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<p>(21) International Application Number: PCT/US98/25828 (22) International Filing Date: 4 December 1998 (04.12.98) (30) Priority Data: 08/986,016 5 December 1997 (05.12.97) US (71) Applicant: THE SCRIPPS RESEARCH INSTITUTE [US/US]; 10550 North Torrey Pines Road, Mail Drop TPC-8, La Jolla, CA 92037 (US). (72) Inventors: BARBAS, Carlos, F., III; 7081 Weller Street, San Diego, CA 92122 (US). RADER, Christoph; 3623 Marlesta Drive, San Diego, CA 92111 (US). (74) Agents: CEPURITIS, Talivaldis; Olson & Hierl, Ltd., 36th floor, 20 North Wacker Drive, Chicago, IL 60606 (US) et al.</p>	<p>(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p>Published <i>With international search report.</i> <i>With an indication in relation to deposited biological material furnished under Rule 13bis separately from the description.</i></p> <div data-bbox="1002 824 1284 996" style="border: 1px solid black; padding: 5px; text-align: center;"> <p>IP AUSTRALIA 28 JUN 1999 RECEIVED</p> </div>	
<p>(54) Title: HUMANIZATION OF MURINE ANTIBODY</p> <p>(57) Abstract</p> <p>A humanized murine antibody is provided. The amino acid sequences of a light chain complementarity determining region from a mouse antibody are grafted onto a human light chain, and a heavy chain complementarity determining region from a mouse antibody are grafted onto a human antibody heavy chain to produce libraries from which a humanized murine antibody having the desired specificity is selected.</p>		

HUMANIZATION OF MURINE ANTIBODY

Technical Field

This invention relates to humanization of murine antibodies.

5 Background of the Invention

Antibodies typically comprise two heavy chains linked together by disulfide bonds and two light chains linked to a respective heavy chain by a disulfide bond. Beginning at one end of each heavy chain there is a variable domain followed by several constant domains. Similarly, each light chain has a variable domain at one
10 end, but only a single constant domain at its other end. There are two types of light chain, which are termed lambda (λ) and kappa (κ) chains. No functional difference has been found between antibodies having λ or κ light chains. The ratio of the two types of light chain varies from species to species, however. In mice, the κ : λ ratio is 20:1, whereas in humans it is 2:1.

15 The variable domains of the light and heavy chains are aligned, as are the constant domain of the light chain and the first constant domain of the heavy chain. The constant domains in the light and heavy chains are not involved directly in binding the antibody to antigen.

It is the variable domains that form the antigen binding site of
20 antibodies. The general structure of each light and heavy chain domain comprises a framework of four regions, whose sequences are relatively conserved, connected by three complementarity determining regions (CDRs). The four framework regions employ a beta-sheet conformation and the CDRs form loops connecting, and in some cases forming part of, the beta-sheet structure. The CDRs are held in close
25 proximity by the framework regions and, with the CDRs from the other domain, contribute to the formation of the antigen binding site.

While cell surface antigens of tumor cells are the traditional targets
for antibody-guided cancer therapy, one of the major limitations for the therapy of solid tumors is the low accessibility of tumor antigens to antibodies circulating in the
30 blood stream. The dense packing of tumor cells and the elevated interstitial pressure in the tumor core present formidable physical barriers.

A solution to the problem of poor penetration of antibodies into solid tumors would be to attack the endothelial cells lining the blood vessels of the

tumor rather than the tumor cells themselves. While it may be difficult to target the mature tumor vasculature specifically, i.e., without destroying healthy tissue, promising strategies aim at the inhibition of neovascularization.

Neovascularization, also termed angiogenesis, is induced by
5 cytokines that are secreted from tumor cells and depends on vascular cell migration and invasion, processes regulated by cell adhesion molecules (CAM) and protease. These molecules are currently considered potential targets for angiogenic inhibitors. In this regard, the vascular integrin $\alpha_v\beta_3$ has recently been identified as a marker of angiogenic blood vessels. *See* Brooks, P.C., et al. (1994), REQUIREMENT OF
10 INTEGRIN $\alpha_v\beta_3$ FOR ANGIOGENESIS, *Science* **264**, 569-571. Moreover, it was shown that the mouse monoclonal antibody (Mab) LM609 directed to integrin $\alpha_v\beta_3$ was able to suppress angiogenesis, indicating that integrin $\alpha_v\beta_3$ has a critical role in angiogenesis.

It has been further demonstrated that LM609 selectively promotes
15 apoptosis of vascular cells that have been stimulated to undergo angiogenesis. *See* Brooks, P.C., et al. (1994), INTEGRIN $\alpha_v\beta_3$ ANTAGONISTS PROMOTE TUMOR REGRESSION BY INDUCING APOPTOSIS OF ANGIOGENIC BLOOD VESSELS, *Cell* **79**, 1157-1164. These findings suggest that integrin $\alpha_v\beta_3$ may be a target and LM609 a tool for cancer diagnosis and therapy.

Indeed, LM609 not only prevented the growth of histologically
20 distinct human tumors implanted on the chorioallantoic membranes of chicken embryos, but also induced their regression. *See*, *Cell* **79**, 1157-1164. Using a more clinically relevant model of tumor growth, it was found that LM609 blocked human breast cancer growth in a SCID mouse/human chimeric model. Importantly, not only
25 did LM609 block tumor growth, but it also inhibited metastasis of the breast carcinomas examined. *See* Brooks, et al. (1995) ANTI-INTEGRIN $\alpha_v\beta_3$ BLOCKS HUMAN BREAST CANCER GROWTH AND ANGIOGENESIS IN HUMAN SKIN, *J. Clin. Invest.* **96**, 1815-1822.

The Brooks et al. results are consistent with previous studies that
30 have suggested that angiogenesis contributes to the metastatic spread of breast tumor cells. *See* Weidner, N., et al. (1991) TUMOR ANGIOGENESIS AND METASTASIS: CORRELATION IN INVASIVE BREAST CARCINOMA, *N.Engl. J. Med.* **324**, 1-8; and Weidner, N., et al. (1992) TUMOR ANGIOGENESIS: A NEW SIGNIFICANT AND

INDEPENDENT PROGNOSTIC INDICATOR IN EARLY-STAGE BREAST CARCINOMA. *J.Natl. Cancer Inst.* **84**, 1875-1887.

5 Within the last few years evidence has been presented that two cytokine-dependent pathways of angiogenesis exist and that these are defined by their dependency on distinct vascular integrins. *See* Friedlander, M., et al. (1995) DEFINITION OF TWO ANGIOGENIC PATHWAYS BY DISTINCT AV INTEGRINS, *Science* **270**, 1500-1502. The results of the Friedlander et al. studies show that anti- $\alpha_v\beta_3$ antibody LM609 blocked angiogenesis in response to bFGF and TNF α , yet have little effect on angiogenesis induced by VEGF, TGF α , or phorbol ester PMA. In contrast, 10 the anti- $\alpha_v\beta_5$ antibody P1F6 blocks angiogenesis induced by VEGF, TGF α , and phorbol ester PMA, while having minimal effects on that induced by bFGF or TNF α .

 It is conceivable, thus, that tumors showing less susceptibility to anti- $\alpha_v\beta_3$ antibodies might secrete cytokines that promote angiogenesis in an $\alpha_v\beta_5$ -dependent manner. Taken together, both anti- $\alpha_v\beta_3$ and anti- $\alpha_v\beta_5$ antibodies are 15 promising tools for diagnosis and therapy of cancer.

 Mouse monoclonal antibodies such as LM609, however, are highly immunogenic in humans, thus limiting their potential use for cancer therapy, especially when repeated administration is necessary. To reduce the immunogenicity of mouse monoclonal antibodies, chimeric monoclonal antibodies were generated, 20 with the variable Ig domains of a mouse monoclonal antibody being fused to human constant Ig domains. *See* Morrison, S.L., et al. (1984) CHIMERIC HUMAN ANTIBODY MOLECULES; MOUSE ANTIGEN-BINDING DOMAINS WITH HUMAN CONSTANT REGION DOMAINS, *Proc. Natl. Acad. Sci. USA* **81**, 6841-6855; and, Boulianne, G.L., et al. (1984) PRODUCTION OF A FUNCTIONAL CHIMAERIC MOUSE/HUMAN ANTIBODY, 25 *Nature* **312**, 643-646. This process is commonly referred to as "humanization" of an antibody.

 In general, the chimeric monoclonal antibodies retain the binding specificity of the mouse monoclonal antibody and exhibit improved interactions with human effector cells. This results in an improved antibody-dependent cellular 30 cytotoxicity which is presumed to be one of the ways of eliminating tumor cells using monoclonal antibodies. *See* Morrison, S.L. (1992) *IN VITRO* ANTIBODIES: STRATEGIES FOR PRODUCTION AND APPLICATION, *Ann. Rev. Immunol.* **10**, 239-265. Though some chimeric monoclonal antibodies have proved less immunogenic in humans, the

mouse variable Ig domains can still lead to a significant human anti-mouse response. See Bruggemann, M., et al. (1989) THE IMMUNOGENICITY OF CHIMERIC ANTIBODIES, *J.Exp. Med.* **170**, 2153-2157. Therefore, for therapeutic purposes it may be necessary to fully humanize a murine monoclonal antibody by altering both the
5 variable and the constant Ig domains.

Full humanization is feasible by introducing the six CDRs from the mouse heavy and light chain variable Ig domains into the appropriate framework regions of human variable Ig domains. This CDR grafting technique (Riechmann, L., et al. (1988) RESHAPING HUMAN ANTIBODIES FOR THERAPY, *Nature* **332**, 323)
10 takes advantage of the conserved structure of the variable Ig domains, with the four framework regions (FR1-FR4) serving as a scaffold to support the CDR loops which are the primary contacts with antigen. U.S. Patent No. 5,502,167 to Waldmann, et al. discloses a "humanised antibody" having the CDR loops LCDR1 through LCDR3 and HCDR1 through HCDR3 from YTH 655(5)6, a rat IgG2b monoclonal antibody,
15 grafted onto a human T cell antibody.

A drawback, however, of the CDR grafting technique is the fact that amino acids of the framework regions can contribute to antigen binding, as well as amino acids of the CDR loops can influence the association of the two variable Ig domains. To maintain the affinity of the humanized monoclonal antibody, the CDR
20 grafting technique relies on the proper choice of the human framework regions and site-directed mutagenesis of single amino acids aided by computer modeling of the antigen binding site (e.g., Co, M.S., et al. (1994) A HUMANIZED ANTIBODY SPECIFIC FOR THE PLATELET INTEGRIN gpIIb/IIIa, *J.Immunol.* **152**, 2968-2976). A number of successful humanizations of mouse monoclonal antibodies by rational design have
25 been reported. Among them are several monoclonal antibodies that are directed to human integrins and have potential clinical application. See, *J.Immunol.* **152**, 2968-2976; Hsiao, K.C., et al. (1994) HUMANIZATION OF 60.3, AN ANTI-CD18 ANTIBODY; IMPORTANCE OF THE L2 LOOP, *Protein Eng.* **7**, 815-822; and, Poul, M.A., et al. (1995) INHIBITION OF T CELL ACTIVATION WITH A HUMANIZED ANTI-BETA 1
30 INTEGRIN CHAIN mAb, *Mol. Immunol.* **32**, 101-116.

