maintain L chain rearrangement. This is in agreement with the results of our $\lambda^{-/-}\kappa^{-/-}$ mice which show H chain rearrangement and cytoplasmic Ig μ expression which reiterates that H and L chain rearrangement and expression are independent events. The critical importance of the BCR in signalling and normal progression of development through the different B-cell maturation stages was further analysed by gene targeting of individual BCR components. The results showed that silencing of some genes, such as the Ig κ L chain locus, had a moderate effect on B-cell development and is well tolerated whilst the function of other genes, such as C μ or Ig β , is essential and blocks any progress in development. The block in B-cell development was frequently accompanied by the accumulation of cells prior to the stage of differentiation when the silenced gene should be active. Surprisingly this is not seen at any pro or pre B-cell stage in the $\lambda^{-/-}\kappa^{-/-}$ mice and the numbers of CD25 $^{+}$ large and small B-cells immediately prior to the block in development are similar to those found in a normal mouse. A reason for this may be that the cells entering the pre B-II stage and those being apoptosed, perhaps half of the CD25 $^{+}$ cells generated in the bone marrow die without maturing into IgM $^{+}$ B-cells, allow to maintain fairly constant cell levels.

[0039] The importance of L chain expression has been studied in RAG-1 and RAG-2 KO mice where B-cell development is arrested at the B220 $^{+}$ CD43 $^{+}$ pro B-cell stage. Upon introduction of a rearranged H chain Ig μ was expressed in the cytoplasm which is in agreement with the observation that L chain facilitates dissociation of H chain binding protein and transport to the cell surface. However, to direct the development of a B-lineage cell population in RAG $^{-/-}$ mice both rearranged H and L chain genes had to be introduced. In the bone marrow of RAG-1 $^{-/-}$ λ 5 $^{-/-}$ mice carrying a rearranged H chain transition from pro B- to pre B-cell and surface IgM expression was only seen when either λ 5 or a rearranged L chain was introduced. Nussenzweig and colleagues argued that when neither λ 5 nor conventional L chain are expressed B cell development cannot proceed past the pro-B-cell stage. This is not seen in our mice with silenced λ and κ light chain locus where B-cell development allows heavy chain expression and developmental progress to the pre B-II cell stage.

Table 1. Cell numbers in spleen and bone marrow of normal, $\kappa^{-/-}$ and C λ deletion mice.

Organ	NM	$\kappa^{-/-}$	$\lambda 1^{-/-} \kappa^{-/-}$	$\lambda 1.3^{-/-} \kappa^{-/-}$	$\lambda 1.3.2^{-/-} \kappa^{-/-}$	$\lambda 1-2\Delta^{-/-} \kappa^{-/-}$
Bone Marrow						
total cell no. $\times 10^6$	18	14	9	6	2	1
C-Kit ⁺ B220 ⁺ pro B-cells	0.52	0.24	0.14	0.08	0.04	0.02
B220 ⁺ CD43 ⁺ pro/pre B-cells	0.95	0.51	0.29	0.16	0.08	0.04
B220 ⁺ CD25 ⁺ immat. B-cells	1.32	1.26	0.36	0.21	0.14	0.10
B220 ⁺ IgM ⁺ immat./ mat. B-cells	1.34	0.33	0.10	0.05	0.01	0.10
B220 ⁺ B-cells	3.89	2.61	1.00	0.48	0.27	0.18
IgM ⁺ B-cells						
Spleen						
total cell no. $\times 10^6$	38	42	28	32	31	24
B220 ⁺	10.40	7.42	3.62	4.31	0.67	0.39
IgM ⁺	9.69	6.60	3.10	3.74	0.03	0.02
IgD ⁺	7.81	3.10	1.18	1.51	<0.01	<0.01
IgL ⁺						

Cells were stained with relevant antibodies for the listed features (see Materials and Methods) and analysed by Total cell numbers were determined by Trypan blue staining. *Cells were from one femur.

