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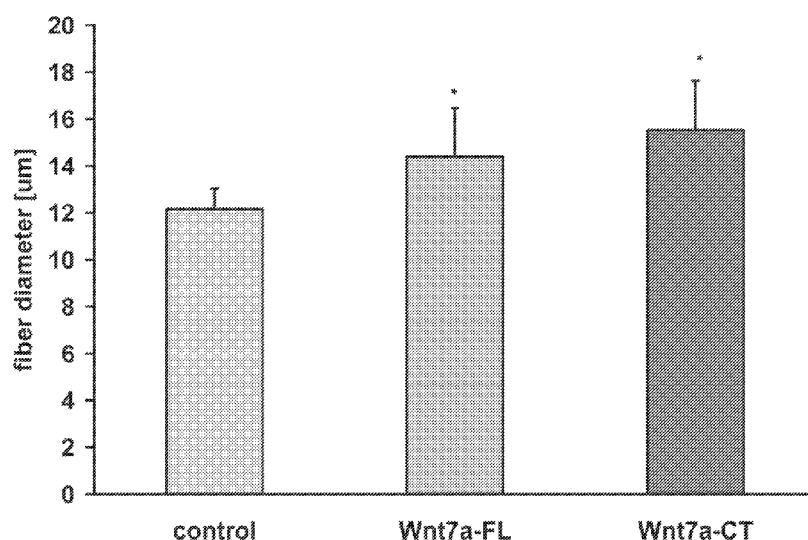
(54) **Title:** WNT7A COMPOSITIONS AND METHODS OF USING THE SAME

FIG. 6

(57) **Abstract:** There are provided compositions and methods for modulating stem cell division, in particular, division symmetry. It has been demonstrated that Wnt7a polypeptide fragments promoting symmetrical expansion of stem cells. The compositions and methods of the invention are useful, for example, in modulating stem cell division symmetry in vitro, ex vivo, and in vivo, in replenishing and expanding the stem cell pool, and in promoting the formation, maintenance, repair and regeneration of tissue.

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WNT7A COMPOSITIONS AND METHODS OF USING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application No. 61/535,915, filed September 16, 2011, which is herein incorporated by reference in its entirety.

STATEMENT REGARDING SEQUENCE LISTING

The Sequence Listing associated with this application is provided in text format in lieu of a paper copy, and is hereby incorporated by reference into the specification. The name of the text file containing the Sequence Listing is FATE_110_01WO_ST25.txt. The text file is 122 KB, was created on September 13, 2012, and is being submitted electronically via EFS-Web.

BACKGROUND

Technical Field

The present invention relates generally to compositions and methods for modulating stem cells, in particular, stem cell division symmetry, and uses thereof.

Description of the Related Art

Stem cells are undifferentiated or immature cells that are capable of giving rise to multiple specialized cell types and ultimately, to terminally differentiated cells. Most adult stem cells are lineage-restricted and are generally referred to by their tissue origin. Unlike any other cells, stem cells are able to renew themselves such that a virtually endless supply of mature cell types can be generated when needed over the lifetime of an organism. Due to this capacity for self-renewal, stem cells are therapeutically useful for the formation, regeneration, repair and maintenance of tissues.

It has recently been determined that satellite cells represent a heterogeneous population composed of stem cells and small mononuclear progenitor cells found in mature muscle tissue (Kuang *et al.*, 2007). Satellite cells in adult skeletal muscle are located in small

depressions between the sarcolemma of their host myofibers and the basal lamina. Satellite cells are involved in the normal growth of muscle, as well as the regeneration of injured or diseased tissue. In undamaged muscle, the majority of satellite cells are quiescent, meaning they neither differentiate nor undergo cell division. Satellite cells express a number of distinctive genetic markers, including the paired-box transcription factor Pax7, which plays a central regulatory role in satellite cell function and survival (Kuang *et al.*, 2006; Seale *et al.*, 2000). Pax7 can thus be used as a marker of satellite cells.

Upon damage, such as physical trauma or strain, repeated exercise, or in disease, satellite cells become activated, proliferate and give rise to a population of transient amplifying progenitors, which are myogenic precursors cells (myoblasts) expressing myogenic regulatory factors (MRF), such as MyoD and Myf5. In the course of the regeneration process, myoblasts undergo multiple rounds of division before committing to terminal differentiation, fusing with the host fibers or generating new myofibers to reconstruct damaged tissue (Charge and Rudnicki, 2004). In several diseases and conditions affecting muscle, a reduction in muscle mass is seen that is associated with reduced numbers of satellite cells and a reduced ability of the satellite cells to repair, regenerate and grow skeletal muscle. A few exemplary diseases and conditions affecting muscle include wasting diseases, such as cachexia, muscular attenuation or atrophy, including sarcopenia, ICU-induced weakness, surgery-induced weakness (*e.g.*, following knee or hip replacement), and muscle degenerative diseases, such as muscular dystrophies. The process of muscle regeneration involves considerable remodeling of extracellular matrix and, where extensive damage occurs, is incomplete. Fibroblasts within the muscle deposit scar tissue, which can impair muscle function, and is a significant part of the pathology of muscular dystrophies.

Muscular dystrophies are genetic diseases characterized by progressive weakness and degeneration of the skeletal or voluntary muscles which control movement. The muscles of the heart and some other involuntary muscles are also affected in some forms of muscular dystrophy. In many cases, the histological picture shows variation in fiber size, muscle cell necrosis and regeneration, and often proliferation of connective and adipose tissue. The progressive muscular dystrophies include at least Duchenne muscular dystrophy (DMD), Becker muscular dystrophy (BMD), Emery-Dreifuss muscular dystrophy, Landouzy-Dejerine muscular dystrophy, facioscapulohumeral muscular dystrophy (FSH), Limb-Girdle

muscular dystrophies, von Graefe-Fuchs muscular dystrophy, oculopharyngeal muscular dystrophy (OPMD), Myotonic dystrophy (Steinert's disease) and congenital muscular dystrophies.

Currently there is no cure for these diseases, but certain medications and therapies have been shown to be effective. For instance, corticosteroids have been shown to slow muscle destruction in Duchene muscular dystrophy patients. While corticosteroids can be effective in delaying progression of the disease in many patients, long-term corticosteroid use is undesirable due to unwanted side effects.

PCT Application No. WO 2004/113513 (Rudnicki *et al.*) discloses methods and compositions for modulating proliferation or lineage commitment of an atypical population of CD45⁺Sca1⁺ stem cells, located outside the satellite stem cell compartment, by modulating myogenic determination of Wnt proteins.

The Wnt family of genes encode over twenty cysteine-rich, secreted Wnt glycoproteins that act by binding to Frizzled (Fzd) receptors on target cells. Frizzled receptors are a family of G-protein coupled receptor proteins. Binding of different members of the Wnt-family to certain members of the Fzd family can initiate signaling by one of several distinct pathways. In the termed canonical pathway, activation of the signaling molecule, Disheveled, leads to the inactivation of glycogen synthase kinase-3 (GSK-3 β), a cytoplasmic serine-threonine kinase. The GSK-3 β target, β -catenin, is thereby stabilized and translocates to the nucleus where it activates TCF (T-cell-factor)-dependant transcription of specific promoters (Wodarz, 1998, Dierick, 1999). In the non-canonical, or planar cell polarity (PCP) pathway, binding of Wnt to Fzd also activates Disheveled, which in this case activates RhoA, a small G protein. Activation of the PCP pathway does not result in nuclear translocation of β -catenin.

Wnt signaling plays a key role in regulating developmental programs through embryonic development, and in regulating stem cell function in adult tissues (Clevers, 2006). Wnts have been demonstrated to be necessary for embryonic myogenic induction in the paraxial mesoderm (Borello *et al.*, 2006; Chen *et al.*, 2005; Tajbakhsh *et al.*, 1998), as well in the control of differentiation during muscle fiber development (Anakwe *et al.*, 2003). Recently, the Wnt planar cell polarity (PCP) pathway has been implicated in regulating elongation of differentiating myocytes in the developing myotome (Gros *et al.*, 2009). In the

adult, Wnt signaling is necessary for the myogenic commitment of adult CD45⁺/Sca1⁺ stem cells in muscle tissue following acute damage (Polesskaya *et al.*, 2003; Torrente *et al.*, 2004). Other studies suggest that canonical Wnt/ β -catenin signaling regulates myogenic differentiation through activation and recruitment of reserve myoblasts. In addition, Wnt/ β -catenin signaling in satellite cells within adult muscle appears to control myogenic lineage progression by limiting Notch signaling and thus promoting differentiation. Thus, traditionally, it has been assumed that Wnt proteins act as stem cell growth factors, promoting the proliferation and differentiation of stem cells and/or progenitor cells.

This has established a potential role for Wnts in the treatment of myodegenerative diseases. However, the poor protein solubility of Wnts has hindered their use in recombinant protein therapy. In addition, Wnt proteins are lipidated during posttranscriptional processing prior to secretion and contain a vast number of hydrophobic amino acid residues, leading to low water solubility and resultantly deterring systemic delivery. Thus, current strategies for delivering Wnts, such as Wnt7a, for example, limit the use of Wnt polypeptide therapies for treating myodegenerative diseases.

Accordingly, there is a need in the art for modified Wnt polypeptides having increased solubility and bioavailability to effectively treat myodegenerative diseases.

BRIEF SUMMARY

The present invention generally provides Wnt polypeptide fragments, and Wnt polypeptides or fragments thereof in combination with fibronectin. In addition, the present invention also provides methods for modulating stem cells, in particular, stem cell division symmetry using the Wnt7a polypeptides and compositions disclosed herein.

In one embodiment, the present invention contemplates, in part, a composition for increasing the symmetric expansion of a stem cell comprising a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5.

In another embodiment, the present invention contemplates, in part, composition for increasing the symmetric expansion of a stem cell comprising an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3.

In a particular embodiment, the composition comprises a polynucleotide encoding a Wnt7a polypeptide according to any of the preceding embodiments.

In a certain embodiment, the polynucleotide comprises an expression vector.

In an additional embodiment, the composition comprises a stem cell or a population of stem cells.

In a further additional embodiment, the composition comprises one or more stem cell modulators.

In a particular additional embodiment, the modulator further increases the rate of stem cell division.

In a certain additional embodiment, the modulator comprises FGF.

In one embodiment, the stem cell is an adult stem cell.

In a particular embodiment, the adult stem cell is a satellite stem cell.

In various embodiments, any of the preceding compositions promote tissue formation, regeneration, maintenance or repair.

In a particular embodiment, the tissue is muscle.

In one particular embodiment, the muscle is skeletal muscle.

In one embodiment, the present invention contemplates, in part, a composition for enhancing tissue formation, regeneration or repair in a mammal comprising as an active agent (a) a Wnt7a polypeptide comprising the amino acid sequence set forth in SEQ ID NO: 3 and further comprising an N-terminal deletion of 210 to 219 amino acids, or (b) a polynucleotide encoding a Wnt7a polypeptide comprising the amino acid sequence set forth in (a).

In another embodiment, the present invention contemplates, in part, a composition for enhancing tissue formation, regeneration or repair in a mammal comprising as an active agent (a) a Wnt7a polypeptide fragment comprising the amino acid sequence set forth in SEQ ID NO: 5, or (b) a polynucleotide encoding a Wnt7a polypeptide comprising the amino acid sequence set forth in SEQ ID NO: 5.

In a particular embodiment, the composition comprises a physiologically acceptable carrier or diluent.

In a certain embodiment, the composition is formulated for injection.

In a certain particular embodiment, the composition is formulated for one or more of intravenous injection, intramuscular injection, intracardiac injection, subcutaneous injection, or intraperitoneal injection.

In a further embodiment, the composition is for promoting formation, maintenance, repair or regeneration of skeletal muscle in a human subject in need thereof.

In an additional embodiment, the subject has, is suspected of having, or is at risk of having, a degenerative disease.

In a related embodiment, the degenerative disease is a muscular dystrophy.

In a particular related embodiment, the muscular dystrophy selected from Duchenne muscular dystrophy (DMD), Becker muscular dystrophy (BMD), Emery- Dreifuss muscular dystrophy, Landouzy-Dejerine muscular dystrophy, facioscapulohumeral muscular dystrophy (FSH), Limb-Girdle muscular dystrophies, von Graefe-Fuchs muscular dystrophy, oculopharyngeal muscular dystrophy (OPMD), Myotonic dystrophy (Steinert's disease) and congenital muscular dystrophies.

In one embodiment, the subject has, is suspected of having, or is at risk of having a disease or condition affecting muscle.

In an additional embodiment, the disease or condition affecting muscle is a wasting disease (*e.g.*, cachexia, which may be associated with an illness such as cancer or AIDS), muscular attenuation or atrophy (*e.g.*, sarcopenia, which may be associated with aging), ICU-induced weakness, prolonged disuse (*e.g.*, coma, injury, paralysis), surgery-induced weakness (*e.g.*, following hip or knee replacement), or a muscle degenerative disease (*e.g.*, muscular dystrophy).

In a further embodiment, subject has, is suspected of having, or is at risk of developing muscle wasting or atrophy associated with injury or illness.

In another embodiment, the present invention contemplates, in part, a composition for synergistically increasing the symmetric expansion of a stem cell comprising: (a) a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; (b) a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5; or (c) a Wnt7a polypeptide fragment having an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; and (d) a fibronectin polypeptide.

In a particular embodiment, the composition comprises a polynucleotide encoding (a) a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; (b) a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5; or (c) a Wnt7a polypeptide fragment having an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; and a polynucleotide encoding a fibronectin polypeptide.

In a certain embodiment, the composition comprises a Wnt7a polynucleotide and a fibronectin polynucleotide, wherein each polynucleotide comprises an expression vector.

In a certain particular embodiment, the composition comprises a stem cell or a population of stem cells.

In a related particular embodiment, the stem cell is an adult stem cell.

In a further particular embodiment, the adult stem cell is a satellite stem cell.

In an additional particular embodiment, the composition comprising a Wnt7a polypeptide or polynucleotide and a fibronectin polypeptide and polynucleotide is for promoting tissue formation, regeneration, maintenance or repair.

In one embodiment, the tissue is muscle.

In a related embodiment, the muscle is skeletal muscle.

In a particular embodiment, the composition comprises a physiologically acceptable carrier or diluent.

In a certain embodiment, the composition is formulated for injection.

In a certain particular embodiment, the composition is formulated for one or more of intravenous injection, intramuscular injection, intracardiac injection, subcutaneous injection, or intraperitoneal injection.

In an additional particular embodiment, the composition comprising a Wnt7a polypeptide or polynucleotide and a fibronectin polypeptide and polynucleotide is for promoting formation, maintenance, repair or regeneration of skeletal muscle in a human subject in need thereof.

In one embodiment, the subject has, is suspected of having, or is at risk of having, a degenerative disease.

In one embodiment, the present invention contemplates, in part, a method for increasing the symmetric expansion of a stem cell comprising contacting the stem cells with a composition comprising a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5, or an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3.

In another embodiment, the present invention contemplates, in part, a method for increasing the symmetric expansion of a stem cell comprising contacting the stem cells with a composition comprising a polynucleotide encoding Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5, or an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3.

In one embodiment, the polynucleotide comprises an expression vector.

In a particular embodiment, the composition comprises a population of stem cells.

In a certain embodiment, the composition is administered to a subject in need thereof.

In a further embodiment, the stem cells are adult stem cells

In an additional embodiment, the adult stem cells comprise satellite stem cells.

In another embodiment, the composition comprises a physiologically acceptable carrier or diluent.

In one embodiment, the composition is formulated for injection.

In an additional embodiment, the method promotes tissue formation, regeneration maintenance, or repair.

In a particular embodiment, the tissue is muscle.

In a further embodiment, the muscle is skeletal muscle.

In a certain embodiment, the method promotes formation, maintenance, repair or regeneration of skeletal muscle in a human subject in need thereof.

In one particular embodiment, the subject has a degenerative disease.

In a related particular embodiment, the degenerative disease is a muscular dystrophy.

In one embodiment, the present invention contemplates, in part, a method for promoting muscle formation, regeneration, maintenance or repair in a mammal comprising administering to the mammal a therapeutically effective amount of a composition as defined in any one of the embodiments disclosed herein.

In a particular embodiment, the present invention contemplates, in part, a method for preventing muscle wasting, atrophy or degeneration in a subject in need thereof comprising administering to the subject a therapeutically effective amount of a composition as defined in any one of the embodiments disclosed herein.

