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(54) **TRANSGENIC NON-HUMAN ANIMALS EXPRESSING A GDF-11 DOMINANT NEGATIVE POLYPEPTIDE, AND METHODS OF MAKING AND USING SAME**

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tion-in-part of application No. 09/019,901, filed on Feb. 6, 1998, now abandoned, which is a continuation-in-part of application No. 08/795,671, filed on Feb. 6, 1997, now Pat. No. 6,008,434, and which is a continuation-in-part of application No. 08/706,958, filed on Sep. 3, 1996, now abandoned, which is a continuation of application No. 08/272,763, filed on Jul. 8, 1994, now abandoned.

Publication Classification

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(57) **ABSTRACT**

A transgenic non-human animal of the species selected from the group consisting of avian, bovine, ovine and porcine having a transgene which results in disrupting the production of and/or activity of growth differentiation factor-11 (GDF-11) chromosomally integrated into the germ cells of the animal is disclosed. Also disclosed are methods for making such animals, and methods of treating animals, including humans, with antibodies or antisense directed to GDF-11. The animals so treated are characterized by increased muscle tissue and bone tissue.

```

1   TCTAGATGTC AAGAGAAGTGGTCACAATGTCTGGGTGGGAGCCGTAAACAAGCCAAGAGG   60
61  TTATGGTTTCTGGTCTGATGCTCCTGTGAGATCAGGAAATGTTTCAGGAAATCCCCCTGTT   120
121 GAGATGTAGGAAACTAAGAGGTAAGAGACATTGTTGAGGGTCATGTCACATCTCTTTCCC   180
181 CTCTCCCTGACCCCTCAGCATCCTTTTCATGGAGCTTCGAGTCCTAGAGAACACGAAAAGGT   240
      H P F M E L R V L E N T K RS
241 CCCC GGGAACCTAGGCCTGGACTGCGATGAACACTCGAGTGAGTCCCCGTGCTGCCGAT   300
      RS N L G L D C D E H S S E S R C C R Y
301 ATCTCTCACAGTGGACTTTGAGGCTTTTGGCTGGGACTGGATCATCCACCTAAGCGCT   360
      P L T V D F E A F G W D W I I A P K R Y
361 ACAAGGCCAACTACTGCTCCGGCCAGTGCGAATACATGTTTCATGCAAAAGTATCCACACA   420
      K A N Y C S G Q C E Y M F M Q K Y P H T
421 CCCACTTGGTGCAACAGGCCAACCCAAGAGGCTCTGCTGGGCCCTGCTGCCACCCCTACCA   480
      H L V Q Q A N P R G S A G P C C T P T K
481 AGATGTCCCCAATCAGCATGCTCTACTTCAATGACAAGCAGCAGATTATCTACGGCAAGA   540
      M S P I N M L Y F N D K Q Q I I Y G K I
541 TCCCTGGCATGGTGGTGGATCGATGTGGCTGCTCCTAAGTTGTGGGCTACAGTGGATGCC   600
      P G M V V D R C G C S *
601 TCCCTCAGACCCCTACCCCAAGAACCCCGC   630

```

FIG. 1a

1 CCGCGGGACTCCGGCGTCCCGCGCGCGCGAGTCCCTCCCGTCCCGTCCAGCATGGTGC 60
M V L
61 TCGCGCGCGCGCGTGGCTGGTGGCGCTTCCTGGCTCCCTCGCGCTCGAGCTCGCGCGCGCGCGGG 120
A A P L L L G F L L L A L E L R P R G E
121 AGCGCGCGCGAGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCGAGCGCGCGCGGG 130
A A E G P A A A A A A A A A A A A G V
131 TCGCGCGCGCGAGCGCTCGAGCG 240
G G E R S S R P A P S V A P E P D G C P
241 CCGTGTCCGTTTGGCG 300
V C V W R Q H S R E L R L E S I K S Q I
301 TCTTGAGCAACTCGCGCTCAAGCGAGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCG 360
L S K L R L K E A P N I S R E V V K Q L
361 TGCTGCGCGAAGCG 420
L P K A P P L Q Q I L D L H D F Q G D A
431 CGCTGCGCGCGCGAGGACTTCCTGCGAGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCG 430
L Q P E D F L E E D E Y H A T T E T V I
431 TTAGCATCGCGCGCGAGAGCG 540
S M A Q E T D P A V Q T D G S P L C C H
541 ATTTTCACTTCAGCG 600
F H F S P K V M F T X V L X A Q L W V Y
601 ACCTACGGCGCTGTACCG 660
L R P V P R P A T V Y L Q I L R L K P L
661 TAACTGGGGAAGCG 720
T G E G T A G G G G G G R R H I R I R S
721 CACTGAAGATTGAGCTGCGACTCAGCGCTCAGCGCGCGCGCGCGCGCGCGCGCGCGCGCG 780
L F I E L E S R S G H W Q S I D F K Q V
781 TGCTACACAGCTGGTTCCCG 840
L H S W F R Q P Q S N W G I E I N A F D
841 ATCCCACTGGCGACAGCGCTGGCGCTCAGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCGCG 900
P S G T D L A V T S L G P G A E G L H P
901 CATTCACTGGAGCTTCGAGTCCCTAGAGAACACAAAACGTTCCCGCGCGCGCGCGCGCGCG 960
F M E L R V L E N T K E S R E N L G L D
961 ACTGCGACGAGCACTCAAGCGAGTCCCGCTGCTGCGCGATATCCCGCTCAGCTGGACTTTG 1020
C D E H S S E S R C C R Y P L T V D F E
1021 AGGCTTTTCGGCTGGGACTGGATCATCGCACCTAAGCGCTACAAGGCGCAACTACTGCTCCG 1080
A F G W D W I I A P K R Y K A N Y C S G
1081 GCCAGTGGGAGTACATGTTTCATGCAAAAATATCCGCATACCCATTTGGTGCAGCAGGCGCA 1140
Q C E Y M F M Q K Y P H T H L V Q Q A N
1141 ATCCAGAGGGCTCTGCTGGGCGCGTGTGTACCGCGCGCGCGCGCGCGCGCGCGCGCGCGCG 1200
P R G S A G P C C T P T K M S P I N M L
1201 TCTACTTCAATGACAAGCAGCAGATTATCTACGGCAAGATCCCTGGCATGGTGGTGGATC 1260
Y F N D K Q Q I I Y G K I P G M V V D R
1261 GCTGTGGCTGCTCTTAAGTGGGTCACTACAAGCTGCTGGAGCAAAGACTTGGTGGGTGGG 1320
C G C S *
1321 TAACTTAACCTCTTTCACAGAGGATAAAAAATGCTTGTGACTATGACAGAAGCGGATTAAC 1380
1381 AGGCTTAAGGGT 1393

FIG. 1b

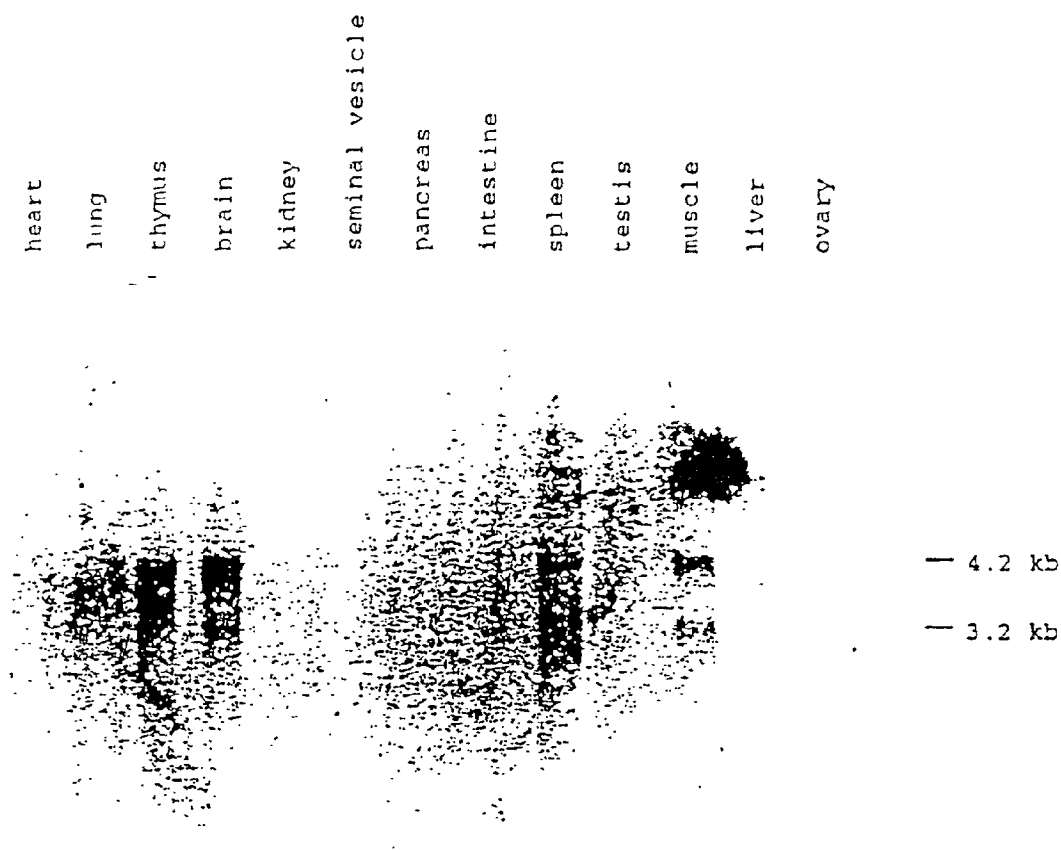


FIG. 2a

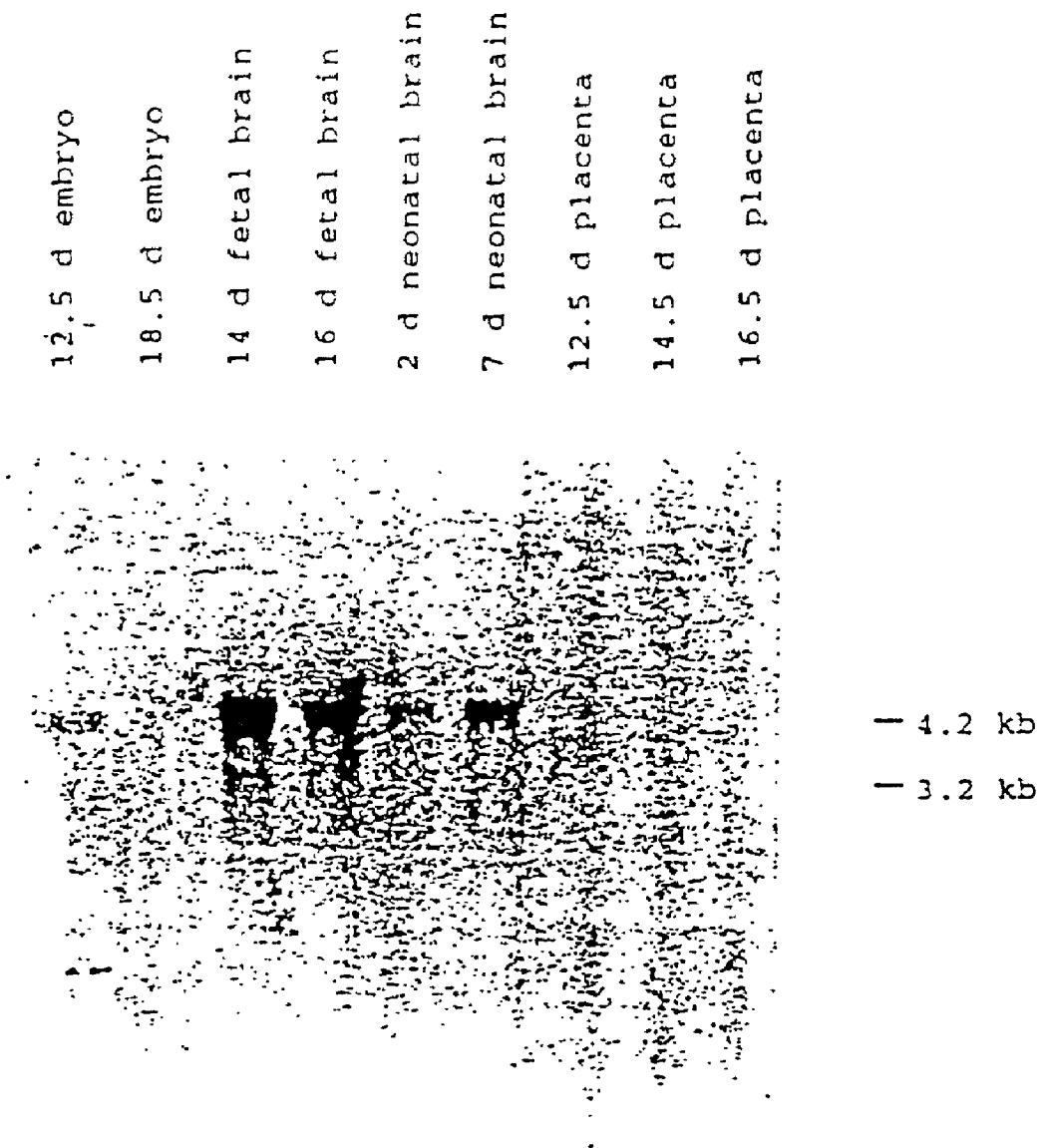


FIG. 2b

[illegible]

36E

1 MVLAAFLLLGFLLLALELRPRGEAAEGFAAAAAAAAAAGVGGERSR 50
| | | | |
1 MQKLQLCVYTYLFML.....IVAGFVDLNENSE 28

51 PAFSVAFEPDCCFVCVWRQHSRELPLESIRSQILSKLRLKEAPNISRETV 100
|
29 QKENVKEE.GLCNACTWRQNTKSSRIEAKIQILSKLRLKETAPNISKQVI 77

101 RQLLPKAPPLQQILDLADFQGDALQPEDFLEEDEYHATTETVISMAGETD 150
|
73 RQLLPKAPPLRELIDQYDVQRED.SSTGSLIEDDYHATTETIITMPTESD 126

151 PAVQTEGSPLCCHFHFSPKVMETKVLKAQLWVYLRFPVPRPATVYLQILRL 200
|
127 FLMQVDGKPKCCFFAFSSXIQYNKVVKAQLWYTLRFVETPTTVFVQILRL 176

201 RPLTGEGTACGGGGGRRHIRIRSLKIELHSRSGHWQSIDFKQVLHSWFRQ 250
|
177 IKPMKEDGT.....RYTGIRSLKLCMNPGTGIWQSIDVKTVLQNLKQ 218

251 PQSNWGIEINAFDPSCGTDLAVTSLGPGAEGLEPFMELRVLENTKPSRNL 300
|
219 PESNLGIEIKALDENGDELAVTFPGGEDGLNPFLEVKVTDTPKPSRDF 268

301 GLDDEHSSSESFCRYPLTVDFEAFGWDWIIAPKRYKANYSGCEVYFM 350
|
269 GLDDEHSTESFCRYPLTVDFEAFGWDWIIAPKRYKANYSGCEVYFL 318

351 QKYPETHLVQANPRGSAGFCCTPTKMSPINMLYFNDKQQIITYGKIPGMV 400
|
319 QKYPETHLVHQNPRGSAGFCCTPTKMSPINMLYFNGKEQIITYGKIPAMV 368

401 VDFGGS 407
| | | | |
369 VDFGGS 375

FIG. 4a

FIGURE 4b

[illegible]