Human immunoglobulin transgenic mice provide a promising alternative to the humanization of mouse monoclonal antibodies. See, e.g., Fishwild, D.M., et al. (1996) HIGH-AVIDITY HUMAN IgGκ MONOCLONAL ANTIBODIES FROM A

NOVEL STRAIN OF MINILOCUS TRANSGENIC MICE, *Nature Biotechnology* **14**, 845-851.
In response to immunization, these mice express human monoclonal antibodies,
which can be accessed by conventional hybridoma technology.

Rational design strategies in protein engineering have been
5 challenged by *in vitro* selection strategies that are mainly based on phage display
libraries. See Clackson, T., and Wells, J.A. (1994) *IN VITRO SELECTION FROM
PROTEIN AND PEPTIDE LIBRARIES*, *TIBTECH* **12**, 173-184. In particular, *in vitro*
selection and evolution of antibodies derived from phage display libraries has become
a powerful tool. See Burton, D.R., and Barbas III, C.F. (1994) HUMAN ANTIBODIES
10 FROM COMBINATORIAL LIBRARIES, *Adv. Immunol.* **57**, 191-280; and, Winter, G., et
al. (1994) MAKING ANTIBODIES BY PHAGE DISPLAY TECHNOLOGY, *Annu. Rev.
Immunol.* **12**, 433-455.

The development of technologies for making repertoires of human
antibody genes, and the display of the encoded antibody fragments on the surface of
15 filamentous bacteriophage, has provided a means for making human antibodies
directly. The antibodies produced by phage technology are produced as antigen
binding fragments—usually Fv or Fab fragments—in bacteria and thus lack effector
functions. Effector functions can be introduced by one of two strategies: The
fragments can be engineered either into complete antibodies for expression in
20 mammalian cells, or into bispecific antibody fragments with a second binding site
capable of triggering an effector function.

Typically, the Fd fragment (V_H-C_{H1}) and light chain (V_L-C_L) of
antibodies are separately cloned by PCR and recombined randomly in combinatorial
phage display libraries, which can then be selected for binding to a particular antigen.
25 The Fab fragments are expressed on the phage surface, i.e., physically linked to the
genes that encode them. Thus, selection of Fab by antigen binding co-selects for the
Fab encoding sequences, which can be amplified subsequently. By several rounds of
antigen binding and reamplification, a procedure termed panning, Fab specific for the
antigen are enriched and finally isolated.

30 In 1994, an approach for the humanization of antibodies, called
"guided selection", was described. Guided selection utilizes the power of the phage
display technique for the humanization of mouse monoclonal antibody. See Jespers,
L.S., et al. (1994) GUIDING THE SELECTION OF HUMAN ANTIBODIES FROM PHAGE

DISPLAY REPERTOIRES TO A SINGLE EPITOPE OF AN ANTIGEN, *Bio/Technology* 12, 899-903. For this, the Fd fragment of the mouse monoclonal antibody can be displayed in combination with a human light chain library, and the resulting hybrid Fab library may then be selected with antigen. The mouse Fd fragment thereby provides a template to
5 guide the selection.

Subsequently, the selected human light chains are combined with a human Fd fragment library. Selection of the resulting library yields entirely human Fab.



10 For the full humanization of murine monoclonal antibodies, the present invention uses a unique combination of CDR grafting and guided selection. The anti-integrin antibody generated is useful for cancer diagnosis and therapy.

Summary of the Invention

In one aspect, the invention provides a method of humanising a mouse monoclonal antibody which comprises the steps of:

15 (a) constructing a human light chain wherein each said light chain comprises at least the variable domain thereof and has complementarity determining region three from antibody LM609;



20 (b) selecting from the constructed human light chain library a human light chain having CDR3 from antibody CM609, wherein the selection comprises using a heavy chain from an antibody which binds a preselected antigen;



(c) constructing a library of human heavy chains wherein each said heavy chain comprises at least the variable domain thereof and has at least one complementarity determining region (CDR) amino acid sequence of a mouse heavy chain;

25 (d) combining the constructed human heavy chain library with the human light chain to produce a humanised library of heavy and light chain pairs, each containing at least one mouse CDR; and

(e) selecting from the humanised library a heavy and light chain pair using the human light chain.

30 In another aspect, the invention provides a method of humanising a mouse monoclonal antibody which comprises the steps of:



(a) constructing a human light chain wherein each said light chain comprises at least the variable domain thereof and has at least one complementarity determining region (CDR) amino acid sequence of a mouse chain;

(b) selecting from the constructed human light chain library a human light chain having a mouse CDR, wherein the selection comprises using a heavy chain from antibody LM609;

(c) constructing a human heavy chain which comprises at least the variable domain thereof and has complementarity determining region (CDR) three from antibody LM609;



10

(d) combining the constructed human light chain library with the human heavy chain to produce a humanised library of heavy and light chain pairs each containing at least one mouse CDR; and

(e) selecting from the humanised library a heavy and light chain pair using the selected human light chain.

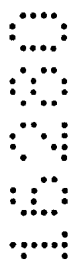
15

In a particular embodiment, a mouse monoclonal antibody can be humanized by constructing a human light chain library in which each light chain includes at least the variable domain thereof and at least one CDR amino acid sequence of a mouse light chain, and a human heavy chain library in which each such heavy chain includes at least the variable domain thereof and at least one CDR amino



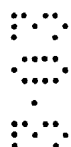
acid sequence of a mouse heavy chain. The heavy chain usually is no more than about 200 amino acid residues in size.

A human light chain having a mouse CDR is selected from the constructed human light chain library using a heavy chain from an antibody which binds a preselected antigen. The constructed heavy chain library is combined with the selected human light having a mouse CDR to produce a humanized library of heavy and light chain pairs, each containing at least one mouse CDR. Thereafter, a heavy and light chain pair with mouse CDR is selected from the aforesaid humanized library using the selected human light chain with mouse CDR. The sequence of aforementioned library construction is not critical.



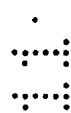
The selection of either the human light chain or human heavy chain having the grafted mouse CDR is preferably made by using a chimeric mouse/human complementary chain as a template.

In CDR grafting onto a human light chain, the human light chain is cloned, then the clones are randomly recombined to form a library such as a combinatorial phage display library. The same method can be followed for grafting onto the human heavy chain.



Brief Description of the Drawings

FIGURE 1 is a schematic illustration showing the sequence of the steps in the combined CDR grafting technique and guided selection technique to form the humanized Fab fragment.



FIGURES 2a and 2b show the amino acid sequences of V_{λ} and V_{κ} , respectively, of mouse monoclonal antibody LM609. The N-terminal two amino acids (Leu)(Glu) of V_{λ} and (Glu)(Leu) of V_{κ} encoded by the vector cloning sites CTCGAG (XhoI) and GAGCTC (SacI), respectively, are artificial. The CDR loops are underlined.

FIGURE 3a through FIGURE 3e show the amino acid sequence alignment of mouse LM609 V_{κ} (top full line of each sequence grouping) and six selected human V_{κ} 's (#1-6). Framework regions (FR1-3) and CDR (CDR1-2) loops are separated. Lines (-) indicate identical amino acids. Note that due to the LCDR3



grafting parts of FR3, entire CDR3 and entire FR4 are identical in mouse LM609 V_{κ} and the selected human V_{κ} 's. Therefore, these two sequences are not shown.

FIGURE 4 shows a comparison of three selected human fragment sequences and four unselected human fragment sequences to the original sequences of the mouse LCDR1 and LCDR2 loops.

FIGURE 5a through FIGURE 5f are line graphs which show the binding of human integrin $\alpha_v\beta_3$ on the cell surface by humanized LM609 clones 2, 4, 7, 11, 24, and control antibody, respectively. Line A indicates untransfected CS-1 hamster cells; Line B indicates human β_3 cDNA transfected CS-1 hamster cells (essentially the same line as line A in FIGURE 5f); and line C indicates human β_3 cDNA transfected CS-1 hamster cells.

FIGURE 6 is a bar graph showing the cross-reactivity of the LM609 antibody, and clones 2, 4, 7, 11, 24, and control antibody, respectively. Columns represent the mean of triplicates, with the left columns indicating binding to human integrin $\alpha_v\beta_3$, the central columns indicating binding to human integrin $\alpha_{Ib}\beta_3$, and the right columns indicating background binding. Error bars indicate standard deviations.

FIGURE 7 is a schematic illustration of a stretch of four amino acids in a light chain complementarity determining region three (LCDR3) and a heavy chain complementarity determining region three (HCDR3) being optimized.

FIGURES 8a and 8b are fragmented illustrations of the V_L amino acid sequences of a mouse antibody compared to the amino acid sequences of five versions of humanized clones represented by group letters A (clones 10, 11, and 37), and B (clones 7, 8, and 22), C (clones 4, 31, and 36), D (clones 24, 34, 35, and 40), and E (clone 2) which are combined.

FIGURES 8c through 8e are fragmented illustrations of the V_H amino acid sequences of a mouse antibody compared to the amino acid sequences of five versions of humanized clones represented by group letters A (clones 10, 11, and 37), B (clones 7, 8, and 22), C (clones 4, 31, and 36), D (clones 24, 34, 35, and 40), and E (clone 2).

Description of a Preferred Embodiment

While the present invention is susceptible to embodiments in many different forms, a preferred embodiment of the invention is described below. It

should be understood, however, that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the specific embodiments illustrated.

cDNA Cloning of mouse monoclonal antibody LM609

5 Beginning with a LM609 hybridoma cell line (ATCC Designation HB 9537), total RNA was prepared from 10^8 LM609 hybridoma cells using an RNA Isolation Kit (Stratagene, La Jolla, CA). Reverse transcription and polymerase chain reaction (PCR) amplification of Fd fragment and κ chain encoding sequences were
10 performed essentially as described in "Combinatorial immunoglobulin libraries in phage 1", (*Methods* 2, 119 (1991)) by A.S. Kang, et al.

Fd fragment and κ chain encoding PCR products were cut with XhoI/SpeI and SacI/XbaI, respectively, and ligated sequentially into the appropriately digested phagemid vector pComb3H. The ligation products were introduced into
15 *E.coli* strain XL1-Blue by electrotransformation and subsequent steps were as described in "Assembly of combinatorial antibody libraries on phage surfaces: the gene III site", (*Proc. Natl. Acad. Sci. USA* 88, 7978-7982) by C.F. Barbas III, et al., to produce phage displaying Fab on their surface. Phage were selected by panning against immobilized integrin $\alpha_v\beta_3$. After two panning rounds single clones were
20 analyzed for LM609 Fab expression. Supernatant from IPTG-induced cultures was tested for binding to immobilized integrin $\alpha_v\beta_3$ by enzyme-linked immunosorbent assay (ELISA) using goat anti-mouse F(ab')₂ conjugated to alkaline phosphatase as a secondary antibody. The sequence of each Fd fragment and each κ chain encoding sequence of positive clones was determined by DNA sequencing.

25

Amplification of human light chain and Fd fragment sequences

Total RNA was prepared from the bone marrow of five donors (Poietic Technologies; Germantown, MD) using TRI Reagent (Molecular Research
30 Center; Cincinnati, OH) and was further purified by lithium chloride precipitation. See Sambrook, J., et al. (1989) MOLECULAR CLONING: A LABORATORY MANUAL, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY. First-strand cDNA was synthesized using the 'SUPERSCRIP^T Preamplification System for First Strand

cDNA Synthesis' kit with oligo (dT) priming (Life Technologies; Gaithersburg, MD). The five generated first-strand cDNAs were subjected to separate PCR amplifications.