REFERENCES CITED IN THE DESCRIPTION

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- 1 -

MUSE-LAMBDA-LETKÆDELOCUS

PATENTKRAV

1. Mus, hvor det endogene muse λ -letkædelocus er funktionelt gjort tavst, kendetegnet ved, at musen har en deletion af λ -letkædegener udvalgt fra følgende del af λ -locusregionen:
 - 5 (a) C2 og C3-C1 eller
 - (b) C2-C1 (dvs. C2-C4-C3-C1).
2. Mus ifølge krav 1, hvor κ -letkædelocuset er funktionelt gjort tavst.
3. Mus ifølge et hvilket som helst af de foregående krav, hvor muse-tungkædelocuset er gjort tavst ved hjælp af en fremgangsmåde med gentargeting (knockout).
- 10 4. Mus ifølge et hvilket som helst af de foregående krav, hvor λ -, κ - og tungkædeloci er blevet knocked-out eller gjort tavse.
5. Mus ifølge et hvilket som helst af de foregående krav, hvilken mus bærer mindst ét transgen, der omfatter ét eller flere gener eller loci fra en tungkæde og/eller gener eller loci fra en letkæde fra en heterolog art.
- 15 6. Mus ifølge krav 5, hvor musen kun frembringer tungkædeantistoffer af den heterologe art.
7. Mus ifølge et af krav 5 eller krav 6, hvor den heterologe art er human.
8. Anvendelse af en mus som defineret i et hvilket som helst af de foregående krav til at frembringe antistoffer.
9. Anvendelse ifølge krav 8, hvor antistofferne frembringes ved immuniseringsprocedurer.
- 20 10. Anvendelse ifølge et af krav 8 eller krav 9, hvor antistofferne er humane.
11. Fremgangsmåde til frembringelse af en mus som defineret i krav 1, hvor λ -letkædelocuset er funktionelt gjort tavst, hvilken fremgangsmåde omfatter trinnet med deletering af generne fra mindst den konstante region C1, C2 og C3 af λ -letkædelocuset.
12. Fremgangsmåde ifølge krav 11, hvor C2-C4-loci og C3-C1-loci deleteres samtidigt eller
- 25 sekventielt.

DRAWINGS

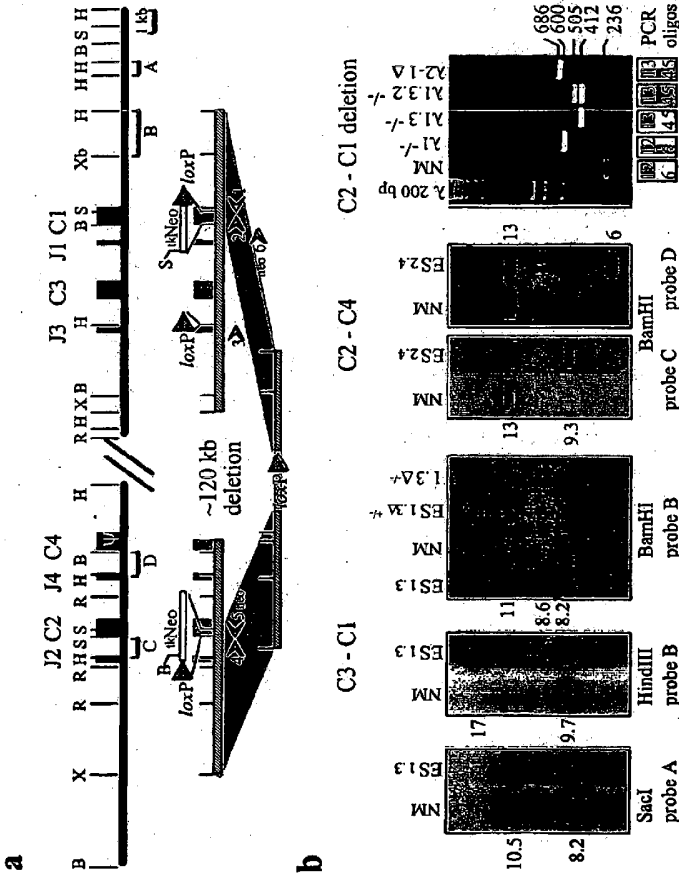
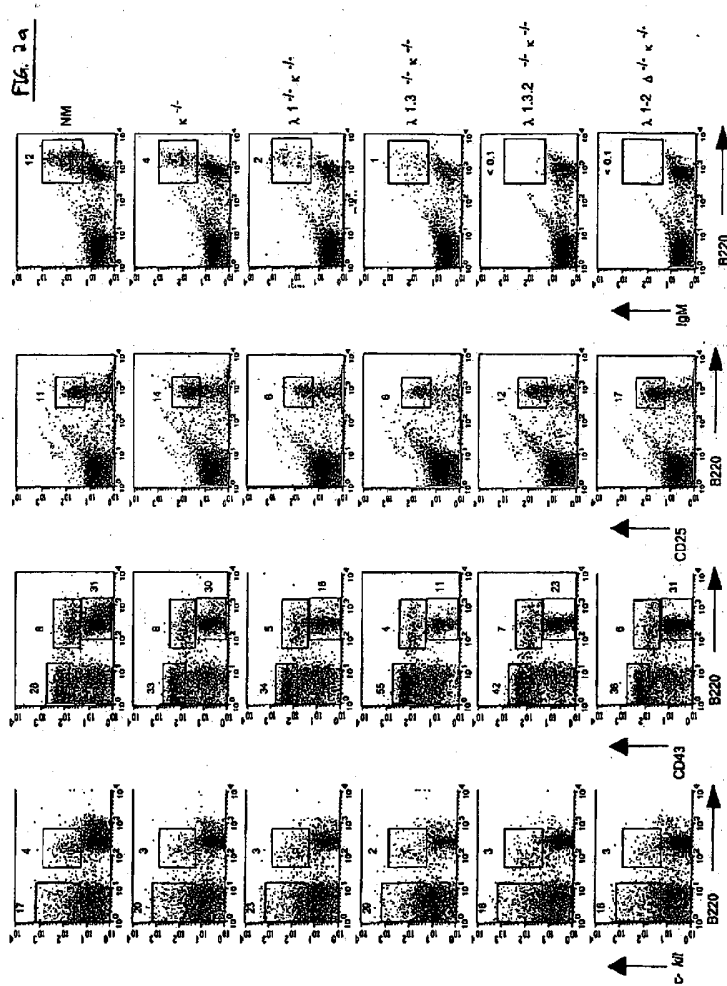