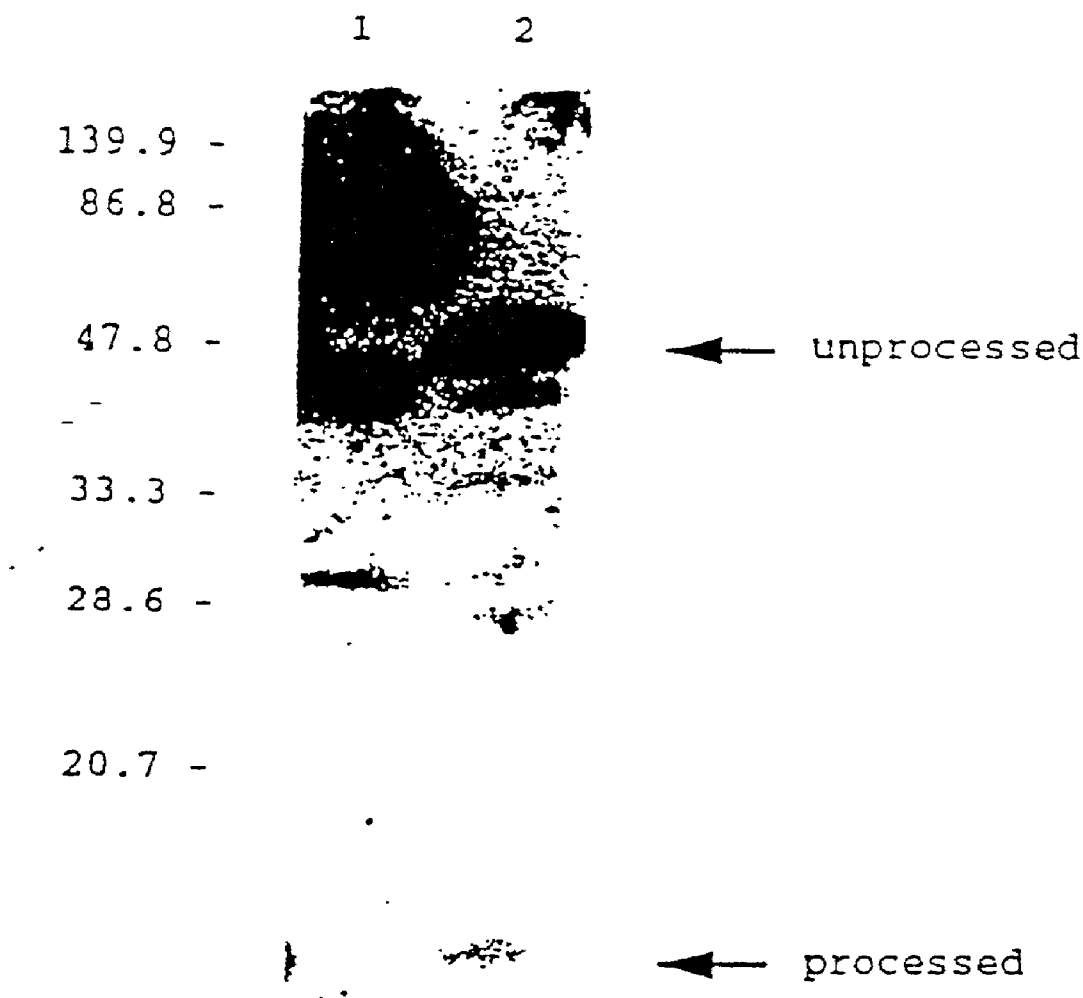


FIG. 5

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 X YCHO M H B1

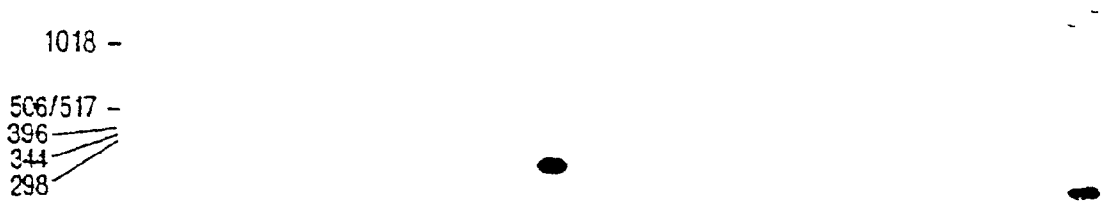


FIG. 6

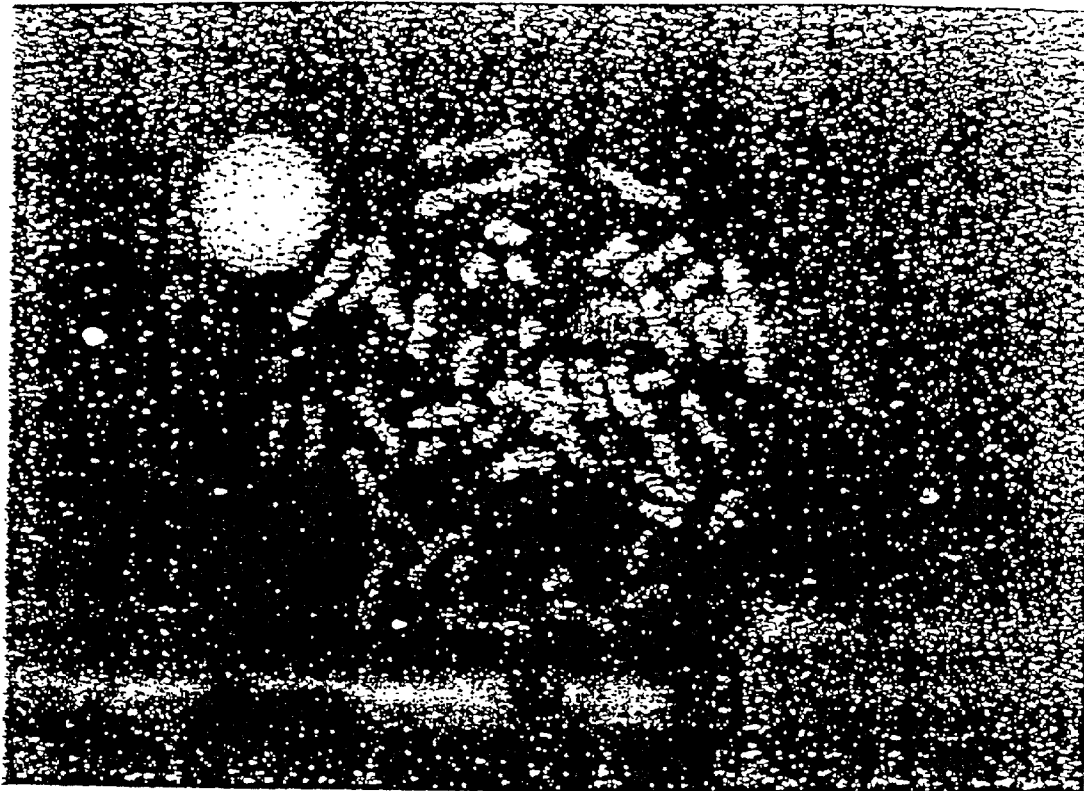


FIG. 7a

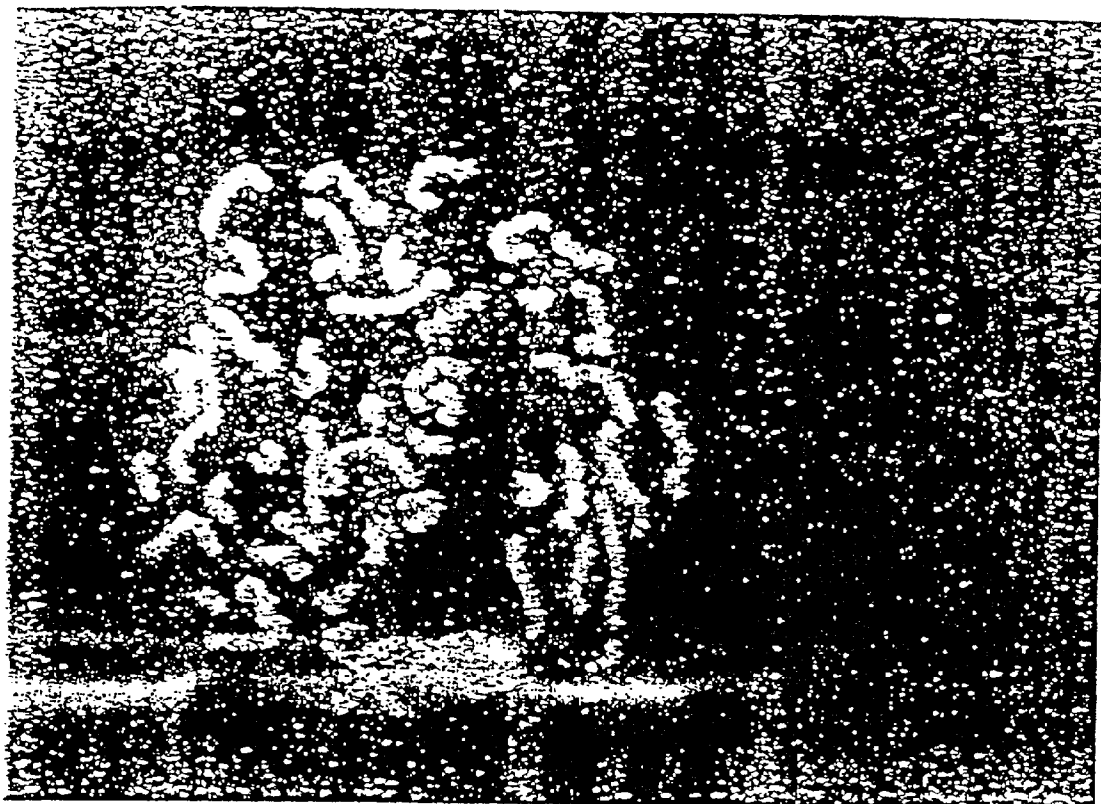


FIG. 7b

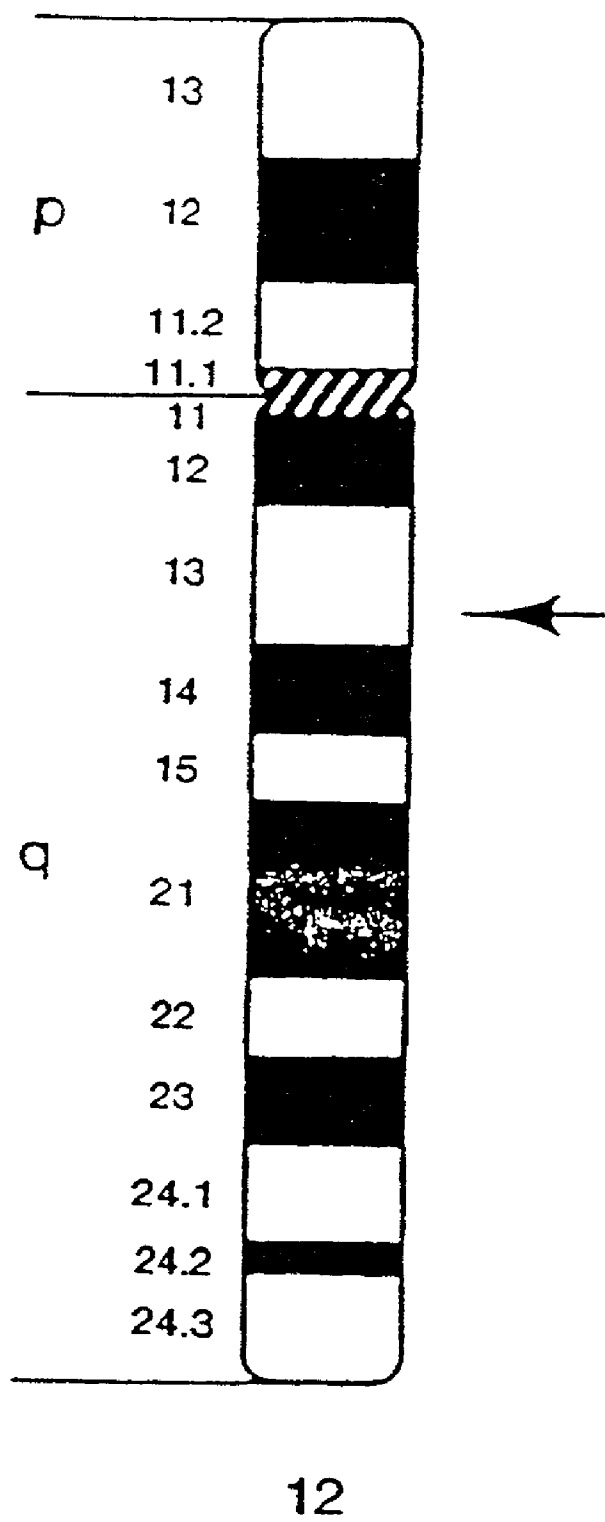


FIG. 7c

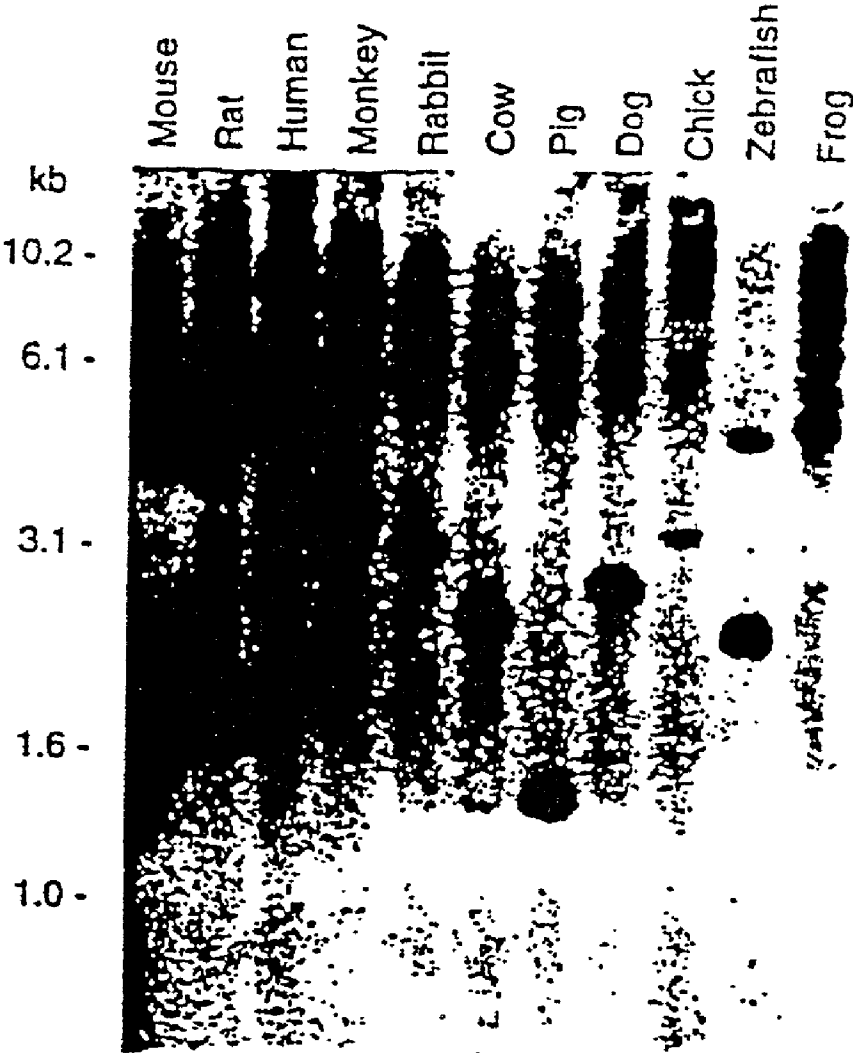


FIG. 8

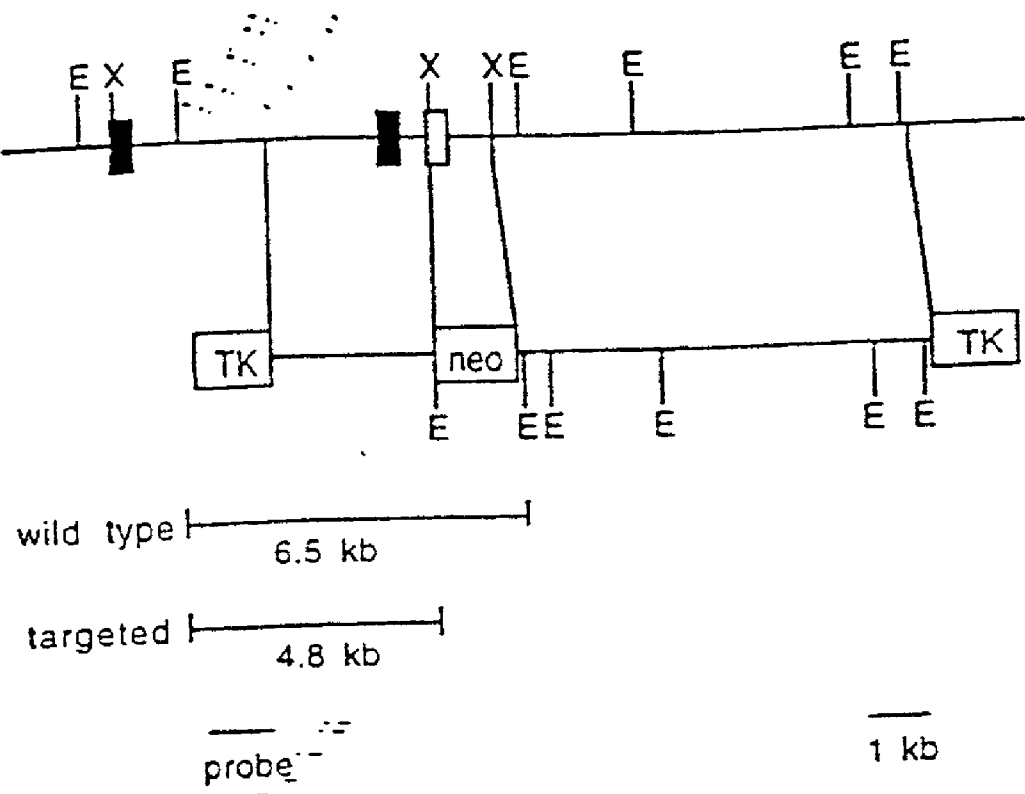


FIG. 9a

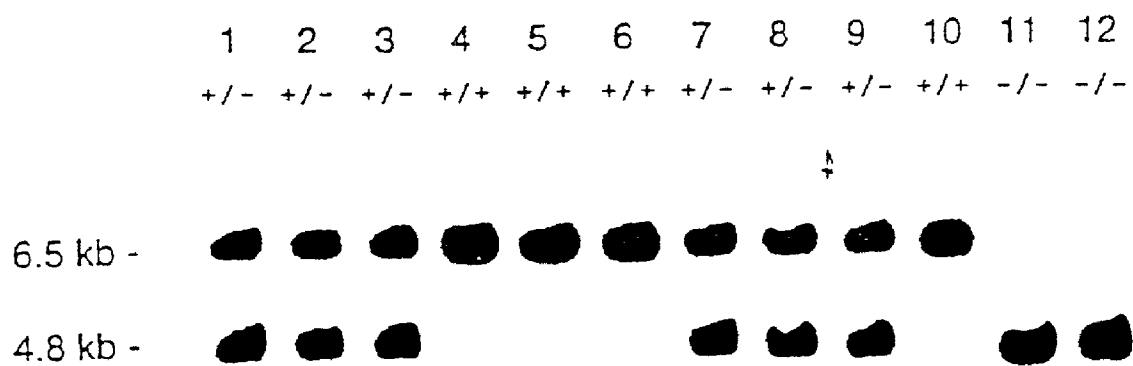


FIG. 9b

FIGURE 10

# of normal size-kidneys	2	1	1	0	0	0
# of small kidneys	0	1	0	2	1	0

+ / +	47	0	0	0	0	0
+ / -	88	0	5	0	0	0
- / -	2	2	9	3	3	28

FIGURE 11a

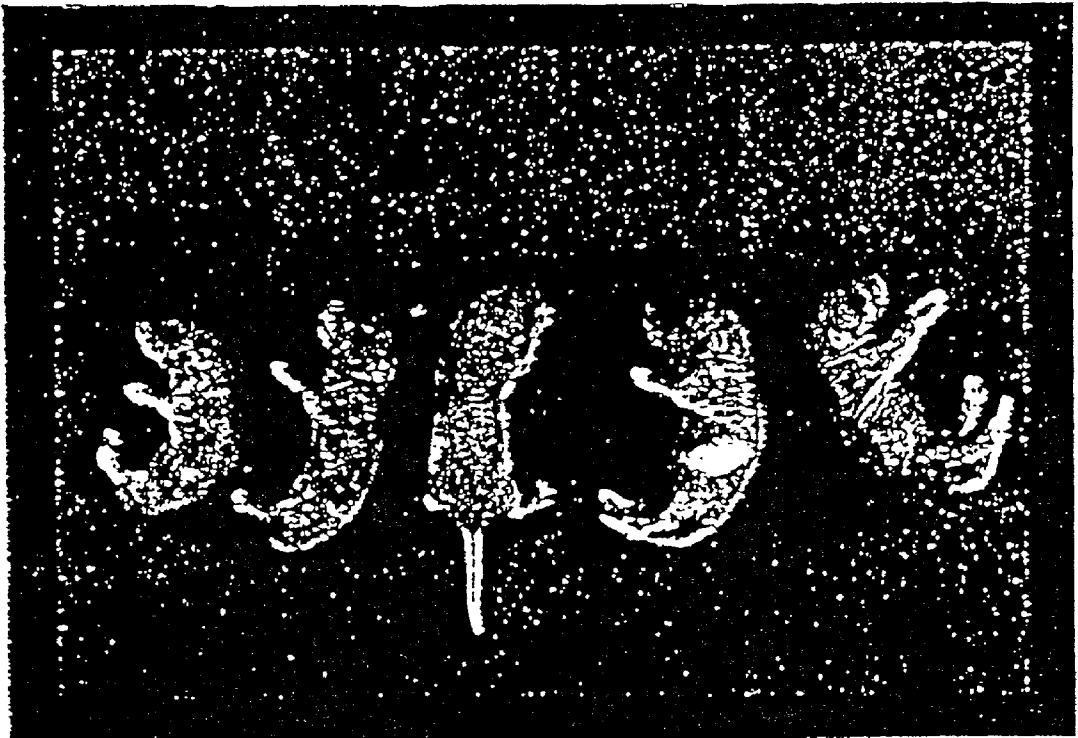


FIGURE 11b



FIGURE 11c

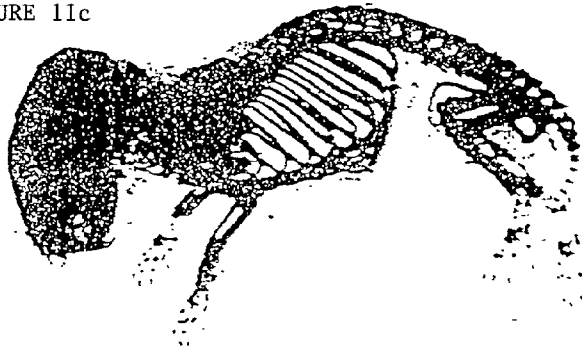


FIGURE 11d

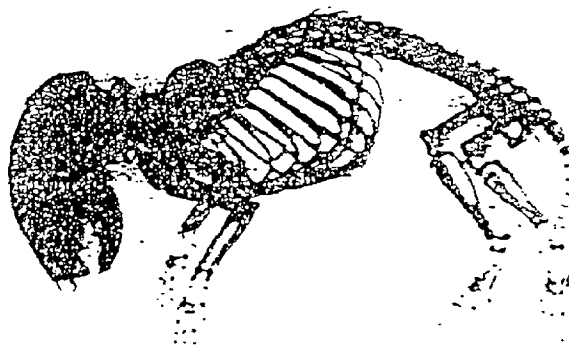


FIGURE 11e

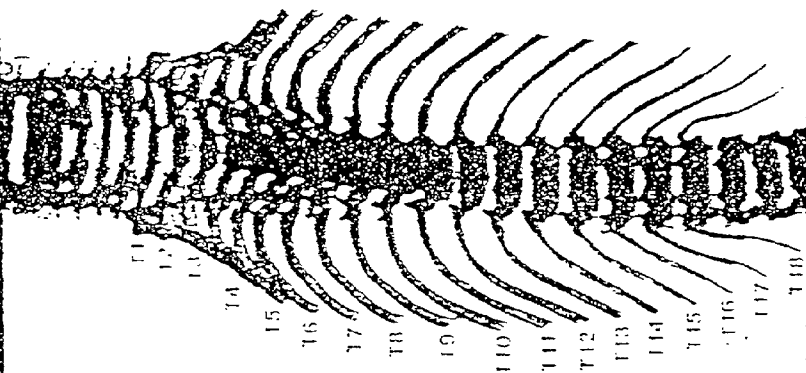


FIGURE 11f

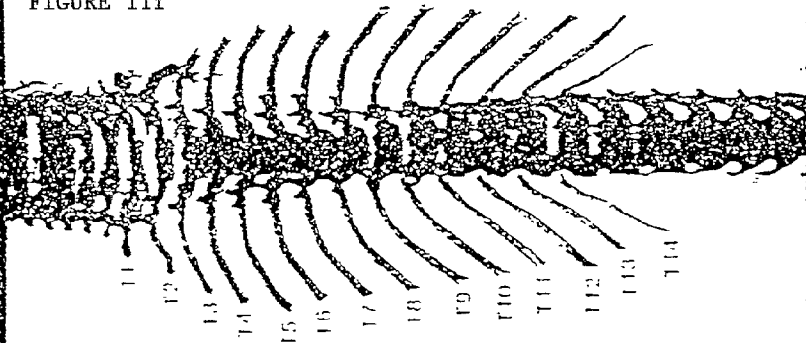
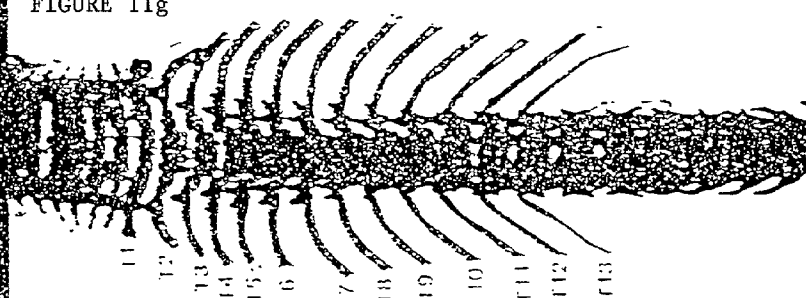