V_κ sequences of each of the first-strand cDNAs were amplified in eight separate reactions by combining four sense and two antisense primers (see list below). V_λ sequences were amplified in nine separate reactions using nine sense and one antisense primer (see list below). The V_λ and V_κ amino acid sequences, including the underlining of the CDR loops, are shown in FIGURES 2a and 2b, respectively (See also, SEQ ID NO:44 and SEQ ID NO:45, respectively).

V_H sequences (See SEQ ID NO:56) were amplified in four reactions using four sense and one antisense primer (see list below). All amplifications were performed under standard PCR conditions using Taq polymerase (Pharmacia; Uppsala, Sweden). While the sense primers hybridize to sequences that encode the N-terminal amino acids of the various V_κ, V_λ, and V_H families, the antisense primers hybridize to a sequence that encodes the C-terminal amino acids of FR3 of V_κ, V_λ, or V_H, respectively, which are highly conserved.

The list of primers used for the amplification of human antibody sequences include:

V_κ sense primers:

	HSCk1 - F	SEQ ID NO:3	HSCLam6	SEQ ID
20	HSCk24 - F	SEQ ID NO:4	NO:14	
	HSCk3 - F	SEQ ID NO:5	HSCLam70	SEQ ID
	HSCk5 - 5	SEQ ID NO:6	NO:15	

V_κ antisense primers:

	BKFR3UN	SEQ ID NO:7	HSCLam78	SEQ ID
25	BK2FR3UN	SEQ ID NO:8	NO:16	
			HSCLam9	SEQ ID

V_λ sense primers:

	HSCLam1a	SEQ ID NO:9	NO:17	
	HSCLam1b	SEQ ID NO:10	V _λ antisense primer:	
	HSCLam2	SEQ ID NO:11	BLFR3UN	SEQ ID
	HSCLam3	SEQ ID NO:12	NO:18	

30	HSCLam4	SEQ ID NO:13	V _H sense primers:	
			HFVH1-F	SEQ ID
			NO:19	

HFVH2-F SEQ ID
NO:20
HFVH35-F SEQ ID NO:21
HFVH4-F SEQ ID NO:22
5 V_H antisense primers:
BFR3UN SEQ ID NO:23

Construction of a chimeric mouse/human Fd fragment by fusing V_H of LM609 to human C_H1

10 The phagemid vector pComb3H containing the LM609 Fab sequences was used as a template for amplification of the N-terminal FR1 through FR3 fragment of LM609's V_H by the PCR primer pair PELSEQ (SEQ ID NO:24) / BFR3UN (SEQ ID NO:25). The sense primer PELSEQ
15 hybridizes to the pe1B leader sequence upstream of the Fd fragment encoding sequence in pComb3H. The antisense primer BFR3UN hybridizes to a sequence that encodes eight C-terminal amino acids of FR3 of V_H, which are highly conserved (SEQ ID NO:26), and differ in one amino acid from the corresponding amino acid sequence of LM609's V_H (SEQ ID NO:27).

20 By overlap extension PCR (*See* McArn Horton, R., and Readington Pease, L. (1991) RECOMBINATION AND MUTAGENESIS OF DNA SEQUENCES USING PCR IN *DIRECTED MUTAGENESIS: A PRACTICAL APPROACH*, ed. M.J. McPherson, IRL Press, Oxford, UK, pp. 217-247), the PELSEQ/BFR3UN product was fused to a PCR fragment encoding the HCDR3 (SEQ ID NO:1) of LM609 coupled to FR4 of
25 V_H and the entire C_H1 domain of the human anti-gp120 antibody b8. This fragment had been amplified by the PCR primer pair CR501 (SEQ ID NO:28) / CR301 (SEQ ID NO:29). The sense primer CR501 encodes a synthetic link of the nine C-terminal amino acids of FR3, the eight amino acids forming the HCDR3 (SEQ ID NO:1) of LM609, and the six N-terminal amino acids of FR4 of b8. The FR4 of b8 is a
30 preferred choice here because it is identical to FR4 of LM609's V_H with the exception of the C-terminal amino acid, which is A for LM609 and S for b8. The 24-bp overlap of CR501 and BFR3UN allowed to fuse the corresponding PCT products by overlap extension PCR.

The sense primer CR301 hybridizes to a sequence that encodes the C terminus of C_H1 and introduces a SpeI site that allows the PCR product to link to the gene III ORF on pComb3H. The product of the overlap extension PCR was cut with XhoI/SpeI, ligated into the appropriately digested phagemid vector pComb3H, and the correct sequence was confirmed by DNA sequencing.

Substitution of the LM609 light chain by a human light chain that contains the LCDR3 of LM609

Using overlap extension PCR, the amplified human sequences encoding the N-terminal FR1 through FR3 fragment of V_κ and V_λ were fused to PCR fragments encoding the LCDR3 (SEQ ID NO:2) of LM609 coupled to FR4 of human V_κ or V_λ and the human C_κ or C_λ domain. Two κ fragments were generated by the PCR primer pairs CR503 (SEQ ID NO:30) / T7B (SEQ ID NO:31) and CR508 (SEQ ID NO:32) / T7B using the sequence of the anti-gp120 antibody b11 in pComb3 as a template.

The sense primers CR503 and CR508 encode a synthetic link of eight C-terminal amino acids of FR3 of human V_κ (SEQ ID NO:33 or SEQ ID NO:34), the nine amino acids forming the LCDR3 (SEQ ID NO:2) of LM609, and the seven N-terminal amino acids of FR4 of b11. FR4 of b11 is the preferred choice because it is identical to FR4 of LM609's V_κ with the exception of the third N-terminal and C-terminal amino acid, which are G and T in LM609 versus Q and A in b11. The 23-bp overlap of CR503 with BKFR3UN and CR508 with BK2FR3UN allowed to fuse the corresponding PCR products by overlap extension PCR.

The backward primer T7B hybridizes to a pComb3 sequence downstream of the light chain encoding sequence. A λ fragment was generated by the PCR primer pair CR510 (SEQ ID NO:35) / CLext (SEQ ID NO:36) using CLext primed first strand cDNA from human bone marrow as a template.

The sense primer CR510 encodes a synthetic link of seven C-terminal amino acids of FR3 of human V_λ (SEQ ID NO:37), the nine amino acids forming the LCDR3 of LM609, and the seven N-terminal amino acids of FR4 of human V_λ (SEQ ID NO:38). The 21-bp overlap of CR510 with BLFR3UN allowed to fuse the corresponding PCR products by overlap extension PCR. The backward

primer CLext hybridizes to the 3' end of the human C_λ encoding sequence and introduces a XbaI site.

The generated light chain encoding sequences were cut with SacI/XbaI and ligated into the appropriately digested phagemid vector pComb3H that contained the chimeric mouse/human Fd fragment. Electrotransformation of the ligation products into *E. coli* strain ER 2537 (New England Biolabs; Beverly, MA) resulted in a light chain library consisting of 1.5 x 10⁸ independent transformants. DNA sequencing revealed the correct assembly of the fused fragments.

Four rounds of panning against immobilized human integrin α_vβ₃ were carried out essentially as described in "High-affinity self-reactive human antibodies by design and selection: targeting the integrin ligand binding site", (*Proc. Natl. Acad. Sci. USA* **90**, 10003-10007 (1993)) by C.F. Barbas, III, et al. using 200 ng protein in 25 μl metal buffer (25 mM Tris-HCl, pH 7.5; 137 mM NaCl; 1 mM KCl; 1 mM MgCl₂; 1 mM CaCl₂; 1 mM MnCl₂) for coating, 0.05 percent Tween 20 in TBS for washing, and 10 mg/ml trypsin in TBS for elution. The washing steps were increased from 5 in the first round, to 10 in the second round and 15 in the third and fourth rounds. The output phage pool of each round was monitored by phage ELISA.

After the fourth round phage were produced from single clones and tested for binding to immobilized integrin α_vβ₃ by phage ELISA. Light chain encoding sequences of positive clones were analyzed by DNA sequencing using the primer OMPSEQ (SEQ ID NO:39) that hybridizes to the ompA leader sequence upstream of the light chain encoding sequence in pComb3H.

25 Substitution of the LM609 Fd fragment by a human Fd fragment that contains the heavy complementarity determining region three (HCDR3) of LM609

Three PCR fragments were fused in one step by overlap extension PCR. Using the selected phagemids from the light chain panning as a template, Fragment 1 was amplified with the PCR primer pair RSC-F (SEQ ID NO:40) / lead-B (SEQ ID NO:41). While the sense primer RSC-F hybridizes to a sequence upstream of the light chain encoding sequence, the antisense primer lead-B hybridizes to a sequence upstream of the Fd fragment encoding sequence. The amplified human

sequences encoding the FR1 through FR3 fragment of VH (see above) were used as fragment 2.

Fragment 3 was amplified with the PCR primer pair CR501 / HIgG1-B (SEQ ID 42) using the hybrid mouse/human Fd fragment (see above) as a template. The antisense primer HIgG1-B hybridizes to the 3' end of the C_H1
5 encoding sequence. Using the 21-bp overlap of lead-B with the HFVH-F primers and the 24-bp overlap of BFR3UN with CR501, the three fragments were fused and amplified with the PCR primer pair RSC-F / RSC-B (SEQ ID NO:43). The
10 antisense primer RSC-B overlaps with HIgG1-B. RSC-F and RSC-B introduce two asymmetric SfiI sites.

To maintain high complexity, separate PCR reactions were performed for each selected phagemid from the light chain panning (Fragment 1) and for each of the five V_H fragment pools derived from the five first strand cDNA
15 sources (Fragment 2). The generated fragments encoding the selected human light chains linked to human Fd fragments were cut with SfiI and ligated into the appropriately digested phagemid vector pComb3H generating a library of 3 x 10⁷ independent transformants.

DNA sequencing revealed the correct assembly of the fused DNA fragments. Four rounds of panning against immobilized human integrin $\alpha_v\beta_3$ were
20 carried out exactly as described for the light chain panning. The output phage pool of each round was monitored by phage ELISA. After the fourth round, light chain and Fd fragment encoding sequences were isolated from the selected phagemids by SfiI digestion and subcloned into the compatible expression vector pPhoA-H6HA.

Lysates of individual clones grown in phosphate-deprived medium
25 were analyzed for binding to immobilized integrin $\alpha_v\beta_3$ by ELISA using goat anti-human F(ab')₂ conjugated to alkaline phosphatase (Pierce) as secondary antibody. Light chain and Fd fragment encoding sequences of positive clones were analyzed by DNA sequencing using the primers OMPSEQ and PELSEQ, respectively.

Results

30 cDNA Cloning of LM609

Starting from LM609 expressing hybridoma cells, cDNAs encoding λ chain Fd fragments and entire κ chains were cloned by PCR. The PCR products

were cloned into the phagemid pComb3H, which is derived from pComb3, and engineered to facilitate the expression of Fab on the surface of M13 filamentous phage. Phage displaying LM609 Fab were selected by panning against integrin $\alpha_v\beta_3$ and the corresponding cDNA sequences were determined. Soluble LM609 Fab
5 purified from *E.coli* was analyzed and found to bind specifically to integrin $\alpha_v\beta_3$ by ELISA.