In a certain embodiment, the present invention contemplates, in part, a method for expanding a population of satellite stem cells *in vivo*, *ex vivo*, or *in vitro* comprising contacting the stem cells with an effective amount of a composition as defined in any one of the embodiments disclosed herein.

In another embodiment, the present invention contemplates, in part, a method for synergistically increasing the symmetric expansion of a stem cell comprising contacting the stem cells with a composition comprising: (a) a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; (b) a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5; or (c) a Wnt7a polypeptide fragment having an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; and (d) a fibronectin polypeptide.

In another embodiment, the present invention contemplates, in part, a method for synergistically increasing the symmetric expansion of a stem cell comprising contacting the stem cells with a composition comprising: (a) a polynucleotide a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; (a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5; or a Wnt7a polypeptide fragment having an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; and (b) a polynucleotide encoding a fibronectin polypeptide.

In one embodiment, each polynucleotide comprises an expression vector.

In a particular embodiment, the composition comprises a population of stem cells.

In an additional particular embodiment, the composition is administered to a subject in need thereof.

In a certain particular embodiment, the stem cells are adult stem cells

In a further particular embodiment, the adult stem cells comprise satellite stem cells.

In a related particular embodiment, the composition comprises a physiologically acceptable carrier or diluent.

In a certain embodiment, the composition is formulated for injection.

In a certain further embodiment, the method promotes tissue formation, regeneration maintenance, or repair.

In a certain additional embodiment, the tissue is muscle.

In one certain embodiment, the muscle is skeletal muscle.

In an additional embodiment, the method promotes formation, maintenance, repair or regeneration of skeletal muscle in a human subject in need thereof.

In a particular embodiment, the subject has a degenerative disease.

In a further embodiment, the degenerative disease is a muscular dystrophy.

In one embodiment, the present invention contemplates, in part, a method for promoting muscle formation, regeneration, maintenance or repair in a mammal comprising administering to the mammal a therapeutically effective amount of a composition comprising a Wnt7a polynucleotide or polypeptide fragment or a Wnt7a polynucleotide or polypeptide or fragment thereof and a fibronectin polynucleotide or polypeptide according to any one of the embodiments disclosed herein.

In a particular embodiment, the present invention contemplates, in part, a method for preventing muscle wasting, atrophy or degeneration in a subject in need thereof comprising administering to the subject a therapeutically effective amount of a composition comprising a Wnt7a polynucleotide or polypeptide fragment or a Wnt7a polynucleotide or polypeptide or fragment thereof and a fibronectin polynucleotide or polypeptide according to any one of the embodiments disclosed herein.

In another embodiment, the present invention contemplates, in part, a method for expanding a population of satellite stem cells *in vivo*, *ex vivo*, or *in vitro* comprising contacting the stem cells with an effective amount of a composition comprising a Wnt7a

polynucleotide or polypeptide fragment or a Wnt7a polynucleotide or polypeptide or fragment thereof and a fibronectin polynucleotide or polypeptide according to any one of the embodiments disclosed herein.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Figure 1 show an *in-silico* protein modeling of Wnt7a that predicts two distinct protein domains. (A) Protein modeling with I-TASSER software predicts the presence of a helicoid N-terminal region and globular C-terminal region in Wnt7a tertiary protein structure. (B) Kyte-Doolittle hydropathy plot of amino acid hydrophobicity reveals a concentration of hydrophobic residues in the N-terminal domain and an almost exclusively hydrophilic C-terminal domain.

Figure 2 shows a computer screen snapshot of 3D Molecule Viewer's rendering of Wnt7a structure. Wnt7a was divided in two regions: the N-terminal region (amino acids 32-212) and the globular C-terminal region (amino acids 213-349). The corresponding amino acid sequence is shown in the bottom panel. Truncated Wnt7a polypeptides representing the two suggested domains were prepared.

Figure 3 shows that the C-terminal domain of Wnt7a is sufficient and necessary to induce myofiber hypertrophy. (A) Weight of mouse tibialis anterior (TA) muscles electroporated with 17.5µg of vector encoding a truncated, C-terminal Wnt7a-HA tagged polypeptide (Wnt7a CT; lacks N-terminal domain), a full-length Wnt7a (Wnt7a FL), or a truncated, N-terminal (Wnt7a NT; lacks C-terminal domain). TA muscles that were electroporated with Wnt7a CT or Wnt7a FL were heavier compared to LacZ or Wnt7a NT electroporated muscle six days after electroporation. (B) Wnt7a CT induces hypertrophy (measured as an increase in muscle fiber diameter) in electroporated muscle fibers, while Wnt7a NT electroporated fibers do not differ from the LacZ control.

Figure 4 shows X-Gal staining in muscles electroporated with Wnt7a constructs. X-Gal staining for LacZ in TA muscle electroporated with 17.5µg of (A) LacZ (B) Wnt7a FL, (C) Wnt7a NT or (D) Wnt7a CT indicates that all constructs had similar electroporation efficiency. Scale bar is 200µm.

Figure 5 shows that the Wnt7a CT polypeptide has increased biodistribution. A), B), and C) Myofibers expressing were stained with an antibody recognizing Wnt7a;

Wnt7a CT expressing fibers are larger, and comprise a greater portion of total muscle fibers than the Wnt7a FL or Wnt7a NT expressing fibers. Scale bar is 500 μ m. (D) Lysate from electroporated muscles shows comparable levels of Wnt expression for LacZ, Wnt7a FL, Wnt7a CT, and Wnt7a NT.

Figure 6 shows the effect on muscle fiber diameter in C2C12 cells cultured for two days with concentrated supernatant from COS cells expressing Wnt7a CT, Wnt7a FL, or control supernatant.

Figure 7 shows the effect on muscle fiber diameter in C2C12 cells cultured for two days with concentrated supernatant from COS cells expressing Wnt7a CT, Wnt7a FL, a Wnt7a C73A mutant, or control supernatant.

Figure 8 shows the microarray-based identification of FN as an ECM molecule that is transiently expressed by satellite cells during their activation. A) Microarray heat map from proliferating myoblasts (Prol.) and 2 or 5 day differentiated (2d diff. / 5d diff.) myofibers. The probe for FN (Fn1) shows the highest signal in proliferating myogenic cells, but substantially downregulated during differentiation. Signal intensities represent the average of N=3 microarrays per condition. B) Quiescent satellite cells which were directly fixed after fiber isolation, only express marginal amounts of FN, whereas proliferating activated satellite cells after 48 hours of fiber culture express high levels of FN. Scale bar = 2.5 μ m. C) Regeneration time course after CTX injury of the TA muscle. FN expression increases at day 5 after CTX compared to the ECM component Lm. Scale bar = 50 μ m. D) qPCR from whole muscle cDNA at the given time points after CTX injury. The expression of FN correlates with Pax7. Data points represent means $\pm$ SEM. n=3. “no injury” was set to 100% for both genes. E) In homeostatic muscle tissue satellite cells are found in close proximity of FN rich areas. Upon injury the muscle is saturated with FN and the satellite cells are embedded within it. Arrows denote Pax7⁺ satellite cells. Scale bar = 50 μ m. F) Microarray heat map representing ECM genes from quiescent satellite cells (Quie.), proliferating myoblasts (Prol.) and 2 or 5 day differentiated (2d diff. / 5d diff.) myofibers. The probe for FN (Fn1) shows the highest signal in proliferating myogenic cells and is substantially lower in Quie. and diff. (Asterisk). Signal intensities represent the average of n=3 microarrays per condition for Prol. and diff. and n=1 microarray for Quie.

Figure 9 shows the microarray based identification of Sdc4 as a candidate receptor for FN on satellite cells and as a component involved in myogenic Wnt signaling.

A) Heat map of microarray data from proliferating myoblasts representing all integrin subunits as well as Syndecans. Sdc4 has the strongest signal while putative FN binding integrin combinations are expressed at lower levels. Signal intensities represent the average of N=3 microarrays per condition. B) qPCR from proliferating myoblasts (Prol.) and 2 or 4 day differentiated (2d diff. / 4d diff.) myofibers comparing Sdc4 expression to the expression of Itga5. Bars represent means $\pm$ SEM. n=3. p values are ***p < 0.001; **p < 0.01. C) Sdc4 colocalizes with FN on proliferating satellite cells. Scale bar = 2.5 μ m. D) Itgb1 does not colocalize with FN on proliferating satellite cells. Scale bar = 2.5 μ m. E) Western blot demonstrating that Sdc4 immunoprecipitates with Wnt7a receptor Fzd7 in mammalian cells. F) Western blot demonstrating that Pax7⁺/YFP⁻ cells express less FN in culture. GAPDH is shown as a loading control. G) In dividing asymmetric satellite cell doublets the Pax7⁺/YFP⁻ cell (asterisk) stains less bright for FN. Scale bar = 2.5 μ m.

Figure 10 shows that Sdc4 and Fzd7 synergize to activate the symmetric expansion of Pax7⁺/YFP⁻ satellite stem cells. A) Myofibers were isolated and cultured for 42 hours in the presence of Collagen (COL), FN, COL and Wnt7a (COL&Wnt7a) or FN and Wnt7a (FN&Wnt7a). FN synergizes with Wnt7a to drive the expansion of Pax7⁺/YFP⁻ cells. Bars represent means $\pm$ SEM. n=4. p values are ***p < 0.001; *p < 0.05. B) Quantification of Pax7⁺/YFP⁻ symmetric divisions after 42 hours in the presence of COL, FN, COL&Wnt7a or FN&Wnt7a. Bars represent means $\pm$ SEM. n=4. p values are **p < 0.01; *p < 0.05. C) Quantification of satellite cell populations after 72 hours in the presence of COL, FN, COL&Wnt7a or FN&Wnt7a. Bars represent means $\pm$ SEM. n=3. p values are **p < 0.01; *p < 0.05. D) Representative pictures illustrating the effect of FN & Wnt7a after 72 hours culture. Arrows indicate Pax7⁺/YFP⁻ cells. Scale bar = 25 μ m. E) and F) Blocking antibodies to Sdc4 prevent the mitogenic effect of Wnt7a on satellite stem cells (α Sdc4&Wnt7a) when compared to an unspecific IgG (IgG&Wnt7a) after 42 hours of fiber culture. Inhibition of Sdc4 also slightly decreased numbers of Pax7⁺/YFP⁺ cells. Bars represent means $\pm$ SEM. n=3. p value is **p < 0.01. G) Quantification of satellite cell populations after 42h of myofiber culture in the presence of PBS vehicle, Tenascin-C (TEN), PBS&Wnt7a or

TEN&Wnt7a. TEN inhibition of FN binding to Sdc4 antagonizes the effect of Wnt7a on satellite stem cells. Bars represent means $\pm$ SEM. n=3. p values is *p < 0.05.

Figure 11 shows that electroporation of Wnt7a with FN increases the amount of satellite stem cells in-situ after 7 days. A) Empty vector (EV), FN, Wnt7a, and FN&Wnt7a were electroporated into muscles of Myf5-LacZ mice. The electro-damage induced regeneration is accompanied by an increase in the amount of Pax7⁺/β-gal⁻ stem cells for Wnt7a and FN&Wnt7a when compared to empty vector. A significant increase in Pax7⁺/β-gal⁻ satellite stem cell numbers can be observed for FN&Wnt7a when compared to Wnt7a alone. . Bars represent means $\pm$ SEM. n=3. p values are ***p < 0.001; **p < 0.01; *p < 0.05. B) Representative pictures illustrating the effect of Wnt7a and FN & Wnt7a. Arrows indicate Pax7⁺/β-gal⁻ satellite stem cells. Scale bar = 50 μm.

Figure 12 shows that exposure of differentiating cells to FN impairs myogenesis. A) Differentiating YFP⁺ cells which have downregulated Pax7 expression decrease FN expression (Arrow). Scale bar = 5 μm. B) qPCR demonstrating that FN expression decreases during myotube formation. Bars represent means $\pm$ SEM. n=3. p values are ***p < 0.001; **p < 0.01. C) Myoblasts were differentiated on either COL or on FN coated plates for 2 days. Impaired myotube formation and expression of Myosin heavy chain (MHC) can be observed for the cells on FN. Mononuclear MHC⁻ cells are abundant in the presence of FN (Arrowheads). Scale bar = 20 μm. D) Significantly fewer MHC⁺ cells were found on FN coated dishes after 2 days of differentiation. Bars represent means $\pm$ SEM. n=3. p value is **p < 0.01. E) Cultured myoblasts express less Myf5 and MyoD after 2 days of differentiation on FN coated dishes when compared to COL coating. Bars represent means $\pm$ SEM. n=3. p values are **p < 0.01; *p < 0.05. F) siRNA knockdown of FN (siFN) from myoblasts before they were differentiated for 1 day facilitates myotube formation and increase MHC levels when compared to the scrambled siRNA control (siScr). Scale bar = 20 μm. H) The fusion index (percentage of nuclei present in myotubes compared to the total number of nuclei) was quantified. Significantly increased myotube formation was observed when FN was knocked down. Bars represent means $\pm$ SEM. n=3. p value is *p < 0.05.

Figure 13 shows that sustained exposure to FN in late stages of muscle regeneration converts satellite cells into myofibroblasts. A) After 21 days of electroporation FN&Wnt7a lead to an accumulation of mononuclear cells in the FN rich periphery of

electroporated fibers when compared to Wnt7a alone. Scale bar = 50 μ m. B) Mononuclear cells in the periphery of FN&Wnt7a expressing fibers are not Pax7⁺. Scale bar = 20 μ m. C) Mononuclear cells in the periphery of FN&Wnt7a expressing fibers stain for alpha smooth muscle actin (α -SMA), a myofibroblast marker. Scale bar = 20 μ m. D) For lineage tracing, satellite cells were irreversibly labeled *in-vivo* with tdTomato prior to EP of FN&Wnt7a. E) Cells which accumulate in the periphery of electroporated fibers are tdTomato positive and therefore satellite cell derived. Scale bar = 20 μ m.

Figure 14 shows that high FN levels in de- and regenerating mdx muscle is accompanied by low levels of committed satellite cells and abundant myofibroblasts. A) The fast TA and the slow Soleus (Sol) muscle of dystrophic mdx mice, were compared for their FN content by immunostaining. Higher levels of FN are found in the Sol of mdx mice. Scale bar = 50 μ m. B) Western blot analysis comparing the absolute FN content of mdx TA and Sol muscles. Similar to the result shown under D, lower levels of FN are found in the TA muscle. α -actinin is shown as a loading control. C) qPCR from whole mdx TA or Sol muscles. Higher levels of FN in the Sol correlate with decreased MyoD expression. Data points represent means $\pm$ SEM. n=4. p values are ***p < 0.001; **p < 0.01. D) Quantification showing that Pax7⁺/MyoD⁺ satellite cells are more abundant in sections from mdx TA when compared to Sol muscles. Data points represent means $\pm$ SEM. n=4. p value is *p < 0.05. E) Quantification showing increased numbers of Pax7⁻/ α -SMA⁺/Vim⁺ myofibroblasts in mdx Sol muscles. Data points represent means $\pm$ SEM. n=3. p value is *p < 0.05.

Figure 15 shows that myoblasts express mainly cellular FN. PCR to detect splice variants of FN1. Proliferating myoblasts express mainly cellular FN1 containing the EIIIA and EIIIB inserts (+). The weaker (-) band reveals that the cells also express low levels of plasma FN1.

Figure 16 shows that qPCR demonstrates lower levels of FN expression in cultured Pax7⁺/YFP⁻ cells. FN alone has no significant effect on satellite cell populations. A) qPCR comparing FN expression of cultured Pax7⁺/YFP⁻ and Pax7⁺/YFP⁺ cells. Lower expression of FN is observed in Pax7⁺/YFP⁻ cells. Bars represent means $\pm$ SEM. n=3 replicates. p value is *p < 0.05. B) Fibers were cultured for 72 hours in the presence of COL

or FN. The presence of FN did not change the proportions of the different satellite cell populations significantly. Bars represent means $\pm$ SEM. n=3 replicates.

Figure 17 shows that mononuclear cells which accumulate in ectopic FN rich areas 21 days after electroporation are not macrophages, granulocytes or killer cells. CD11b staining of sections from muscle that was electroporated with FN&Wnt7a-HA for 21 days or sections through the spleen as a positive control. No CD11b reactivity can be observed in the periphery of the fibers expressing FN&Wnt7a-HA while strong staining is observed in the spleen. Scale bar = 20 μ m.