FIGURE 11g



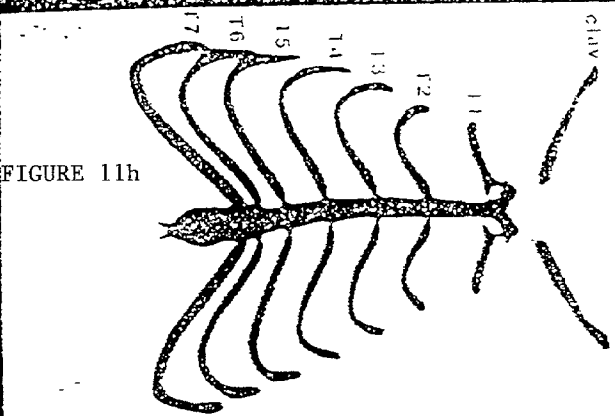


FIGURE 11h

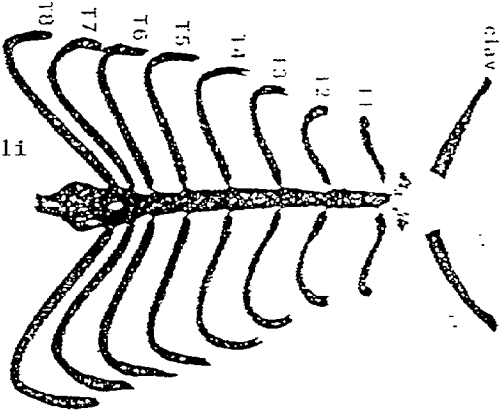


FIGURE 11i

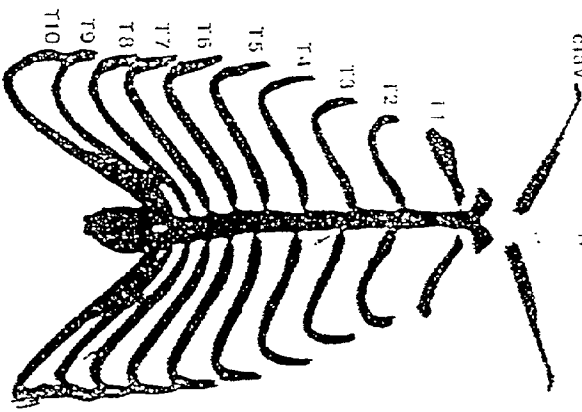


FIGURE 11j

FIGURE 12

Anterior transformations in wild-type, heterozygous and homozygous GDF-11 mice

	Wild-type		Heterozygous		Homozygous	
	Hybrid	129/SvJ	Hybrid	129/SvJ	Hybrid	129/SvJ
Presacral vertebrae ^a						
25	4	1	-	-	-	-
26	18	6	1	-	-	-
27	-	-	58	6	-	-
33	-	-	-	-	18	2
34	-	-	-	-	5	-
Vertebral pattern ^{a,b}						
C7 T13 L5	4	1	-	-	-	-
C7 T13 L6	18	6	-	-	-	-
C7 T13 L7 ^c	-	1	-	-	-	-
C7 T14 L5	-	-	1	-	-	-
C7 T14 L6	-	-	58	6	-	-
C7 T17 L9	-	-	-	-	1	1
C7 T18 L8	-	-	-	-	17	1
C7 T18 L9	-	-	-	-	5	-
C7 T18 L7 ^c	-	-	-	-	-	1
Anterior tuberculus on						
No vertebrae	-	1	-	-	-	-
C6	22	7	59	5	21	1
C6 and C7 ^d	-	-	-	1	2	2
Attached/unattached ribs ^b						
7/6	22	8	-	-	-	-
8/6	-	-	59	6	-	-
10/7	-	-	-	-	-	1
10/8 ^e	-	-	-	-	13	2
11/6	-	-	-	-	1	-
11/7	-	-	-	-	4	-
10 + 11/8 + 7 ^f	-	-	-	-	5	-
Longest spinous process on						
T2	22	5	41	-	2	-
T3	-	-	6	6	16	-
T2 + T3 equal	-	1	8	-	1	-
T3 + T4 equal	-	-	-	-	-	2
Transitional spinous process on						
T10	22	8	3	-	-	-
T11	-	-	56	6	-	-
T12	-	-	-	-	1	-
T13	-	-	-	-	22	3
Transitional articular process on ^g						
T10	22	8	1	-	-	-
T11	-	-	58	6	-	-
T13	-	-	-	-	23	3

^aVertebrae that were lumbar on one side and sacral on the other were scored as sacral. These vertebrae were seen in 2 wild-type, 3 heterozygous and 8 homozygous mutants in the hybrid background.

^bOne hybrid heterozygous, 9 hybrid homozygous and 2 129/SvJ homozygous mutants had rudimentary ribs on the most caudal thoracic segment.

^cThe number of lumbar vertebrae could not be counted due to extensive fusion of lumbar segments.

^dThese animals had a unilateral transformation of the anterior tuberculi. One 129/SvJ homozygous mutant retained one tuberculus on C6 but had bilateral tuberculi on C7.

^eOne 129/SvJ homozygous mutant had the first rib attached to the second rather than the sternum on one side only. Ten ribs were attached to the sternum on the other side.

^fRibs were asymmetrically attached.

^gOne wild-type 129/SvJ had one transitional articular process on T10 and one on T11 (scored as T10). One hybrid heterozygous mutant mice had one process on T11 and one on T12 (scored as T11).

**TRANSGENIC NON-HUMAN ANIMALS
EXPRESSING A GDF-11 DOMINANT NEGATIVE
POLYPEPTIDE, AND METHODS OF MAKING AND
USING SAME**

[0001] This application is a continuation-in-part application of U.S. application Ser. No. 09/019,901, filed Feb. 6, 1998 which is a continuation-in-part of U.S. application Ser. No. 08/795,671, filed Feb. 6, 1997 and U.S. application Ser. No. 08/706,958, filed Sep. 3, 1996, which is a continuation of U.S. application Ser. No. 08/272,763, filed Jul. 8, 1994 now abandoned.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The invention relates generally to growth factors and specifically to a new member of the transforming growth factor beta (TGF- β) superfamily, which is denoted, growth differentiation factor-11 (GDF-11) and methods of use for modulating muscle cell, bone, kidney and adipose tissue growth.

[0004] 2. Description of Related Art

[0005] The transforming growth factor β (TGF- β) superfamily encompasses a group of structurally-related proteins which affect a wide range of differentiation processes during embryonic development. The family includes, Mullerian inhibiting substance (MIS), which is required for normal male sex development (Behringer, et al., *Nature*, 345:167, 1990), Drosophila decapentaplegic (DPP) gene product, which is required for dorsal-ventral axis formation and morphogenesis of the imaginal disks (Padgett, et al., *Nature*, 325:81-84, 1987), the Xenopus Vg-1 gene product, which localizes to the vegetal pole of eggs (Weeks, et al., *Cell*, 51:861-867, 1987), the activins (Mason, et al., *Biochem. Biophys. Res. Commun.*, 135:957-964, 1986), which can induce the formation of mesoderm and anterior structures in Xenopus embryos (Thomsen, et al., *Cell*, 63:485, 1990), and the bone morphogenetic proteins (BMPs, osteogenin, OP-1) which can induce de novo cartilage and bone formation (Sampath, et al., *J. Biol. Chem.*, 265:13198, 1990). The TGF- β s can influence a variety of differentiation processes, including adipogenesis, myogenesis, chondrogenesis, hematopoiesis, and epithelial cell differentiation (for review, see Massague, *Cell* 49:437, 1987).

[0006] The proteins of the TGF- β family are initially synthesized as a large precursor protein which subsequently undergoes proteolytic cleavage at a cluster of basic residues approximately 110-140 amino acids from the C-terminus. The C-terminal regions, or mature regions, of the proteins are all structurally related and the different family members can be classified into distinct subgroups based on the extent of their homology. Although the homologies within particular subgroups range from 70% to 90% amino acid sequence identity, the homologies between subgroups are significantly lower, generally ranging from only 20% to 50%. In each case, the active species appears to be a disulfide-linked dimer of C-terminal fragments. Studies have shown that when the pro-region of a member of the TGF- β family is coexpressed with a mature region of another member of the TGF- β family, intracellular dimerization and secretion of biologically active homodimers occur (Gray, A. et al., *Science*, 247:1328, 1990). Additional studies by Hammonds, et

al., (*Molec. Endocrin.* 5:149, 1991) showed that the use of the BMP-2 pro-region combined with the BMP-4 mature region led to dramatically improved expression of mature BMP-4. For most of the family members that have been studied, the homodimeric species has been found to be biologically active, but for other family members, like the inhibins (Ling, et al., *Nature*, 321:779, 1986) and the TGF- β s (Cheifetz, et al., *Cell*, 48:409, 1987), heterodimers have also been detected, and these appear to have different biological properties than the respective homodimers.

[0007] In addition, it is desirable to produce livestock and game animals, such as cows, sheep, pigs, chicken and turkey, fish which are relatively high in musculature and protein, and low in fat content. Many drug and diet regimens exist which may help increase muscle and protein content and lower undesirably high fat and/or cholesterol levels, but such treatment is generally administered after the fact, and is begun only after significant damage has occurred to the vasculature. Accordingly, it would be desirable to produce animals which are genetically predisposed to having higher muscle content, without any ancillary increase in fat levels.

[0008] The food industry has put much effort into increasing the amount of muscle and protein in foodstuffs. This quest is relatively simple in the manufacture of synthetic foodstuffs, but has been met with limited success in the preparation of animal foodstuffs. Attempts have been made, for example, to lower cholesterol levels in beef and poultry products by including cholesterol-lowering drugs in animal feed (see e.g. Elkin and Rogler, *J. Agric. Food Chem.* 1990, 38, 1635-1641). However, there remains a need for more effective methods of increasing muscle and reducing fat and cholesterol levels in animal food products.

SUMMARY OF THE INVENTION

[0009] The present invention provides a cell growth and differentiation factor, GDF-11, a polynucleotide sequence which encodes the factor, and antibodies which are immunoreactive with the factor. This factor appears to relate to various cell proliferative disorders, especially those involving muscle, nerve, bone, kidney and adipose tissue.

[0010] In one embodiment, the invention provides a method for detecting a cell proliferative disorder of muscle, nerve, bone, kidney or fat origin and which is associated with GDF-11. In another embodiment, the invention provides a method for treating a cell proliferative disorder by suppressing or enhancing GDF-11 activity.

[0011] In another embodiment, the subject invention provides non-human transgenic animals which are useful as a source of food products with high muscle, bone and protein content, and reduced fat and cholesterol content. The animals have been altered chromosomally in their germ cells and somatic cells so that the production of GDF-11 is produced in reduced amounts, or is completely disrupted, resulting in animals with decreased levels of GDF-11 in their system and higher than normal levels of muscle tissue and bone tissue, such as ribs, preferably without increased fat and/or cholesterol levels. Accordingly, the present invention also includes food products provided by the animals. Such food products have increased nutritional value because of the increase in muscle tissue and bone tissue to which the muscle attaches. The transgenic non-human animals of the invention include bovine, porcine, ovine and avian animals, for example.

[0012] The subject invention also provides a method of producing animal food products having increased muscle content. The method includes modifying the genetic makeup of the germ cells of a pronuclear embryo of the animal, implanting the embryo into the oviduct of a pseudopregnant female thereby allowing the embryo to mature to full term progeny, testing the progeny for presence of the transgene to identify transgene-positive progeny, cross-breeding transgene-positive progeny to obtain further transgene-positive progeny and processing the progeny to obtain foodstuff. The modification of the germ cell comprises altering the genetic composition so as to disrupt or reduce the expression of the naturally occurring gene encoding for production of GDF-11 protein. In a particular embodiment, the transgene comprises antisense polynucleotide sequences to the GDF-11 protein. Alternatively, the transgene may comprise a non-functional sequence which replaces or intervenes in the native GDF-11 gene.

[0013] The subject invention also provides a method of producing animal food products having increased bone content. The method includes modifying the genetic makeup of the germ cells of a pronuclear embryo of the animal, implanting the embryo into the oviduct of a pseudopregnant female thereby allowing the embryo to mature to full term progeny, testing the progeny for presence of the transgene to identify transgene-positive progeny, cross-breeding transgene-positive progeny to obtain further transgene-positive progeny and processing the progeny to obtain foodstuff. The modification of the germ cell comprises altering the genetic composition so as to disrupt or reduce the expression of the naturally occurring gene encoding for production of GDF-11 protein. In a particular embodiment, the transgene comprises antisense polynucleotide sequences to the GDF-11 protein. Alternatively, the transgene may comprise a non-functional sequence which replaces or intervenes in the native GDF-11 gene.

[0014] The subject invention also provides a method of producing avian food products having improved muscle and/or bone content. The method includes modifying the genetic makeup of the germ cells of a pronuclear embryo of the avian animal, implanting the embryo into the oviduct of a pseudopregnant female into an embryo of a chicken, culturing the embryo under conditions whereby progeny are hatched, testing the progeny for presence of the genetic alteration to identify transgene-positive progeny, cross-breeding transgene-positive progeny and processing the progeny to obtain foodstuff.

[0015] The invention also provides a method for treating a muscle, bone, kidney or adipose tissue disorder in a subject. The method includes administering a therapeutically effective amount of a GDF-11 agent to the subject, thereby affecting growth of muscle, bone, kidney or adipose tissue. The GDF-11 agent may include an antibody, a GDF-11 antisense molecule or a dominant negative polypeptide, for example. In one aspect, a method for inhibiting the growth regulating actions of GDF-11 by contacting an anti-GDF-11 monoclonal antibody, a GDF-11 antisense molecule or a dominant negative polypeptide (or polynucleotide encoding a dominant negative polypeptide) with fetal or adult muscle cells or progenitor cells is included. These agents can be administered to a patient suffering from a disorder such as muscle wasting disease, neuromuscular disorder, muscle atrophy, obesity or other

adipocyte cell disorders, and aging, for example. In another aspect of the invention, the agent may be an agonist of GDF-11 activity.

[0016] The invention also provides a method for identifying a compound that affects GDF-11 activity or gene expression including incubating the compound with GDF-11 polypeptide, or with a recombinant cell expressing GDF-11 under conditions sufficient to allow the compounds to interact and determining the effect of the compound on GDF-11 activity or expression.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] FIG. 1 shows the nucleotide and predicted amino acid sequences of murine (FIG. 1a) and human (FIG. 1b) GDF-11. The putative proteolytic processing sites are shown by the shaded boxes. In the human sequence, the potential N-linked glycosylation signal is shown by the open box, and the consensus polyadenylation signal is underlined; the poly A tail is not shown.

[0018] FIG. 2 shows Northern blots of RNA prepared from adult (FIG. 2a) or fetal and neonatal (FIG. 2b) tissues probed with a murine GDF-11 probe.

[0019] FIG. 3 shows amino acid homologies among different members of the TGF- β superfamily. Numbers represent percent amino acid identities between each pair calculated from the first conserved cysteine to the C-terminus. Boxes represent homologies among highly-related members within particular subgroups.

[0020] FIG. 4a shows an alignment of the predicted amino acid sequences of human GDF-11 (top lines) with human GDF-8 (bottom lines). Vertical lines indicate identities. Dots represent gaps introduced in order to maximize the alignment. Numbers represent amino acid positions relative to the N-terminus. The putative proteolytic processing sites are shown by the open box. The conserved cysteine residues on the C-terminal region are shown by the shaded boxes.

[0021] FIG. 4b shows the predicted amino acid sequences of murine and human GDF-11 aligned with murine (McPherron et al., 1997) and human (McPherron and Lee, 1997) myostatin (MSTN). Shaded boxes represent amino acid homology with the murine and human GDF-11 sequences. Amino acids are numbered relative to the human GDF-11 sequence. The predicted proteolytic processing sites are located at amino acids 295-298.

[0022] FIG. 5 shows the expression of GDF-11 in mammalian cells. Conditioned medium prepared from Chinese hamster ovary cells transfected with a hybrid GDF-8/GDF-11 gene (see text) cloned into the MSXND expression vector in either the antisense (lane 1) or sense (lane 2) orientation was dialyzed, lyophilized, and subjected to Western analysis using antibodies directed against the C-terminal portion of GDF-8 protein. Arrows at right indicate the putative unprocessed (pro-GDF-8/GDF-11) or processed GDF-11 proteins. Numbers at left indicate mobilities of molecular weight standards.

[0023] FIG. 6 shows the chromosomal mapping of human GDF-11. DNA samples prepared from human/rodent somatic cell lines were subjected to PCR, electrophoresed on agarose gels, blotted, and probed. The human chromo-

some contained in each of the hybrid cell lines is identified at the top of each of the first 24 lanes (1-22, X, and Y). In the lanes designated CHO, M, and H, the starting DNA template was total genomic DNA from hamster, mouse, and human sources, respectively. In the lane marked B1, no template DNA was used. Numbers at left indicate the mobilities of DNA standards.

[0024] FIG. 7 shows the FISH localization of GDF-11. Metaphase chromosomes derived from peripheral blood lymphocytes were hybridized with digoxigenin-labeled human GDF-11 probe (a) or a mixture of human GDF-11 genomic and chromosome 12-specific centromere probes (b) and analyzed as described in the text. A schematic showing the location of GDF-11 at position 12q13 is shown in panel (c).