The approach for the sequential humanization of LM609 by a combination of guided selection and CDR grafting is illustrated in FIGURE 1. For the human light chain selection, the mouse Fd fragment is substituted by a chimeric
10 Fd fragment composed of mouse V_H linked to human C_H1 to stabilize the hybrid Fab of the first selection step by the interaction of two matching human constant domains, C_κ and C_H1 . A stabilization of the hybrid Fab also stabilizes the antigen binding site.

The guided selection is started by substituting the κ light chain of LM609 with a human κ and λ light chain library that contained the grafted Lcdr3
15 loop of LM609. The corresponding phage libraries displaying hybrid Fab are then selected by four rounds of panning against immobilized integrin $\alpha_v\beta_3$. Though the output number does not increase from round to round, analysis of the output phage pool from each round for binding to integrin $\alpha_v\beta_3$ by phage ELISA reveals an increasing signal. After the fourth round, phage are produced from clones and tested
20 for binding to integrin $\alpha_v\beta_3$ by phage ELISA.

While the majority of these clones give signals that reveal some binding above background, in the present case, six clones gave very strong signals (See FIGURES 3a through 3e). DNA sequence analysis of these clones revealed 3 different light chain sequences. Two light chain sequences found in five out of six
25 positive clones differ only in four amino acids, i.e., are 96 percent identical. The third light chain sequence shares about 80 percent identity with the other two. However, this sequence had two parts, each of which could be aligned to germ-lines of different V_κ families, and, thus is deemed likely to have arisen from PCR cross-over, an artifact that has been reported to occur frequently in the amplification
30 antibody sequences.

Referring to FIGURES 3a through 3e, analysis of the six human V_κ revealed two groups of highly related κ chain sequences. In addition, the CDR1 loops of all six selected human V_κ , which are believed to play a role in the assembly

of V_{κ} and V_{λ} , resemble the corresponding region of LM609 V_{κ} . This indicates that the template V_{λ} of LM609 together with the LM609 antigen, the human integrin $\alpha_V\beta_3$, selected for human κ chains that are related to the LM609 κ chain. The fact that no repeated sequences were found may indicate that the grafted LCDR3 loop of LM609, which is identical in all selected human κ chains, is mainly responsible for the contribution of the LM609 κ chain to antigen binding.

This supposition is supported by two additional observations. First, the initial humanization approach was based on the original human κ chain libraries. Four rounds of panning selected a repeated human κ chain with a sequence related to the LM609 κ chain. However, the corresponding hybrid Fab appeared to bind only weakly to human integrin $\alpha_V\beta_3$. Therefore, the LCDR3 loop of LM609 was grafted in the human κ chain libraries, and, though only roughly estimated from ELISA, the binding of the corresponding selected hybrid Fab to human integrin $\alpha_V\beta_3$ improved.

Second, the selected phage were selected by two further rounds of panning against immobilized human integrin $\alpha_V\beta_3$. Again, soluble ones derived from selected phagemids were analyzed for binding to immobilized human integrin $\alpha_V\beta_3$ by ELISA. This time, all of the analyzed 20 clones were found to bind specifically. However, sequencing of 16 clones revealed no repeated sequences. It appears, thus, that a number of different human κ chain sequences that contain the LCDR3 loop of LM609 can substitute the LM609 κ chain without much difference in binding to human integrin $\alpha_V\beta_3$. This finding is believed to be of importance for the therapeutic application of humanized LM609.

Due to allotypic sequence variability, humanized antibodies can be neutralized by the patient's immune system after repeated injections. This problem is avoided by using humanized antibodies with identical antigen binding properties but different amino acid sequences for repeated administrations.

As with the original LM609 light chain, the selected light chains are each κ light chains. Moreover, database screening revealed that they were derived from the same germ-line, namely DPK-26, belonging to the $V_{\kappa}6$ family. This speaks in favor of a strong selection towards these sequences because the $V_{\kappa}6$ family is not frequently found in human antibodies. An obvious reason for this strong selection is a relatively high sequence similarity of the selected human light chains with the original mouse light chain.

Referring to FIGURE 4, for comparison, four clones from the unselected library were picked randomly and their light chain sequences determined. Three selected human light chains used in the comparison consist of eleven LCDR1 amino acids, the length of the original mouse LCDR1, while only one out of four unselected human light chains shared the same LCDR1 length with the original mouse sequence (see FIGURE 4).

Moreover, both LCDR1 and LCDR2 of the selected human light chains are highly similar to the corresponding mouse sequence. The C-terminal amino acid of framework region 2 of the original mouse light chain sequence, a lysine (Lys) shown in brackets in FIGURE 4, is an unusual amino acid at this position and, thus may be involved in the formation of the antigen binding site. Interestingly, all the selected human light chain sequences contain a lysine at this position, while all the unselected sequences contain a tyrosine (Tyr) instead. As a matter of fact, the $V_{\kappa 6}$ family is the only human V_{κ} family that contains a lysine at that position.

Taken together, this evidence shows that the mouse V_H template and the antigen selected for unbiased human V_{κ} sequences are related to the original mouse V_{κ} sequence. Three clones from the light chain selection, revealing weaker binding to integrin $\alpha_v\beta_3$ than the six clones discussed above but still having significant binding above background, were also analyzed by DNA sequencing. These analyses revealed three unrelated V_{κ} sequences, together with selected V_{κ} sequences—except the one that stemmed from the PCR cross-over artefact— were used as templates in the humanization of the heavy chain of LM609.

Based on the aforescribed humanization strategy, five humanized versions of the anti-human integrin $\alpha_v\beta_3$ monoclonal antibody LM609 were generated. The five version were revealed through the sequence analysis of 14 humanized clones that bind to $\alpha_v\beta_3$. Referring to FIGURES 8a and 8b, the amino acid sequences of a mouse V_L (SEQ ID NO:45) are compared to the amino acid sequences of the version A, and the combined versions (or groups) B, C, D, and E.

Similarly FIGURES 8c through 8e compare the amino acid sequences of a mouse V_H (SEQ ID NO:56) to the amino acid sequences of the five versions (or groups) A-E. Four of these versions, represented by clones 7, 8, and 22 (group B); 4, 31, and 36 (group C); 24, 34, and 40 (group D); and 2 (group E), are

highly related in amino acid sequence. The sequence group BCDE in FIGURES 8a and 8b represent the four versions that share an identical V_L domain (SEQ ID NO:49). The amino acid sequence identity of their V_H domains (SEQ ID NOS:50-53), which are all derived from the germ-line DP-65 or the highly related DP-78, is at least 90% for each version.

In contrast, version five includes clones 10, 11, and 37 (A), and represents a humanized version with a V_H domain (SEQ ID NO:54) that is derived from a different germ-line family. This humanized version also contains a different V_L domain (SEQ ID NO:55), which is, however, 95% identical and derived from the same germ-line. Germ-lines were determined by nucleic acid sequence alignment using DNAPLOT software provided by the VBASE Directory of Human V Gene Sequences from the MRC Centre for Protein Engineering.

By preserving the original complementarity determining region sequences such as the LCDR3 (SEQ ID NO:2) and HCDR3 (SEQ ID NO:1) sequences of LM609, the disclosed humanization strategy ensures epitope conservation. Epitope conservation is a critical demand in the humanization of antibodies, especially in the case of LM609. The function-blocking anti-human integrin $\alpha_V\beta_3$ mouse monoclonal antibody LM609 binds to a yet unidentified nonlinear epitope that involves both the α_V and β_3 polypeptide chains. Importantly, by binding to this epitope LM609 induces apoptosis in $\alpha_V\beta_3$ expressing vascular cells, a unique feature among a number of anti-human integrin $\alpha_V\beta_3$ mouse monoclonal antibodies. LM609 does not recognize the related human integrin $\alpha_{IIb}\beta_3$. Any cross-reactivity with human $\alpha_{IIb}\beta_3$, which is expressed on platelets, precludes the use of LM609 as a tool in cancer therapy.

The five humanized versions of LM609, clones 2, 4, 7, 11, and 24, which had been selected by binding to immobilized, thus potentially denatured human integrin $\alpha_V\beta_3$, were tested for binding to native human integrin $\alpha_V\beta_3$ expressed on the cell surface. For this, binding of humanized LM609 to untransfected CS-1 hamster cells and CS-1 hamster cells transfected with either human β_3 or β_5 cDNA was analyzed by flow cytometry. Like mouse LM609, but in contrast to a control antibody, all five humanized versions of LM609 revealed specific binding to CS-1 hamster cells transfected with human β_3 cDNA (See FIGURES 5a-5f).

Potential cross-reactivity of humanized LM609 with human integrin $\alpha_{IIB}\beta_3$ was analyzed by ELISA. While antibody Fab-9 with known cross-reactivity bound to both immobilized human integrin $\alpha_V\beta_3$ and $\alpha_{IIB}\beta_3$, cross-reactivity was detected neither for mouse LM609 nor its five humanized versions (See FIGURE 6).

5 Thus, all evidence speaks in favor of epitope conservation through the process of humanization of LM609.

Affinity maturation is a highly relevant step in engineering antibodies for therapeutic applications. By increasing the target affinity, the *in vivo* concentration of an antibody that must be reached to be effective for therapy is
10 lowered. In addition to reducing the costs of antibody therapy, low effective *in vivo* concentrations will help to reduce the chance of immune response.

The CDR walking strategy for the affinity maturation of antibodies has been described elsewhere, and is known in the relevant art. For the affinity maturation of humanized LM609 a sequential optimization of LCDR3 and HCDR3
15 was chosen (See FIGURE 7). The randomized region in both CDRs was confined to a stretch of four amino acids that revealed highest variability in human antibody sequences. See Kabat, E.A. et al. (1991) SEQUENCES OF PROTEINS OF IMMUNOLOGICAL INTEREST, U.S. Dept of Health and Human Services, Washington, D.C. Using NNK doping (Barbas, C.F. et al., (1994) *IN VITRO* EVOLUTION OF A
20 NEUTRALIZING HUMAN ANTIBODY TO HIV-1 TO ENHANCE AFFINITY AND BROADEN STRAIN CROSS-REACTIVITY, *Proc. Natl. Acad. Sci. USA* **91**, 3809-3813) the randomization of four codons results in 32^4 or 1×10^6 different nucleotide sequences. Based on this and assuming a Poisson distribution (Clackson, T., and Wells, J.A. (1994) *IN VITRO* SELECTION FROM PROTEIN AND PEPTIDE LIBRARIES, *Trends in*
25 *Biotechnol.* **12**, 173-184), 5×10^6 independent transformants are required for a complete library with 99 percent confidence. For each of the five humanized versions of LM609 independent LCDR3 randomized libraries were generated. The number of independent transformants in each library lay well above 5×10^6 (see Experimental Procedures, below). Ten completely different LCDR3 sequences were
30 obtained when two clones of each of the five libraries were analyzed by DNA sequencing. The three libraries that were based on humanized LM609 clones 2, 4, and 24, which contain identical light chains and highly related heavy chains derived from germ-line DP-65, were pooled. Corresponding to their underlying germ-line

sequences the three remaining libraries were named DPK-26ranLCDR3/DP-10, DPK-26ranLCDR3/DP-65, and DPK-26ranLCDR3/DP-78. These three libraries were selected in parallel.