Figure 18 shows that the Pax7-tdTomato lineage driver specifically labels Pax7 expressing satellite cells whose fusion with myofibers after muscle injury leads to tdTomato expression from myonuclei. A) Satellite cells on fibers that were isolated after tamoxifen induction from Pax7-Cre-ERT-ROSA-tdTomato mice express tdTomato. Scale bar = 20 μ m. B) In tamoxifen induced Pax7-Cre-ERT-ROSA-tdTomato mice myonuclei start to express tdTomato after injury. This is due to the fusion of differentiated labeled satellite cells. Scale bar = 10 μ m.

Figure 19 shows the FN receptor Sdc4 forms a functional complex with Fzd7. A) Co-IP of Sdc4 with the Wnt7a receptor Fzd7 from satellite cell derived primary myoblasts overexpressing (OE) Fzd7-Flag and Sdc4-YFP. Co-IP was performed with an anti-YFP antibody or with an IgG control. B) Proximity ligation assay (PLA) of Sdc4 and Fzd7 in activated satellite cells after 42 hours of fiber culture. No interaction was observed in siSdc4 treated cells. Scale bar = 5 μ m. C) Proximity ligation assay (PLA) of Sdc4 and FN in activated satellite cells after 42 hours of fiber culture. No interaction was observed in siSdc4 treated cells. Scale bar = 5 μ m. D) Co-IP of Fzd7 with FN from satellite cell derived primary myoblasts overexpressing (OE) Fzd7-Flag and FN. Co-IP was performed with an anti-YFP antibody. siRNA knockdown of endogenous Sdc4 (siSdc4) prevented Co-IP of FN with Fzd7 when compared to siSCR. E) Co-IP of Sdc4 with Wnt7a from satellite cell derived primary myoblasts that overexpress (OE) Sdc4-YFP and Wnt7a-HA. Co-IP was performed with an anti-flag antibody. siRNA knockdown of endogenous Fzd7 prevented Co-IP of Sdc4 with Wnt7a. F) Rac1 activation assay. Total Rac1 is shown as a loading control. Densitometric quantification represents average grey values $\pm$ SEM after subtraction of the

background and normalization to total Rac1. The average grey value obtained for empty vector (EV) was set to 100%, n=3, p values are ***p < 0.001, **p < 0.01, *p < 0.05.

Figure 20 shows the effect of FN, TEN and Wnt7a on Pax7⁺/YFP⁺ satellite cells. A) Fibers were cultured for 42h in the presence of COL, FN, COL&Wnt7a or FN&Wnt7a. At this time point no detectable effect was observed on Pax7⁺/YFP⁺ cells. Bars represent means ± SEM. n=3. B) At 72h of fiber culture, FN&Wnt7a led to a slight increase in the number of Pax7⁺/YFP⁺ cells. Bars represent means ± SEM. n=3. p value is *p < 0.05. C) At 42h of culture, PBS, TEN, Wnt7a nor TEN&Wnt7a had no effect on Pax7⁺/YFP⁺ cells. Bars represent means ± SEM. n=3.

Figure 21 shows that activated satellite cells express FN to remodel their niche. A) Quiescent satellite cells were directly fixed after fiber isolation, and expressed marginal amounts of FN, whereas proliferating activated satellite cells expressed higher levels of FN than quiescent cells after 42h of fiber culture. Scale bar = 5 μm. B) FN expression in freshly FACS isolated cells from injured and uninjured muscle. Quiescent satellite cells (QSC) and activated satellite cells (ASC) are compared to non-satellite cells from uninjured (nSC-U) and injured (nSC-I) muscle. Bars represent means ± SEM. n=3. p value is *p < 0.05. C) 42h activated satellite cells were stained with FN antibody before permeabilization (non perm.). Scale bar = 10 μm. D) Activated satellite cells on fibers were directly fixed after isolation from regenerating muscle five days after CTX injury and expressed high levels of FN underneath the intact basal-lamina. Scale bar = 5 μm. E) After 42 hours of culture, satellite stem cells (Pax7⁺/YFP⁺) in dividing asymmetric satellite cell doublets on fibers contained lower levels of FN than the apical satellite myogenic cell (Pax7⁺/YFP⁺). Scale bar = 5 μm. F) Background corrected, pooled average grey values of FN staining from >10 asymmetric divisions (as illustrated in Figure 24A). The area that was densitometrically analyzed for each cell in an individual division was kept constant. The YFP⁺ cell was set to 100% for each individual division.

Figure 22 shows a comparison of expression markers in freshly isolated quiescent and activated cells and FN expression in newly activated satellite cells. A), B) and C) *Pax7*, *MyoD* and *Srpyl* expression in freshly FACS isolated cells from injured and uninjured muscle. Quiescent satellite cells (QSC) and activated satellite cells (ASC) were compared to non-satellite cells from uninjured (nSC-U) and injured (nSC-I) muscle. Bars

represent means $\pm$ SEM. $n=3$. p value are $**p < 0.01$; $*p < 0.05$. D) PCR over the EIIIA and EIIIB splice sites revealed that myogenic cells mostly express cellular FN containing both splice inserts (+). EIIIA and EIIIB negative transcripts are expressed at low levels (-). E) Western blot for FN in gelatin-sepharose treated fiber culture medium confirms removal of pFN from treated medium. F) After 8h of isolation of single fibers, activated satellite cells expressed high levels of FN in pFN free culture conditions. Scale bar = 5 μ m.

Figure 23 shows that knock down of FN in satellite cells impairs their repopulation of muscle. A) FN was knocked down in satellite cells on isolated myofibers in pFN free culture medium for 42h. siFN reduces the number of Pax7⁺/YFP⁺ cells per fiber when compared to the siSCR control. Bars represent means $\pm$ SEM. $n=3$. p values are $**p < 0.01$; $*p < 0.05$. B) siFN reduced the number of symmetric Pax7⁺/YFP⁺ divisions. Bars represent means $\pm$ SEM. $n=3$. p value is $*p < 0.05$. C) Knockdown of FN severely reduced the number of Pax7⁺/YFP⁻ cells per fiber. Bars represent means $\pm$ SEM. $n=3$. p value is $*p < 0.05$. D) No symmetric Pax7⁺/YFP⁻ division was detected (n.d.= none detected) in the siFN condition when compared to siSCR. Bars represent means $\pm$ SEM. $n=3$. E) Freshly FACS purified satellite cells from Pax7-zsGreen mice were transfected with siFN or siSCR and injected into regenerating muscle. Three weeks after transplantation, donor derived cells are observed as zsGreen⁺/Pax7⁺ cells (yellow arrowheads) in host tissue. Scale bar = 50 μ m. F) Knockdown of FN in transplanted satellite cells resulted in a 65% reduction in their number. Only Pax7⁺/zsGreen⁺ donor cells were included in the quantification. Resident Pax7⁺/zsGreen⁻ satellite cells displayed no significant change in their numbers (see Figure 25B). Bars represent means $\pm$ SEM. $n=3$. p value is $*p < 0.05$. G) Whole-muscle knockdown of FN by intramuscular injection of a self-delivering siFN reduced the number of satellite cells by 59% at day ten. Bars represent means $\pm$ SEM. $n=3$. p value is $*p < 0.05$.

Figure 24 shows FN expression in satellite cell subpopulations. A) Representative examples of asymmetric divisions that were densitometrically quantified for immunostaining grey values for FN. The YFP⁺ cell is outlined and the YFP⁻ cell is marked by an asterisk in the picture showing single FN staining for each division. Scale bar = 5 μ m. B) and C) qPCR comparing Myf5 and FN expression in early passages of primary cells derived from Pax7⁺/YFP⁻ and Pax7⁺/YFP⁺ satellite cells. Pax7⁺/YFP⁻ cells expressed lower levels of Myf5 and FN. Bars represent means $\pm$ SEM. $n=3$. p value is $*p < 0.05$. D) Western

blot showing that myoblasts derived from satellite stem cells (Pax7⁺/YFP⁻) expressed less FN than myoblasts derived from satellite myogenic cells (Pax7⁺/YFP⁺). GAPDH is shown as a loading control.

Figure 25 shows the knockdown efficiency of FN siRNA and endogenous satellite cells after transplantation. A) siFN transfection of freshly FACS purified satellite cells from Pax7-zsGreen mice led to a significant knockdown after three days of plating when compared to siSCR. Bars represent means $\pm$ SEM. n=3. p value is *p < 0.05. B) The number of endogenous satellite cells was not significantly changed by transplantation of siFN or siSCR treated satellite cells. Bars represent means $\pm$ SEM. n=3. C) Intramuscular injection of self-delivering siRNA at day two post CTX injury led to a significant knockdown of FN (siFN) by day five when compared to the scrambled control (siSCR). Bars represent means $\pm$ SEM. n=3. p value is **p < 0.01. D) Intramuscular injection of self-delivering siFN at day two post CTX injury led to a lower abundance of satellite cells (Arrowheads) in regenerating muscle. Scale bar = 50 μ m.

BRIEF DESCRIPTION OF THE SEQUENCE IDENTIFIERS

SEQ ID NO: 1 sets forth a cDNA sequence of human Wnt7a.

SEQ ID NO: 2 sets forth the amino acid sequence of a mouse Wnt7a polypeptide.

SEQ ID NO: 3 sets forth the amino acid sequence of the human Wnt7a polypeptide encoded by SEQ ID NO: 1.

SEQ ID NO: 4 sets forth amino acids 32-212 of SEQ ID NO: 3.

SEQ ID NO: 5 sets forth amino acids 213-349 of SEQ ID NO: 3.

SEQ ID NO: 6 sets forth the amino acid sequence of a rat Wnt7a polypeptide.

SEQ ID NO: 7 sets forth the amino acid sequence of a bovine Wnt7a polypeptide.

SEQ ID NO: 8 sets forth the amino acid sequence of a chicken Wnt7a polypeptide.

SEQ ID NOs: 9-38 set forth the polynucleotide sequences of oligonucleotide primers.

SEQ ID NO: 39 sets forth a cDNA sequence of human fibronectin.

SEQ ID NO: 40 sets forth the amino acid sequence encoded by the polynucleotide sequence of SEQ ID NO: 39.

SEQ ID NO: 41 sets forth the amino acid sequence of a human fibronectin splice variant.

SEQ ID NO: 42 sets forth the amino acid sequence of a human fibronectin splice variant.

SEQ ID NO: 43 sets forth the amino acid sequence of a human fibronectin splice variant.

SEQ ID NO: 44 sets forth the amino acid sequence of a human fibronectin splice variant.

SEQ ID NOs: 45-50 set forth the polynucleotide sequences for siRNA oligonucleotides.

DETAILED DESCRIPTION

Generally, the present invention provides compositions and methods for modulating stem cells, in particular, adult stem cells. More particularly, the present invention provides compositions and methods for modulating stem cell division. Various uses of the compositions and methods described herein are also provided, including therapeutic uses, for example, for promoting tissue formation, regeneration, repair or maintenance.

Stem cells, and therapies targeting stem cells, have the potential for providing benefit in a variety of clinical settings. A limitation of many potential therapeutic applications has been obtaining a sufficient number of undifferentiated stem cells, and stimulating terminal differentiation into mature tissue-specific cells without depleting the stem cell reservoir. Much current stem cell research focuses on directing the proliferation and differentiation of stem cells, in particular, transiently amplifying progenitors to repair or regenerate damaged tissue. In addition to concerns about stem cell depletion, another concern with stimulating proliferation and differentiation of stem cells is abnormal or poorly-formed tissue.

Activation of the planar cell polarity (PCP) pathway in stem cells, *e.g.*, adult stem cells, promotes symmetrical stem cell division. Symmetrical division gives rise to two daughter cells and results in expansion of the stem cell pool. Conversely, inhibition of PCP

signaling in stem cells inhibits symmetrical division, resulting in an increase in asymmetrical (apical-basal) cell division, which does not expand the stem cell pool. Promotion of symmetrical stem cell division via activation the PCP pathway does not appear to affect the rate of cell division.

Wnt7a is an important developmental factor regulates the satellite stem cell niche. Recently, Wnt signaling through the non-canonical Planar Cell Polarity (PCP) pathway was found to induce symmetric satellite stem cell expansion and increase muscle regeneration. Without wishing to be bound to any particular theory, it is thought that Wnt7a acts via the Frizzled7 (Fzd7) receptor and activates of PCP signaling in adult stem cells, *e.g.*, satellite stem cells. Satellite stem cells are adult stem cells that give rise to muscle cells. Overexpression of Wnt7a by electroporation of CMV-Wnt7a plasmid into the Tibialis Anterior (TA) muscle of 3 month old mice increases muscle regeneration, marked by an 18% increase in muscle mass and a 50% increase in muscle fiber cross sectional area compared to control mice, suggesting that Wnt7a dramatically enhances muscle regeneration. Moreover, it has been shown that administration of Wnt7a polypeptide, or a polynucleotide encoding a Wnt7a polypeptide, increased satellite stem cell numbers *in vitro* and *in vivo*, and promoted tissue formation *in vivo*, leading to enhanced repair and regeneration in injured and diseased muscle tissue.

Thus, Wnt7a is a novel target that modulates stem cell division, and promotes tissue formation, regeneration, maintenance and repair. However, Wnt7a is poorly soluble because of post-translation lipidification and thus, use of Wnt7a polypeptides in recombinant protein therapy has been hindered. Delipidation of canonical Wnts through site-directed mutagenesis increases the water solubility of the protein to nearly 100% without compromising its activity. However, increased bioavailability of Wnt polypeptide therapies has yet to be realized. Surprisingly, the present inventors have identified that the N-terminal signal peptide is not necessary for Wnt7a signaling and that the C-terminal domain of Wnt7a is both sufficient and necessary to induce myofiber hypertrophy. Collectively, this novel Wnt7a comprising the C-terminal domain increases bioavailability in electroporated muscles and thus, offers advantages as a potential therapeutic modality over current Wnt7a polypeptides in the art.

In various embodiments, the present invention contemplates, in part, that compositions comprising novel Wnt7a polypeptide truncations or fragments and methods of using the same to increase stem cell expansion and provide therapy to subjects having myodegenerative disorders.

The invention also provides synergistic compositions and methods comprising the Wnt7a polypeptides of the invention. Using a microarray screening approach for ECM components synthesized by myogenic cells, the inventors discovered that during the initial proliferative response to injury, satellite cells release FN into their niche. FN activates the Fzd7/Sdc4 receptor complex in conjunction with Wnt7a leading to an expansion of the Myf5 negative satellite stem cell pool. It is contemplated that a high tissue content of satellite stem cells will ultimately facilitate the generation of committed daughter cells through asymmetric divisions.

Without wishing to be bound to any particular theory, the present invention contemplates, in part, that by expanding the satellite stem cell pool, the transient FN fibrosis during early adult myogenesis indirectly guarantees sufficient mitotically competent committed satellite myogenic cells which are available to resupply the myogenic pool for subsequent terminal differentiation.

Thus, the present invention contemplates, in part, a novel physiological mechanism to synergistically increase satellite cell pool during muscle regeneration. In various embodiments, the present invention contemplates, in part, compositions comprising a Wnt7a polypeptide or novel truncations or fragments thereof and a fibronectin polypeptide and methods of using the same to synergistically increase stem cell expansion and provide therapy to subjects having myodegenerative disorders.

A. Definitions

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention pertains.

The term “stem cell”, as used herein, refers to an undifferentiated cell that is capable of differentiating into a number of final, differentiated cell types. Different stem cells may have different potency. Totipotent stem cells typically have the capacity to develop into

any cell type and are usually embryonic in origin. Pluripotent stem cells are capable of differentiating into cells of the endoderm, mesoderm, and ectoderm. Multipotent stem cells can differentiate into a number of cells, but only those of a single lineage. Unipotent stem cells can produce only one cell type, their own, but have the property of self-renewal which distinguishes them from non-stem cells. A muscle stem cell is an example of stem cell that is traditionally thought to be unipotent, giving rise to muscle cells only.

An “adult stem cell” is a stem cell found in a developed organism. Adult stem cells include, but are not limited to, hematopoietic stem cells, mesenchymal stem cells, neural stem cells, endothelial stem cells and muscle stem cells.

A “satellite stem cell” is an example of an adult stem cell that gives rise to muscle cells.

The term “progenitor cell”, as used herein, refers to a cell that is committed to a particular cell lineage and which gives rise to cells of this lineage by a limited series of cell divisions. A myoblast is an example of a progenitor cell, which is capable of differentiation to only one type of cell, but is itself not fully mature or fully differentiated.

The term “symmetrical division”, as used herein in reference to stem cells, refers to a cell division that increases the number of cells of the same type. The term “planar division” may also be used. Symmetrical stem cell division gives rise to two daughter stem cells, thereby expanding the stem cell pool. The term “expansion” therefore refers to an increase in the number of cells of a particular type as a result of symmetrical division.