[0025] FIG. 8 shows a genomic Southern analysis of DNA isolated from different species.

[0026] FIG. 9 shows the construction of GDF-11 null mice by homologous targeting. a) is a map of the GDF-11 locus (top line) and targeting construct (second line). The black and stippled boxes represent coding sequences for the pro- and C-terminal regions, respectively. The targeting construct contains a total of 11 kb of homology with the GDF-11 gene. A probe derived from the region upstream of the 3' homology fragment and downstream of the first EcoRI site shown hybridizes to a 6.5 kb EcoRI fragment in the GDF-11 gene and a 4.8 kb fragment in a homologously targeted gene. Abbreviations: X, XbaI; E, EcoRI. b) Geneomic Southern of DNA prepared from F1 heterozygous mutant mice (lanes 1 and 2) and offspring derived from a mating of these mice (lanes 3-12).

[0027] FIG. 10 shows kidney abnormalities in GDF-11 knockout mice. Kidneys of newborn animals were examined and classified according to the number of normal sized or small kidneys as shown at the top. Numbers in the table indicate number of animals falling into each classification according to genotype.

[0028] FIG. 11 shows homeotic transformations in GDF-11 mutant mice. a) Newborn pups with missing (first and second from left) and normal looking tails. b-j) Skeleton preparations for newborn wild-type (b, e, h), heterozygous (c, f, i) and homozygous (d, g, j) mutant mice. Whole skeleton preparations (b-d), vertebral columns (e-g), vertebral ribs (h-j) showing transformations and defects in homozygous and heterozygous mutant mice. Numbers indicate thoracic segments.

[0029] FIG. 12 is a table summarizing the anterior transformations in wild-type, heterozygous and homozygous GDF-11 mice.

DETAILED DESCRIPTION OF THE INVENTION

[0030] The present invention provides a growth and differentiation factor, GDF-11, and a polynucleotide sequence encoding GDF-11. GDF-11 is expressed at highest levels in muscle, brain, uterus, spleen, and thymus and at lower levels in other tissues.

[0031] The TGF- β superfamily consists of multifunctional polypeptides that control proliferation, differentiation, and other functions in many cell types. Many of the peptides

have regulatory, both positive and negative, effects on other peptide growth factors. The structural homology between the GDF-11 protein of this invention and the members of the TGF- β family, indicates that GDF-11 is a new member of the family of growth and differentiation factors. Based on the known activities of many of the other members, it can be expected that GDF-11 will also possess biological activities that will make it useful as a diagnostic and therapeutic reagent.

[0032] Certain members of this superfamily have expression patterns or possess activities that relate to the function of the nervous system. For example, one family member, namely GDNF, has been shown to be a potent neurotrophic factor that can promote the survival of dopaminergic neurons (Lin, et al., *Science*, 260:1130). Another family member, namely dorsalin-1, is capable of promoting the differentiation of neural crest cells (Basler, et al., *Cell*, 73:687, 1993). The inhibins and activins have been shown to be expressed in the brain (Meunier, et al., *Proc. Nat'l. Acad. Sci., USA*, 85:247, 1988; Sawchenko, et al., *Nature*, 334:615, 1988), and activin has been shown to be capable of functioning as a nerve cell survival molecule (Schubert, et al., *Nature*, 344:868, 1990). Another family member, namely GDF-1, is nervous system-specific in its expression pattern (Lee, *Proc. Nat'l. Acad. Sci., USA*, 88:4250, 1991), and certain other family members, such as Vgr-1 (Lyons, et al., *Proc. Nat'l. Acad. Sci., USA*, 86:4554, 1989; Jones, et al., *Development*, 111:581, 1991), OP-1 (Ozkaynak, et al., *J. Biol. Chem.*, 267:25220, 1992), and BMP4 (Jones, et al., *Development*, 111:531, 1991), are also known to be expressed in the nervous system. The expression of GDF-11 in brain and muscle suggests that GDF-11 may also possess activities that relate to the function of the nervous system. In particular, it is known, for example, that skeletal muscle produces a factor or factors that promote the survival of motor neurons (Brown, *Trends Neurosci.*, 7:10, 1984). The known neurotrophic activities of other members of this family and the expression of GDF-11 in muscle suggest that one activity of GDF-11 may be as a trophic factor for motor neurons; indeed, GDF-11 is highly related to GDF-8, which is virtually muscle-specific in its expression pattern. Alternatively, GDF-11 may have neurotrophic activities for other neuronal populations. Hence, GDF-11 may have in vitro and in vivo applications in the treatment of neurodegenerative diseases, such as amyotrophic lateral sclerosis, or in maintaining cells or tissues in culture prior to transplantation.

[0033] GDF-11 may also have applications in treating disease processes involving the musculoskeletal system, such as in musculodegenerative diseases, osteoporosis or in tissue repair due to trauma. In this regard, many other members of the TGF- β family are also important mediators of tissue repair. TGF- β has been shown to have marked effects on the formation of collagen and to cause a striking angiogenic response in the newborn mouse (Roberts, et al., *Proc. Natl. Acad. Sci., USA* 83:4167, 1986). TGF- β has also been shown to inhibit the differentiation of myoblasts in culture (Massague, et al., *Proc. Natl. Acad. Sci., USA* 83:8206, 1986). Moreover, because myoblast cells may be used as a vehicle for delivering genes to muscle for gene therapy, the properties of GDF-11 could be exploited for maintaining cells prior to transplantation or for enhancing the efficiency of the fusion process. GDF-11 may also have applications in treating disease processes involving the kidney or in kidney repair due to trauma.

[0034] GDF-11 may also have applications in the treatment of immunologic disorders. In particular, TGF- β has been shown to have a wide range of immunoregulatory activities, including potent suppressive effects on B and T cell proliferation and function (for review, see Palladino, et al., *Ann. N.Y. Acad. Sci.*, 593:181, 1990). The expression of GDF-11 in spleen and thymus suggests that GDF-11 may possess similar activities and therefore, may be used as an anti-inflammatory agent or as a treatment for disorders related to abnormal proliferation or function of lymphocytes.

[0035] The animals contemplated for use in the practice of the subject invention are those animals generally regarded as useful for the processing of food stuffs, i.e. avian such as meat bred and egg laying chicken and turkey, ovine such as lamb, bovine such as beef cattle and milk cows, piscine and porcine. For purposes of the subject invention, these animals are referred to as "transgenic" when such animal has had a heterologous DNA sequence, or one or more additional DNA sequences normally endogenous to the animal (collectively referred to herein as "transgenes") chromosomally integrated into the germ cells of the animal. The transgenic animal (including its progeny) will also have the transgene fortuitously integrated into the chromosomes of somatic cells.

[0036] The TGF- β superfamily consists of multifunctional polypeptides that control proliferation, differentiation, and other functions in many cell types. Many of the peptides have regulatory, both positive and negative, effects on other peptide growth factors. The structural homology between the GDF-11 protein of this invention and the members of the TGF- β family, indicates that GDF-11 is a new member of the family of growth and differentiation factors. Based on the known activities of many of the other members, it can be expected that GDF-11 will also possess biological activities that will make it useful as a diagnostic and therapeutic reagent.

[0037] In particular, certain members of this superfamily have expression patterns or possess activities that relate to the function of the nervous system. For example, the inhibins and activins have been shown to be expressed in the brain (Meunier, et al., *Proc. Natl. Acad. Sci., USA*, 85:247, 1988; Sawchenko, et al., *Nature*, 334:615, 1988), and activin has been shown to be capable of functioning as a nerve cell survival molecule (Schubert, et al., *Nature*, 344:868, 1990). Another family member, namely, GDF-1, is nervous system-specific in its expression pattern (Lee, S. J., *Proc. Natl. Acad. Sci., USA*, 88:4250, 1991), and certain other family members, such as Vgr-1 (Lyons, et al., *Proc. Natl. Acad. Sci., USA*, 86:4554, 1989; Jones, et al., *Development*, 111:531, 1991), OP-1 (Ozkaynak, et al., *J. Biol. Chem.*, 267:25220, 1992), and BMP-4 (Jones, et al., *Development*, 111:531, 1991), are also known to be expressed in the nervous system. Because it is known that skeletal muscle produces a factor or factors that promote the survival of motor neurons (Brown, *Trends Neurosci.*, 7:10, 1984), the expression of GDF-11 in muscle suggests that one activity of GDF-11 may be as a trophic factor for neurons. In this regard, GDF-11 may have applications in the treatment of neurodegenerative diseases, such as amyotrophic lateral sclerosis or muscular dystrophy, or in maintaining cells or tissues in culture prior to transplantation.

[0038] The expression of GDF-11 in adipose tissue also raises the possibility of applications for GDF-11 in the treatment of obesity or of disorders related to abnormal proliferation of adipocytes. In this regard, TGF- β has been shown to be a potent inhibitor of adipocyte differentiation in vitro (Ignatz and Massague, *Proc. Natl. Acad. Sci., USA* 82:8530, 1985).

[0039] Polypeptides, Polynucleotides, Vectors and Host Cells

[0040] The invention provides substantially pure GDF-11 polypeptide and isolated polynucleotides that encode GDF-11. The term "substantially pure" as used herein refers to GDF-11 which is substantially free of other proteins, lipids, carbohydrates or other materials with which it is naturally associated. One skilled in the art can purify GDF-11 using standard techniques for protein purification. The substantially pure polypeptide will yield a single major band on a non-reducing polyacrylamide gel. The purity of the GDF-11 polypeptide can also be determined by amino-terminal amino acid sequence analysis. GDF-11 polypeptide includes functional fragments of the polypeptide, as long as the activity of GDF-11 remains. Smaller peptides containing the biological activity of GDF-11 are included in the invention.

[0041] The invention provides polynucleotides encoding the GDF-11 protein. These polynucleotides include DNA, cDNA and RNA sequences which encode GDF-11. It is understood that all polynucleotides encoding all or a portion of GDF-11 are also included herein, as long as they encode a polypeptide with GDF-11 activity. Such polynucleotides include naturally occurring, synthetic, and intentionally manipulated polynucleotides. For example, GDF-11 polynucleotide may be subjected to site-directed mutagenesis. The polynucleotide sequence for GDF11 also includes antisense sequences. The polynucleotides of the invention include sequences that are degenerate as a result of the genetic code. There are 20 natural amino acids, most of which are specified by more than one codon. Therefore, all degenerate nucleotide sequences are included in the invention as long as the amino acid sequence of GDF-11 polypeptide encoded by the nucleotide sequence is functionally unchanged.

[0042] Specifically disclosed herein is a DNA sequence containing the human GDF-11 gene. The sequence contains an open reading frame encoding a polypeptide 407 amino acids in length. The sequence contains a putative RXXXR proteolytic cleavage site at amino acids 295-298. Cleavage of the precursor at this site would generate an active C-terminal fragment 109 amino acids in length with a predicted molecular weight of approximately 12,500 kD. Also disclosed herein is a partial murine genomic sequence. Preferably, the human GDF-11 nucleotide sequence is SEQ ID NO:1 and the mouse nucleotide sequence is SEQ ID NO:3.

[0043] The polynucleotide encoding GDF-11 includes SEQ ID NO:1 and 3, as well as nucleic acid sequences complementary to SEQ ID NO's:1 and 3. A complementary sequence may include an antisense nucleotide. When the sequence is RNA, the deoxynucleotides A, G, C, and T of SEQ ID NO:1 and 3 are replaced by ribonucleotides A, G, C, and U, respectively. Also included in the invention are fragments of the above-described nucleic acid sequences that are at least 15 bases in length, which is sufficient to permit the fragment to selectively hybridize to DNA that

encodes the protein of SEQ ID NO: 2 or 4 under physiological conditions (e.g., under stringent conditions).

[0044] In nucleic acid hybridization reactions, the conditions used to achieve a particular level of stringency will vary, depending on the nature of the nucleic acids being hybridized. For example, the length, degree of complementarity, nucleotide sequence composition (e.g., GC v. AT content), and nucleic acid type (e.g., RNA v. DNA) of the hybridizing regions of the nucleic acids can be considered in selecting hybridization conditions. An additional consideration is whether one of the nucleic acids immobilized, for example, on a filter.

[0045] An example of progressively higher stringency conditions is as follows: 2×SSC/0.1% SDS at about room temperature (hybridization conditions); 0.2×SSC/0.1% SDS at about room temperature (low stringency conditions); 0.2×SSC/0.1% SDS at about 42° C. (moderate stringency conditions); and 0.1×SSC at about 68° C. (high stringency conditions). Washing can be carried out using only one of these conditions, e.g., high stringency conditions, or each of the conditions can be used, e.g., for 10-15 minutes each, in the order listed above, repeating any or all of the steps listed. However, as mentioned above, optimal conditions will vary, depending on the particular hybridization reaction involved, and can be determined empirically.

[0046] The C-terminal region of GDF-11 following the putative proteolytic processing site shows significant homology to the known members of the TGF- β superfamily. The GDF-11 sequence contains most of the residues that are highly conserved in other family members (see **FIG. 1**). Like the TGF- β s and inhibin β s, GDF-11 contains an extra pair of cysteine residues in addition to the 7 cysteines found in virtually all other family members. Among the known family members, GDF-11 is most homologous to GDF-8 (92% sequence identity) (see **FIG. 3**).

[0047] Minor modifications of the recombinant GDF-11 primary amino acid sequence may result in proteins which have substantially equivalent activity as compared to the GDF-11 polypeptide described herein. Such modifications may be deliberate, as by site-directed mutagenesis, or may be spontaneous. All of the polypeptides produced by these modifications are included herein as long as the biological activity of GDF-11 still exists. Further, deletion of one or more amino acids can also result in a modification of the structure of the resultant molecule without significantly altering its biological activity. This can lead to the development of a smaller active molecule which would have broader utility. For example, one can remove amino or carboxy terminal amino acids which are not required for GDF-11 biological activity.

[0048] The nucleotide sequence encoding the GDF-11 polypeptide of the invention includes the disclosed sequence and conservative variations thereof. The term "conservative variation" as used herein denotes the replacement of an amino acid residue by another, biologically similar residue. Examples of conservative variations include the substitution of one hydrophobic residue such as isoleucine, valine, leucine or methionine for another, or the substitution of one polar residue for another, such as the substitution of arginine for lysine, glutamic for aspartic acid, or glutamine for asparagine, and the like. The term "conservative variation" also includes the use of a substituted amino acid in place of

an unsubstituted parent amino acid provided that antibodies raised to the substituted polypeptide also immunoreact with the unsubstituted polypeptide.

[0049] DNA sequences of the invention can be obtained by several methods. For example, the DNA can be isolated using hybridization techniques which are well known in the art. These include, but are not limited to: 1) hybridization of genomic or cDNA libraries with probes to detect homologous nucleotide sequences, 2) polymerase chain reaction (PCR) on genomic DNA or cDNA using primers capable of annealing to the DNA sequence of interest, and 3) antibody screening of expression libraries to detect cloned DNA fragments with shared structural features.

[0050] Preferably the GDF-11 polynucleotide of the invention is derived from a mammalian organism, and most preferably from mouse, rat, cow, pig, or human. GDF-11 polynucleotides from chicken, fish and other species are also included herein. Screening procedures which rely on nucleic acid hybridization make it possible to isolate any gene sequence from any organism, provided the appropriate probe is available. Oligonucleotide probes, which correspond to a part of the sequence encoding the protein in question, can be synthesized chemically. This requires that short, oligopeptide stretches of amino acid sequence must be known. The DNA sequence encoding the protein can be deduced from the genetic code, however, the degeneracy of the code must be taken into account. It is possible to perform a mixed addition reaction when the sequence is degenerate. This includes a heterogeneous mixture of denatured double-stranded DNA. For such screening, hybridization is preferably performed on either single-stranded DNA or denatured double-stranded DNA. Hybridization is particularly useful in the detection of cDNA clones derived from sources where an extremely low amount of mRNA sequences relating to the polypeptide of interest are present. In other words, by using stringent hybridization conditions directed to avoid non-specific binding, it is possible, for example, to allow the autoradiographic visualization of a specific cDNA clone by the hybridization of the target DNA to that single probe in the mixture which is its complete complement (Wallace, et al., *Nucl. Acid Res.* 9:879, 1981).

[0051] The development of specific DNA sequences encoding GDF-11 can also be obtained by: 1) isolation of double-stranded DNA sequences from the genomic DNA; 2) chemical manufacture of a DNA sequence to provide the necessary codons for the polypeptide of interest; and 3) in vitro synthesis of a doublestranded DNA sequence by reverse transcription of mRNA isolated from a eukaryotic donor cell. In the latter case, a double-stranded DNA complement of mRNA is eventually formed which is generally referred to as cDNA.

[0052] Of the three above-noted methods for developing specific DNA sequences for use in recombinant procedures, the isolation of genomic DNA isolates is the least common. This is especially true when it is desirable to obtain the microbial expression of mammalian polypeptides due to the presence of introns.

[0053] The synthesis of DNA sequences is frequently the method of choice when the entire sequence of amino acid residues of the desired polypeptide product is known. When the entire sequence of amino acid residues of the desired polypeptide is not known, the direct synthesis of DNA

sequences is not possible and the method of choice is the synthesis of cDNA sequences. Among the standard procedures for isolating cDNA sequences of interest is the formation of plasmid- or phage-carrying cDNA libraries which are derived from reverse transcription of mRNA which is abundant in donor cells that have a high level of genetic expression. When used in combination with polymerase chain reaction technology, even rare expression products can be cloned. In those cases where significant portions of the amino acid sequence of the polypeptide are known, the production of labeled single or double-stranded DNA or RNA probe sequences duplicating a sequence putatively present in the target cDNA may be employed in DNA/DNA hybridization procedures which are carried out on cloned copies of the cDNA which have been denatured into a single-stranded form (Jay, et al., *Nucl. Acid Res.*, 11:2325, 1983).

[0054] A cDNA expression library, such as lambda gt11, can be screened indirectly for GDF-11 peptides having at least one epitope, using antibodies specific for GDF-11. Such antibodies can be either polyclonally or monoclonally derived and used to detect expression product indicative of the presence of GDF-11 cDNA.

[0055] DNA sequences encoding GDF-11 can be expressed in vitro by DNA transfer into a suitable host cell. "Host cells" are cells in which a vector can be propagated and its DNA expressed. The term also includes any progeny of the subject host cell. It is understood that all progeny may not be identical to the parental cell since there may be mutations that occur during replication. However, such progeny are included when the term "host cell" is used. Methods of stable transfer, meaning that the foreign DNA is continuously maintained in the host, are known in the art.

[0056] In the present invention, the GDF-11 polynucleotide sequences may be inserted into a recombinant expression vector. The term "recombinant expression vector" refers to a plasmid, virus or other vehicle known in the art that has been manipulated by insertion or incorporation of the GDF-11 genetic sequences. Such expression vectors contain a promoter sequence which facilitates the efficient transcription of the inserted genetic sequence of the host. The expression vector typically contains an origin of replication, a promoter, as well as specific genes which allow phenotypic selection of the transformed cells. Vectors suitable for use in the present invention include, but are not limited to the T7-based expression vector for expression in bacteria (Rosenberg, et al., *Gene*, 56:125, 1917), the pMSXND expression vector for expression in mammalian cells (Lee and Nathans, *J. Biol. Chem.*, 263:3521, 1988) and baculovirus-derived vectors for expression in insect cells. The DNA segment can be present in the vector operably linked to regulatory elements, for example, a promoter (e.g., T7, metallothionein 1, or polyhedrin promoters).