To improve the selection of higher affinity LCDR3 mutants, a solid phase off-rate selection (Yang, W.P. et al. (1995) CDR WALKING MUTAGENESIS FOR THE AFFINITY MATURATION OF A POTENT HUMAN ANTI-HIV-1 ANTIBODY INTO THE PICOMOLAR RANGE, *J.Mol Biol.* **254**, 392-403) was used. In five subsequent cycles of selection 20 μg LM609 IgG was added to the well with 200 or 50 ng immobilized human integrin $\alpha_v\beta_3$ following phage incubation and washing. After 24 hours at room temperature, the well was washed again and bound phage eluted with trypsin. This off-rate selection step is discussed in the following paragraph.

Protein interactions are characterized by thermodynamic and kinetic parameters. While the affinity constant ($K_a = k_{on}/k_{off}$) is an equilibrium constant, the association (k_{on}) and dissociation (k_{off}) rate constants are more relevant to *in vivo* processes which are beyond equilibrium. See Williams, A.F. (1991) OUT OF EQUILIBRIUM, *Nature* **352**, 473-474. In fact, to occur *in vivo*, interactions with high affinity, i.e., high K_a values, still rely on rapid association, i.e., high k_{on} values. Antibodies are subject to kinetic selection based on binding target antigens rapidly, in parallel with thermodynamic selection for high affinity binding in order to allow sufficient time for antigen clearance. See Foote, J., and Milstein, C. (1991) KINETIC MATURATION OF AN IMMUNE RESPONSE, *Nature* **352**, 530-532. A typical antibody/antigen interaction with a K_a value in the range of 10^9 M^{-1} associates rapidly with a k_{on} value in the range of 10^5 to $10^6 \text{ M}^{-1}\text{s}^{-1}$ and dissociates slowly with a k_{off} value in the range of 10^{-3} to 10^{-4} s^{-1} . An off-rate selection for affinity maturation, i.e., decreasing k_{off} , requires consideration of the half-life of the antibody/antigen interactions that is given by $t_{1/2} = \ln 2/k_{off}$. An antibody/antigen interaction with $k_{off} = 1 \times 10^{-4} \text{ s}^{-1}$ has a half-life of about 2 hours. A tenfold lower dissociation constant, i.e., $k_{off} = 1 \times 10^{-5} \text{ s}^{-1}$, results in a tenfold longer half-life, i.e., about 20 hours. These long half-lives limit the off-rate selection in our affinity maturation protocol. Using a reasonable time frame, antibodies with dissociation constants below $1 \times 10^{-6} \text{ s}^{-1}$ can not be enriched even after multiple selection cycles. However, using a similar protocol, an antibody was selected against gp120 with a k_{off} value in the range of 10^{-6} s^{-1} . The

corresponding affinity constant was in the range of 10^{11} M⁻¹, a more than 400-fold improvement of the parental antibody.

Eight clones from each of the three independently selected libraries were analyzed by DNA sequencing. The L_{CDR3} sequences are shown in Table 1, below. A strong selection towards a consensus sequence that is highly related to the original sequence took place. All 24 analyzed clones contain a serine (Ser) in Position 91 and a glutamine (Gln) in Position 92 of the randomized region. The corresponding amino acids in the parental L_{CDR3} are serine (Ser) and asparagine (Asn), respectively. Interestingly, all three serine codons of the NNK genetic code (TCT, TCG, and ACT) are found in Position 91. Position 94, a tryptophane (Trp) in the parental L_{CDR3}, was re-selected in 22 out of 24 clones. Two clones contain a histidine (His) instead. Only Position 93 reveals greater diversity. The original serine (Ser) is substituted by an aromatic or hydrophobic amino acid, either phenylalanine (Phe-13/24), tryptophane (Trp-6/24), valine (Val-3/24), tyrosine (Tyr-1/24) or histidine (His-1/24). Analysis of the heavy chain sequences revealed that no cross-contamination between the three independently selected libraries took place. All eight clones selected from library DPK-26ranL_{CDR3}/DP-65, which contained the pool of the three highly related heavy chains encoding sequences derived from germline DP-65, were identical and derived from humanized LM609 clone 24.

The conserved L_{CDR3} sequence speaks in favor of a highly defined epitope on human integrin $\alpha_v\beta_3$. Though binding to native human integrin $\alpha_v\beta_3$ on the cell surface needs to be proved yet, an epitope shift towards denatured human integrin $\alpha_v\beta_3$ is unlikely. The selected phage pools were analyzed for binding to human integrin $\alpha_v\beta_3$ by phage ELISA and in competition with LM609 IgG. These analyses suggest a significantly lower dissociation constant of the selected clones in comparison with LM609 as well as humanized LM609. The substitution of the original serine in Position 3 by an aromatic residue may give rise to a new hydrophobic interaction with a strong impact on the overall affinity.

TABLE 1
Selected LCDR3 Mutants

Kabat position ¹	91	92	93	94
LM609	Ser	Asn	Ser	Trp
5 Library DPK- 26ranLCDR3/DP-10 ²	Ser Ser Ser Ser Ser Ser Ser Ser	Gln Gln Gln Gln Gln Gln Gln Gln	Trp Trp Trp Trp Val Phe Phe Phe	Trp Trp Trp Trp Trp Trp His His
Library DPK- 26ranLCDR3/DP-65 ³	Ser Ser Ser Ser Ser Ser Ser Ser	Gln Gln Gln Gln Gln Gln Gln Gln	Phe Phe Phe Phe Phe Phe Phe Phe	Trp Trp Trp Trp Trp Trp Trp Trp
10 Library DPK- 26ranLCDR3/DP-78 ⁴	Ser Ser Ser Ser Ser Ser Ser Ser	Gln Gln Gln Gln Gln Gln Gln Gln	Trp Trp Val Val Phe Phe Phe Tyr His	Trp Trp Trp Trp Trp Trp Trp Trp Trp

¹ cf. Kabat, et al. (1991)

² based on humanized LM609 clone 11

³ based on humanized LM609 clones 2, 4, and 24

⁴ based on humanized LM609 clone 7

15

Experimental Procedures

Materials

LM609 IgG purified from hybridoma cultures was provided by Dr.

20 David A. Cheresh. Human integrin $\alpha_v\beta_3$ and human integrin $\alpha_{IIb}\beta_3$ were from sources described in HIGH-AFFINITY SELF-REACTIVE HUMAN ANTIBODIES BY DESIGN AND SELECTION: TARGETING THE INTEGRIN LIGAND BINDING SITE, Barbas III, C.F., et al. (1993) *Proc. Natl. Acad. Sci. USA*, **90**, 10003-10007. Untransfected CS-1

hamster cells and CS-1 hamster cells transfected with either human β_3 or β_5 cDNA were obtained from Dr. David A. Cheresh (Filardo, E.J., et al. (1995)

REQUIREMENT OF THE NPXY MOTIF IN THE INTEGRIN β_3 SUBUNIT CYTOPLASMIC TAIL FOR MELANOMA CELL MIGRATION *IN VITRO* AND *IN VIVO*, *J. Cell Biol.* **130**, 441-450)

5 and maintained in RPMI medium supplemented with 5% fetal calf serum (FCS) at 37°C in 7% CO₂.

***E. coli* expression of soluble humanized LM609 Fab**

Following phage library panning, the SfiI insert of the selected
10 humanized LM609 phagemid pool was cloned into the *E. coli* expression vector pPhoA-H6HA (See Rader, C., and Barbas III, C.F. (1997) PHAGE DISPLAY OF COMBINATORIAL ANTIBODY LIBRARIES, *Curr. Opin. Biotechnol.* **8**, 503-508) for detection of $\alpha_v\beta_3$ binders. Sequence determination of 14 clones revealed five different humanized LM609 versions, represented by clones 2, 4, 7, 11, and 24.
15 cDNAs of these clones were cut out by SacI/SpeI digestion and ligated into SacI/NheI cut pComb3H, thereby removing the gene III fragment encoding cDNA of pComb3H and allowing for production of soluble Fab (See Rader, C. (1997) *Curr. Opin. Biotechnol.* **8**, 503-508). The ligation products were electrotransformed into *E. coli* strain XL1-Blue. Fab production was induced by addition of isopropyl β -D-
20 thiogalactopyranoside as described (Barbas III, C.F., et al. (1991) ASSEMBLY OF COMBINATORIAL ANTIBODY LIBRARIES ON PHAGE SURFACES: THE GENE III SITE, *Proc. Natl. Acad. Sci. USA* **88**, 7978-7982).

ELISA

25 Human integrins $\alpha_v\beta_3$ and $\alpha_{IIb}\beta_3$ were coated for 90 minutes at 37°C on a 96-well plate (Costar #3690) at a concentration of 60 ng/25 μ l metal buffer (25 mM Tris-HCl, pH 7.5; 137 mM NaCl; 1 mM KCl; 1 mM MgCl₂; 1 mM CaCl₂; 1 mM MnCl₂) per well. Following blocking with 150 μ l 3% BSA/TBS for 1 hour at 37°C, 25 μ l crude supernatants from overnight cultures of *E. coli* strain XL1-Blue
30 expressing soluble LM609 or humanized LM609 Fab were added to the well and incubated for 2 hours at 37°C. Binding of each of the supernatants to wells coated with human integrin $\alpha_v\beta_3$ and $\alpha_{IIb}\beta_3$ as well as to uncoated but blocked wells was analyzed in triplicates. As a positive control, 25 μ l of 50 ng/ μ l purified Fab-9, an

antibody binding to both human integrin $\alpha_v\beta_3$ and $\alpha_{IIb}\beta_3$ (Barbas III, et al. (1993) *Proc. Natl. Acad. Sci. USA* 90, 10003-10007), and as a negative control, 25 μ l of plain bacterial culture medium were used. After extensive washing with tap water, 25 μ l of a 1:2,000 dilution of goat anti-mouse F(ab')₂ or goat anti-human F(ab')₂ conjugated with alkaline phosphatase (Pierce #31324 or 31312, respectively) in 1% BSA/TBS was added to the well and incubated for 1 hour at 37°C. Following another extensive washing with tap water, 50 μ l of alkaline phosphatase substrate (5 mg disodium p-nitrophenyl phosphate hexahydrate (Sigma #104-105) dissolved in 5 ml 10% diethanolamine, 1 mM MgCl₂, 3 mM NaN₃, pH 9.8) were added to the well. The plate was analyzed with an ELISA reader (Molecular Devices) after 15 minutes incubation at room temperature.

Flow cytometry

Flow cytometry was performed using a Becton Dickinson FACScan instrument. For each determination, 5x10⁵ untransfected hamster CS-1 cells or hamster CS-1 cells expressing either human β_3 or β_5 , were analyzed. Indirect immunofluorescence staining was achieved with crude lysates of *E. coli* strain XL1-Blue expressing soluble humanized LM609 Fab or, as a negative control, an unrelated human Fab. A 1:100 dilution of FITC-conjugated goat anti-human F(ab')₂ (Jackson #109-096-097) was used for detection.