The term “asymmetrical division”, as used herein in reference to stem cells, refers to a cell division that gives rise to one daughter stem cell and one progenitor cell, with no increase in stem cell number. The term “apical-basal division” may also be used.

By “promoting”, “enhancing” or “increasing” symmetrical stem cell division, it is meant that the ratio of symmetrical to asymmetrical cell division is increased compared to normal or control, *e.g.*, the ratio in the absence of a particular active agent, composition or treatment method. For example, the ratio of symmetrical to asymmetrical cell division may be increased by at least 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%, 125%, 150%, 175%, 200%, or even greater.

The term “differentiation”, as used herein, refers to a developmental process whereby cells become specialized for a particular function, for example, where cells acquire

one or more morphological characteristics and/or functions different from that of the initial cell type. The term “differentiation” includes both lineage commitment and terminal differentiation processes. States of differentiation may be assessed, for example, by assessing or monitoring the presence or absence of biomarkers using immunohistochemistry or other procedures known to a person skilled in the art.

The term “lineage commitment”, as used herein, refers to the process in which a stem cell becomes committed to forming a particular limited range of differentiated cell types. Lineage commitment arises, for example, when a stem cell gives rise to a progenitor cell during apical-basal division. Committed progenitor cells are often capable of self-renewal or cell division.

The term “terminal differentiation”, as used herein, refers to the final differentiation of a cell into a mature, fully differentiated cell. Usually, terminal differentiation is associated with withdrawal from the cell cycle and cessation of proliferation.

The term “Wnt” refers to a family of related genes and proteins. The Wnt genes encode over twenty cysteine-rich, secreted, Wnt proteins (glycoproteins) that act by binding to Frizzled (Fzd) receptors on target cells. A number of Wnt polypeptides are known in the art, including Wnt 1, Wnt 2, Wnt 2b, Wnt 3, Wnt 3a, Wnt 4, Wnt 5a, Wnt 5b, Wnt 6, Wnt 7a, Wnt 7b, Wnt 8a, Wnt 8b, Wnt 9a, Wnt 9b, Wnt 10a, Wnt 10b, Wnt 11 and Wnt 16. Homologues from other species are also known and accessible to a person skilled in the art. Members of the Wnt family demonstrate marked evolutionary conservation and thus a high degree of homology is observed between species.

“Frizzled” (Fzd) receptors are a family of G-protein coupled receptor proteins to which Wnt molecules are known to bind. Sequences of various Fzd receptors are available to those skilled in the art. Fzd7 is expressed on satellite stem cells. Other stem cells that express Fzd7 include human embryonic stem cells (hESC) and neural stem cells (NSC).

Binding of different members of the Wnt family to certain members of the Fzd family on specific cells can initiate signaling by one of several distinct pathways, including canonical and non-canonical Wnt signaling pathways.

As used herein, the term “canonical pathway”, refers to a Wnt signaling pathway comprising activation of the signaling molecule Disheveled, which inactivates

glycogen synthase kinase-3 (GSK-3 β), a cytoplasmic serine-threonine kinase. The GSK-3 β target, β -catenin, is thereby stabilized and translocates to the nucleus where it activates TCF (T-cell-factor)-dependant transcription of specific promoters. This pathway is also described as the “Wnt/ β -catenin” pathway herein. Canonical Wnt-signaling plays a well-documented role in regulating myogenic growth and differentiation.

As used herein, the term “non-canonical” refers to a Wnt signaling pathway, also referred to as the “planar cell polarity” (PCP) pathway; binding of Wnt to Fzd also activates Disheveled (Dvl), which in this case activates RhoA, a small g protein, triggering a cascade that is unique from the canonical pathway. For example, in contrast to the canonical pathway, activation or stimulation of the PCP pathway does not result in nuclear translocation of β -catenin.

As used herein, “effector” molecule refers to a post-receptor signaling molecule, also referred to as a “downstream effector” molecule. Effector molecules may include, for example, cytosolic signaling molecules or nuclear signaling molecules and transcription factors, or molecules in a cell membrane, such as receptors or co-receptors.

Illustrative examples of effectors include, but are not limited to proteins, polynucleotides and peptides. Further illustrative examples of effector molecules in the PCP pathway include CelsM, Celsr2, Celsr3, DvM, Dvl2, Dvl3, Pk1, Pk2, Pk3, Pk4, Rac/RhoA, VangM, Vangl2, Syndecan 4 (Sdc4) and α 7- β 1-integrin.

In the context of a signaling pathway, “activation” may include one or more of, *e.g.*, changes in phosphorylation, conformation, polarization, localization or distribution of a molecule within the cell or cell membrane. Activation may occur directly via activation, stimulation or upregulation of an activating component of a signaling pathway, or may occur indirectly by inhibiting an inhibitory component. The converse is also true where “inhibition” may occur directly or indirectly.

The term “modulator”, as used herein, refers to both “activators” and “inhibitors” of a signaling event or pathway, *e.g.*, modulators of the Wnt7a signaling pathway. A modulator of the Wnt7a signaling pathway may be a compound or molecule that stimulates or inhibits the activity or expression of a Wnt7a polypeptide, or an upstream (activator) or downstream (effector) molecule in the Wnt7a signaling pathway, including modulators of the Frizzled7 (Fzd7) receptor. Candidate modulators of the Wnt7a signaling

pathway may stimulate or inhibit the activity of a Wnt7a polypeptide directly or indirectly. Direct modulators may act on a Wnt7a polypeptide, or a gene encoding a Wnt7a polypeptide, whereas indirect modulators may act on one or more proteins, or genes encoding proteins, that act upstream (“activators”) or downstream (“effectors”) of a Wnt7a polypeptide in the Wnt7a signaling pathway. A modulator can act at a genetic level, for example to upregulate or downregulate the expression of a gene encoding a Wnt7a polypeptide or an activator or effector of Wnt7a signaling, or at the protein level to interfere with the activity of a Wnt7a polypeptide or an activator or effector of Wnt7a signaling. Modulators may themselves be Wnt polypeptides, or active fragments, derivatives or variants thereof. A modulator can be, for example, a polypeptide, peptide, polynucleotide, oligonucleotide, antibody or antibody fragment, or a small molecule activator or inhibitor. Small molecule modulators can be organic or inorganic.

A “stem cell modulator” is a modulator that activates or inhibits a function of a stem cell. For example, a stem cell modulator may modify stem cell division, proliferation, differentiation, or survival. For example, Wnt7a, is a modulator of stem cell division.

The term “Wnt7a signaling pathway,” as used herein in reference to stem cells, refers to the Wnt7a-Fzd7 signaling pathway in adult stem cells, *e.g.*, satellite stem cells, which was shown to activate PCP signaling. Wnt7a signaling was shown to induce polarized distribution of Vangl2 and α 7-integrin, two known effector molecules in the PCP pathway, thereby promoting symmetrical stem cell division. Thus, the Wnt7a signaling pathway referred to herein is the PCP signaling pathway. In certain other cell types, Wnt7a may activate other Wnt signaling pathways.

Component members of the Wnt7a signaling pathway demonstrate marked evolutionary conservation, *e.g.*, in vertebrates and mammals. Human and mouse Wnt7a proteins share about 98% sequence identity, while corresponding Fzd7 homologues are about 96% identical and Vangl2 homologues are about 99% identical. Such high degree of homology often results in cross-species activity. For instance, it has been demonstrated that human Wnt7a is active in the mouse system. Therefore, experimental findings can often be extrapolated across species.

The terms “protein”, “polypeptide”, and “peptide,” as used herein, refer to a sequence of amino acid residues linked together by peptide bonds or modified peptide bonds.

Polypeptides of the invention include, but are not limited to Wnt, *e.g.*, Wnt7a, and fibronectin polypeptides as described elsewhere herein. Typically, a polypeptide is at least six amino acids long and a peptide is at least 3 amino acids long. The polypeptide or peptide can be naturally occurring, recombinant, synthetic, or a combination of these. The polypeptide or peptide can be a fragment of a naturally occurring protein or polypeptide.

The present invention further contemplates that polypeptides of the invention may be isolated from a number of sources, *e.g.*, mouse, cow, sheep, goat, pig, dog, cat, rat, rabbit, primate, or human.

The terms polypeptide and peptide also encompass analogues, derivatives and peptidomimetic compounds. Such compounds are well known in the art and may have significant advantages over naturally occurring peptides, including, for example, greater chemical stability, increased resistance to proteolytic degradation, enhanced pharmacological properties (such as, half-life, absorption, potency and efficacy), altered specificity (for example, a broad-spectrum of biological activities) or reduced antigenicity.

Specific proteins or polypeptides referred to herein, *e.g.*, Wnts and fibronectins, encompass proteins and polypeptides having amino acid sequences corresponding to naturally occurring sequences, as well as variant or homologous polypeptide sequences, fragments, and derivatives having an activity at least substantially identical to a wild-type protein. Likewise, specific genes (*e.g.*, Wnt7a, fibronectin) encompass nucleic acid sequences or partial sequences encoding proteins having a polypeptide sequence corresponding to naturally occurring sequences as well as variant or homologous polypeptide sequences, fragments, analogies and derivatives having an activity at least substantially identical to a wild-type protein. Polypeptides, including variants, fragments, analogues and derivatives thereof, having an increased activity compared to wild-type polypeptides are also contemplated.

A functional “activity”, as used herein in reference to a polypeptide or gene or portion thereof, refers to a polypeptide, gene or portion thereof that displays one or more activities associated with a naturally-occurring protein or gene. Functional activity in regard to a polypeptide or portion thereof may include, for example, the ability to specifically bind to and/or activate a receptor or ligand for the polypeptide.

“Naturally occurring”, as used herein in reference to an object, indicates that the object can be found in nature. For example, a naturally occurring polypeptide or polynucleotide sequence would be one that is present in an organism, and can be isolated from the organism, and which has not been intentionally modified by man in the laboratory. The term “wild-type” is often used interchangeably with naturally occurring.

In the context of the present invention, a polypeptide, or fragment, variant, analogue or derivative thereof, is considered to have at least substantially the same activity as the wild-type protein when it exhibits about 50% of the activity of the wild-type protein, preferably at least 60%, 75%, or 80% of the activity of the wild-type protein. In preferred embodiments, the polypeptide, variant, fragment, analogue or derivative exhibits at least about 85% of the activity of the wild-type protein, *e.g.* 88%, 90%, 95%, 99%, 100%. In certain embodiments, an activity greater than wild-type activity may be achieved. Activity of a Wnt7a polypeptide, variant, fragment, analogue or derivative, for example, can be determined by measuring its ability to promote symmetrical stem cell expansion and comparing to a wild-type protein. Methods of measuring and characterizing stem cell division are known in the art.

A “fragment” of a polypeptide includes, but is not limited to, an amino acid sequence wherein one or more amino acids are deleted in comparison to the wild-type sequence or another reference sequence. In various embodiments, polypeptide fragments include, but are not limited to truncated Wnt polypeptides, *e.g.*, a Wnt polypeptide, *e.g.*, Wnt7a, comprising one or more N-terminal or C-terminal amino acid deletions. Without wishing to be bound to any particular theory, the present invention contemplates that Wnt7a comprises two polypeptide domains: a hydrophobic N-terminal region (amino acids 32-212; amino acids 1-31 comprise a Wnt7a signal peptide, which is likely cleaved during protein processing) and a hydrophilic C-terminal region (amino acids 213-349), which retain the Wnt signaling activity of the naturally occurring Wnt7a.

In particular embodiments, polypeptide fragments include, but are not limited to fibronectin polypeptides comprising one or more N-terminal or C-terminal amino acid deletions.

In one embodiment, a Wnt polypeptide fragment comprises a deletion of 210, 211, 212, 213, 214, 215, 216, 217, 218, or 219 N-terminal amino acids. In another

embodiment, a fragment exists when one or more amino acids from the amino terminal, carboxy terminal or both are removed. In a particular embodiment, the Wnt polypeptide fragment is a Wnt7a polypeptide fragment. Further, one or more amino acids internal to the polypeptide may be deleted. Active fragments are fragments that retain functional characteristics, *e.g.*, of the native sequence or other reference sequence. Typically, active fragments are fragments that retain substantially the same activity as the wild-type protein. A fragment may, for example, contain a functionally important domain, *e.g.*, Wnt7a C-terminal domain, such as a domain that is important for receptor or ligand binding.

A “variant” polypeptide or variant fragment is one in which one or more amino acid residues have been deleted, added, or substituted for those that appear in the amino acid sequence of a wild-type sequence or another reference sequence. In the context of the present invention, a variant preferably retains substantially the same activity as the wild-type sequence or other reference sequence, or has better activity than the wild type protein. The present invention includes, but is not limited to variants of Wnt7a and fibronectin.

A variant may contain one or more amino acid substitutions, which may be “conservative” or “non-conservative” substitutions. As is known in the art, the twenty naturally occurring amino acids can be grouped according to the physicochemical properties of their side chains. Suitable groupings include alanine, valine, leucine, isoleucine, proline, methionine, phenylalanine and tryptophan (hydrophobic side chains); glycine, serine, threonine, cysteine, tyrosine, asparagine, and glutamine (polar, uncharged side chains); aspartic acid and glutamic acid (acidic side chains) and lysine, arginine and histidine (basic side chains). Another grouping of amino acids is phenylalanine, tryptophan, and tyrosine (aromatic side chains). A conservative substitution involves the substitution of an amino acid with another amino acid from the same group, while a non-conservative substitution involves the substitution of an amino acid with another amino acid from a different group.

Typically, variant amino acid sequences comprise greater than about 70%, more preferably greater than about 80%, 85%, 90%, 91 %, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99% identity to the wild-type or reference sequence. The degree of identity may also be represented by a range defined by any two of the values listed above or any value therein

between. Variants include “mutants” in which the reference sequence is the wild-type sequence.

A “derivative” is a peptide or polynucleotide containing additional chemical or biochemical moieties not normally a part of a naturally occurring molecule. Peptide derivatives include peptides in which one or more amino acid side chain and/or the amino-terminus and/or the carboxy-terminus has been derivatized with a suitable chemical substituent group, as well as cyclic peptides, dual peptides, multimers of the peptides, peptides fused to other proteins or carriers glycosylated peptides, phosphorylated peptides, peptides conjugated to lipophilic moieties (for example, caproyl, lauryl, stearyl moieties) and peptides conjugated to an antibody or other biological ligand. Examples of chemical substituent groups that may be used to derivatize a peptide include, but are not limited to, alkyl, cycloalkyl and aryl groups; acyl groups, including alkanoyl and aroyl groups; esters; amides; halogens; hydroxyls; carbamyls, and the like. The substituent group may also be a blocking group such as Fmoc (fluorenylmethyl-O-CO-), carbobenzoxy(benzyl-CO-), monomethoxysuccinyl naphthyl-NH--CO~, acetylamino-caproyl and adamantyl-NH-CO-. Other derivatives include C-terminal hydroxymethyl derivatives, O-modified derivatives (for example, C-terminal hydroxymethyl benzyl ether) and N-terminally modified derivatives including substituted amides such as alkylamides and hydrazides.

An “analogue” is a polypeptide or peptide comprising one or more non-naturally occurring amino acids. As is known in the art, substitution of all D-amino acids for all L- amino acids within a peptide can result in an “inverse” peptide, or in a “retro-inverso” peptide (see Goodman *et al.* “Perspectives in Peptide Chemistry” pp. 283-294 (1981); U.S. Patent No. 4,544,752), both of which are considered to be analogues in the context of the present invention. An “inverse” peptide is one in which all L-amino acids of a sequence have been replaced with D-amino acids, and a “retro-inverso” peptide is one in which the sequence of the amino acids has been reversed (“retro”) and all L- amino acids have been replaced with D-amino acids.

“Peptidomimetics” are compounds that are structurally similar to peptides and contain chemical moieties that mimic the function of the polypeptide or peptide of the invention. For example, if a polypeptide contains two charged chemical moieties having functional activity, a mimetic places two charged chemical moieties in a spatial orientation

and constrained structure so that the charged chemical function is maintained in three-dimensional space. The term peptidomimetic thus is intended to include isosteres. The term “isostere” refers to a chemical structure that can be substituted for a polypeptide or peptide because the steric conformation of the chemical structure is similar to that of the peptide or polypeptide, for example, the structure fits a binding site specific for the polypeptide or peptide.

One skilled in the art will appreciate that not all amino acids in a peptide or polypeptide need be modified. Similarly not all amino acids need be modified in the same way. Peptide derivatives, analogues and peptidomimetics of the present invention include chimeric molecules which contain two or more chemically distinct regions, each region comprising at least one amino acid or modified version thereof.