[0057] Polynucleotide sequences encoding GDF-11 can be expressed in either prokaryotes or eukaryotes. Hosts can include microbial, yeast, insect and mammalian organisms. Methods of expressing DNA sequences having eukaryotic or viral sequences in prokaryotes are well known in the art. Biologically functional viral and plasmid DNA vectors capable of expression and replication in a host are known in the art. Such vectors are used to incorporate DNA sequences of the invention. Preferably, the mature C-terminal region of

GDF-11 is expressed from a cDNA clone containing the entire coding sequence of GDF-11. Alternatively, the C-terminal portion of GDF-11 can be expressed as a fusion protein with the pro-region of another member of the TGF- β family or co-expressed with another pro-region (see for example, Hammonds, et al., *Molec. Endocrin.*, 5:149, 1991; Gray, A., and Mason, A., *Science*, 247:1328, 1990).

[0058] Transformation of a host cell with recombinant DNA may be carried out by conventional techniques as are well known to those skilled in the art. Where the host is prokaryotic, such as *E. coli*, competent cells which are capable of DNA uptake can be prepared from cells harvested after exponential growth phase and subsequently treated by the CaCl_2 method using procedures well known in the art. Alternatively, MgCl_2 or RbCl can be used. Transformation can also be performed after forming a protoplast of the host cell if desired.

[0059] When the host is a eukaryote, such methods of transfection of DNA as calcium phosphate co-precipitates, conventional mechanical procedures such as microinjection, electroporation, insertion of a plasmid encased in liposomes, or virus vectors may be used. Eukaryotic cells can also be cotransformed with DNA sequences encoding the GDF-11 of the invention, and a second foreign DNA molecule encoding a selectable phenotype, such as the herpes simplex thymidine kinase gene. Another method is to use a eukaryotic viral vector, such as simian virus 40 (SV40) or bovine papilloma virus, to transiently infect or transform eukaryotic cells and express the protein. (see for example, *Eukaryotic Viral Vectors*, Cold Spring Harbor Laboratory, Gluzman ed., 1982).

[0060] Isolation and purification of microbial expressed polypeptide, or fragments thereof, provided by the invention, may be carried out by conventional means including preparative chromatography and immunological separations involving monoclonal or polyclonal antibodies.

[0061] GDF-11 Antibodies and Methods of Use

[0062] The invention includes antibodies immunoreactive with GDF-11 polypeptide or functional fragments thereof. Antibody which consists essentially of pooled monoclonal antibodies with different epitopic specificities, as well as distinct monoclonal antibody preparations are provided. Monoclonal antibodies are made from antigen containing fragments of the protein by methods well known to those skilled in the art (Kohler, et al., *Nature*, 256:495, 1975). The term antibody as used in this invention is meant to include intact molecules as well as fragments thereof, such as Fab and F(ab')_2 , Fv and SCA fragments which are capable of binding an epitopic determinant on GDF-11.

[0063] (1) An Fab fragment consists of a monovalent antigen-binding fragment of an antibody molecule, and can be produced by digestion of a whole antibody molecule with the enzyme papain, to yield a fragment consisting of an intact light chain and a portion of a heavy chain.

[0064] (2) An Fab' fragment of an antibody molecule can be obtained by treating a whole antibody molecule with pepsin, followed by reduction, to yield a molecule consisting of an intact light chain and a portion of a heavy chain. Two Fab' fragments are obtained per antibody molecule treated in this manner.

[0065] (3) An (Fab')₂ fragment of an antibody can be obtained by treating a whole antibody molecule with the enzyme pepsin, without subsequent reduction. A (Fab')₂ fragment is a dimer of two Fab' fragments, held together by two disulfide bonds.

[0066] (4) An Fv fragment is defined as a genetically engineered fragment containing the variable region of a light chain and the variable region of a heavy chain expressed as two chains.

[0067] (5) A single chain antibody ("SCA") is a genetically engineered single chain molecule containing the variable region of a light chain and the variable region of a heavy chain, linked by a suitable, flexible polypeptide linker.

[0068] As used in this invention, the term "epitope" refers to an antigenic determinant on an antigen, such as a GDF-11 polypeptide, to which the paratope of an antibody, such as an GDF-11-specific antibody, binds. Antigenic determinants usually consist of chemically active surface groupings of molecules, such as amino acids or sugar side chains, and can have specific three-dimensional structural characteristics, as well as specific charge characteristics.

[0069] As is mentioned above, antigens that can be used in producing GDF-11-specific antibodies include GDF-11 polypeptides or GDF-11 polypeptide fragments. The polypeptide or peptide used to immunize an animal can be obtained by standard recombinant, chemical synthetic, or purification methods. As is well known in the art, in order to increase immunogenicity, an antigen can be conjugated to a carrier protein. Commonly used carriers include keyhole limpet hemocyanin (KLH), thyroglobulin, bovine serum albumin (BSA), and tetanus toxoid. The coupled peptide is then used to immunize the animal (e.g., a mouse, a rat, or a rabbit). In addition to such carriers, well known adjuvants can be administered with the antigen to facilitate induction of a strong immune response.

[0070] The term "cell-proliferative disorder" denotes malignant as well as non-malignant cell populations which often appear to differ from the surrounding tissue both morphologically and genotypically. Malignant cells (i.e. cancer) develop as a result of a multistep process. The GDF-11 polynucleotide that is an antisense molecule or that encodes a dominant negative GDF-11 is useful in treating malignancies of the various organ systems, particularly, for example, cells in muscle, bone, kidney or adipose tissue. Essentially, any disorder which is etiologically linked to altered expression of GDF-11 could be considered susceptible to treatment with a GDF-11 agent (e.g., a suppressing or enhancing agent). One such disorder is a malignant cell proliferative disorder, for example.

[0071] The invention provides a method for detecting a cell proliferative disorder of muscle, bone, kidney, uterine or neural tissue, for example, which comprises contacting an anti-GDF-11 antibody with a cell suspected of having a GDF-11 associated disorder and detecting binding to the antibody. The antibody reactive with GDF-11 is labeled with a compound which allows detection of binding to GDF-11. For purposes of the invention, an antibody specific for GDF-11 polypeptide may be used to detect the level of GDF-11 in biological fluids and tissues. Any specimen containing a detectable amount of antigen can be used. A preferred sample of this invention is muscle, bone, kidney,

uterus, spleen, thymus, or neural tissue. The level of GDF-11 in the suspect cell can be compared with the level in a normal cell to determine whether the subject has a GDF-11-associated cell proliferative disorder. Such methods of detection are also useful using nucleic acid hybridization to detect the level of GDF-11 mRNA in a sample or to detect an altered GDF-11 gene. Preferably the subject is human.

[0072] The antibodies of the invention can be used in any subject in which it is desirable to administer in vitro or in vivo immunodiagnosis or immunotherapy. The antibodies of the invention are suited for use, for example, in immunoassays in which they can be utilized in liquid phase or bound to a solid phase carrier. In addition, the antibodies in these immunoassays can be detectably labeled in various ways. Examples of types of immunoassays which can utilize antibodies of the invention are competitive and non-competitive immunoassays in either a direct or indirect format. Examples of such immunoassays are the radioimmunoassay (RIA) and the sandwich (immunometric) assay. Detection of the antigens using the antibodies of the invention can be done utilizing immunoassays which are run in either the forward, reverse, or simultaneous modes, including immunohistochemical assays on physiological samples. Those of skill in the art will know, or can readily discern, other immunoassay formats without undue experimentation.

[0073] The antibodies of the invention can be bound to many different carriers and used to detect the presence of an antigen comprising the polypeptide of the invention. Examples of well-known carriers include glass, polystyrene, polypropylene, polyethylene, dextran, nylon, amylases, natural and modified celluloses, polyacrylamides, agaroses and magnetite. The nature of the carrier can be either soluble or insoluble for purposes of the invention. Those skilled in the art will know of other suitable carriers for binding antibodies, or will be able to ascertain such, using routine experimentation.

[0074] There are many different labels and methods of labeling known to those of ordinary skill in the art. Examples of the types of labels which can be used in the present invention include enzymes, radioisotopes, fluorescent compounds, colloidal metals, chemiluminescent compounds, phosphorescent compounds, and bioluminescent compounds. Those of ordinary skill in the art will know of other suitable labels for binding to the antibody, or will be able to ascertain such, using routine experimentation.

[0075] Another technique which may also result in greater sensitivity consists of coupling the antibodies to low molecular weight haptens. These haptens can then be specifically detected by means of a second reaction. For example, it is common to use such haptens as biotin, which reacts with avidin, or dinitrophenyl, puridoxal, and fluorescein, which can react with specific antihapten antibodies.

[0076] In using the monoclonal antibodies of the invention for the in vivo detection of antigen, the detectably labeled antibody is given a dose which is diagnostically effective. The term "diagnostically effective" means that the amount of detectably labeled monoclonal antibody is administered in sufficient quantity to enable detection of the site having the antigen comprising a polypeptide of the invention for which the monoclonal antibodies are specific.

[0077] The concentration of detectably labeled monoclonal antibody which is administered should be sufficient

such that the binding to those cells having the polypeptide is detectable compared to the background. Further, it is desirable that the detectably labeled monoclonal antibody be rapidly cleared from the circulatory system in order to give the best target-to-background signal ratio.

[0078] As a rule, the dosage of detectably labeled monoclonal antibody for in vivo diagnosis will vary depending on such factors as age, sex, and extent of disease of the individual. Such dosages may vary, for example, depending on whether multiple injections are given, antigenic burden, and other factors known to those of skill in the art.

[0079] For in vivo diagnostic imaging, the type of detection instrument available is a major factor in selecting a given radioisotope. The radioisotope chosen must have a type of decay which is detectable for a given type of instrument. Still another important factor in selecting a radioisotope for in vivo diagnosis is that deleterious radiation with respect to the host is minimized. Ideally, a radioisotope used for in vivo imaging will lack a particle emission, but produce a large number of photons in the 140-250 keV range, which may readily be detected by conventional gamma cameras.

[0080] For in vivo diagnosis radioisotopes may be bound to immunoglobulin either directly or indirectly by using an intermediate functional group. Intermediate functional groups which often are used to bind radioisotopes which exist as metallic ions to immunoglobulins are the bifunctional chelating agents such as diethylenetriaminepentaacetic acid (DTPA) and ethylenediaminetetraacetic acid (EDTA) and similar molecules. Typical examples of metallic ions which can be bound to the monoclonal antibodies of the invention are ^{111}In , ^{97}Ru , ^{67}Ga , ^{68}Ga , ^{72}As , ^{89}Zr and ^{201}Tl .

[0081] The monoclonal antibodies of the invention can also be labeled with a paramagnetic isotope for purposes of in vivo diagnosis, as in magnetic resonance imaging (MRI) or electron spin resonance (ESR). In general, any conventional method for visualizing diagnostic imaging can be utilized. Usually gamma and positron emitting radioisotopes are used for camera imaging and paramagnetic isotopes for MRI. Elements which are particularly useful in such techniques include ^{157}Gd , ^{55}Mn , ^{162}Dy , ^{52}Cr , and ^{56}Fe .

[0082] The monoclonal antibodies of the invention can be used in vitro and in vivo to monitor the course of amelioration of a GDF-11-associated disease in a subject. Thus, for example, by measuring the increase or decrease in the number of cells expressing antigen comprising a polypeptide of the invention or changes in the concentration of such antigen present in various body fluids, it would be possible to determine whether a particular therapeutic regimen aimed at ameliorating the GDF-11-associated disease is effective. The term "ameliorate" denotes a lessening of the detrimental effect of the GDF-11-associated disease in the subject receiving therapy.

[0083] Additional Methods of Treatment and Diagnosis

[0084] The present invention identifies a nucleotide sequence that can be expressed in an altered manner as compared to expression in a normal cell, therefore it is possible to design appropriate therapeutic or diagnostic techniques directed to this sequence. Treatment includes administration of a reagent which modulates activity. The term "modulate" envisions the suppression or expression of

GDF-11 when it is over-expressed, or augmentation of GDF-11 expression when it is underexpressed. When a muscle-associated disorder is associated with GDF-11 over-expression, such suppressive reagents as antisense GDF-11 polynucleotide sequence, dominant negative sequences or GDF-11 binding antibody can be introduced into a cell. In addition, an anti-idiotypic antibody which binds to a monoclonal antibody which binds GDF-11 of the invention, or an epitope thereof, may also be used in the therapeutic method of the invention. Alternatively, when a cell proliferative disorder is associated with underexpression or expression of a mutant GDF-11 polypeptide, a sense polynucleotide sequence (the DNA coding strand) or GDF-11 polypeptide can be introduced into the cell. Such muscle-associated disorders include cancer, muscular dystrophy, spinal cord injury, traumatic injury, congestive obstructive pulmonary disease (COPD), AIDS or cachexia. Neurodegenerative, musculoskeletal, and kidney disorders are also envisioned as treated by the method of the invention. In addition, the method of the invention can be used in the treatment of obesity or of disorders related to abnormal proliferation of adipocytes. One of skill in the art can determine whether or not a particular therapeutic course of treatment is successful by several methods described herein (e.g., muscle fiber analysis or biopsy; determination of fat content). The present examples demonstrate that the methods of the invention are useful for decreasing fat content, and therefore would be useful in the treatment of obesity and related disorders (e.g., diabetes).

[0085] Thus, where a cell-proliferative disorder is associated with the expression of GDF-11, nucleic acid sequences that interfere with GDF-11 expression at the translational level can be used. This approach utilizes, for example, antisense nucleic acid and ribozymes to block translation of a specific GDF-11 mRNA, either by masking that mRNA with an antisense nucleic acid or by cleaving it with a ribozyme. Such disorders include neurodegenerative diseases, for example. In addition, dominant-negative GDF-11 mutants would be useful to actively interfere with function of "normal" GDF-11.

[0086] Antisense nucleic acids are DNA or RNA molecules that are complementary to at least a portion of a specific mRNA molecule (Weintraub, *Scientific American*, 262:40, 1990). In the cell, the antisense nucleic acids hybridize to the corresponding mRNA, forming a double-stranded molecule. The antisense nucleic acids interfere with the translation of the mRNA, since the cell will not translate a mRNA that is double-stranded.

[0087] Antisense oligomers of about 15 nucleotides are preferred, since they are easily synthesized and are less likely to cause problems than larger molecules when introduced into the target GDF-11-producing cell. The use of antisense methods to inhibit the in vitro translation of genes is well known in the art (Marcus-Sakura, *Anal. Biochem.*, 172:289, 1988).

[0088] Ribozymes are RNA molecules possessing the ability to specifically cleave other single-stranded RNA in a manner analogous to DNA restriction endonucleases. Through the modification of nucleotide sequences which encode these RNAs, it is possible to engineer molecules that recognize specific nucleotide sequences in an RNA molecule and cleave it (Cech, *J. Amer. Med. Assn.*, 260:3030, 1988).

A major advantage of this approach is that, because they are sequence-specific, only mRNAs with particular sequences are inactivated.

[0089] There are two basic types of ribozymes namely, tetrahymena-type (Hasselhoff, *Nature*, 334:585, 1988) and "hammerhead"-type. Tetrahymena-type ribozymes recognize sequences which are four bases in length, while "hammerhead"-type ribozymes recognize base sequences 11-18 bases in length. The longer the recognition sequence, the greater the likelihood that the sequence will occur exclusively in the target mRNA species. Consequently, hammerhead-type ribozymes are preferable to tetrahymena-type ribozymes for inactivating a specific mRNA species and 18-based recognition sequences are preferable to shorter recognition sequences.

[0090] In another embodiment of the present invention, a nucleotide sequence encoding a GDF-11 dominant negative protein is provided. For example, a genetic construct that contain such a dominant negative encoding gene may be operably linked to a promoter, such as a tissue-specific promoter. For example, a skeletal muscle specific promoter (e.g., human skeletal muscle α -actin promoter) or developmentally specific promoter (e.g., MyHC 3, which is restricted in skeletal muscle to the embryonic period of development, or an inducible promoter (e.g., the orphan nuclear receptor TIS1).

[0091] Such constructs are useful in methods of modulating a subject's skeletal mass. For example, a method include transforming an organism, tissue, organ or cell with a genetic construct encoding a dominant negative GDF-11 protein and suitable promoter in operable linkage and expressing the dominant negative encoding GDF-11 gene, thereby modulating muscle mass, bone content and/or kidney growth by interfering with wild-type GDF-11 activity.

[0092] GDF-11 most likely forms dimers, homodimers or heterodimers and may even form heterodimers with other GDF family members, such as GDF-11 (see Example 4). Hence, while not wanting to be bound by a particular theory, the dominant negative effect described herein may involve the formation of non-functional homodimers or heterodimers of dominant negative and wild-type GDF-11 monomers. More specifically, it is possible that any non-functional homodimer or any heterodimer formed by the dimerization of wild-type and dominant negative GDF-11 monomers produces a dominant effect by: 1) being synthesized but not processed or secreted; 2) inhibiting the secretion of wild type GDF-11; 3) preventing normal proteolytic cleavage of the preprotein thereby producing a nonfunctional GDF-11 molecule; 4) altering the affinity of the non-functional dimer (e.g., homodimeric or heterodimeric GDF-11) to a receptor or generating an antagonistic form of GDF-11 that binds a receptor without activating it; or 5) inhibiting the intracellular processing or secretion of GDF-11 related or TGF- β family proteins.

[0093] Non-functional GDF-11 can function to inhibit the growth regulating actions of GDF-11 on muscle cells that include a dominant negative GDF-11 gene. Deletion or missense dominant negative forms of GDF-11 that retain the ability to form dimers with wild-type GDF-11 protein but do not function as wild-type GDF-11 proteins may be used to inhibit the biological activity of endogenous wild-type GDF-11. For example, in one embodiment, the proteolytic pro-

cessing site of GDF-11 may be altered (e.g., deleted) resulting in a GDF-11 molecule able to undergo subsequent dimerization with endogenous wild-type GDF-11 but unable to undergo further processing into a mature GDF-11 form. Alternatively, a non-functional GDF-11 can function as a monomeric species to inhibit the growth regulating actions of GDF-11 on muscle cells, bone cells and kidney cells at any point in a tissue's or organism's development.

[0094] Any genetic recombinant method in the art may be used, for example, recombinant viruses may be engineered to express a dominant negative form of GDF-11 which may be used to inhibit the activity of wild-type GDF-11. Such viruses may be used therapeutically for treatment of diseases resulting from aberrant over-expression or activity of GDF-11 protein, such as in denervation hypertrophy or as a means of controlling GDF-11 expression when treating disease conditions involving muscle, such as in musculodegenerative diseases or in tissue repair due to trauma or in modulating GDF-11 expression in animal husbandry (e.g., transgenic animals for agricultural purposes).

[0095] In addition, the expression of GDF-11 may be used, for example to help in kidney development. The method includes administering a therapeutically effective amount of a GDF-11 agent to the subject, thereby promoting kidney cell growth and differentiation in kidney tissue. The agent may be an antagonist or agonist of GDF-11 activity. For example, the agent may include a GDF-11 antisense molecule or a dominant negative polypeptide.

[0096] The invention provides a method for treating a muscle, kidney (chronic or acute) or adipose tissue disorder in a subject. The method includes administering a therapeutically effective amount of a GDF-11 agent to the subject, thereby inhibiting abnormal growth of muscle or adipose tissue or stimulating growth in kidney tissue. The GDF-11 agent may include a GDF-11 antisense molecule or a dominant negative polypeptide, for example. A "therapeutically effective amount" of a GDF-11 agent is that amount that ameliorates symptoms of the disorder or inhibits GDF-11 induced growth of muscle, for example, as compared with a normal subject.

[0097] The present invention also provides gene therapy for the treatment of cell proliferative or immunologic disorders which are mediated by GDF-11 protein. Such therapy would achieve its therapeutic effect by introduction of the GDF-11 antisense polynucleotide or dominant negative encoding polynucleotide sequences into cells having the proliferative disorder. Delivery of antisense GDF-11 polynucleotide can be achieved using a recombinant expression vector such as a chimeric virus or a colloidal dispersion system. Especially preferred for therapeutic delivery of antisense or dominant negative sequences is the use of targeted liposomes. In contrast, when it is desirable to enhance GDF-11 production, a "sense" GDF-11 polynucleotide is introduced into the appropriate cell(s).