Construction of Lcdr3 libraries

Humanized LM609 clones 2, 4, 7, 11, and 24 in pPhoA-H6HA were separately utilized as templates for overlap extension PCR mutagenesis as described (Barbas III, et al. (1994) *IN VITRO EVOLUTION OF A NEUTRALIZING HUMAN ANTIBODY TO HIV-1 TO ENHANCE AFFINITY AND BROADEN STRAIN CROSS-REACTIVITY*, *Proc. Natl. Acad. Sci. USA* 91, 3809-3813). The two fragments required for this procedure were obtained with the PCR primer pairs OMPSEQ (SEQ ID NO:39) / CR320 (SEQ ID NO:46) and CR520 (SEQ ID NO:47) / DPSEQ (SEQ ID NO:48), respectively. The resulting five cDNAs with randomized Lcdr3 were cut with SfiI, ligated into the appropriately digested phagemid vector pComb3H, and electrotransformed into *E. coli* strain ER 2537. Two clones of each of the five libraries were analyzed by DNA sequencing and revealed correct assembly as well as

10 different LCDR3 sequences. Prior to selection, libraries based on clones 2, 4, and 24 (V_L germ-line DP-26; V_H germ-line DP-65) were combined to give a complexity of 6×10^7 independent transformants. Libraries based on clone 11 (V_L germ-line DP-26; V_H germ-line DP-10) and 7 (V_L germ-line DP-26; V_H germ-line DP-78) were kept separate with a complexity of 3×10^7 and 4×10^7 independent transformants, respectively.

Selection of LCDR3 libraries

The three LCDR3 libraries were separately selected by panning against immobilized integrin $\alpha_v\beta_3$ for six cycles. Panning was performed substantially as described hereinabove for the LM609 humanization. The concentration of human integrin $\alpha_v\beta_3$ for coating was 200 ng/25 μ l in the first through fourth cycles and 50 ng/25 μ l in the fifth and sixth cycles. Also, the input number of phage, in the range of 10^{12} in the first through fourth cycles as usual, was decreased by a factor of 10 in the fifth cycle and by a factor of 100 in the sixth cycle. In the second through the sixth cycles of selection 20 μ g LM609 IgG in 50 μ l metal buffer (25 mM Tris-HCl, pH 7.5; 137 mM NaCl; 1 mM KCl; 1 mM $MgCl_2$; 1 mM $CaCl_2$; 1 mM $MnCl_2$) was added to the well following removal of unbound phage by five to ten washing steps. The plate was then incubated for 24 hours at room temperature (off-rate selection) prior to five additional washing steps and trypsin elution as described. After the sixth cycle phage were produced from single clones and tested for binding to immobilized human integrin $\alpha_v\beta_3$ by phage ELISA using a sheep anti-M13 antibody conjugated with horseradish peroxidase (Pharmacia #27-9411-01) as a secondary antibody. Light chain and heavy chain encoding sequences of positive clones were analyzed by DNA sequencing using the primers OMPSEQ (SEQ ID NO:39) and PELSEQ (SEQ ID NO:24), respectively.

Optimization of LM609 by CDR randomization

In addition to the humanization, LM609 can be optimized in two respects: First, by increasing the affinity to $\alpha_v\beta_3$ and, second, by broadening the species cross-reactivity. Increased affinity of engineered LM609 increases the potency and decreases the cost of a potential cancer therapy.

The original mouse monoclonal antibody LM609 already has a broad species cross-reactivity. It binds to human, dog, cat, bovine, rabbit, and chick but not mouse $\alpha_V\beta_3$. The fact that LM609 does not recognize host $\alpha_V\beta_3$ in the mouse models of human cancer is a major concern for the therapeutic applicability of LM609.

- 5 Engineered LM609 binding to both human and mouse $\alpha_V\beta_3$ would be an important tool towards clinical trials. *In vitro* methods for the improvement of monoclonal antibody affinity include *chain shuffling* (See Marks, J.D., et al. (1992) BY-PASSING IMMUNIZATION: BUILDING HIGH HUMAN ANTIBODIES BY CHAIN SHUFFLING, *Bio/Technology* 10, 779-783). Binding to $\alpha_V\beta_3$ can be further improved by subsequent
- 10 CDR randomization, an approach termed *CDR walking* (See Barbas III, C.F., et al. (1994) *IN VITRO* EVOLUTION OF A NEUTRALIZING HUMAN ANTIBODY TO HIV-1 TO ENHANCE AFFINITY AND BROADEN STRAIN CROSS-REACTIVITY, *Proc. Natl. Acad. Sci. USA* 91, 3809-3813). The *in vitro* strategies for humanization and affinity improvement of LM609 are likely to generate cross-reactivity with mouse $\alpha_V\beta_3$ concurrently.
- 15 Directed selection for mouse $\alpha_V\beta_3$ recognition is complicated by the fact that mouse $\alpha_V\beta_3$ has not been purified yet. However, several mouse cell lines, e.g., NIH/3T3, are known to express $\alpha_V\beta_3$ and, thus, may be included in the screening procedure.

The foregoing discussion and the accompanying examples are presented as illustrative, and are not to be taken as limiting. Still other variations within

20 the spirit and scope of this invention are possible and will readily present themselves to those skilled in the art.

- In the claims which follow and in the preceding summary of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprising" is used in the sense of "including", i.e.
- 25 the features specified may be associated with further features in various embodiments of the invention.

It is to be understood that a reference herein to a prior art publication 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.



EDITORIAL NOTE 16280/99

SEQUENCE LISTING PAGES 1/9 TO 9/9 AND THE DEPOSIT RECEIPT
ARE PART OF THE DESCRIPTION AND ARE FOLLOWED BY CLAIM
PAGES 27 TO 28.

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INDICATIONS RELATING TO A DEPOSITED MICROORGANISM

(PCT Rule 13bis)

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Date of deposit 15 SEP 87	Accession Number HB 9537
C. ADDITIONAL INDICATIONS (leave blank if not applicable) This information is continued on an additional sheet <input type="checkbox"/>	
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D. DESIGNATED STATES FOR WHICH INDICATIONS ARE MADE (if the indications are not for all designated States)	
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E. SEPARATE FURNISHING OF INDICATIONS (leave blank if not applicable)	
The indications listed below will be submitted to the International Bureau later (specify the general nature of the indications e.g., "Accession Number of Deposit")	
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Authorized Wendell Meadows Paralegal Specialist IAPD-PCT Operations 800-865-8745	Authorized officer

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of humanising a mouse monoclonal antibody which comprises the steps of:

5 (a) constructing a human light chain wherein each said light chain comprises at least the variable domain thereof and has complementarity determining region three from antibody LM609;

(b) selecting from the constructed human light chain library a human light chain having CDR3 from antibody LM609, wherein the selection
10 comprises using a heavy chain from an antibody which binds a preselected antigen;

(c) constructing a library of human heavy chains wherein each said heavy chain comprises at least the variable domain thereof and has at least one complementarity determining region (CDR) amino acid sequence of a mouse heavy chain;

15 (d) combining the constructed human heavy chain library with the human light chain to produce a humanised library of heavy and light chain pairs, each containing at least one mouse CDR; and

(e) selecting from the humanised library a heavy and light chain pair using the human light chain.

20

2. A method of humanising a mouse monoclonal antibody which comprises the steps of:

(a) constructing a human light chain wherein each said light chain comprises at least the variable domain thereof and has at least one complementarity
25 determining region (CDR) amino acid sequence of a mouse chain;

(b) selecting from the constructed human light chain library a human light chain having a mouse CDR, wherein the selection comprises using a heavy chain from antibody LM609;

30 (c) constructing a human heavy chain which comprises at least the variable domain thereof and has complementarity determining region (CDR) three from antibody LM609;



(d) combining the constructed human light chain library with the human heavy chain to produce a humanised library of heavy and light chain pairs each containing at least one mouse CDR; and

(e) selecting from the humanised library a heavy and light chain pair using the selected human light chain.

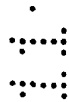


10

15



20



25

3. The method of claim 1 or 2 further comprising converting the selected heavy and light chain pair to whole antibody.

4. The method of claim 1 or 2 wherein the heavy chain is Fd.

5. The method of claim 4 wherein the Fd is a member of the group consisting of a chimeric mouse/human heavy chain fragment and a template mouse heavy chain fragment.

6. The method of claim 4 or 5 wherein the Fd is a chimeric mouse/human heavy chain.

7. The method of claim 4 wherein the Fd is a template mouse heavy chain fragment.

8. A method of humanising a mouse monoclonal antibody according to claim 1 substantially as hereinbefore described with reference to the Results.

Dated this 10th day of March 2003

THE SCRIPPS RESEARCH INSTITUTE

By their Patent Attorneys

GRIFFITH HACK

30



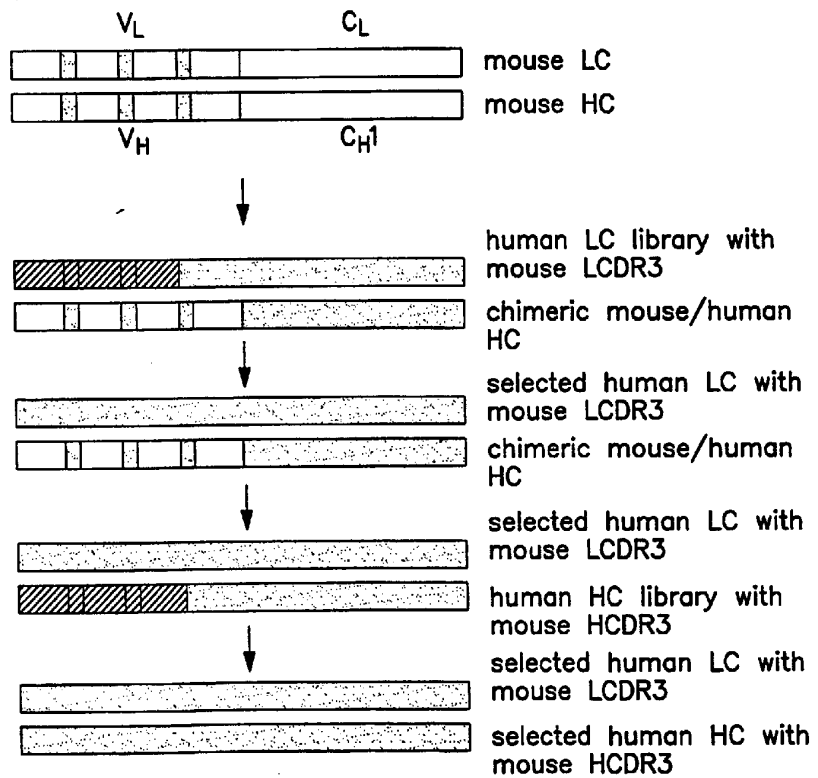


FIG. 1

V₁

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 25 30 35 40
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 115 120 125 130

FIGURE 2a

V_k

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 70 75 80 85
 Gln Gln Ser Asn Ser Trp Pro His Thr Phe Gly Gly Thr Lys Leu Glu Ile Lys Arg Ala
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FIGURE 2b

FR 1
V_K
#1
#2
#3
#4
#5
#6

.. Thr Gln Thr Pro Ala Thr Leu Ser Val Thr Pro Gly Asp Ser Val Ser Leu Ser Cys
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.. - Ser - Gly Thr - - Leu Ser - - Glu Arg Ala Thr - -
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.. - Ser - Ser Ser - - Ala Ser Val - - * - Thr Ile Thr -
.. - Ser - Ser Ser - - Ala Ser Val - - Arg - Thr Ile Thr -

FIGURE 3a

CDR1
V_K
#1
#2
#3
#4
#5
#6

Arg Ala Ser Gln Ser Ile Ser Asn His Leu His
- - - - Val - Ser Ser Tyr Leu Ala
- - - - Val - Ser Ser Phe Leu Ala
- - - - Val Thr Ser Ser Tyr Leu Ala
- - - - Thr Phe - Asn
- - - - Ser Tyr - Asn
- - - - Ser Tyr - Asn