A “Wnt7a polypeptide,” as used herein, encompasses a Wnt7a protein or fragments thereof, having a polypeptide sequence corresponding to a wild-type Wnt7a sequence, or having a sequence that is at least about as 70%, more preferably about 80%, 85%, 90%, 91 %, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or about 100%, identical to a naturally occurring Wnt7a sequence. Identity may be assessed over at least about 50, 100, 200, 300, or more contiguous amino acids, or may be assessed over the full length of the sequence. Methods for determining % identity or % homology are known in the art and any suitable method may be employed for this purpose. Wnt7a polypeptides also include variants, fragments, analogues and derivatives having an activity substantially identical to a wild-type Wnt7a polypeptide, *e.g.*, binding to Fzd7. Exemplary Wnt7a polypeptides include polypeptides comprising the amino acid sequence shown in SEQ ID NO: 2-5, as well as active fragments, variants or derivatives thereof.

A “fibronectin polypeptide,” as used herein, encompasses a fibronectin protein or fragments thereof, splice variants, *e.g.*, EIIIA, EIIIB, having a polypeptide sequence corresponding to a wild-type fibronectin sequence, or having a sequence that is at least about as 70%, more preferably about 80%, 85%, 90%, 91 %, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99% or about 100%, identical to a naturally occurring fibronectin sequence. Identity may be assessed over at least about 50, 100, 200, 300, or more contiguous amino acids, or may be assessed over the full length of the sequence. Methods for determining % identity or % homology are known in the art and any suitable method may be employed for this purpose.

Fibronectin contributes to survival of cells *in vitro*, *ex vivo*, and *in vivo*. It is expressed by fibroblasts in skin, in most other tissues and many other cell types (*e.g.*, endothelial cells) and made in the liver. Fibronectin, (m.w. 440,000) is a dimer of two large subunits joined by disulfide bonds at one end. The single large gene contains about 50 exons of similar size. Over 50 alternately spliced variants exist and are known in the art. The tetrapeptide, Arg-Gly-Asp-Ser, assists cell adhesion. Fibronectin has fibrin, Clq, heparin, transglutaminase, collagen types I, II, III, V, VI and sulfated proteoglycans binding sites. Fibronectin functions in cell-substrate adhesion, contact inhibition, cell migration, cell differentiation, inflammation and wound healing. Plasma fibronectin is soluble and differs from insoluble cellular fibronectin by the absence of the two commonly spliced domains EIIIA and EIIIB.

Fibronectin polypeptides also include variants, fragments, analogues and derivatives having an activity substantially identical to a wild-type Fibronectin polypeptide, *e.g.*, binding to Fzd7/Sdc4 and/or Wnt7a. Exemplary fibronectin polypeptides include polypeptides comprising the amino acid sequence shown in SEQ ID NO: 40-44, as well as active fragments, variants or derivatives thereof.

The polypeptides of the present invention can be prepared by methods known in the art, such as purification from cell extracts or the use of recombinant techniques. Polypeptides as described herein will preferably involve purified or isolated polypeptide preparations. In certain embodiments, purification of the polypeptide may utilize recombinant expression methods well known in the art, and may involve the incorporation of an affinity tag into the expression construct to allow for affinity purification of the target polypeptide.

Shorter sequences can also be chemically synthesized by methods known in the art including, but not limited to, exclusive solid phase synthesis, partial solid phase synthesis, fragment condensation or classical solution synthesis (Merrifield (1963) *Am. Chem. Soc.* 85:2149; Merrifield (1986) *Science* 232:341). The polypeptides of the present invention can be purified using standard techniques such as chromatography (*e.g.*, ion exchange, affinity, and sizing column chromatography or high performance liquid chromatography), centrifugation, differential solubility, or by other techniques familiar to a worker skilled in the art. The polypeptides can also be produced by recombinant techniques. Typically this

involves transformation (including transfection, transduction, or infection) of a suitable host cell with an expression vector comprising a polynucleotide encoding the protein or polypeptide. The nucleic acid sequences for human and mouse Wnt7a gene and various other components of the PCP signaling pathway are known in the art (*see*, for example, GenBank Accession Nos 000755, P24383, NPJD04616, G36470, PF6706, P28047, H36470, NM_004625, and M89801) and may be used as a basis for the polynucleotides of the invention.

The polypeptides and peptides of the present invention can also be produced as fusion proteins. One use of such fusion proteins is to improve the purification or detection of the polypeptide or peptide. For example, a polypeptide or peptide can be fused to an immunoglobulin Fc domain and the resultant fusion protein can be readily purified using a protein A column. Other examples of fusion proteins include polypeptides or peptides fused to histidine tags (allowing for purification on Nickel resin columns), to glutathione-S-transferase (allowing purification on glutathione columns) or to biotin (allowing purification on streptavidin columns or with streptavidin labeled - 19 magnetic beads). Once the fusion protein has been purified, the tag may be removed by site-specific cleavage using chemical or enzymatic methods known in the art.

As used herein, the term “polynucleotide sequence” or “nucleic acid sequence,” refers to any nucleotide sequence (*e.g.*, RNA or DNA), the manipulation of which may be deemed desirable for any reason (*e.g.*, modulate cell function, treat disease, *etc.*), by one of ordinary skill in the art. Such nucleotide sequences include, but are not limited to, coding sequences of genes (*e.g.*, reporter genes, selection marker genes, oncogenes, disease resistance genes, growth factors, *etc.*), and non-coding regulatory sequences which may not encode an mRNA (*e.g.*, promoter sequence, polyadenylation sequence, termination sequence, enhancer sequence, *etc.*).

By the terms “regulatory sequence”, “regulatory region”, “regulatory element” it is meant a portion of nucleic acid typically, but not always, upstream of the protein or polypeptide coding region of a nucleotide sequence, which may be comprised of either DNA or RNA, or both DNA and RNA. When a regulatory region is active, and in operative association with a nucleotide sequence of interest, this may result in expression of the nucleotide sequence of interest. A regulatory element may be capable of mediating organ

specificity, or controlling developmental or temporal nucleotide sequence activation. A “regulatory region” includes promoter elements, core promoter elements exhibiting a basal promoter activity, elements that are inducible in response to a stimulus, elements that mediate promoter activity such as negative regulatory elements or transcriptional enhancers.

“Regulatory region”, as used herein, also includes elements that are active following transcription, for example, regulatory elements that modulate nucleotide sequence expression such as translational and transcriptional enhancers, translational and transcriptional repressors, upstream activating sequences, and mRNA instability determinants. Several of these latter elements may be located proximal to the coding region.

The terms “complementary” and “complementarity” refer to polynucleotides (*i.e.*, a sequence of nucleotides) related by the base-pairing rules. For example, the sequence “A-G-T-” is complementary to the sequence “T-C-A.” Complementarity may be “partial,” in which only some of the nucleic acids' bases are matched according to the base pairing rules. Or, there may be “complete” or “total” complementarity between the nucleic acids. The degree of complementarity between nucleic acid strands has significant effects on the efficiency and strength of hybridization between nucleic acid strands. This is of particular importance in amplification reactions, as well as detection methods that depend upon binding between nucleic acids.

The term “recombinant” when made in reference to a nucleic acid molecule refers to a nucleic acid molecule that is comprised of segments of nucleic acid joined together by means of molecular biological techniques. The term “recombinant” when made in reference to a protein or a polypeptide refers to a protein molecule that is expressed using a recombinant nucleic acid molecule.

The term “isolated” when used in relation to a polynucleotide, refers to a nucleic acid sequence that is identified and separated from at least one contaminant nucleic acid with which it is ordinarily associated in its natural source. Isolated nucleic acid molecule is present in a form or setting that is different from that in which it is found in nature. In contrast, non-isolated nucleic acids, such as DNA and RNA, are found in the state they exist in nature. For example, a given DNA sequence (*e.g.*, a gene) is found on the host cell chromosome in proximity to neighboring genes; RNA sequences, such as a specific mRNA sequence encoding a specific protein, are found in the cell as a mixture with numerous other

mRNAs that encode a multitude of proteins. However, isolated nucleic acid molecule encoding a particular protein includes, by way of example, such nucleic acid in cells ordinarily expressing the protein, where the nucleic acid is in a chromosomal location different from that of natural cells, or is otherwise flanked by a different nucleic acid sequence than that found in nature. The isolated nucleic acid may be present in single-stranded or double-stranded form. When an isolated nucleic acid is to be utilized to express a protein, the polynucleotide will contain at a minimum the sense or coding strand (*i.e.*, the polynucleotide may be single-stranded), but may contain both the sense and anti-sense strands (*i.e.*, the polynucleotide may be double-stranded).

The term “purified” refers to molecules, including nucleic or amino acid sequences that are removed from their natural environment isolated or separated. An “isolated nucleic acid sequence” is therefore a purified nucleic acid sequence.

“Substantially purified” molecules are at least 60% free, at least 75% free, or typically at least 90%, 95% or 99% free from other components with which they are naturally associated. As used herein, the terms “purified” and “to purify” also refer to the removal of contaminants from a sample. The removal of contaminating molecules, including proteins, results in an increase in the percent of polypeptide of interest in the sample. In another example, recombinant polypeptides are expressed in bacteria, yeast, or mammalian host cells and the polypeptides are purified by the removal of host cell proteins; the percent of recombinant polypeptides is thereby increased in the sample.

Nucleic acid sequences corresponding to genes or encoding polypeptides relating to the present invention can be readily purchased or purified from a suitable source by standard techniques, or can be synthesized chemically. The nucleic acids can be genomic DNA, RNA, cDNA prepared from isolated mRNA, or DNA amplified from a naturally occurring nucleic acid sequence by standard techniques. Alternatively, the known sequences may be used to prepare probes to obtain other nucleic acid sequences encoding a Wnt7a polypeptide or fragment thereof or a fibronectin polypeptide from various sources using standard techniques. Suitable sources for obtaining the nucleic acids are those cells or tissues which are known to express the proteins of interest, such as skeletal muscle tissue and other tissues with measurable Wnt7a or fibronectin transcripts.

Polynucleotides encoding fragments or variants of the naturally occurring Wnt7a or fibronectin proteins can be constructed by deletion, addition, and/or substitution of one or more nucleotides within the coding sequence using standard techniques, such as site-directed mutagenesis techniques.

Specific initiation signals may be required for efficient translation of cloned polynucleotide. These signals include the ATG initiation codon and adjacent sequences. In cases where an entire wild-type gene or cDNA, including its own initiation codon and adjacent sequences, is inserted into the appropriate expression vector, additional translational control signals may not be needed. In other cases, exogenous translational control signals, including, perhaps, the ATG initiation codon, must be provided. Furthermore, the initiation codon must be in phase with the reading frame of the desired coding sequence to ensure translation of the entire insert. The exogenous translational control signals and initiation codons can be natural or synthetic. The efficiency of expression may be enhanced by the inclusion of appropriate transcription enhancer elements and/or transcription terminators (Bittner *et al.* (1987) *Methods in Enzymol.* 153, 516).

In some instances, it may be desirable to link the coding sequence of a particular gene to an amino- or carboxyl-terminal epitope tag to facilitate detection or purification of expressed protein. Suitable epitope tags may include, but are not limited to, hemagglutinin (HA), myc, FLAG, 6X His, V5, glutathione-S-transferase (GST), *etc.*

An “expression vector”, also known as an expression construct, is used to introduce a specific gene into a target cell. Once the expression vector is inside the cell, the protein that is encoded by the gene is produced by the cellular-transcription and translation machinery. The vector is frequently engineered to contain regulatory sequences that act as enhancer and promoter regions and lead to efficient transcription of the gene carried on the expression vector. The goal of a well-designed expression vector is the production of large amounts of stable messenger RNA.

Suitable expression vectors include, but are not limited to, plasmids, phagemids, viral particles and vectors, phages and the like. The entire expression vector, or a part thereof, can be integrated into the host cell genome. In some circumstances, it is desirable to employ an inducible expression vector as are known in the art, *e.g.*, the LACSWITCH Inducible Expression System (Stratagene, LaJolla, CA). Suitable expression

vectors may comprise promoters for driving expression in a particular host cell. Some expression vectors may comprise a CMV promoter. The expression vectors may be, for example, pCMV or pCMV-Sportβ.

Those skilled in the field of molecular biology will understand that a wide variety of expression systems can be used to provide the recombinant polypeptide or peptide. The polypeptide or peptide can be produced in a prokaryotic host (*e.g.*, *E. coli* or *B. subtilis*) or in a eukaryotic host (*e.g.*, *Saccharomyces* or *Pichia*; mammalian cells, such as COS, NIH 3T3, CHO, BHK, 293, or HeLa cells, insect cells, or plant cells). The methods of transformation or transfection and the choice of expression vector will depend on the host system selected and can be readily determined by one skilled in the art. Transformation and transfection methods are described, for example, in Ausubel *et al.* (1994) *Current Protocols in Molecular Biology*, John Wiley & Sons, New York; and various expression vectors may be chosen from those provided, *e.g.* in *Cloning Vectors: A Laboratory Manual* (Ponwels *et al.*, 1985, Supp. 1987) and by various commercial suppliers.

In addition, a host cell may be chosen which modulates the expression of the inserted sequences, or modifies and processes the gene product in a specific, desired fashion. Such modifications (*e.g.* glycosylation) and processing (*e.g.* cleavage) of protein products may be important for the activity of the protein. Different host cells have characteristic and specific mechanisms for the post-translational processing and modification of proteins and gene products. Appropriate cell lines or host systems can be chosen by one skilled in the art to ensure the correct modification and processing of the expressed heterologous protein. The host cells harboring the expression vehicle can be cultured in conventional nutrient media adapted as needed for activation of a chosen gene, repression of a chosen gene, selection of transformants, or amplification of a chosen gene according to known procedures.

With reference to the polypeptide and polynucleotide sequences defined herein, the term “substantially identical” in reference to sequence identity means at least 70%, preferably at least 80%, 85%, 90%, 91 %, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99% sequence identity. By “identity” is meant the number of conserved amino acids or nucleotides as determined by standard alignment algorithms or programs known in the art, used with default parameters established by each supplier. It will be understood that the degree of identity may be represented by a range defined by any two of the values listed

above or any value therebetween. Identity may be assessed, for example, over at least about 50, 100, 200, 300, or more contiguous amino acids, or at least about 50, 100, 200, 300, 500, 750, 1000 or more nucleotides, or may be assessed over the full length of the sequence. The terms “homology” and “identity” are often used interchangeably. Methods for determining % identity or % homology are known in the art and any suitable method may be employed for this purpose. In general, sequences are aligned so that an optimized match is obtained. An example of an algorithm that is suitable for determining percent sequence identity is algorithms such as the BLAST algorithm, as is well known to those skilled in the art. Software for performing BLAST analyses is publicly available through the National Center for Biotechnology Information (www.ncbi.nlm.nih.gov). Other commercially or publicly available programs include the DNASTar MegAlign program (Madison, WI) and the University of Wisconsin Genetics Computer Group (UWG) Gap program (Madison WI).

As used herein, the term at “least 90% identical” would refer to percent identities from 90 to 99.99% relative to a reference polynucleotide or polypeptide. Identity at a level of 90% or more is indicative of the fact that, assuming for exemplification purposes a test and reference polynucleotide or polypeptide length of 100 nucleotides or amino acids are compared, no more than 10% of the respective nucleotides or amino acids in the test polypeptide would differ from corresponding aligned positions of the reference nucleotides/polypeptides. Differences may be represented as point mutations randomly distributed over the entire length of an polynucleotide or amino acid sequence or may be clustered in one or more locations of varying length up to the maximum allowable, *e.g.*, 10 of 100 nucleotide/amino acid differences for the above “at least 90% identity” example. Differences may be defined as nucleic acid or amino acid substitutions or deletions.

Substantially identical nucleic acid molecules would hybridize typically at moderate stringency or at high stringency conditions along the length of the nucleic acid or along at least about 70%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, or 99% of the full length nucleic acid molecule of interest. In the case of coding sequences, also contemplated are nucleic acid molecules that contain degenerate codons in place of codons in the hybridizing nucleic acid molecule.

As used herein, “domain” refers to a portion of a molecule, *e.g.*, polypeptide or the encoding polynucleotide that is structurally and/or functionally distinct from other

portions of the molecule. For example, Wnt7a comprises an N-terminal hydrophobic domain (SEQ ID NO: 4) and a C-terminal hydrophobic domain (SEQ ID NO: 5).