[0098] Various viral vectors which can be utilized for gene therapy as taught herein include adenovirus, herpes virus, vaccinia, or, preferably, an RNA virus such as a retrovirus. Preferably, the retroviral vector is a derivative of a murine or avian retrovirus. Examples of retroviral vectors in which a single foreign gene can be inserted include, but are not limited to: Moloney murine leukemia virus (MoMuLV), Harvey murine sarcoma virus (HaMuSV), murine mammary

tumor virus (MuMTV), and Rous Sarcoma Virus (RSV). A number of additional retroviral vectors can incorporate multiple genes. All of these vectors can transfer or incorporate a gene for a selectable marker so that transduced cells can be identified and generated. By inserting a GDF-11 sequence of interest into the viral vector, along with another gene which encodes the ligand for a receptor on a specific target cell, for example, the vector is now target specific. Retroviral vectors can be made target specific by attaching, for example, a sugar, a glycolipid, or a protein. Preferred targeting is accomplished by using an antibody to target the retroviral vector. Those of skill in the art will know of, or can readily ascertain without undue experimentation, specific polynucleotide sequences which can be inserted into the retroviral genome or attached to a viral envelope to allow target specific delivery of the retroviral vector containing the GDF-11 antisense polynucleotide.

[0099] Since recombinant retroviruses are defective, they require assistance in order to produce infectious vector particles. This assistance can be provided, for example, by using helper cell lines that contain plasmids encoding all of the structural genes of the retrovirus under the control of regulatory sequences within the LTR. These plasmids are missing a nucleotide sequence which enables the packaging mechanism to recognize an RNA transcript for encapsulation. Helper cell lines which have deletions of the packaging signal include, but are not limited to $\psi 2$, PA317 and PA12, for example. These cell lines produce empty virions, since no genome is packaged. If a retroviral vector is introduced into such cells in which the packaging signal is intact, but the structural genes are replaced by other genes of interest, the vector can be packaged and vector virion produced.

[0100] Alternatively, NIH 3T3 or other tissue culture cells can be directly transfected with plasmids encoding the retroviral structural genes gag, pol and env, by conventional calcium phosphate transfection. These cells are then transfected with the vector plasmid containing the genes of interest. The resulting cells release the retroviral vector into the culture medium.

[0101] Another targeted delivery system for GDF-11 antisense polynucleotides is a colloidal dispersion system. Colloidal dispersion systems include macromolecule complexes, nanocapsules, microspheres, beads, and lipid-based systems including oil-in-water emulsions, micelles, mixed micelles, and liposomes. The preferred colloidal system of this invention is a liposome. Liposomes are artificial membrane vesicles which are useful as delivery vehicles in vitro and in vivo. It has been shown that large unilamellar vesicles (LUV), which range in size from 0.2-4.0 μm can encapsulate a substantial percentage of an aqueous buffer containing large macromolecules. RNA, DNA and intact virions can be encapsulated within the aqueous interior and be delivered to cells in a biologically active form (Fraley, et al., *Trends Biochem. Sci.*, 6:77, 19111). In addition to mammalian cells, liposomes have been used for delivery of polynucleotides in plant, yeast and bacterial cells. In order for a liposome to be an efficient gene transfer vehicle, the following characteristics should be present: (1) encapsulation of the genes of interest at high efficiency while not compromising their biological activity; (2) preferential and substantial binding to a target cell in comparison to non-target cells; (3) delivery of the aqueous contents of the vesicle to the target cell

cytoplasm at high efficiency; and (4) accurate and effective expression of genetic information (Manning, et al., *Biotechniques*, 6:682, 1988).

[0102] The composition of the liposome is usually a combination of phospholipids, particularly high-phase-transition-temperature phospholipids, usually in combination with steroids, especially cholesterol. Other phospholipids or other lipids may also be used. The physical characteristics of liposomes depend on pH, ionic strength, and the presence of divalent cations.

[0103] Examples of lipids useful in liposome production include phosphatidyl compounds, such as phosphatidylglycerol, phosphatidylcholine, phosphatidylserine, phosphatidylethanolamine, sphingolipids, cerebrosides, and gangliosides. Particularly useful are diacylphosphatidylglycerols, where the lipid moiety contains from 14-18 carbon atoms, particularly from 16-18 carbon atoms, and is saturated. Illustrative phospholipids include egg phosphatidylcholine, dipalmitoylphosphatidylcholine and distearoylphosphatidylcholine.

[0104] The targeting of liposomes can be classified based on anatomical and mechanistic factors. Anatomical classification is based on the level of selectivity, for example, organ-specific, cell-specific, and organelle-specific. Mechanistic targeting can be distinguished based upon whether it is passive or active. Passive targeting utilizes the natural tendency of liposomes to distribute to cells of the reticulo-endothelial system (RES) in organs which contain sinusoidal capillaries. Active targeting, on the other hand, involves alteration of the liposome by coupling the liposome to a specific ligand such as a monoclonal antibody, sugar, glycolipid, or protein, or by changing the composition or size of the liposome in order to achieve targeting to organs and cell types other than the naturally occurring sites of localization.

[0105] The surface of the targeted delivery system may be modified in a variety of ways. In the case of a liposomal targeted delivery system, lipid groups can be incorporated into the lipid bilayer of the liposome in order to maintain the targeting ligand in stable association with the liposomal bilayer. Various linking groups can be used for joining the lipid chains to the targeting ligand.

[0106] Due to the expression of GDF-11 in muscle and adipose tissue, there are a variety of applications using the polypeptide, polynucleotide, and antibodies of the invention, related to these tissues. Such applications include treatment of cell proliferative disorders involving these and other tissues, such as neural tissue. In addition, GDF-11 may be useful in various gene therapy procedures. In embodiments where GDF-11 polypeptide is administered to a subject, the dosage range is about 0.1 $\mu\text{g/kg}$ to 100 mg/kg ; more preferably from about 1 $\mu\text{g/kg}$ to 75 mg/kg and most preferably from about 10 mg/kg to 50 mg/kg .

[0107] Chromosomal Location of GDF-11

[0108] The data in Example 6 shows that the human GDF-11 gene is located on chromosome 2. By comparing the chromosomal location of GDF-11 with the map positions of various human disorders, it should be possible to determine whether mutations in the GDF-11 gene are involved in the etiology of human diseases. For example, an autosomal recessive form of juvenile amyotrophic lateral sclerosis has been shown to map to chromosome 2 (Hentati, et al.,

Neurology, 42 [Suppl.3]:201, 1992). More precise mapping of GDF-11 and analysis of DNA from these patients may indicate that GDF-11 is, in fact, the gene affected in this disease. In addition, GDF-11 is useful for distinguishing chromosome 2 from other chromosomes.

[0109] Transgenic Animals and Methods of Making the Same

[0110] Various methods to make the transgenic animals of the subject invention can be employed. Generally speaking, three such methods may be employed. In one such method, an embryo at the pronuclear stage (a "one cell embryo") is harvested from a female and the transgene is microinjected into the embryo, in which case the transgene will be chromosomally integrated into both the germ cells and somatic cells of the resulting mature animal. In another such method, embryonic stem cells are isolated and the transgene incorporated therein by electroporation, plasmid transfection or microinjection, followed by reintroduction of the stem cells into the embryo where they colonize and contribute to the germ line. Methods for microinjection of mammalian species is described in U.S. Pat. No. 4,873,191. In yet another such method, embryonic cells are infected with a retrovirus containing the transgene whereby the germ cells of the embryo have the transgene chromosomally integrated therein. When the animals to be made transgenic are avian, because avian fertilized ova generally go through cell division for the first twenty hours in the oviduct, microinjection into the pronucleus of the fertilized egg is problematic due to the inaccessibility of the pronucleus. Therefore, of the methods to make transgenic animals described generally above, retrovirus infection is preferred for avian species, for example as described in U.S. Pat. No. 5,162,215. If microinjection is to be used with avian species, however, a recently published procedure by Love et al., (*Biotechnology*, Jan. 12, 1994) can be utilized whereby the embryo is obtained from a sacrificed hen approximately two and one-half hours after the laying of the previous laid egg, the transgene is microinjected into the cytoplasm of the germinal disc and the embryo is cultured in a host shell until maturity. When the animals to be made transgenic are bovine or porcine, microinjection can be hampered by the opacity of the ova thereby making the nuclei difficult to identify by traditional differential interference-contrast microscopy. To overcome this problem, the ova can first be centrifuged to segregate the pronuclei for better visualization.

[0111] The "non-human animals" of the invention bovine, porcine, ovine and avian animals (e.g., cow, pig, sheep, chicken). The "transgenic non-human animals" of the invention are produced by introducing "transgenes" into the germline of the non-human animal. Embryonal target cells at various developmental stages can be used to introduce transgenes. Different methods are used depending on the stage of development of the embryonal target cell. The zygote is the best target for micro-injection. The use of zygotes as a target for gene transfer has a major advantage in that in most cases the injected DNA will be incorporated into the host gene before the first cleavage (Brinster et al., *Proc. Natl. Acad. Sci. USA* 82:4438-4442, 1985). As a consequence, all cells of the transgenic non-human animal will carry the incorporated transgene. This will in general

also be reflected in the efficient transmission of the transgene to offspring of the founder since 50% of the germ cells will harbor the transgene.

[0112] The term "transgenic" is used to describe an animal which includes exogenous genetic material within all of its cells. A "transgenic" animal can be produced by cross-breeding two chimeric animals which include exogenous genetic material within cells used in reproduction. Twenty-five percent of the resulting offspring will be transgenic i.e., animals which include the exogenous genetic material within all of their cells in both alleles. 50% of the resulting animals will include the exogenous genetic material within one allele and 25% will include no exogenous genetic material.

[0113] In the microinjection method useful in the practice of the subject invention, the transgene is digested and purified free from any vector DNA e.g. by gel electrophoresis. It is preferred that the transgene include an operatively associated promoter which interacts with cellular proteins involved in transcription, ultimately resulting in constitutive expression. Promoters useful in this regard include those from cytomegalovirus (CMV), Moloney leukemia virus (MLV), and herpes virus, as well as those from the genes encoding metallothionin, skeletal actin, P-enolpyruvate carboxylase (PEPCK), phosphoglycerate (PGK), DHFR, and thymidine kinase. Promoters for viral long terminal repeats (LTRs) such as Rous Sarcoma Virus can also be employed. When the animals to be made transgenic are avian, preferred promoters include those for the chicken β -globin gene, chicken lysozyme gene, and avian leukosis virus. Constructs useful in plasmid transfection of embryonic stem cells will employ additional regulatory elements well known in the art such as enhancer elements to stimulate transcription, splice acceptors, termination and polyadenylation signals, and ribosome binding sites to permit translation.

[0114] Retroviral infection can also be used to introduce transgene into a non-human animal, as described above. The developing non-human embryo can be cultured in vitro to the blastocyst stage. During this time, the blastomeres can be targets for retro viral infection (Jaenich, R., *Proc. Natl. Acad. Sci. USA* 73:1260-1264, 1976). Efficient infection of the blastomeres is obtained by enzymatic treatment to remove the zona pellucida (Hogan, et al. (1986) in *Manipulating the Mouse Embryo*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y.). The viral vector system used to introduce the transgene is typically a replication-defective retro virus carrying the transgene (Jahner, et al., *Proc. Natl. Acad. Sci. USA* 82:6927-6931, 1985; Van der Putten, et al., *Proc. Natl. Acad. Sci. USA* 82:6148-6152, 1985). Transfection is easily and efficiently obtained by culturing the blastomeres on a monolayer of virus-producing cells (Van der Putten, supra; Stewart, et al., *EMBO J.* 6:383-388, 1987). Alternatively, infection can be performed at a later stage. Virus or virus-producing cells can be injected into the blastocoel (D. Jahner et al., *Nature* 298:623-628, 1982). Most of the founders will be mosaic for the transgene since incorporation occurs only in a subset of the cells which formed the transgenic nonhuman animal. Further, the founder may contain various retro viral insertions of the transgene at different positions in the genome which generally will segregate in the offspring. In addition, it is also possible to introduce transgenes into the germ line, albeit

with low efficiency, by intrauterine retroviral infection of the midgestation embryo (D. Jahner et al., supra).

[0115] A third type of target cell for transgene introduction is the embryonic stem cell (ES). ES cells are obtained from pre-implantation embryos cultured in vitro and fused with embryos (M. J. Evans et al. *Nature* 292:154-156, 1981; M. O. Bradley et al., *Nature* 309: 255-258, 1984; Gossler, et al., *Proc. Natl. Acad. Sci USA* 83: 9065-9069, 1986; and Robertson et al., *Nature* 322:445-448, 1986). Transgenes can be efficiently introduced into the ES cells by DNA transfection or by retro virus-mediated transduction. Such transformed ES cells can thereafter be combined with blastocysts from a nonhuman animal. The ES cells thereafter colonize the embryo and contribute to the germ line of the resulting chimeric animal. (For review see Jaenisch, R., *Science* 240: 1468-1474, 1988).

[0116] "Transformed" means a cell into which (or into an ancestor of which) has been introduced, by means of recombinant nucleic acid techniques, a heterologous nucleic acid molecule. "Heterologous" refers to a nucleic acid sequence that either originates from another species or is modified from either its original form or the form primarily expressed in the cell.

[0117] "Transgene" means any piece of DNA which is inserted by artifact into a cell, and becomes part of the genome of the organism (i.e., either stably integrated or as a stable extrachromosomal element) which develops from that cell. Such a transgene may include a gene which is partly or entirely heterologous (i.e., foreign) to the transgenic organism, or may represent a gene homologous to an endogenous gene of the organism. Included within this definition is a transgene created by the providing of an RNA sequence which is transcribed into DNA and then incorporated into the genome. The transgenes of the invention include DNA sequences which encode GDF-11, and include GDF-sense and antisense polynucleotides and dominant negative encoding polynucleotides, which may be expressed in a transgenic non-human animal. The term "transgenic" as used herein additionally includes any organism whose genome has been altered by in vitro manipulation of the early embryo or fertilized egg or by any transgenic technology to induce a specific gene knockout. The term "gene knockout" as used herein, refers to the targeted disruption of a gene in vivo with complete loss of function that has been achieved by any transgenic technology familiar to those in the art. In one embodiment, transgenic animals having gene knockouts are those in which the target gene has been rendered nonfunctional by an insertion targeted to the gene to be rendered non-functional by homologous recombination. As used herein, the term "transgenic" includes any transgenic technology familiar to those in the art which can produce an organism carrying an introduced transgene or one in which an endogenous gene has been rendered non-functional or "knocked out." An example of a transgene used to "knockout" GDF-11 function in the present Examples is described in Example 6 and **FIG. 9**. Thus, in another embodiment, the invention provides a transgene wherein the entire mature C-terminal region of GDF-11 is deleted.

[0118] The transgene to be used in the practice of the subject invention is a DNA sequence comprising a modified GDF-11 coding sequence. In a preferred embodiment, the GDF-11 gene is disrupted by homologous targeting in

embryonic stem cells. For example, the entire mature C-terminal region of the GDF-11 gene may be deleted as described in the examples below. Optionally, the GDF-11 disruption or deletion may be accompanied by insertion of or replacement with other DNA sequences, such as a non-functional GDF-11 sequence. In other embodiments, the transgene comprises DNA antisense to the coding sequence for GDF-11. In another embodiment, the transgene comprises DNA encoding an antibody or receptor peptide sequence which is able to bind to GDF-11. The DNA and peptide sequences of GDF-11 are known in the art, the sequences, localization and activity disclosed in WO95/08543 and pending U.S. patent application Ser. No. 08/706,958, filed on Sep. 3, 1996, incorporated by reference in its entirety. The disclosure of both of these applications are hereby incorporated herein by reference. Where appropriate, DNA sequences that encode proteins having GDF-11 activity but differ in nucleic acid sequence due to the degeneracy of the genetic code may also be used herein, as may truncated forms, allelic variants and interspecies homologues.

[0119] Therefore the invention also includes animals having heterozygous mutations in GDF-11. A heterozygote would likely have an intermediate increase in muscle mass as compared to the homozygote.

[0120] After an embryo has been microinjected, colonized with transfected embryonic stem cells or infected with a retrovirus containing the transgene (except for practice of the subject invention in avian species which is addressed elsewhere herein) the embryo is implanted into the oviduct of a pseudopregnant female. The consequent progeny are tested for incorporation of the transgene by Southern blot analysis of blood samples using transgene specific probes. PCR is particularly useful in this regard. Positive progeny (G0) are crossbred to produce offspring (G1) which are analyzed for transgene expression by Northern blot analysis of tissue samples. To be able to distinguish expression of like-species transgenes from expression of the animals endogenous GDF-11 gene(s), a marker gene fragment can be included in the construct in the 3' untranslated region of the transgene and the Northern probe designed to probe for the marker gene fragment. The serum levels of GDF-11 can also be measured in the transgenic animal to establish appropriate expression. Expression of the GDF-11 transgenes, thereby decreasing the GDF-11 in the tissue and serum levels of the transgenic animals and consequently increasing the muscle tissue content results in the foodstuffs from these animals (i.e. eggs, beef, pork, poultry meat, milk, etc.) having markedly increased muscle content, and preferably without increased, and more preferably, reduced levels of fat and cholesterol. By practice of the subject invention, a statistically significant increase in muscle content, preferably at least a 2% increase in muscle content (e.g., in chickens), more preferably a 25% increase in muscle content as a percentage of body weight, more preferably greater than 40% increase in muscle content in these foodstuffs can be obtained.

[0121] In addition decrease in GDF-11 in the tissue and serum levels of the transgenic animals can be used to increase the bone content of animals use as foodstuffs, for example the transgenic animals having reduced GDF-11 can be provided to have an additional number of ribs.

[0122] Additional Methods of Use

[0123] Thus, the present invention includes methods for increasing muscle mass and/or rib content in domesticated animals, characterized by inactivation or deletion of the gene encoding growth and differentiation factor-11 (GDF-11). The domesticated animal is preferably selected from the group consisting of ovine, bovine, porcine, piscine and avian. The animal may be treated with an isolated polynucleotide sequence encoding growth and differentiation factor-11 which polynucleotide sequence is also from a domesticated animal selected from the group consisting of ovine, bovine, porcine, piscine and avian. The present invention includes methods for increasing the muscle mass or rib content in domesticated animals characterized by administering to a domesticated animal monoclonal antibodies directed to the GDF-11 polypeptide. The antibody may be an anti-GDF-11, and may be either a monoclonal antibody or a polyclonal antibody.

[0124] The invention includes methods comprising using an anti-GDF-11 monoclonal antibody, antisense, or dominant negative mutants as a therapeutic agent to inhibit the growth regulating actions of GDF-11 on muscle cells. Muscle cells are defined to include fetal or adult muscle cells, as well as progenitor cells which are capable of differentiation into muscle. The monoclonal antibody may be a humanized (e.g., either fully or a chimeric) monoclonal antibody, of any species origin, such as murine, ovine, bovine, porcine or avian. Methods of producing antibody molecules with various combinations of "humanized" antibodies are well known in the art and include combining murine variable regions with human constant regions (Cabily, et al. *Proc.Natl.Acad.Sci. USA*, 81:3273, 1984), or by grafting the murine-antibody complementary determining regions (CDRs) onto the human framework (Richmann, et al., *Nature* 332:323, 1988). Other general references which teach methods for creating humanized antibodies include Morrison, et al., *Science*, 229:1202, 1985; Jones, et al., *Nature*, 321:522, 1986; Monroe, et al., *Nature* 312:779, 1985; Oi, et al., *BioTechniques*, 4:214, 1986; European Patent Application No. 302,620; and U.S. Pat. No. 5,024, 834. Therefore, by humanizing the monoclonal antibodies of the invention for in vivo use, an immune response to the antibodies would be greatly reduced.