FIGURE 3b

FR2

V _k	Trp	Tyr	Gln	Gln	Lys	Ser	His	Glu	Ser	Pro	Arg	Leu	Leu	Ile	Lys
#1	-	-	-	-	-	Pro	Gly	Gln	Ala	-	-	-	-	-	Tyr
#2	-	-	-	-	-	Pro	Gly	Gln	Ala	-	-	-	-	-	Tyr
#3	-	-	-	-	-	Pro	Gly	Gln	Ala	-	-	-	-	-	Tyr
#4	-	-	-	-	-	Pro	Gly	Lys	Ala	-	Lys	Phe	-	-	Tyr
#5	-	-	-	Arg	-	Pro	Gly	Lys	Ala	-	Lys	Leu	-	-	Tyr
#6	-	-	-	-	-	Pro	Gly	Lys	Ala	-	Lys	Leu	-	-	Tyr

FIGURE 3c

CDR2

V _k	Tyr	Ala	Ser	Gln	Ser	Ile	Ser
#1	Gly	-	-	Ser-Arg-Ala-Thr	-	-	-
#2	Gly	-	-	Ser-Arg-Ala-Thr	-	-	-
#3	Gly	-	-	Ser-Arg-Ala-Thr	-	-	-
#4	Ala	-	-	Thr Leu Gln	-	-	-
#5	Ala	-	-	Thr Leu Gln	-	-	-
#6	Ala	-	-	Thr Leu Gln	-	-	-

FIGURE 3d

	Gly	Ile	Pro	Ser	Arg	Phe	Ser	Gly	Ser	Gly	Ser	Gly	Thr	Asp	Phe	Thr	Leu	Ser	Ile	Asn	Ser
V _k	Val	Glu	Thr	Glu	Asp	Phe	Gly	Met	Tyr	Phe	Cys										
#1	-	-	-	Asp	-	-	-	-	-	-	-	-	-	-	-	Ile	-	Thr	-	Ser	Arg
	Leu	-	Pro	-	-	-	Ala	Val	-	Tyr	-										
#2	-	-	-	Asp	-	-	-	-	-	-	-	-	-	Val	-	-	-	Thr	-	Ser	Arg
	Leu	-	Pro	-	-	-	Ala	Val	-	Tyr	-										
#3	-	-	-	Asp	-	-	-	-	-	-	-	-	-	-	-	Ile	Phe	Thr	-	Ser	Arg
	Leu	-	Pro	-	-	-	Ala	Val	-	Tyr	-										
#4	-	Val	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Thr	-	Ser	-
	Leu	Gln	Pro	-	-	-	Ala	Val	-	Tyr	-										
#5	-	Val	-	-	-	-	-	-	-	-	-	Ala	-	-	-	-	-	Thr	-	Ser	-
	Leu	Gln	Pro	-	-	-	Ala	Val	-	Tyr	-										
#6	-	Val	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Thr	-	Ser	-
	Leu	Gln	Pro	-	-	-	Ala	Val	-	Tyr	-										

FIGURE 3e

	----- LCDR1 -----	----- LCDR2 -----
mouse	Arg Ala Ser Gln Ser Ile Ser Asn	(Lys) Tyr Ala Ser Gln Ser Ile Ser
selected human		
3 x	Arg Ala Ser Gln Asp Ile Gly Thr	(Lys) Tyr Ala Ser Gln Pro Val Phe
2 x	Arg Ala Ser Gln Asp Ile Gly Asn	(Lys) Tyr Ala Ser Gln Pro Val Phe
1 x	Arg Ala Ser Gln Ser Ile Gly Trp	(Lys) Tyr Ala Ser Gln Ser Ile Ser
unselected human		
	Arg Ser Ser Gln Ser Ile Asn Ile	(Tyr) His Ala Ser Lys Arg Ala Ser
	Arg Ala Ser Gln Ser Val Ser Asn Asn	(Tyr) Arg Ala Ser Ser Arg Ala Thr
	Arg Ser Ser Gln Ser Leu Val Tyr Ser Asp Gly Asn Thr	(Tyr) Lys Val Ser Asn Arg Asp Ser
	Thr Ala Ser Gln Ser Leu Val Tyr Thr Asp Gly Asn Thr	(Tyr) Met Val Ser Asn Arg Asp Ser