As used herein, “gene therapy” includes both *ex vivo* and *in vivo* techniques. Thus host cells can be genetically engineered *ex vivo* with a polynucleotide, with the engineered cells then being provided to a patient to be treated. Delivery of the active agent *in vivo* may involve a process that effectively introduces a molecule of interest (*e.g.*, Wnt-7a polypeptide or other activator of PCP-signaling) into the cells or tissue being treated. In the case of polypeptide-based active agents, this can be effected directly or, alternatively, by transfecting transcriptionally active DNA into living cells such that the active polypeptide coding sequence is expressed and the polypeptide is produced by cellular machinery. Transcriptionally active DNA may be delivered into the cells or tissue, *e.g.*, muscle, being treated using transfection methods including, but not limited to, electroporation, microinjection, calcium phosphate coprecipitation, DEAE dextran facilitated transfection, cationic liposomes and retroviruses. In certain embodiments, the DNA to be transfected is cloned into a vector. Such vectors may include plasmids effective for delivery and expression of the DNA within a host cell. Such vectors may include but are not limited to plasmids derived from human cytomegalovirus (hCMV) or other suitable promoters such as hPGK-1 or hACT.

Alternatively, cells can be engineered *in vivo* by administration of the polynucleotide using techniques known in the art. For example, by direct injection of a “naked” polynucleotide (Feigner and Rhodes, (1991) *Nature* 349:351-352; U.S. Patent No. 5,679,647) or a polynucleotide formulated in a composition with one or more other agents which facilitate uptake of the polynucleotide by the cell, such as saponins (*see*, for example, U.S. Patent No. 5,739,118) or cationic polyamides (*see*, for example, U.S. Patent No. 5,837,533); by microparticle bombardment (for example, through use of a “gene gun”, Biolistic, Dupont); by coating the polynucleotide with lipids, cell-surface receptors or transfecting agents; by encapsulation of the polynucleotide in liposomes, microparticles, or microcapsules; by administration of the polynucleotide linked to a peptide which is known to enter the nucleus; or by administration of the polynucleotide linked to a ligand subject to receptor-mediated endocytosis (*see*, for example, Wu and Wu, (1987) *J. Biol. Chem.* 262:4429-4432), which can be used to target cell types specifically expressing the receptors.

Alternatively, a polynucleotide-ligand complex can be formed in which the ligand comprises a fusogenic viral peptide to disrupt endosomes, allowing the polynucleotide to avoid lysosomal degradation; or the polynucleotide can be targeted for cell specific uptake and expression *in vivo* by targeting a specific receptor (see, for example, International Patent Applications WO 92/06180, WO 92/22635, WO92/203167 WO93/14188 and WO 93/20221). The present invention also contemplates the intracellular introduction of the polynucleotide and subsequent incorporation within host cell DNA for expression by homologous recombination (*see*, for example, Koller and Smithies (1989) *Proc. Natl. Acad. Sci. USA* 86:8932- 8935; Zijlstra *et al.* (1989) *Nature* 342:435-438).

The polynucleotide can be incorporated into a suitable expression vector. A number of vectors suitable for gene therapy applications are known in the art (*see*, for example, *Viral Vectors: Basic Science and Gene Therapy*, Eaton Publishing Co. (2000)) and may be used. The expression vector may be a plasmid vector. Methods of generating and purifying plasmid DNA are rapid and straightforward. In addition, plasmid DNA typically does not integrate into the genome of the host cell, but is maintained in an episomal location as a discrete entity eliminating genotoxicity issues that chromosomal integration may raise. A variety of plasmids are now readily available commercially and include those derived from *Escherichia coli* and *Bacillus subtilis*, with many being designed particularly for use in mammalian systems. Examples of plasmids that may be used in the present invention include, but are not limited to, the expression vectors pRc/CMV (Invitrogen), pCR2. 1 (Invitrogen), pAd/CMV and pAd/TR5/GFPq (Massie *et al.*, (1998) *Cytotechnology* 28:53-64). In an exemplary embodiment, the plasmid is pRc/CMV, pRc/CMV2 (Invitrogen), pAdCMV5 (IRB-NRC), pcDNA3 (Invitrogen), pAdMLP5 (IRB-NRC), or pVAX (Invitrogen).

Alternatively, the expression vector can be a viral-based vector. Examples of viral-based vectors include, but are not limited to, those derived from replication deficient retrovirus, lentivirus, adenovirus and adeno-associated virus. These vectors provide efficient delivery of genes into cells, and the transferred polynucleotides are stably integrated into the chromosomal DNA of the host.

As used herein, "subject" may be a mammalian subject, for example, but not limited to mouse, cow, sheep, goat, pig, dog, cat, rat, rabbit, primate, or human.

A “pharmaceutical composition”, often used interchangeably with composition, includes at least one active agent for carrying out a desired effect. The pharmaceutical composition further comprises one or more physiologically acceptable diluents, carriers or excipients. Pharmaceutical compositions and methods of preparing pharmaceutical compositions are known in the art and are described, for example, in “Remington: The Science and Practice of Pharmacy” (formerly “Remington’s Pharmaceutical Sciences”); Gennaro, A., Lippincott, Williams & Wilkins, Philadelphia, PA (2000).

A “cell composition” is a composition that contains cells together with one or more physiologically acceptable diluents, carriers or excipients. The cell composition may further comprise one or more active agents. In some cases, the cells may be transformed to express a gene or protein of interest.

A “stem cell composition” is a composition that contains stem cells together with one or more physiologically acceptable diluents, carriers or excipients. The stem cell composition may comprise one or more active agents, such as a stem cell modulator. In some cases, the stem cells may be transformed to express a gene or protein of interest.

An “effective amount” is an amount sufficient to achieve a beneficial or desired result. An effective amount may be effective amount *in vitro* or *in vivo*. *In vivo*, an effective amount may also be referred to as a “therapeutically effective amount”, which can be administered to a patient in one or more doses. In terms of treatment of disease or damage, an effective amount may be an amount that is sufficient to palliate, ameliorate, stabilize, reverse or slow the progression of the disease or damage. The effective amount is generally determined by the physician on a case-by-case basis and is within the skill of one in the art. Several factors are typically taken into account when determining an appropriate dosage to achieve an effective amount. These factors include age, sex and weight of the patient, the condition being treated, the severity of the condition and the form and effective concentration of the antigen-binding fragment administered.

As used herein, the term “about” refers to a +/-5% variation from the nominal value. It is to be understood that such a variation is always included in any given value provided herein, whether or not it is specifically referred to.

Reference throughout this specification to “one embodiment,” “an embodiment,” “a particular embodiment,” “a related embodiment,” “a certain embodiment,” “an additional embodiment,” or “a further embodiment” or combinations thereof means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the foregoing phrases in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

Embodiments of the invention are included within the definitions above, which may be relied upon to define the invention.

B. Compositions and Formulations

In one aspect, there is provided a composition for modulating the division symmetry of a stem cell comprising as an active agent, a Wnt7a polypeptide fragment that modulates planar cell polarity (PCP) signaling in the stem cell. In another aspect, a composition for modulating the division symmetry of a stem cell comprising one or more active agents selected from the group consisting of a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide that synergistically modulates planar cell polarity (PCP) signaling in the stem cell. Preferably, the stem cell is an adult stem cell, for example, a satellite stem cell.

In particular embodiments, the compositions of the invention further comprise a stem cell or population of stem cells. Preferably, the stem cell is an adult stem cell, for example, a satellite stem cell.

In some embodiments, a Wnt7a polypeptide fragment is an activator of PCP signaling capable of promoting symmetrical division of the stem cell. Polypeptide and peptide activators of the PCP signaling pathway include direct activators, as well as activators that exert their activating effect by inhibiting the activity or expression of proteins that inhibit Wnt7a signaling, *i.e.*, indirect activators.

In other embodiments, a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide are a synergistic activator of PCP signaling capable of promoting symmetrical division of the stem cell.

The compositions described herein are useful *in vitro* or *in vivo* to promote stem cell expansion. It was demonstrated that activation of the PCP pathway, or components thereof, in satellite stem cells promotes symmetrical stem cell division, largely expanding the stem cell pool without affecting the rate of cell division.

The active agent may, for example, comprise a small molecule, a polynucleotide, a peptide, a polypeptide, a macromolecule, or a combination thereof, *e.g.*, a Wnt7a polypeptide or fragment thereof, a fibronectin polypeptide.

The components of the PCP pathway, including Wnt7a, Fzd7, fibronectin, and syndecan-4 (Sdc4) tend to be highly conserved across species. Therefore, polypeptides and polynucleotides derived from various species are contemplated within the scope of the invention so long as they have the desired characteristics and activity.

In some embodiments, the active agent comprises a peptide or polypeptide capable of binding to and/or activating Fzd7 on the stem cell, *e.g.*, a Wnt7a polypeptide fragment. Fzd7 may be particularly important for interaction with Wnt7a. Thus, a polypeptide capable of activating Fzd7 may comprise a polypeptide capable of binding to a Wnt-binding domain of Fzd7.

In other embodiments, the composition comprises one or more active agents that are peptides or polypeptides capable of binding to and/or activating Fzd7/Sdc4 receptor complex on the stem cell, *e.g.*, a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide. The Fzd7/Sdc4 receptor complex may be particularly important for interaction with Wnt7a and fibronectin that drives a synergistic increase in stem cell expansion.

In some embodiments, the active agent is a Wnt7a polypeptide fragment or an active analogue, variant, or derivative thereof capable of binding to and activating Fzd7. In some embodiments, the active agent is a polypeptide having a sequence of a Wnt7a polypeptide, or a sequence that is at least about 70%, 80%, 85%, 90%, 91 %, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99% identical to a Wnt7a polypeptide. Exemplary Wnt7a polypeptides are set forth in SEQ ID NO: 3 and 5. In related embodiments, the composition further comprises a fibronectin polypeptide or active fragment thereof as another active agent. An exemplary fibronectin polypeptide is shown in SEQ ID NO: 7.

In some embodiments, the % identity is assessed over at least about 50, 100, 200, 300, or more contiguous amino acids. In some embodiments, the % identity is assessed over the full length of the mature peptide sequence.

In certain embodiments, the active agent comprises a Wnt7a polypeptide. In some embodiments, the Wnt7a polypeptide is a human Wnt7a polypeptide. In some embodiments, the Wnt7a polypeptide is a murine Wnt7a polypeptide. Other species are also contemplated. In certain embodiments, a composition comprises one or more active agents selected from the group consisting of: a human or murine Wnt7a polypeptide and a fibronectin polypeptide.

In some embodiments, the Wnt7a polypeptide has an amino acid sequence comprising or consisting of SEQ ID NO: 3 or 5. In some embodiments, the active agent comprises an isolated polynucleotide encoding a peptide or polypeptide capable of binding to and/or activating Fzd7. The peptide or polypeptide capable of binding to and/or activating Fzd7 may be as described above. Thus, in some embodiments, the polynucleotide encodes a Wnt7a polypeptide or an active analogue, variant, fragment, or derivative thereof capable of binding to and activating Fzd7. In particular embodiments, the composition comprises one or more active agents comprising a polynucleotide encoding a Wnt7a polypeptide or an active analogue, variant, fragment, or derivative thereof and a polynucleotide encoding a fibronectin polypeptide, where the Wnt7a polypeptide and fibronectin polypeptide synergistically bind to and activate a Fzd7/Sdc4 complex.

An exemplary Wnt7a polynucleotide is shown in SEQ ID NO: 1. An exemplary fibronectin polynucleotide is shown in SEQ ID NO: 6.

In some embodiments, the active agent comprises a polynucleotide encoding a Wnt7a polypeptide having an amino acid sequence comprising SEQ ID NO: 5, or a sequence that is at least about 70%, 80%, 85%, 90%, 91 %, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99% identical to SEQ ID NO: 3 or 5. In some embodiments, the active agent comprises a polynucleotide having an amino acid sequence comprising SEQ ID NO: 1, or a sequence that is at least about 70%, 80%, 85%, 90%, 91 %, 92%, 93%, 94%, 95%, 96%, 97%, 98% or 99% identical to SEQ ID NO: 1.

In some embodiments, the % identity is assessed over at least about 50, 100, 200, 300, 500, 750 or 100 or more contiguous nucleotides. In some embodiments, the %

identity is assessed over the full length of the polynucleotide. In some embodiments, the polynucleotide comprises a Wnt7a polynucleotide sequence comprising or consisting of SEQ ID NO: 1, or a fragment thereof.

In some embodiments, the polypeptides correspond to modulators of Wnt7a signaling, for example, fibronectin and/or Syndecan 4 (Sdc4) and α 7- β 1-integrin, or active fragments, variants or derivatives thereof.

In some embodiments, the active agent comprises a polynucleotide or polypeptide capable of modulating a downstream effector molecule in the PCP pathway to thereby promote or inhibit symmetrical cell division. Exemplary polarity effectors that may be modulated to affect cell division in adult stem cells include Prickle, Flamingo (Celsr2), Disheveled (Dsh) or PTK7. Exemplary targets of modulation in the PCP pathway include, but are not limited to, fibronectin, Fzd7, Vangl1, Vangl2, Dvl2, Dvl3, PM, Pk2, Celsr2, Sdc4 and α 7-integrin.

In some embodiments, the active agent comprises a polynucleotide or polypeptide capable of activating a downstream effector molecule in the PCP pathway to thereby promote symmetrical stem cell division. The downstream effector molecule may, for example be, Fzd7, Vangl1, Vangl2, Dvl2, Dvl3, PM, Pk2, Celsr2, Sdc4 and α 7-integrin.

In some embodiments, the composition additionally comprises one or more stem cell modulators. The stem cell modulator may, for example, promote one more of stem cell proliferation, differentiation, lineage commitment, or terminal differentiation of committed progenitor cells.

In some embodiments, the modulator increases the rate of stem cell division. Any suitable activator of stem cell division rate can be used, such as a suitable growth factor. Known growth factors include FGF, HGF and SDF. In some embodiments, a growth factor that increases stem cell division rate without promoting differentiation is selected.

In some embodiments, the modulator is one that increases proliferation in a population of expanding stem cells, or one that promotes differentiation in a population of stem cells that have been previously expanded by treatment with a Wnt7a polypeptide or a Wnt7a truncated polypeptide and a fibronectin polypeptide as discussed elsewhere herein.

In one embodiment, there is provided a composition for enhancing tissue formation, regeneration, maintenance or repair in a mammal comprising as an active agent (a)

a Wnt7a polypeptide fragment, or variant, analogue or derivative thereof capable of binding to and activating Fzd7, or (b) a polynucleotide encoding a Wnt7a polypeptide fragment, or variant, analogue or derivative thereof capable of binding to and activating Fzd7. In a particular embodiment the Wnt7a polypeptide fragment comprises the amino acid sequence set forth in SEQ ID NO: 5.

In another embodiment, there is provided a composition for promoting symmetrical stem cell division comprising as active agents, a) a Wnt7a polypeptide or fragment thereof and b) a fibronectin polypeptide, wherein the composition activates a Fzd7/Sdc4 receptor signaling complex in adult stem cells. In other embodiments, a composition comprises a stem cell or population of stem cells, a Wnt7a polypeptide or fragment thereof, and/or a fibronectin polypeptide.

In some embodiments, the adult stem cells are satellite stem cells.

The compositions described herein may be used to deliver one or more polynucleotides of interest into a cell or tissue. In some embodiments, the composition comprises an expression vector carrying a polynucleotide encoding a Wnt7a polypeptide or fragment thereof and/or a polynucleotide encoding a fibronectin polypeptide, wherein the composition is capable of activating PCP signaling in a stem cell, to thereby promote symmetrical stem cell expansion. The composition may be administered *in vitro*, for example, to expand a population of stem cells, or *in vivo*, for example, in a gene therapy method. A number of exemplary modulators have been described above, *e.g.*, Wnt7a polypeptides and fragments, Frz7, fibronectin and Sdc4.

In some embodiments, a cell or tissue is transformed to overexpress a Wnt7a polypeptide or fragment thereof and/or a polynucleotide encoding a fibronectin polypeptide, thereby inducing symmetrical division of a stem cell. Wnt7a polypeptides and/or fibronectin polypeptides may be secreted from the transformed cell and may act on the cell from which is it secreted or may act on a nearby stem cell. In some embodiments, the transformed cell is a helper cell that may be co-cultured or co-administered with the stem cell. The helper cell may also be a resident cell in a tissue that is transformed to overexpress Wnt7a or a fragment thereof and/or a fibronectin polypeptide. In some embodiments, the helper cell is a myoblast or muscle cell transformed to overexpress Wnt7a and/or fibronectin polypeptides of the

invention. The inventive Wnt7a polypeptides comprise increased solubility compared to naturally occurring Wnt7a polypeptides.