Fig. 1



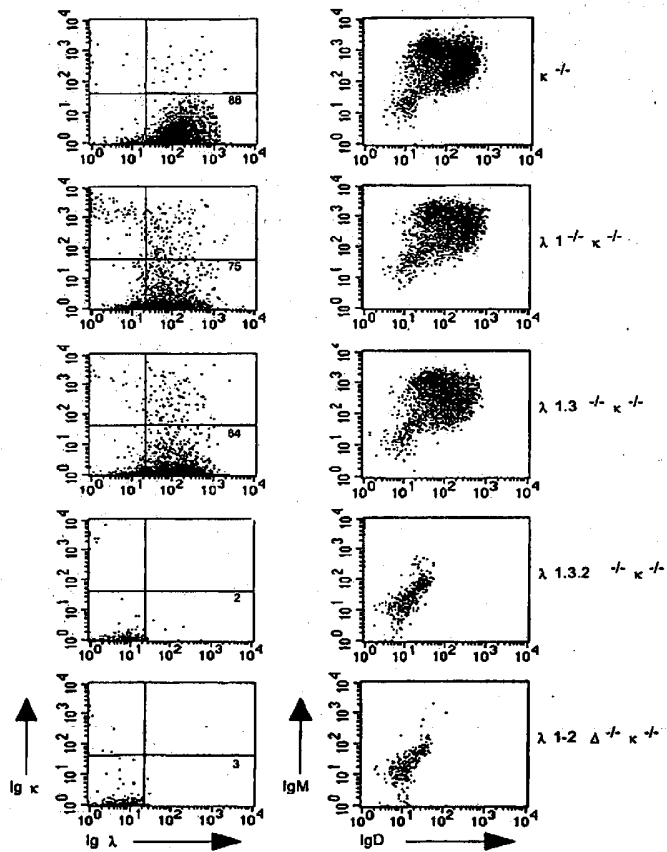


FIG. 2b

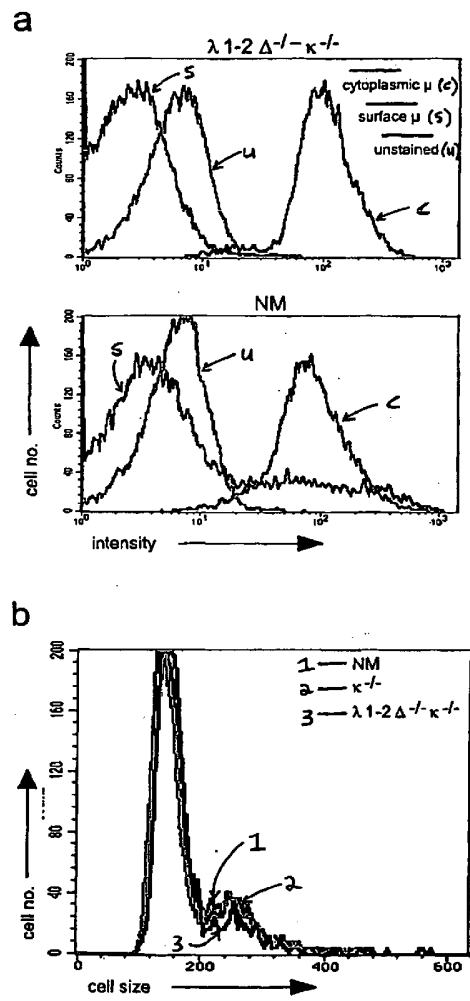


FIG. 3

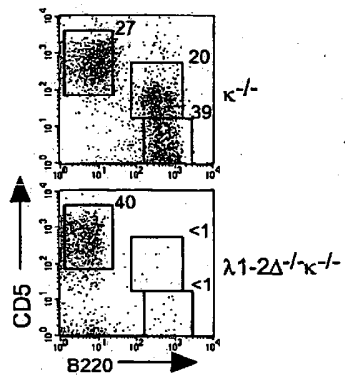


FIG. 4

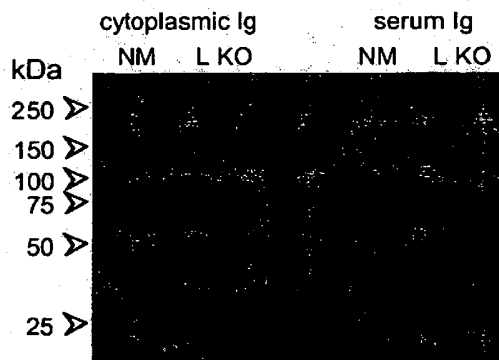


FIG. 5