FIGURE 4

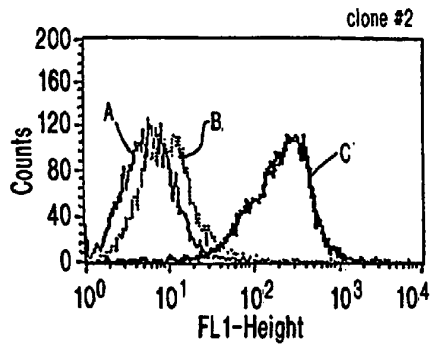


FIG. 5a

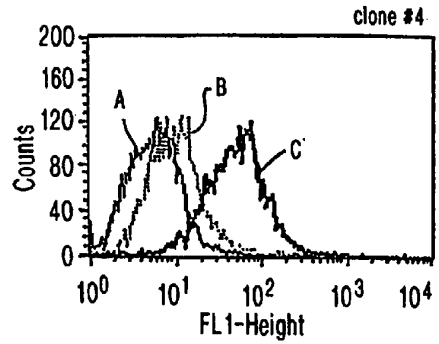


FIG. 5b

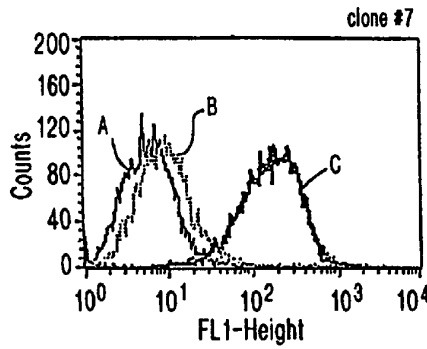


FIG. 5c

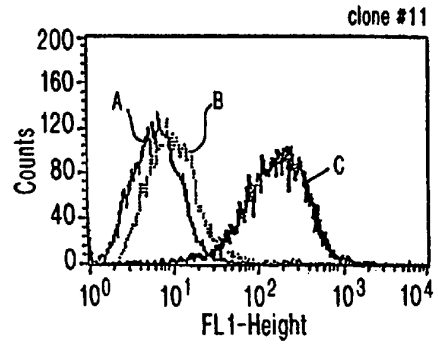


FIG. 5d

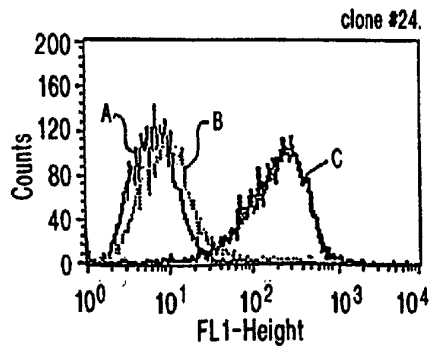


FIG. 5e

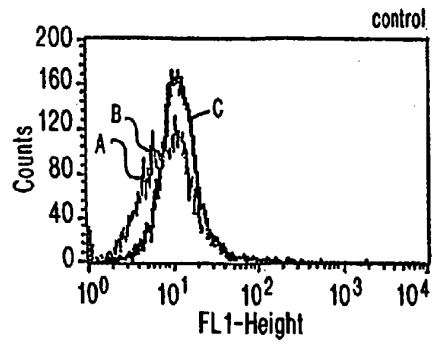


FIG. 5f

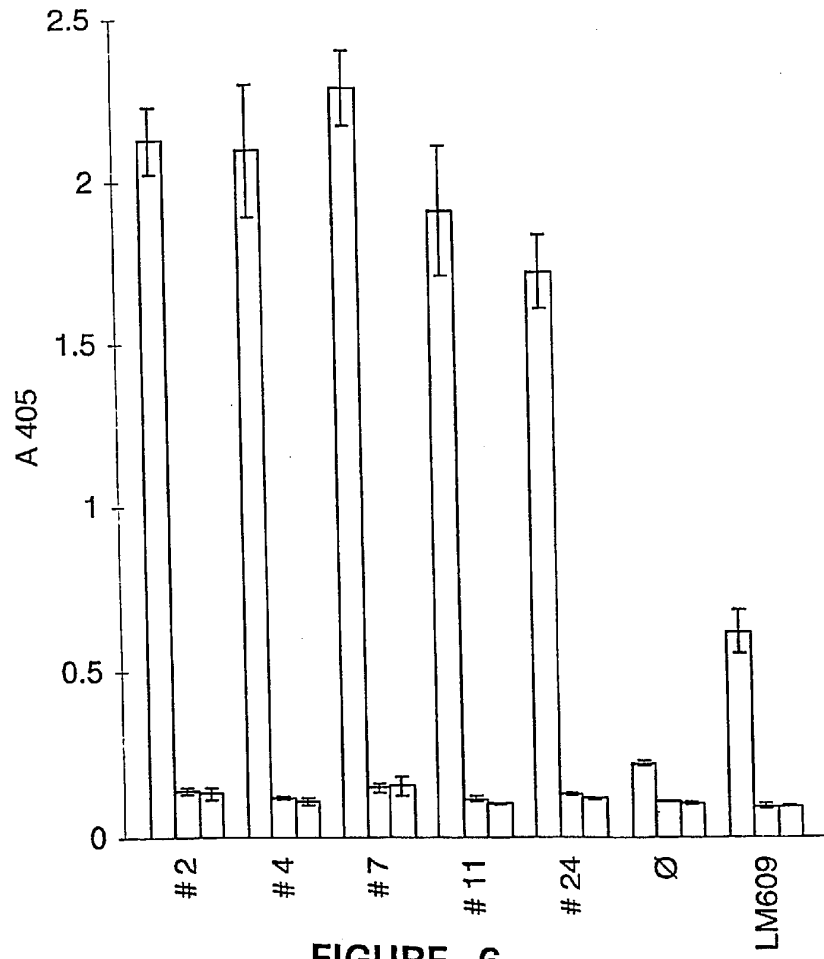


FIGURE 6

9/14

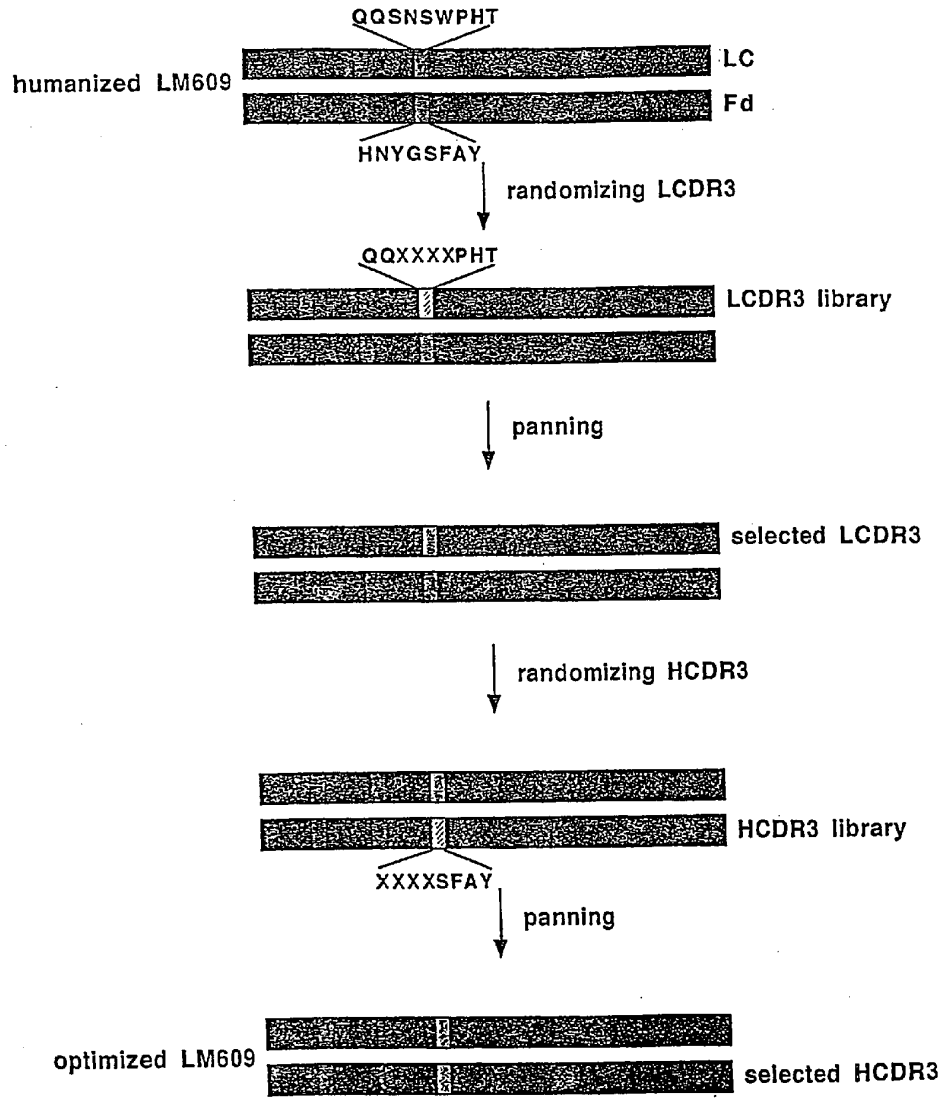


FIGURE 7

FIGURE 8a

V_L amino acid sequences

FR1
 mouse
 Glu Leu Val Met Thr Gln Thr Pro Ala Thr Leu Ser Val Thr Pro Gly Asp Ser Val Ser Leu Ser Cys
 human (Group A)
 Glu Leu Val Met Thr Gln Ser Pro Glu Phe Gln Ser Val Thr Pro Lys Glu Thr Val Thr Ile Thr Cys
 human (Groups BCDE)
 Glu Leu Val Met Thr Gln Ser Pro Glu Phe Gln Ser Val Thr Pro Lys Glu Thr Val Thr Ile Thr Cys

CDR1
 mouse
 Arg Ala Ser Gln Ser Ile Ser Asn His Leu His
 human (Group A)
 Arg Ala Ser Gln Asp Ile Gly Thr Ser Leu His
 human (Groups BCDE)
 Arg Ala Ser Gln Asp Ile Gly Asn Ser Leu His

FR2
 mouse
 Trp Tyr Gln Gln Lys Ser His Glu Ser Pro Arg Leu Leu Ile Lys
 human (Group A)
 Trp Tyr Gln Gln Lys Pro Gly Gln Ser Pro Lys Leu Leu Ile Lys
 human (Groups BCDE)
 Trp Tyr Gln Gln Lys Pro Gly Gln Ser Pro Lys Leu Leu Ile Lys

CDR2
 mouse
 Tyr Ala Ser Gln Ser Ile Ser
 human (Group A)
 Tyr Ala Ser Gln Pro Val Phe
 human (Groups BCDE)
 Tyr Ala Ser Gln Pro Val Phe

FIGURE 8b

V_L amino acid sequences

FR3	mouse	Gly Ile Pro Ser Arg Phe Ser Gly Ser Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Ser Ile Asn Ser Val
	human (Group A)	Glu Thr Glu Asp Phe Gly Met Tyr Phe Cys
	human (Group BCDE)	Gly Val Pro Ser Arg Phe Arg Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Thr Ile Tyr Ser Leu
	human (Group BCDE)	Glu Ala Glu Asp Phe Ala Val Tyr Tyr Cys
	human (Group BCDE)	Gly Val Pro Ser Arg Phe Arg Gly Ser Gly Ser Gly Thr Asp Phe Thr Leu Thr Ile Ser Arg Leu
	human (Group BCDE)	Glu Pro Glu Asp Phe Ala Val Tyr Tyr Cys
CDR3	mouse	Gln Gln Ser Asn Ser Trp Pro His Thr
	human (Group A)	Gln Gln Ser Asn Ser Trp Pro His Thr
	human (Group BCDE)	Gln Gln Ser Asn Ser Trp Pro His Thr
	human (Group BCDE)	Gln Gln Ser Asn Ser Trp Pro His Thr
FR4	mouse	Phe Gly Gly Gly Thr Lys Leu Glu Ile Lys Arg Ala
	human (Group A)	Phe Gly Gln Gly Thr Lys Leu Glu Ile Lys Arg Thr
	human (Group BCDE)	Phe Gly Gln Gly Thr Lys Leu Glu Ile Lys Arg Thr

FIGURE 8c

V_H amino acid sequences

FRI
 mouse
 Glu Val Gln Leu Glu Ser Gly Gly Leu Val Lys Pro Gly Gly Ser Leu Lys Leu Ser Cys
 Ala Ala Ser Gly Phe Ala Phe Ser
 human (Group A)
 Gln Val Gln Leu Val Gln Ser Gly Ala Glu Val Arg Lys Pro Gly Ser Val Arg Val Ser Cys
 Lys Ala Ser Gly Gly Thr Phe Ser
 human (Group B)
 Gln Val Gln Leu Gln Glu Ser Gly Pro Gly Leu Val Lys Pro Ser Gln Thr Leu Ser Leu Thr Cys
 Thr Val Ser Gly Ala Ser Ile Ser
 human (Group C)
 Gln Val Gln Leu Gln Glu Ser Gly Pro Gly Leu Val Lys Pro Ser Gln Thr Leu Phe Leu Thr Cys
 Thr Val Ser Gly Gly Ser Ile Ser
 human (Group D)
 Gln Val Gln Leu Gln Glu Ser Gly Pro Gly Leu Val Lys Pro Ser Glu Thr Leu Ser Leu Thr Cys
 Thr Val Ser Gly Gly Ser Ile Ser
 human (Group E)
 Gln Val Gln Leu Gln Glu Ser Gly Pro Gly Leu Val Lys Pro Ser Glu Thr Leu Ser Leu Thr Cys
 Ser Val Ser Gly Gly Ser Ile Ser

CDR1
 mouse
 Ser Tyr Asp Met Ser
 human (Group A)
 Gly Phe Ala Val Ser
 human (Group B)
 Arg Gly Gly Tyr Tyr Trp Ser
 human (Group C)
 Ser Gly Gly Tyr Tyr Trp Ser
 human (Group D)
 Ser Gly Gly Tyr Tyr Trp Ser
 human (Group E)
 Ser Gly Gly Tyr Tyr Trp Ser

FR2
 mouse
 Trp Val Arg Gln Ile Pro Glu Lys Arg Leu Glu Trp Val Ala
 human (Group A)
 Trp Val Arg Gln Ala Pro Gly Gln Arg Phe Glu Trp Leu Gly
 human (Group B)
 Trp Ile Arg Gln Tyr Pro Gly Lys Gly Leu Glu Trp Ile Gly
 human (Group C)
 Trp Ile Arg His His Pro Gly Lys Leu Glu Trp Ile Gly
 human (Group D)
 Trp Ile Arg Gln His Pro Gly Lys Gly Leu Glu Trp Ile Gly
 human (Group E)
 Trp Ile Arg His His Pro Gly Lys Gly Leu Glu Trp Ile Gly

FIGURE 8d

V_H amino acid sequences

CDR2
 mouse Lys Val Ser Ser Gly Gly Ser Thr Tyr Tyr Leu Asp Thr Val Gln Gly
 human_(Group A) Gly Ile Val Ala Ser Leu Gly Ser Thr Asp Tyr Ala Gln Lys Phe Gln Asp
 human_(Group B) Tyr Ile His His Ser Gly Ser Thr Tyr Tyr Asn Pro Ser Leu Lys Ser
 human_(Group C) Tyr Ile His His Arg Ala Ala Pro Tyr Tyr Asn Pro Ser Leu Lys Ser
 human_(Group D) Tyr Ile His His Ser Ala Gly Thr Tyr Tyr Asn Pro Ser Leu Lys Ser
 human_(Group E) Tyr Ile His His Ser Ala Gly Thr Tyr Tyr Asn Pro Ser Leu Lys Ser

FR3
 mouse Arg Phe Thr Ile Ser Arg Asp Asn Ala Lys Asn Thr Leu Tyr Leu Gln Met Ser Ser Leu Asn Ser
 Glu Asp Thr Ala Ala Met Tyr Tyr Cys Ala Arg
 human_(Group A) Lys Leu Thr Ile Thr Val Asp Glu Ser Thr Ala Thr Val Tyr Met Glu Met Arg Asn Leu Arg Ser
 Asp Asp Thr Ala Val Tyr Tyr Cys Ala Ar
 human_(Group B) Arg Val Thr Ile Ala Ile Asp Thr Ser Lys Asn Gln Leu Ser Leu Arg Leu Thr Ser Val Thr Ala
 Ala Asp Thr Ala Val Tyr Tyr Cys Ala Arg
 human_(Group C) Arg Val Thr Ile Ser Val Asp Thr Ser Arg Asn Gln Ile Ser Leu Lys Leu Arg Ser Val Thr Ala
 Ala Asp Thr Ala Val Tyr Tyr Cys Ala Arg
 human_(Group D) Arg Val Thr Met Ser Val Asp Thr Ser Lys Asn Gln Leu Ser Leu Lys Leu Thr Ser Val Thr Ala
 Ala Asp Thr Ala Val Tyr Tyr Cys Ala Arg
 human_(Group E) Arg Val Thr Met Ser Ala Asp Thr Ser Lys Asn Gln Leu Ser Leu Lys Leu Ala Ser Val Thr Ala
 Ala Asp Thr Ala Val Tyr Tyr Cys Ala Arg

FIGURE 8e

V_H amino acid sequences

CDR3	FR4
mouse	mouse
His Asn Tyr Gly Ser Phe Ala Tyr	Trp Gly Gln Gly Thr Leu Val Thr Val Ser Ala
human_Group A1	human_Group A1
His Asn Tyr Gly Ser Phe Ala Tyr	Trp Gly Gln Gly Thr Leu Val Thr Val Ser Ser
human_Group B1	human_Group B1
His Asn Tyr Gly Ser Phe Ala Tyr	Trp Gly Gln Gly Thr Leu Val Thr Val Ser Ser
human_Group C1	human_Group C1
His Asn Tyr Gly Ser Phe Ala Tyr	Trp Gly Gln Gly Thr Leu Val Thr Val Ser Ser
human_Group D1	human_Group D1
His Asn Tyr Gly Ser Phe Ala Tyr	Trp Gly Gln Gly Thr Leu Val Thr Val Ser Ser
human_Group E1	human_Group E1
His Asn Tyr Gly Ser Phe Ala Tyr	Trp Gly Gln Gly Thr Leu Val Thr Val Ser Ser