In some embodiments, muscle tissue is transformed to overexpress truncated Wnt7a polypeptides or Wnt7a polypeptide fragments that expand the satellite stem cell pool *in vivo*, increase satellite cell numbers, and promote muscle regeneration and repair compared to the naturally occurring Wnt7a. In certain embodiments, the tissue is further transformed to transiently overexpress fibronectin.

In some embodiments, a composition comprises cells and may therefore be a cell composition. For example, the composition may comprise a cell transformed to express and secrete Wnt7a polypeptide fragments and/or Wnt7a polypeptides and fragments thereof and a fibronectin polypeptide. In some embodiments, the cell is a myoblast or muscle cell. In some embodiments, the composition comprises stem cells and is therefore a stem cell composition.

In some embodiments, stem cells may be expanded *in vitro* using a method according to the invention and may subsequently be added to a composition of the invention to form a stem cell composition. For instance, stem cells can be cultured and expanded *in vitro* using methods of the invention and then administered to a subject as a therapeutic stem cell composition according to methods known to skilled persons.

In some embodiments, the composition comprises: a stem cell; and one or more activators of PCP signaling in the stem cell, *e.g.*, a Wnt7a polypeptide or fragment thereof and/or fibronectin. In some embodiments, the stem cell is a satellite stem cell.

In some embodiments, the composition comprises a stem cell transformed to express a polynucleotide of interest that encodes a Wnt7a polypeptide or fragment thereof and/or fibronectin. Any suitable transformation method known in the art may be employed.

In one embodiment, there is provided a composition for enhancing tissue regeneration or repair comprising: a stem cell; and one or more activators or effectors of PCP signaling such as, for example, a Wnt7a polypeptide or fragment thereof and/or fibronectin.

In some embodiments, the composition comprises a stem cell transformed to overexpress an activator or effector of the PCP pathway, for example, a Wnt7a polypeptide fragment. In particular embodiments, the stem cell is further transformed to overexpress fibronectin.

The composition may comprise a physiologically acceptable diluent, carrier or excipient. Methods of making various pharmaceutical compositions for various routes of administration are known in the art and are further described elsewhere herein.

The present invention further provides pharmaceutical compositions comprising one or more active agents selected from the group consisting of a Wnt7a polypeptide, an analogue, derivative, variant or active fragment thereof, a fibronectin polypeptide, and another activator or effector of PCP signaling; and a pharmaceutically acceptable diluent or excipient. Pharmaceutical compositions and methods of preparing pharmaceutical compositions are known in the art and are described, for example, in “Remington: The Science and Practice of Pharmacy” (formerly “Remington’s Pharmaceutical Sciences”); Gennaro, A., Lippincott, Williams & Wilkins, Philadelphia, PA (2000).

The pharmaceutical compositions may optionally further comprise one or more stem cell modulators, one or more stem cells, or a combination thereof. Administration of the pharmaceutical compositions may be via a number of routes depending upon whether local or systemic treatment is desired and upon the area to be treated. Typically, the compositions are administered systemically or locally to the area to be treated.

Administration may be topical (including ophthalmic and to mucous membranes including vaginal and rectal delivery), pulmonary (*e.g.*, by inhalation or insufflation of powders or aerosols, including by nebulizer), intratracheal, intranasal, epidermal and transdermal, oral or parenteral. Parenteral administration includes intravenous, intraarterial, subcutaneous, intraperitoneal or intramuscular injection, for example, but not limited to intracardial injection or infusion, or intracranial, *e.g.*, intrathecal or intraventricular administration. In some embodiments, compositions are administered by injection or infusion.

The compositions of the present invention may be delivered in combination with a pharmaceutically acceptable vehicle. Preferably, such a vehicle would enhance the stability and/or delivery properties. Examples include liposomes, microparticles or microcapsules. In various embodiments of the invention, the use of such vehicles may be beneficial in achieving sustained release of the active component. When formulated for parenteral injection, the pharmaceutical compositions are preferably used in the form of a

sterile solution, containing other solutes, for example, enough saline or glucose to make the solution isotonic.

For administration by inhalation or insufflation, the pharmaceutical compositions can be formulated into an aqueous or partially aqueous solution, which can then be utilized in the form of an aerosol. For topical use, the modulators or pharmaceutical compositions comprising the modulators can be formulated as dusting powders, creams or lotions in pharmaceutically acceptable vehicles, which are applied to effected portions of the skin.

The dosage requirements for the pharmaceutical compositions vary with the particular compositions employed, the route of administration and the particular subject being treated. Dosage requirements can be determined by standard clinical techniques known to a worker skilled in the art. Treatment will generally be initiated with small dosages less than the optimum dose of each compound. Thereafter the dosage is increased until the optimum effect under the circumstances is reached. In general, the pharmaceutical compositions are administered at a concentration that will generally afford effective results without causing any harmful or deleterious side effects. Administration can be either as a single unit dose or, if desired, the dosage can be divided into convenient subunits that are administered at suitable times throughout the day.

When *in vitro* or *ex vivo* methods of treating the stem cells are employed, the stem cells can be administered to the subject by a variety of procedures. Typically, administration of the stem cells is localized. The stem cells can be administered by injection as a cell suspension in a pharmaceutically acceptable liquid medium. Alternatively, the stem cells can be administered in a biocompatible medium which is, or becomes in site a semi-solid or solid matrix. For example, the matrix maybe an injectable liquid which forms a semi-solid gel at the site of tissue damage or degeneration, such as matrices comprising collagen and/or its derivatives, polylactic acid or polyglycolic acid, or it may comprise one or more layers of a flexible, solid matrix that is implanted in its final form, such as impregnated fibrous matrices. Such matrices are letdown in the art (for example, Gelfoam available from Upjohn, Kalamazoo, Mich.) and function to hold the cells in place at the site of injury, which enhances the opportunity for the administered cells to expand and thereby for a reservoir of stem cells, to develop.

The stem cells may or may not be cryopreserved prior to, or after treatment of the cells.

In some embodiments, the stem cells are administered with a compound for promoting stem cell expansion to minimize risk of stem cell depletion following transplantation. In some embodiments, the transplanted stem cells have been transformed to overexpress an activator of PCP signaling, as described elsewhere herein. In some embodiments, the stem cells are co-administered with muscle cells or other satellite cells transformed to overexpress and secrete a Wnt7a polypeptide or fragment thereof and/or a fibronectin polypeptide. In some embodiments, the stem cells are injected intramuscularly.

In a preferred embodiment, satellite stem cells or a composition comprising satellite stem cells is injected into muscle tissue, preferably in an area proximal to diseased, injured or damaged tissue. However, injection into the circulation or at a distal site is also contemplated. Intracardiac administration is also contemplated.

C. Methods

The invention provides, in part, for methods of modulating stem cells, in particular, methods of modulating division symmetry of adult stem cells, such as satellite stem cells comprising contacting the stem cells with a composition comprising a Wnt7a polypeptide fragment as described elsewhere herein. The invention also provides a method of synergistically modulating division symmetry of adult stem cells, such as satellite stem cells comprising contacting the stem cells with a composition comprising a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide as described elsewhere herein.

In particular embodiments, it is therapeutically beneficial to pharmacologically treat fibrotic muscle pathology in intervals. Such treatment would simulate both physiological states of muscle regeneration, fibrotic conditions triggering satellite stem cell expansion, and lower levels of FN fostering lineage progression and the differentiation of myoblasts.

In some embodiments, stem cell division symmetry is modulated by the compositions of the invention *in vivo*, *ex vivo*, or *in vitro*.

In some embodiments, there is provided a use of a composition a Wnt7a polypeptide fragment as described herein for the manufacture of a medicament for promoting

stem cell expansion. In some embodiments, there is provided a use of a composition a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide as described herein for the manufacture of a medicament for promoting stem cell expansion.

In some embodiments, there is provided a composition a Wnt7a polypeptide fragment as described herein for use in the manufacture of a medicament for promoting stem cell expansion. In some embodiments, there is provided a use of a composition a Wnt7a polypeptide fragment as described herein for the manufacture of a medicament for promoting muscle formation, maintenance, repair, or regeneration of muscle in a subject in need thereof. In some embodiments, there is provided a composition a Wnt7a polypeptide fragment as described herein for use in the manufacture of a medicament for promoting muscle formation, maintenance, repair, or regeneration of muscle in a subject in need thereof. In related embodiments, the compositions comprise a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide.

In some embodiments, the inventive compositions are used for promoting muscle regeneration or repair in a subject.

The composition may be administered in an effective amount, such as a therapeutically effective amount.

As described in the embodiments above, the composition comprises a Wnt7a polypeptide or a fragment thereof and/or a fibronectin polypeptide as an active agent a modulator of planar cell polarity (PCP) signaling in the stem cell. In some embodiments, the method thereby promotes stem cell expansion. Such methods are useful, for example, for increasing the relative proportion of symmetrical to asymmetrical cell divisions in a population of stem cells *in vivo* or *in vitro*. Such methods are therefore useful for expanding a population of stem cells *in vivo* or *in vitro*.

In some embodiments, the methods disclosed herein are capable of promoting symmetrical stem cell division without altering the rate of stem cell division. In some embodiments, the methods may be useful for promoting survival of a population of stem cells. In some embodiments, the methods are administered *in vitro*.

In some embodiments, the methods are administered *in vivo*. In some embodiments, the *in vivo* method comprises administering the composition to a subject in need thereof. In some embodiments, a method for expanding a population of satellite stem

cells *in vivo* or *in vitro* comprises contacting the stem cells with an effective amount of a composition comprising (a) a Wnt7a polypeptide fragment, or an active variant, analogue or derivative thereof capable of binding to and activating Fzd7, or (b) a polynucleotide encoding a Wnt7a polypeptide fragment, or an active variant, analogue or derivative thereof capable of binding to and activating Fzd7.

In other embodiments, the invention provides an *in vivo*, *ex vivo*, or *in vitro* method for expanding a population of satellite stem cells comprising administering or contacting the population of satellite stem cells with a composition comprising (a) a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide capable of binding to and activating Fzd7/Sdc4 receptor complex, or (b) one or more polynucleotides encoding a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide capable of binding to and activating Fzd7/Sdc4 receptor complex.

In some embodiments, the active agent is a Wnt7a polypeptide fragment, or an analogue, derivative, variant or active thereof. In other embodiments, a composition comprises one or more active agents selected from the group consisting of: a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide.

In some embodiments, there is provided a method of promoting satellite stem cell expansion comprising contacting the satellite stem cell with a composition comprising one or more active agents. In particular embodiments, it is contemplated that one or more agents may synergistically promote satellite stem cell expansion.

In another embodiment, a method of increasing the number of satellite cells in a tissue, and thereby providing enhanced regeneration potential of the tissue, comprises contacting the stem cells with a composition as described herein. In particular embodiments, it is contemplated that one or more agents may synergistically promote tissue regeneration.

In some embodiments, the methods of the invention are used *in vivo* for treatment of resident stem cells in a tissue, *e.g.* resident satellite stem cells in muscle tissue.

In some embodiments, the method may additionally comprise contacting the stem cell with one or more stem cell modulators, for example, a modulator that increases the rate of stem cell division or increases stem cell survival. In some embodiments, the method comprises administering cells to a subject. The cells may, for example, be administered simultaneously or sequentially with a composition described herein.

In some embodiments, the method comprises administering stem cells to a subject. The stem cells may, for example, be administered simultaneously or sequentially with a composition described herein that promotes stem cell expansion. For example, the stem cells may be administered prior to administration of the composition (*i.e.* the composition may be administered after a desired period). In some embodiments, the composition itself may comprise the stem cells to be administered.

Stem cells may be maintained and expanded *in vitro* for subsequent experimental or therapeutic uses. In some embodiments, stem cells, *e.g.*, satellite stem cells, are expanded *in vitro* or *ex vivo* and are subsequently administered to a subject in need thereof. For instance, stem cells can be cultured and expanded *in vitro* or *ex vivo* using methods of the invention and then administered to a patient as a therapeutic stem cell composition according to methods known to skilled persons.

In some embodiments, stem cells may be obtained from an individual and maintained in culture. The population of cultured stem cells may be treated with a Wnt7a polypeptide fragment or polynucleotide encoding the same, and/or another activator of PCP signaling, *e.g.*, fibronectin, to promote symmetrical expansion *in vitro* or *ex vivo*.

In some embodiments, the method may comprise administering helper cells to a subject, such as cells of the stem cell niche. The helper cells may, for example, be administered simultaneously or sequentially with the composition. In some embodiments, the composition itself may comprise helper cells. The present invention also contemplates administration of polynucleotides encoding Wnt7a active fragment, a variant or thereof, or another activator of PCP signaling, *e.g.*, fibronectin, and optionally a stem cell modulator, which then express the encoded product *in vivo*, by various gene therapy methods known in the art.

In one embodiment, satellite stem cells are co-cultured with muscle cells transformed with a CMV-Wnt7a polypeptide fragment construct to overexpress and secrete the Wnt7a polypeptide fragment. Any suitable expression vector may be used, including but not limited to those described previously. Where *in vivo* methods are performed, cell- or tissue-specific vectors or promoters may also be used. In one embodiment, the vector is a muscle-specific AAV vector. An inducible promoter may optionally be used. Polypeptide activators or effectors of PCP-signaling may be directly introduced into cells, bypassing the

DNA transfection step. Means to directly deliver polypeptides into cells include, but are not limited to, microinjection, electroporation, cationic lipids and the construction of viral fusion proteins. Typically, transfection of a suitable expression system carrying a polynucleotide will be used.

The methods of promoting stem cell expansion can be used to stimulate the *ex vivo* or *in vitro* expansion of stem cells and thereby provide a population of cells suitable for transplantation or administration to a subject in need thereof. The stem cells to be administered may be treated with a stem cell modulator, for example, a modulator that promotes survival of a stem cell. Sequential methods that promote expansion followed by proliferation and/or differentiation of stem cells are also contemplated. For example, a stem cell population may be expanded *in vitro* by contacting the cells, directly or indirectly, with a Wnt7a polypeptide fragment or a Wnt7a polypeptide or fragment thereof and a fibronectin polypeptide. The expanded population of cells may then be treated with one or more stem cell modulators *in vitro* or *in vivo*, *e.g.*, that promotes proliferation and/or differentiation of the stem cells *in situ* or promotes stem cell survival. Alternatively, both steps may be conducted *in vitro* prior to administration of the cells to a subject.

For *in vivo* and *ex vivo* transplant methods, the stem cells can be autologous, allogeneic or xenogeneic. In embodiments where stem cells from a donor subject are transplanted into a recipient subject in need thereof, preferably, the donor and recipient are matched for immunocompatibility. Not wishing to be limiting, it is preferable that the donor and the recipient are matched for compatibility to the major histocompatibility complex (MHC) (human leukocyte antigen (HLA))-class I (*e.g.*, loci A, B, C) and -class II (*e.g.*, loci DR, DQ, DRW) antigens. Immunocompatibility between donor and recipient may be determined according to methods generally known in the art (*see, e.g.*, Charron, D. J., *Curr. Opin. Hematol.*, 3: 416-422 (1996); Goldman, J., *Curr. Opin. Hematol.*, 5: 417-418 (1998); and Boisjoly, H. M. *et al.*, *Ophthalmology*, 93: 1290-1297 (1986)).

In one embodiment of the present invention, the gene therapy vector is an adenovirus-derived vector or a lentiviral vector. In one embodiment, the gene therapy vector is administered to a patient, wherein the vector comprises a Wnt7a polypeptide fragment under the control of a muscle-specific promoter or vector.

The methods described herein have a number of applications. For example, the methods can be used *in vitro* to promote expansion of stem cells wherein the cells are destined for further *in vitro* use, for example, for research or diagnostic purposes. The methods can be used for maintaining stem cell cultures *in vitro* and also have potential application in the development of new *in vitro* models for drug testing or screening.

The compositions and methods described herein are also useful for various therapeutic applications. In particular, the compositions and methods described herein are useful for promoting tissue formation, regeneration, repair or maintenance in a subject in need thereof. In some embodiments, the tissue is muscle. In some embodiments, the muscle is skeletal muscle.