[0125] The invention includes methods comprising using an anti-GDF-11 monoclonal antibody, antisense, or dominant negative mutants as a therapeutic agent to inhibit the growth regulating actions of GDF-11 on bone cells. Bone cells are defined to include fetal or adult bone cells, as well as progenitor cells which are capable of differentiation into bone. The monoclonal antibody may be a humanized (e.g., either fully or a chimeric) monoclonal antibody, of any species origin, such as murine, ovine, bovine, porcine or avian. Methods of producing antibody molecules with various combinations of "humanized" antibodies are well known in the art and include combining murine variable regions with human constant regions (Cabily, et al. *Proc.Natl.Acad.Sci. USA*, 81 3273, 1984), or by grafting the murine-antibody complementary determining regions (CDRs) onto the human framework (Richmann, et al., *Nature* 332:323, 1988). Other general references which teach methods for creating humanized antibodies include Morrison, et al., *Science*, 229:1202, 1985; Jones, et al., *Nature*, 321:522, 1986; Monroe, et al., *Nature* 312:779,

1985; Oi, et al., *BioTechniques*, 4:214, 1986; European Patent Application No. 302,620; and U.S. Pat. No. 5,024, 834. Therefore, by humanizing the monoclonal antibodies of the invention for in vivo use, an immune response to the antibodies would be greatly reduced.

[0126] The monoclonal antibody, GDF-11 polypeptide, or GDF-11 polynucleotide (all "GDF-11 agents") may have the effect of increasing the development of skeletal muscles or skeletal bones. In preferred embodiments of the claimed methods, the GDF-11 monoclonal antibody, polypeptide, or polynucleotide is administered to a patient suffering from a disorder selected from the group consisting of muscle wasting disease, neuromuscular disorder, muscle atrophy or aging. In another preferred embodiment the invention provides a method for treating bone degenerative disorders, such as osteoporosis by administering to a patient suffering from a disorder antibodies, polypeptides or polynucleotides effecting GDF-11 activity. The GDF-11 agent may also be administered to a patient suffering from a disorder selected from the group consisting of muscular dystrophy, spinal cord injury, traumatic injury, congestive obstructive pulmonary disease (COPD), AIDS or cachexia.

[0127] In a preferred embodiment, the GDF-11 agent is administered to a patient with muscle or bone wasting disease or disorder by intravenous, intramuscular or subcutaneous injection; preferably, a monoclonal antibody is administered within a dose range between about 0.1 mg/kg to about 100 mg/kg; more preferably between about 1 ug/kg to 75 mg/kg; most preferably from about 10 mg/kg to 50 mg/kg. The antibody may be administered, for example, by bolus injection or by slow infusion. Slow infusion over a period of 30 minutes to 2 hours is preferred. The GDF-11 agent may be formulated in a formulation suitable for administration to a patient. Such formulations are known in the art.

[0128] The dosage regimen will be determined by the attending physician considering various factors which modify the action of the GDF-11 protein, e.g. amount of tissue desired to be formed, the site of tissue damage, the condition of the damaged tissue, the size of a wound, type of damaged tissue, the patient's age, sex, and diet, the severity of any infection, time of administration and other clinical factors. The dosage may vary with the type of matrix used in the reconstitution and the types of agent, such as anti-GDF-11 antibodies, to be used in the composition. Generally, systemic or injectable administration, such as intravenous (IV), intramuscular (IM) or subcutaneous (Sub-Q) injection. Administration will generally be initiated at a dose which is minimally effective, and the dose will be increased over a preselected time course until a positive effect is observed. Subsequently, incremental increases in dosage will be made limiting such incremental increases to such levels that produce a corresponding increase in effect, while taking into account any adverse effects that may appear. The addition of other known growth factors, such as IGF I (insulin like growth factor I), human, bovine, or chicken growth hormone which may aid in increasing muscle mass, to the final composition, may also affect the dosage. In the embodiment where an anti-GDF-11 antibody is administered, the anti-GDF-11 antibody is generally administered within a dose range of about 0.1 ug/kg to about 100 mg/kg; more preferably between about 10 mg/kg to 50 mg/kg.

[0129] Progress can be monitored by periodic assessment of tissue growth and/or repair. The progress can be monitored, for example, x-rays, histomorphometric determinations and tetracycline labeling.

[0130] Screening for GDF-11 Modulating Compounds

[0131] In another embodiment, the invention provides a method for identifying a compound or molecule that modulates GDF-11 protein activity or gene expression. The method includes incubating components comprising the compound, GDF-11 polypeptide or with a recombinant cell expressing GDF-11 polypeptide, under conditions sufficient to allow the components to interact and determining the effect of the compound on GDF-11 activity or expression. The effect of the compound on GDF-11 activity can be measured by a number of assays, and may include measurements before and after incubating in the presence of the compound. Compounds that affect GDF-11 activity or gene expression include peptides, peptidomimetics, polypeptides, chemical compounds and biologic agents. Assays include Northern blot analysis of GDF-11 mRNA (for gene expression), Western blot analysis (for protein level) and muscle fiber analysis (for protein activity).

[0132] The above screening assays may be used for detecting the compounds or molecules that bind to the GDF-11 receptor or GDF-11 polypeptide, in isolating molecules that bind to the GDF-11 gene, for measuring the amount of GDF-11 in a sample, either polypeptide or RNA (mRNA), for identifying molecules that may act as agonists or antagonists, and the like. For example, GDF-11 antagonists are useful for treatment of muscular and adipose tissue disorders (e.g., obesity).

[0133] Incubating includes conditions which allow contact between the test compound and GDF-11 polypeptide or with a recombinant cell expressing GDF-11 polypeptide. Contacting includes in solution and in solid phase, or in a cell. The test compound may optionally be a combinatorial library for screening a plurality of compounds. Compounds identified in the method of the invention can be further evaluated, detected, cloned, sequenced, and the like, either in solution or after binding to a solid support, by any method usually applied to the detection of a specific DNA sequence such as PCR, oligomer restriction (Saiki, et al., *Bio/Technology*, 3:1008-1012, 1985), allele-specific oligonucleotide (ASO) probe analysis (Conner, et al., *Proc. Natl. Acad. Sci. USA*, 80:278, 1983), oligonucleotide Landegren, et al., *Science*, 241:1077, 1988), and the like. Molecular techniques for DNA analysis have been reviewed (Landegren, et al., *Science*, 242:229-237, 1988).

[0134] All references cited herein are hereby incorporated by reference in their entirety.

[0135] The following examples are intended to illustrate but not limit the invention. While they are typical of those that might be used, other procedures known to those skilled in the art may alternatively be used.

EXAMPLE 1

Identification and Isolation of a Novel TGF- β Family Member

[0136] To identify novel members of the TGF- β superfamily, a murine genomic library was screened at reduced

stringency using a murine GDF-8 probe (**FIG. 8**; nucleotides 865-1234) spanning the region encoding the C-terminal portion of the GDF-8 precursor protein. Hybridization was carried out as described (Lee, *Mol. Endocrinol.*, 4:1034, 1990) at 65° C., and the final wash was carried out at the same temperature in a buffer containing 0.5 M NaCl. Among the hybridizing phage was one that could be distinguished from GDF-8-containing phage on the basis of its reduced hybridization intensity to the GDF-8 probe. Partial nucleotide sequence analysis of the genomic insert present in this weakly hybridizing phage showed that this clone contained a sequence highly related to but distinct from murine GDF-8.

[0137] A partial nucleotide sequence of the genomic insert present in this phage is shown in **FIG. 1a**. The sequence contained an open reading frame extending from nucleotides 198 to 575 that showed significant homology to the known members of the TGF- β superfamily (see below). Preceding this sequence was a 3' splice consensus sequence at precisely the same position as in the GDF-8 gene. This new TGF- β family member was given the designation GDF-11 (growth/differentiation factor-11).

EXAMPLE 2

Expression of GDF-11

[0138] To determine the expression pattern of GDF-11, RNA samples prepared from a variety of tissues were screened by Northern analysis. RNA isolation and Northern analysis were carried out as described previously (Lee, *Mol. Endocrinol.*, 4:1034, 1990) except that the hybridization was carried out in 5 $\times$ SSPE, 10% dextran sulfate, 50% formamide, 1% SDS, 200 μ g/ml salmon DNA, and 0.1% each of bovine serum albumin, ficoll, and polyvinylpyrrolidone. Five micrograms of twice poly A-selected RNA prepared from each tissue (except for 2 day neonatal brain, for which only 3.3 μ g RNA were used) were electrophoresed on formaldehyde gels, blotted, and probed with GDF-11. As shown in **FIG. 2**, the GDF-11 probe detected two RNA species, approximately 4.2 and 3.2 kb in length, in adult thymus, brain, spleen, uterus, and muscle as well as in whole embryos isolated at day 12.5 or 18.5 and in brain samples taken at various stages of development. On longer exposures of these blots, lower levels of GDF-11 RNA could also be detected in a number of other tissues.

EXAMPLE 3

Isolation of cDNA Clones Encoding GDF-11

[0139] In order to isolate cDNA clones encoding GDF-11, a cDNA library was prepared in the lambda ZAP II vector (Stratagene) using RNA prepared from human adult spleen. From 5 μ g of twice poly A-selected RNA prepared from human spleen, a cDNA library consisting of 21 million recombinant phage was constructed according to the instructions provided by Stratagene. The library was screened without amplification. Library screening and characterization of cDNA inserts were carried out as described previously (Lee, *Mol. Endocrinol.*, 4:1034, 1990). From this library, 23 hybridizing phage were obtained.

[0140] The entire nucleotide sequence of the clone extending furthest toward the 5' end of the gene was determined. The 1258 base pair sequence contained a single long open

reading frame beginning from the 5' end of the clone and extending to a TAA stop codon. Because the open reading frame and the homology with GDF-8 (see below) extended to the very 5' end of the clone, it seemed likely that this clone was missing the coding sequence corresponding to the N-terminal portion of the GDF-11 precursor protein. In order to obtain the remaining portion of the GDF-11 sequence, several genomic clones were isolated by screening a human genomic library with the human GDF-11 cDNA probe. Partial sequence analysis of one of these genomic clones showed that this clone contained the GDF-11 gene. From this clone, the remaining GDF-11 coding sequence was obtained. **FIG. 1b** shows the predicted sequence of GDF-11 assembled from the genomic and cDNA sequences. Nucleotides 136 to 1393 represent the extent of the sequence obtained from a cDNA clone. Nucleotides 1 to 135 were obtained from a genomic clone. The sequence has been arbitrarily numbered beginning with a Sac II site present in the genomic clone, but the location of the mRNA start site is not known. The sequence contains a putative initiating methionine at nucleotide 54. Whether the sequence upstream of this methionine codon is all present in the mRNA is not known. Beginning with this methionine codon, the open reading frame extends for 407 amino acids. The sequence contains one potential N-linked glycosylation site at asparagine 94. The sequence contains a predicted RXXR proteolytic cleavage site at amino acids 295 to 298, and cleavage of the precursor at this site would generate an active C-terminal fragment 109 amino acids in length with a predicted molecular weight of approximately 12,500 kD. In this region, the predicted murine and human GDF-11 amino acid sequences are 100% identical. The high degree of sequence conservation across species suggests that GDF-11 plays an important role in vivo.

[0141] The C-terminal region following the predicted cleavage site contains all the hallmarks present in other TGF- β family members. GDF-11 contains most of the residues that are highly conserved in other family members, including the seven cysteine residues with their characteristic spacing. Like the TGF- β 's, the inhibin β 's, and GDF-8, GDF-11 also contains two additional cysteine residues. In the case of TGF- β 2, these additional cysteine residues are known to form an intramolecular disulfide bond (Daopin, et al., *Science*, 257:369, 1992; Schlunegger and Grutter, *Nature*, 358:430, 1992). A tabulation of the amino acid sequence homologies between GDF-11 and the other TGF- β family members is shown in **FIG. 3**. Numbers represent percent amino acid identities between each pair calculated from the first conserved cysteine to the C-terminus. Boxes represent homologies among highly-related members within particular subgroups. In this region, GDF-11 is most highly related to GDF-8 (92% sequence identity).

[0142] An alignment of GDF-8 (SEQ ID NO:5) and GDF-11 (SEQ ID NO:6) amino acid sequences is shown in **FIG. 4a**. The two sequences contain potential N-linked glycosylation signals (NIS) and putative proteolytic processing sites (RSRR) at analogous positions. The two sequences are related not only in the C-terminal region following the putative cleavage site (90% amino acid sequence identity), but also in the pro-region of the molecules (45% amino acid sequence identity).

EXAMPLE 4

Construction of a Hybrid GDF-8/GDF11 Gene

[0143] In order to express GDF-11 protein, a hybrid gene was constructed in which the N-terminal region of GDF-11 was replaced by the analogous region of GDF-8. Such hybrid constructs have been used to produce biologically-active BMP-4 (Hammonds, et al., *Mol. Endocrinol.*, 5:149, 1991) and Vg-1 (Thomsen and Melton, *Cell*, 74:433, 1993). In order to ensure that the GDF-11 protein produced from the hybrid construct would represent authentic GDF-11, the hybrid gene was constructed in such a manner that the fusion of the two gene fragments would occur precisely at the predicted cleavage sites. In particular, an *Ava*II restriction site is present in both sequences at the location corresponding to the predicted proteolytic cleavage site. The N-terminal pro-region of GDF-8 up to this *Ava*II site was obtained by partial digestion of the clone with *Ava*II and fused to the C-terminal region of GDF-11 beginning at this *Ava*II site. The resulting hybrid construct was then inserted into the pMSXND mammalian expression vector (Lee and Nathans, *J. Biol. Chem.*, 263:3521) and transfected into Chinese hamster ovary cells. As shown in **FIG. 5**, Western analysis of conditioned medium from G418-resistant cells using antibodies raised against the C-terminal portion of GDF-8 showed that these cells secreted GDF-11 protein into the medium and that at least some of the hybrid protein was proteolytically processed. Furthermore, these studies demonstrate that the antibodies directed against the C-terminal portion of GDF-8 will also react with GDF-11 protein.

EXAMPLE 5

Chromosomal Localization of GDF-11

[0144] In order to map the chromosomal location of GDF-11, DNA samples from human/rodent somatic cell hybrids (Drwinga, et al., *Genomics*, 16:311-313, 1993; Dubois and Naylor, *Genomics*, 16:315-319, 1993) were analyzed by polymerase chain reaction followed by Southern blotting. Polymerase chain reaction was carried out using primer #101, 5'-GAGTCCCGCTGCTGCGATATCC-3', (SEQ ID NO:7) and primer #102, 5'-TAGAGCATGTTGATTGGGGACAT-3', (SEQ ID NO:8) for 35 cycles at 94° C. for 2 minutes, 58° C. for 1 minutes, and 72° C. for 1 minute. These primers correspond to nucleotides 981 to 1003 and the reverse complement of nucleotides 1182 to 1204, respectively, in the human GDF-11 sequence. PCR products were electrophoresed on agarose gels, blotted, and probed with oligonucleotide #104, 5'-AAATATCCGCATACCCATT-3', (SEQ ID NO:9) which corresponds to a sequence internal to the region flanked by primer #101 and #102. Filters were hybridized in 6 $\times$ SSC, 1 $\times$ Denhardt's solution, 100 μ g/ml yeast transfer RNA, and 0.05% sodium pyrophosphate at 50° C.

[0145] As shown in **FIG. 6**, the human-specific probe detected a band of the predicted size (approximately 224 base pairs) in the positive control sample (total human genomic DNA) and in a single DNA sample from the human/rodent hybrid panel. This positive signal corresponds to human chromosome 12. The human chromosome contained in each of the hybrid cell lines is identified at the top of each of the first 24 lanes (1-22, X, and Y). In the lanes designated CHO, M, and H, the starting DNA template was

total genomic DNA from hamster, mouse, and human sources, respectively. In the lane marked B1, no template DNA was used. Numbers at left indicate the mobilities of DNA standards. These data show that the human GDF-11 gene is located on chromosome 12.

[0146] In order to determine the more precise location of GDF-11 on chromosome 12, the GDF-11 gene was localized by fluorescence in situ hybridization (FISH). These FISH localization studies were carried out by contract to BIOS laboratories (New Haven, Conn.). Purified DNA from a human GDF-11 genomic clone was labelled with digoxigenin dUTP by nick translation. Labelled probe was combined with sheared human DNA and hybridized to normal metaphase chromosomes derived from PHA stimulated peripheral blood lymphocytes in a solution containing 50% formamide, 10% dextran sulfate and 2×SSC. Specific hybridization signals were detected by incubating the hybridized slides in fluorescein-conjugated sheep anti-digoxigenin antibodies. Slides were then counterstained with propidium iodide and analyzed. As shown in **FIG. 7a**, this experiment resulted in the specific labelling of the proximal long arm of a group C chromosome, the size and morphology of which were consistent with chromosome 12. In order to confirm the identity of the specifically labelled chromosome, a second experiment was conducted in which a chromosome 12-specific centromere probe was cohybridized with GDF-11. As shown in **FIG. 7b**, this experiment clearly demonstrated that GDF-11 is located at a position which is 23% of the distance from the centromere to the telomere of the long arm of chromosome 12, an area which corresponds to band 12q13 (**FIG. 7c**). A total of 85 metaphase cells were analyzed and 80 exhibited specific labelling.

EXAMPLE 6

GDF-11 Homology in Mammalian Species

[0147] Like most other TGF- β family member, GDF-11 also appears to be highly conserved across species. By genomic Southern analysis, homologous sequences were detected in all mammalian species examined as well as in chickens and frogs (**FIG. 4b**). In most species, the GDF-11 probe also detected a second, more faintly hybridizing fragment corresponding to the myostatin gene (McPherron et al., 1997).

EXAMPLE 7

GDF-11 Transgenic Knockout Mice

[0148] To determine the biological function of GDF-11, we disrupted the GDF-11 gene by homologous targeting in embryonic stem cells. A murine 129 SV/J genomic library was prepared in lambda FIXII according to the instructions provided by Stratagene (La Jolla, Calif.). The structure of the GDF-11 gene was deduced from restriction mapping and partial sequencing of phage clones isolated from the library. Vectors for preparing the targeting construct were kindly provided by Philip Soriano and Kirk Thomas. To ensure that the resulting mice would be null for GDF-11 function, the entire mature C-terminal region was deleted and replaced by a neo cassette (**FIGS. 9a,b**). R1 ES cells were transfected with the targeting construct, selected with gancyclovir (2 μ M) and G418 (250 μ g/ml), and analyzed by Southern

analysis. Homologous targeting of the GDF-11 gene was seen in 8/155 gancyclovir/G418 doubly resistant ES cell clones. Following injection of several targeted clones into C57BL/6J blastocysts, we obtained chimeras from one ES clone that produced heterozygous pups when crossed to both C57BL/6J and 129/SvJ females. Crosses of C57BL/6J/129/SvJ hybrid F1 heterozygotes produced 49 wild-type (34%), 94 heterozygous (66%) and no homozygous mutant adult offspring. Similarly, there were no adult homozygous null animals seen in the 129/SvJ background (32 wild-type (36%) and 56 heterozygous mutant (64%) animals).

[0149] To determine the age at which homozygous mutants were dying, we genotyped litters of embryos isolated at various gestational ages from heterozygous females that had been mated to heterozygous males. At all embryonic stages examined, homozygous mutant embryos were present at approximately the predicted frequency of 25%. Among hybrid newborn mice, the different genotypes were also represented at the expected Mendelian ratio of 1:2:1 (34 +/+ (28%), 61 +/- (50%), and 28 -/- (23%)). Homozygous mutant mice were born alive and were able to breath and nurse. All homozygous mutants died, however, within the first 24 hours after birth. The precise cause of death was unknown, but the lethality may have been related to the fact that the kidneys in homozygous mutants were either severely hypoplastic or completely absent. A summary of the kidney abnormalities in these mice is shown in **FIG. 10**.

EXAMPLE 8

Anatomical Differences in Knockout Mice

[0150] Homozygous mutant animals were easily recognizable by their severely shortened or absent tails (**FIG. 11a**). To further characterize the tail defects in these homozygous mutant animals, we examined their skeletons to determine the degree of disruption of the caudal vertebrae. A comparison of wild-type and mutant skeleton preparations of late stage embryos and newborn mice, however, revealed differences not only in the caudal region of the animals but in many other regions as well. In nearly every case where differences were noted, the abnormalities appeared to represent homeotic transformations of vertebral segments in which particular segments appeared to have a morphology typical of more anterior segments. These transformations, which are summarized in **FIG. 12**, were evident throughout the axial skeleton extending from the cervical region to the caudal region. Except for the defects seen in the axial skeleton, the rest of the skeleton, such as the cranium and limb bones, appeared normal.

[0151] Anterior transformations of the vertebrae in mutant newborn animals were most readily apparent in the thoracic region, where there was a dramatic increase in the number of thoracic (T) segments. All wild-type mice examined showed the typical pattern of 13 thoracic vertebrae each with its associated pair of ribs (**FIGS. 11(b,e)**). In contrast, homozygous mutant mice showed a striking increase in the number of thoracic vertebrae. All homozygous mutants examined had 4 to 5 extra pairs of ribs for a total of 17 to 18 (**FIGS. 11(d,g)**) although in over 1/3 of these animals, the 18th rib appeared to be rudimentary. Hence, segments that would normally correspond to lumbar (L) segments L1 to L4 or L5 appeared to have been transformed into thoracic segments in mutant animals.

[0152] Moreover, transformations within the thoracic region in which one thoracic vertebra had a morphology characteristic of another thoracic vertebra were also evident. For example, in wild-type mice, the first 7 pairs of ribs attach to the sternum, and the remaining 6 are unattached or free (FIGS. 11(e,h)). In homozygous mutants, there was an increase in the number of both attached and free pairs of ribs to 10-11 and 7-8, respectively (FIGS. 11(g,j)). Therefore, thoracic segments T8, T9, T10, and in some cases even T11, which all have free ribs in wild-type animals, were transformed in mutant animals to have a characteristic typical of more anterior thoracic segments, namely, the presence of ribs attached to the sternum. Consistent with this finding, the transitional spinous process and transitional articular processes which are normally found on T10 in wild-type animals were instead found on T13 in homozygous mutants (data not shown). Additional transformations within the thoracic region were also noted in certain mutant animals. For example, in wild-type mice, the ribs derived from T1 normally touch the top of the sternum. However, in $\frac{2}{3}$ hybrid and $\frac{2}{3}$ 129/SvJ homozygous mutant mice examined, T2 appeared to have been transformed to have a morphology resembling that of T1; that is, in these animals, the ribs derived from T2 extended to touch the top of the sternum. In these cases, the ribs derived from T1 appeared to fuse to the second pair of ribs. Finally, in 82% of homozygous mutants, the long spinous process normally present on T2 was shifted to the position of T3. In certain other homozygous mutants, asymmetric fusion of a pair of vertebrostermal ribs was seen at other thoracic levels.

[0153] The anterior transformations were not restricted to the thoracic region. The anterior most transformation that we observed was at the level of the 6th cervical vertebra (C6). In wild-type mice, C6 is readily identifiable by the presence of two anterior tuberculi on the ventral side. In several homozygous mutant mice, although one of these two anterior tuberculi was present on C6, the other was present at the position of C7 instead. Hence, in these mice, C7 appeared to have been partially transformed to have a morphology resembling that of C6. One other homozygous mutant had 2 anterior tuberculi on C7 but retained one on C6 for a complete C7 to C6 transformation but a partial C6 to C5 transformation.

[0154] Transformations of the axial skeleton also extended into the lumbar region. Whereas wild-type animals normally have only 6 lumbar vertebrae, homozygous mutants had 8-9. At least 6 of the lumbar vertebrae in the mutants must have derived from segments that would normally have given rise to sacral and caudal vertebrae as the data described above suggest that 4 to 5 lumbar segments were transformed into thoracic segments. Hence, homozygous mutant mice had a total of 33-34 presacral vertebrae compared to 26 presacral vertebrae normally present in wild-type mice. The most common presacral vertebral patterns were C7/T18/L8 and C7/T18/L9 for mutant mice compared to C7/T13/L6 for wild-type mice. The presence of additional presacral vertebrae in mutant animals was obvious even without detailed examination of the skeletons as the position of the hindlimbs relative to the forelimbs was displaced posteriorly by 7-8 segments.

[0155] Although the sacral and caudal vertebrae were also affected in homozygous mutant mice, the exact nature of each transformation was not as readily identifiable. In wild-

type mice, sacral segments S1 and S2 typically have broad transverse processes compared to S3 and S4. In the mutants, there did not appear to be an identifiable S1 or S2 vertebra. Instead, mutant animals had several vertebrae that appeared to have morphology similar to S3. In addition, the transverse processes of all 4 sacral vertebrae are normally fused to each other although in newborns often only fusions of the first 3 vertebrae are seen. In homozygous mutants, however, the transverse processes of the sacral vertebrae were usually unfused. In the caudalmost region, all mutant animals also had severely malformed vertebrae with extensive fusions of cartilage. Although the severity of the fusions made it difficult to count the total number of vertebrae in the caudal region, we were able to count up to 15 transverse processes in several animals. We were unable to determine whether these represented sacral or caudal vertebrae in the mutants because we could not establish morphologic criteria for distinguishing S4 from caudal vertebrae even in wild-type newborn animals. Regardless of their identities, the total number of vertebrae in this region was significantly reduced from the normal number of approximately 30. Hence, although the mutants had significantly more thoracic and lumbar vertebrae than wild-type mice, the total number of segments was reduced in the mutants due to the truncation of the tails.

[0156] Heterozygous mice also showed abnormalities in the axial skeleton although the phenotype was much milder than in homozygous mice. The most obvious abnormality in heterozygous mice was the presence of an additional thoracic segment with an associated pair of ribs (FIGS. 11(c,f)). This transformation was present in every heterozygous animal examined, and in every case, the additional pair of ribs was attached to the sternum (FIG. 11(i)). Hence, T8, whose associated rib normally does not touch the sternum, appeared to have been transformed to a morphology characteristic of a more anterior thoracic vertebra, and L1 appeared to have been transformed to a morphology characteristic of a posterior thoracic vertebra. Other abnormalities indicative of anterior transformations were also seen to varying degrees in heterozygous mice. These included a shift of the long spinous process characteristic of T2 by one segment to T3, a shift of the articular and spinous processes from T10 to T11, a shift of the anterior tuberculus on C6 to C7, and transformation of T2 to T1 where the rib associated with T2 touched the top of the sternum.

[0157] In order to understand the basis for the abnormalities in axial patterning seen in GDF-11 mutant mice, we examined mutant embryos isolated at various stages of development and compared them to wild-type embryos. By gross morphological examination, homozygous mutant embryos isolated up to day 9.5 of gestation were not readily distinguishable from corresponding wild-type embryos. In particular, the number of somites present at any given developmental age was identical between mutant and wild-type embryos, suggesting that the rate of somite formation was unaltered in the mutants. By day 10.5-11.5 p.c., mutant embryos could be easily distinguished from wild-type embryos by the posterior displacement of the hindlimb by 7-8 somites. The abnormalities in tail development were also readily apparent at this stage. Taken together, these data suggest that the abnormalities observed in the mutant skeletons represented true transformations of segment identities rather than the insertion of additional segments, for example, by an enhanced rate of somitogenesis.

[0158] Alterations in expression of homeobox containing genes are known to cause transformations in *Drosophila* and in vertebrates. To see if the expression patterns of Hox genes (the vertebrate homeobox containing genes) were altered in GDF-11 null mutants we determined the expression pattern of 3 representative Hox genes, Hoxc-6, Hoxc-8 and Hoxc-11, in day 12.5 p.c. wild-type, heterozygous and homozygous mutant embryos by whole mount in situ hybridization. The expression pattern of Hoxc-6 in wild-type embryos spanned prevertebrae 8-15 which correspond to thoracic segments T1-T8. In homozygous mutants, however, the Hoxc-6 expression pattern was shifted posteriorly and expanded to prevertebrae 9-18 (T2-T11). A similar shift was seen with the Hoxc-8 probe. In wild-type embryos, Hoxc-8 was expressed in prevertebrae 13-18 (T6-T11) but, in homozygous mutant embryos, Hoxc-8 was expressed in prevertebrae 14-22 (T7-T15). Finally, Hoxc-11 expression was also shifted posteriorly in that the anterior boundary of expression changed from prevertebrae 28 in wild-type embryos to prevertebrae 36 in mutant embryos. (Note that because the position of the hindlimb is also shifted posteriorly in mutant embryos, the Hoxc-11 expression patterns in wild-type and mutant appeared similar relative to the hindlimbs). These data provide further evidence that the skeletal abnormalities seen in mutant animals represent homeotic transformations.

[0159] The phenotype of GDF-11 mice suggested that GDF-11 acts early during embryogenesis as a global regulator of axial patterning. To begin to examine the mechanism by which GDF-11 exerts its effects, we determined the expression pattern of GDF-11 in early mouse embryos by whole mount in situ hybridization. At these stages the primary sites of GDF-11 expression correlated precisely with the known sites at which mesodermal cells are generated. Expression of GDF-11 was first detected at day 8.25-8.5 p.c. (8-10 somites) in the primitive streak region, which is the site at which ingressing cells form the mesoderm of the developing embryo. Expression was maintained in the primitive streak at day 8.75, but by day 9.5 p.c., when the tail bud replaces the primitive streak as the source of new mesodermal cells, expression of GDF-11 shifted to the tail bud. Hence at these early stages, GDF-11 appears to be synthesized in the region of the developing embryo where new mesodermal cells arise and presumably acquire their positional identity.

[0160] The phenotype of GDF-11 knockout mice in several respects resembles the phenotype of mice carrying a

deletion of a receptor for some members of the TGF- β superfamily, the activin type IIB receptor (ActRIIB). As in the case of GDF-11 knockout mice, the ActRIIB knockout mice have extra pairs of ribs and a spectrum of kidney defects ranging from hypoplastic kidneys to complete absence of kidneys. The similarity in the phenotypes of these mice raises the possibility that ActRIIB may be a receptor for GDF-11. However, ActRIIB cannot be the sole receptor for GDF-11 because the phenotype of GDF-11 knockout mice is more severe than the phenotype of ActRIIB mice. For example, whereas the GDF-11 knockout animals have 4-5 extra pairs of ribs and show homeotic transformations throughout the axial skeleton, the ActRIIB knockout animals have only 3 extra pairs of ribs and do not show transformations at other axial levels. In addition, the data indicate that the kidney defects in the GDF-11 knockout mice are also more severe than those in ActRIIB knockout mice. The ActRIIB knockout mice show defects in left/right axis formation, such as lung isomerism and a range of heart defects that we have not yet observed in GDF-11 knockout mice. ActRIIB can bind the activins and certain BMPs, although none of the knockout mice generated for these ligands show defects in left/right axis formation.

[0161] If GDF-11 does act directly on mesodermal cells to establish positional identity, the data presented here would be consistent with either short range or morphogen models for GDF-11 action. That is, GDF-11 may act on mesodermal precursors to establish patterns of Hox gene expression as these cells are being generated at the site of GDF-11 expression, or alternatively, GDF-11 produced at the posterior end of the embryo may diffuse to form a morphogen gradient. Whatever the mechanism of action of GDF-11 may be, the fact that gross anterior/posterior patterning still does occur in GDF-11 knockout animals suggests that GDF-11 may not be the sole regulator of anterior/posterior specification. Nevertheless, it is clear that GDF-11 plays an important role as a global regulator of axial patterning and that further study of this molecule will lead to important new insights into how positional identity along the anterior/posterior axis is established in the vertebrate embryo.

[0162] Although the invention has been described with reference to the presently preferred embodiment, it should be understood that various modifications can be made without departing from the spirit of the invention. Accordingly, the invention is limited only by the following claims.

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Ile	Ile	Ala	Pro	Lys	Arg	Tyr	Lys	Ala	Asn	Tyr	Cys	Ser	Gly	Gln	Cys		
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Cys	Cys	His	Phe	His	Phe	Ser	Pro	Lys	Val	Met	Phe	Thr	Lys	Val	Leu
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Val	Tyr	Leu	Gln	Ile	Leu	Arg	Leu	Lys	Pro	Leu	Thr	Gly	Glu	Gly	Thr
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Tyr	Pro	His	Thr	His	Leu	Val	Gln	Gln	Ala	Asn	Pro	Arg	Gly	Ser	Ala
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Gly	Pro	Cys	Cys	Thr	Pro	Thr	Lys	Met	Ser	Pro	Ile	Asn	Met	Leu	Tyr
	370						375				380				
Phe	Asn	Asp	Lys	Gln	Gln	Ile	Ile	Tyr	Gly	Lys	Ile	Pro	Gly	Met	Val
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Val	Asp	Arg	Cys	Gly	Cys	Ser									
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<211> LENGTH: 23

<212> TYPE: DNA

<213> ORGANISM: Artificial sequence

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<220> FEATURE:

<223> OTHER INFORMATION: Primer for PCR

<400> SEQUENCE: 7

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<210> SEQ ID NO 8

<211> LENGTH: 23

<212> TYPE: DNA

<213> ORGANISM: Artificial sequence

<220> FEATURE:

<223> OTHER INFORMATION: Primer for PCR

<400> SEQUENCE: 8

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23

<210> SEQ ID NO 9

<211> LENGTH: 20

<212> TYPE: DNA

<213> ORGANISM: Artificial sequence

<220> FEATURE:

<223> OTHER INFORMATION: Oligonucleotide probe for GDF-11

<400> SEQUENCE: 9

aaatatccgc ataccattt

20

<210> SEQ ID NO 10

<211> LENGTH: 376

<212> TYPE: PRT

<213> ORGANISM: Mouse

<400> SEQUENCE: 10

Met Met Gln Lys Leu Gln Met Tyr Val Tyr Ile Tyr Leu Phe Met Leu
1 5 10 15Ile Ala Ala Gly Pro Val Asp Leu Asn Glu Gly Ser Glu Arg Glu Glu
20 25 30Asn Val Glu Lys Glu Gly Leu Cys Asn Ala Cys Ala Trp Arg Gln Asn
35 40 45Thr Arg Tyr Ser Arg Ile Glu Ala Ile Lys Ile Gln Ile Leu Ser Lys
50 55 60Leu Arg Leu Glu Thr Ala Pro Asn Ile Ser Lys Asp Ala Ile Arg Gln
65 70 75 80Leu Leu Pro Arg Ala Pro Pro Leu Arg Glu Leu Ile Asp Gln Tyr Asp
85 90 95Val Gln Arg Asp Asp Ser Ser Asp Gly Ser Leu Glu Asp Asp Asp Tyr
100 105 110His Ala Thr Thr Glu Thr Ile Ile Thr Met Pro Thr Glu Ser Asp Phe
115 120 125Leu Met Gln Ala Asp Gly Lys Pro Lys Cys Cys Phe Phe Lys Phe Ser
130 135 140Ser Lys Ile Gln Tyr Asn Lys Val Val Lys Ala Gln Leu Trp Ile Tyr
145 150 155 160Leu Arg Pro Val Lys Thr Pro Thr Thr Val Phe Val Gln Ile Leu Arg
165 170 175Leu Ile Lys Pro Met Lys Asp Gly Thr Arg Tyr Thr Gly Ile Arg Ser
180 185 190

Leu Lys Leu Asp Met Ser Pro Gly Thr Gly Ile Trp Gln Ser Ile Asp

-continued

195						200						205					
Val	Lys	Thr	Val	Leu	Gln	Asn	Trp	Leu	Lys	Gln	Pro	Glu	Ser	Asn	Leu		
210						215						220					
Gly	Ile	Glu	Ile	Lys	Ala	Leu	Asp	Glu	Asn	Gly	His	Asp	Leu	Ala	Val		
225				230						235				240			
Thr	Phe	Pro	Gly	Pro	Gly	Glu	Asp	Gly	Leu	Asn	Pro	Phe	Leu	Glu	Val		
			245						250			255					
Lys	Val	Thr	Asp	Thr	Pro	Lys	Arg	Ser	Arg	Arg	Asp	Phe	Gly	Leu	Asp		
			260						265			270					
Cys	Asp	Glu	His	Ser	Thr	Glu	Ser	Arg	Cys	Cys	Arg	Tyr	Pro	Leu	Thr		
			275						280			285					
Val	Asp	Phe	Glu	Ala	Phe	Gly	Trp	Asp	Trp	Ile	Ile	Ala	Pro	Lys	Arg		
290						295						300					
Tyr	Lys	Ala	Asn	Tyr	Cys	Ser	Gly	Glu	Cys	Glu	Phe	Val	Phe	Leu	Gln		
305				310						315				320			
Lys	Tyr	Pro	His	Thr	His	Leu	Val	His	Gln	Ala	Asn	Pro	Arg	Gly	Ser		
			325						330			335					
Ala	Gly	Pro	Cys	Cys	Thr	Pro	Thr	Lys	Met	Ser	Pro	Ile	Asn	Met	Leu		
			340			345						350					
Tyr	Phe	Asn	Gly	Lys	Glu	Gln	Ile	Ile	Tyr	Gly	Lys	Ile	Pro	Ala	Met		
			355			360						365					
Val	Val	Asp	Arg	Cys	Gly	Cys	Ser										
370						375											

1. A method of producing animal food products having an increased number of ribs comprising:

- introducing a transgene disrupting or interfering with expression of growth differentiation factor-11 (GDF-11) into an embryo into germ cells of a pronuclear embryo of the animal;
- implanting the embryo into the oviduct of a pseudopregnant female thereby allowing the embryo to mature to full term progeny;
- testing the progeny for presence of the transgene to identify transgene-positive progeny;
- cross-breeding transgene-positive progeny to obtain further transgene-positive progeny; and
- processing the progeny to obtain foodstuff.

2. The method of claim 1, wherein the transgene comprises GDF-11 antisense polynucleotides.

3. The method of claim 1, wherein the transgene comprises a gene encoding a dominant negative GDF-11 polypeptide.

4. A method of producing avian, porcine or bovine food products having an increased number of ribs comprising:

- introducing a transgene disrupting or interfering with expression of growth differentiation factor-11 (GDF-11) into an embryo of an avian, porcine or bovine animal;

- culturing the embryo under conditions whereby progeny are hatched;

- testing the progeny for presence of the transgene to identify transgene-positive progeny;

- cross-breeding transgene-positive progeny; and

- processing the progeny to obtain foodstuff.

5. The method of claim 4, wherein the transgene comprises GDF-11 antisense polynucleotides.

6. The method of claim 4, wherein the transgene comprises a gene encoding a dominant negative GDF-11 polypeptide.

7. The transgenic animal of claim 4, wherein the transgene comprises a polynucleotide encoding a truncated GDF-11 polypeptide.

8. A method of treating a chronic or acute renal disease in a subject having such a disease, comprising:

administering to the subject, a reagent which affects GDF-11 activity or expression.

9. The method of claim 8, wherein the reagent is an agonist of GDF-11.

10. The method of claim 8, wherein the reagent is an antagonist of GDF-11.

11. The method of claim 10, wherein the antagonist is an antibody to GDF-11.

12. The method of claim 10, wherein the antagonist is an antisense polynucleotide to GDF-11.

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