Relevant therapeutic applications may pertain to situations where there is a need to regenerate lost or damaged muscle tissue, for example, after chemotherapy or radiation therapy, after muscle injury, or in the treatment or management of diseases and conditions affecting muscle. In some embodiments, the disease or condition affecting muscle may include a wasting disease (*e.g.* cachexia, which may be associated with an illness such as cancer or AIDS), muscular attenuation or atrophy (*e.g.* sarcopenia, which may be associated with aging), ICU-induced weakness, prolonged disuse (*e.g.* coma, paralysis), surgery-induced weakness (*e.g.* following hip or knee replacement), or a muscle degenerative disease (*e.g.* muscular dystrophies). This list is not exhaustive.

In some embodiments, compositions and methods described herein are employed where there is a need to prevent loss of tissue, as in wasting diseases or atrophy.

In some embodiments, compositions and methods described herein are employed where there is a need or desire to increase the proportion of resident stem cells, or committed precursor cells, in a muscle tissue, for example, to replace damaged or defective tissue, or to prevent muscle atrophy or loss of muscle mass, in particular, in relation to diseases and disorders such as muscular dystrophy, neuromuscular and neurodegenerative diseases, muscle wasting diseases and conditions, atrophy, cardiovascular disease, stroke, heart failure, myocardial infarction, cancer, HIV infection, AIDS, and the like.

In some embodiments, the methods can be used with satellite stem cells in the treatment, management or prevention of degenerative muscle disorders.

In some embodiments, the compositions and methods are useful for promoting muscle cell formation, for example, for repairing or regenerating dysfunctional skeletal muscle, for instance, in subjects having muscle degenerative diseases.

The subject may therefore have, be suspected of having, or be at risk of at having skeletal muscle damage, degeneration or atrophy. The skeletal muscle damage may be disease related or non-disease related. The human subject may exhibit or be at risk of exhibiting muscle degeneration or muscle wasting. The muscle degeneration or muscle wasting may be caused in whole or in part by a disease, for example AIDS, cancer, a muscular degenerative disease, or a combination thereof. Muscle degeneration may be due to a muscle degeneration disease such as muscular dystrophy.

Illustrative examples of muscular dystrophies include, but are not limited to: Duchenne muscular dystrophy (DMD), Becker muscular dystrophy (BMD), myotonic dystrophy (also known as Steinert's disease), limb-girdle muscular dystrophies, facioscapulohumeral muscular dystrophy (FSH), congenital muscular dystrophies, oculopharyngeal muscular dystrophy (OPMD), distal muscular dystrophies and Emery-Dreifuss muscular dystrophy.

In some forms of urinary incontinence, the culprit muscle can be treated with a composition or method of the invention, for example, by electroporation of the muscle. Thus, in one embodiment, the method is useful for treating urinary incontinence.

In one aspect, there is provided a method for promoting muscle formation, regeneration or repair in a subject in need thereof comprising administering to the mammal a composition comprising one or more active agents as disclosed elsewhere herein.

In another aspect, there is provided a method for preventing muscle wasting, atrophy or degeneration in a subject in need thereof comprising administering to the mammal a therapeutically effective amount of a composition as disclosed elsewhere herein.

In some aspects, the compositions and methods described herein are useful for promoting formation, maintenance, repair or regeneration of skeletal muscle in a human subject in need thereof. In one aspect, there is provided a method for enhancing tissue formation, regeneration, maintenance or repair in a mammal comprising administering to a subject in need thereof a composition as described elsewhere herein.

The promotion of muscle cell formation can further be, in an embodiment, for preventing or treating muscle destruction or atrophy of a subject, *e.g.*, in subjects with disuse atrophy or sarcopenia. In some embodiments, the compositions are used to treat or prevent atrophy and to maintain muscle mass. The promotion of muscle cell formation can also be, in an embodiment, for repairing damaged muscle tissue. In an alternative embodiment, the promotion of muscle cell formation can be for increasing muscle mass in a subject.

In a further embodiment, damaged or dysfunctional muscle tissue may be caused by an ischemic event. For instance, the damaged muscle tissue may be cardiac muscle damaged by a cardiovascular event such as myocardial infarct, or heart failure.

In a further embodiment, damaged or dysfunctional muscle tissue may be cardiac muscle. For instance, the damaged muscle tissue may be cardiac muscle damaged by a cardiovascular event such as myocardial infarct, or heart failure, where the target stem cell would be a cardiac stem cell. In accordance with another aspect of the present invention, there is provided a method of promoting cardiac stem cell expansion in a mammal comprising administering to said mammal an effective amount of a composition as described herein.

The compositions and methods described herein may be used in combination with other known treatments or standards of care for given diseases, injury, or conditions. For example, in the context of muscular dystrophy, a composition of the invention for promoting symmetrical stem cell expansion can be administered in conjunction with such compounds as cardiotrophin polypeptide (CT-1), prednisone or myostatin. The treatments may be administered together, separately or sequentially.

The dosage regimen and treatment regime will vary depending on the disease being treated, based on a variety of factors, including the type of injury, the age, weight, sex, medical condition of the individual, the severity of the condition, the route of administration, and the particular compound employed. Thus, the dosage regimen and treatment regimes can vary, but can be determined routinely by a physician using standard methods. Dosage levels of the order of between 0.1 ng/kg and 10 mg/kg body weight of the active agents per body weight are useful for all methods of use disclosed herein.

Treatment may continue with subsequent administration of a composition of the invention. In a particular embodiment of the invention, a subject undergoes repeated

cycles of treatment according to the method of this invention. Therapy may be administered for 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12 times per day, per week, per month, or per year at dosages determined based on the disease or condition being treated, age, weight, route of administration, and other factors. In all of these embodiments, the compositions of the invention can be administered either prior to, simultaneously with, or subsequent to a planned medical procedure, onset of disease or injury.

All publications, patent applications, and issued patents cited in this specification are herein incorporated by reference as if each individual publication, patent application, or issued patent were specifically and individually indicated to be incorporated by reference.

Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it will be readily apparent to one of ordinary skill in the art in light of the teachings of this invention that certain changes and modifications may be made thereto without departing from the spirit or scope of the appended claims. The following examples are provided by way of illustration only and not by way of limitation. Those of skill in the art will readily recognize a variety of noncritical parameters that could be changed or modified to yield essentially similar results.

EXAMPLES

EXAMPLE 1

WNT7A MODELING

Background

Therapeutic application of Wnt7a has been hindered by the hydrophobicity of the protein, preventing its use in systemic delivery. Understanding the structure of the protein is difficult due to the complex posttranscriptional modification of Wnt proteins, which renders Wnts insoluble and hard to crystallize. Consequently, the structure of these proteins remains unknown.

Experimental Results

A model of Wnt7a's tertiary structure using I-TASSER homology protein modeling software was created (Figure 1A). This predicted structure indicated that at least two functional domains are present in Wnt7a: a helicoid N-terminal domain (NT) which contained the two lipid adducts that are added to Wnt7a posttranslationally; and a globular C-terminal domain (CT). Although a number of recent studies have shown that lipidation of the NT region of Wnts are necessary Wnt secretion and activation of canonical signaling pathways, the inventors have surprisingly discovered that Wnt7a function may not be entirely dependent on the N-terminal domain and that Wnt7a function is independent of lipidation.

To investigate the differences in the two proposed Wnt7a domains a Kyte-Doolittle Hydropathy Plot was used to examine the solubility of these regions based on their primary amino acid sequence. The N-terminal region contained a significant number of hydrophobic residues, which were virtually absent from the highly hydrophilic C-terminus (Figure 1B).

These results indicated that the C-terminal domain could be the receptor-binding region of the protein, and may be able to induce a response in the absence of the hydrophobic N-terminus.

EXAMPLE 2

WNT7A-CT ACTIVATES WNT7A SIGNALING PATHWAYS *IN VIVO*

Background

Two truncated mutants were created to verify that the C-terminal domain of Wnt7a is the receptor binding region of the protein: the NT region comprised amino acids 32-212 of Wnt7a, which includes the two lipidation sites on Wnt7a, and the CT region comprised amino acids 213-349; the full length processed Wnt7a protein contains amino acid residues 32-349 (Figure 2). Amino acids 1-31 form the signal peptide that targets Wnt7a for secretion, which is likely cleaved off during processing of the protein.

Experimental Results

Wnt7a CT increases TA weight and fiber diameter compared to LacZ controls

In order to preserve protein secretability, both regions, as well as the full length protein were cloned with the signal peptide fused to the N-terminus of the coding

sequence tested. A large quantity of plasmid was prepared using a plasmid prep kit and dissolved in saline solution (0.9% NaCl). Before injection, an equal quantity of LacZ plasmid DNA was added to each Wnt7a sample to be used as a marker of electroporation efficiency. A total volume of 50 μ L of solution containing 17.5 μ g of a Wnt7a construct and 17.5 μ g of LacZ was electroporated into the TA muscle of adult mice. A small quantity of plasmid was used to ensure that only a fraction of the fibers in the muscle were electroporated, thus, creating a contrast between fibers affected by Wnt7a and the remaining fibers.

Six days after electroporation, the electroporated TA muscles were collected and divided in two, with one half sectioned for staining and the other half crushed and used for Western Blotting. Following excision, muscles electroporated with Wnt7a CT or FL genes were significantly heavier than Wnt7a NT and LacZ control muscles, which were the same weight (Figure 3A).

Muscle sections were stained with X-Gal staining solution to confirm that the electroporation had only affected select muscle fibers (Figure 4). The positive X-Gal staining also indicated that the mice used in the study had been successfully electroporated. Muscle sections were then stained with α 2-laminin and α HA antibodies to outline the perimeter of muscle fibers and to mark fibers expressing Wnt7a, respectively.

Selectively measuring the diameter of Wnt7a-HA expressing fibers revealed a significant increase in hypertrophy in Wnt7a FL-electroporated fibers over the LacZ control (Figure 3B). The introduction of two exogenous amino acids following the signal peptide, which likely prevented its cleavage, did not compromise the functioning of the protein. This indicated that cleavage of the signal peptide on Wnt7a was not a necessary event during trafficking and excretion of the protein.

The measured diameter of Wnt7a CT expressing muscles resembled that of the full length Wnt7a (Figure 3B), whereas Wnt7a NT did not induce hypertrophy over the size of fibers observed in the LacZ control. Muscles electroporated with Wnt7a FL and the Wnt7a CT truncated mutant had an average fiber diameter of 46.0 μ m $\pm$ 6.0 μ m and 55.3 μ m $\pm$ 7.2 μ m, respectively, compared to a control fiber diameter of 31.8 μ m $\pm$ 3.6 μ m (LacZ), indicating an overall increase in fiber caliber of 44% (Wnt7a FL) and 74% (Wnt7a CT).

These data indicated that the C-terminal domain of Wnt7a has retained the activity of the full length protein and was both necessary and sufficient to induce hypertrophy in myofibers; conversely, the N-terminal domain was not necessary for Wnt7a signaling. In addition, the removal of the N-terminal region may have increased the activity of the protein.

Wnt7a CT has increased bioavailability compared to Wnt7a FL

Examination of the entire muscle sections revealed that Wnt7a CT had an increased biodistribution profile, *i.e.*, Wnt7a CT was secreted over a much greater area in the electroporated muscle when compared to Wnt7a WT (Figure 5). Although the same number of fibers was initially electroporated as shown by the X-Gal staining (Figure 4), the delipidated Wnt7a (Wnt7a CT) had dispersed to adjacent fibers that endocytosed the protein, resulting in the observed sarcoplasmic staining and increased biodistribution profile.

It was confirmed that the Wnt7a CT biodistribution profile was not a location-dependent observation by staining sections from both the middle (“belly”) and tip of the muscle. The muscle lysate was probed with α HA antibody and it was confirmed that all Wnt7a variants were being expressed to the same extent (Figure 5D), showing that the widespread staining is due to increased dispersion of the hydrophilic protein rather than differences in expression levels.

Summary

The results indicated that Wnt7a is composed of two protein domains, where the C-terminal region (amino acids 213-349) is significantly more hydrophilic than the N-terminus (amino acids 32-212). The CT domain was both necessary and sufficient to induce muscle cell hypertrophy. The truncated Wnt7a CT mutant was significantly more water soluble than the full length protein, had greater affectability in muscles and was sufficiently small to more easily circumvent the capillary endothelium, which would augment Wnt7a’s therapeutic effects in treatment of myodegenerative disorders.

EXAMPLE 3

SECRETED WNT7A-CT ACTIVATES WNT7A SIGNALING PATHWAYS IN C2C12 CELLS

COS cells were transfected with Wnt7a FL, Wnt7a C73A (a Wnt7a delipidation mutant), or Wnt7a CT. After allowing for expression of transfected genes, tissue

culture supernatants from the transfected COS cells was harvested and applied to C2C12 primary myoblast cells that had been growing in differentiation conditions for three days. The fiber diameter of the C2C12 cells was measured two days after addition of the COS cell supernatants that contained the secreted Wnt7a proteins that were tested. Figure 6 shows that Wnt7a CT, Wnt7a C73A, or Wnt7a FL supernatants increased muscle fiber diameter in C2C12 cells compared to the control COS cell supernatant.

EXAMPLE 4

WNT7A-CT ACTIVATES WNT7A SIGNALING PATHWAYS IN C2C12 CELLS

C2C12 cells were transiently transfected with Wnt7a FL, Wnt7a C73A (a Wnt7a delipidation mutant), or Wnt7a CT. The transfected C2C12 primary myoblast cells were grown in differentiation conditions for five days. The fiber diameter of the C2C12 cells was measured on day five. Figure 7 shows that C2C12 cells transfected with Wnt7a CT, Wnt7a C73A, or Wnt7a FL supernatants had increased muscle fiber diameter compared to the control transfected C2C12 cells.

EXAMPLE 5

ACTIVATED SATELLITE CELLS REMODEL THEIR NICHE WITH FN

Introduction

The spatiotemporal regulation of satellite cells during muscle regeneration is remarkably fine-tuned and highly dependent on a variety of extrinsic signals (Bentzinger *et al.*, 2010; Kuang *et al.*, 2008). Apart from classic signaling molecules, mechanical and structural properties of the niche play an important role for satellite cell function (Cosgrove *et al.*, 2009).

Structural properties of the satellite cell niche are largely determined by the fiber sarcolemma and the complex extracellular matrix (ECM) secreted by myogenic cells, which surrounds muscle fibers as the basement membrane. The basement membrane is primarily composed of collagens, laminins and non-collagenous glycoproteins (Sanes, 2003).

A screening approach was used to identify ECM components synthesized by myogenic cells and lead to the discovery of the glycoprotein Fibronectin (FN) as a transient component of the satellite cell niche during muscle regeneration. Upon muscle injury, the

inventors found that FN modulated the initial proliferative response of satellite stem cells in cooperation with Wnt signaling, whereas in later stages of regeneration FN levels drop and allow lineage progression and differentiation of committed satellite myogenic cells for tissue repair.

Results

A microarray analysis of proliferating and differentiating satellite cell derived primary myoblasts was performed to determine how myogenic cells contribute to the ECM (Figure 8A). FN showed the highest signal intensity among a selection of classic ECM components, and was substantially downregulated during myotube differentiation (Table 2). PCR over potential splice sites revealed that the majority of FN transcripts in proliferating myogenic cells code for cellular FN containing EIIIA and EIIIB inserts (Figure 15).

Table 2

Gene name	Prol.1	Prol.2	Prol.3	AV Prol.	SE Prol.	2d diff.1	2d diff.2	2d diff.3	AV 2d diff.	SE 2d diff.	5d diff.1	5d diff.2	5d diff.3	AV 5d diff.	SE 5d diff.
<i>Fnl</i>	761	911	821	828	44	244	256	237	245	6	53	70	62	61	5
<i>Lamb1-1</i>	448	523	471	480	22	86	87	87	87	1	33	33	28	32	2
<i>Tnc</i>	379	457	406	413	23	40	40	39	39	0	10	12	10	11	1
<i>Col4a3bp</i>	346	403	390	379	17	718	766	684	722	24	333	400	393	374	21
<i>Col3a1</i>	367	378	359	368	6	67	68	68	68	0	41	32	36	36	2
<i>Col3a2</i>	332	369	344	348	11	129	140	140	136	4	57	59	53	56	2
<i>Col18a1</i>	318	352	320	330	11	68	69	69	68	0	51	42	47	46	3
<i>Lamb2</i>	168	189	169	175	7	362	368	359	363	3	511	443	442	464	23
<i>Col4a1</i>	163	192	147	167	13	50	53	51	51	1	47	46	39	44	2
<i>Hspg2</i>	155	167	160	161	4	170	177	172	173	2	149	142	153	148	3
<i>Lama2</i>	147	163	159	156	5	159	159	159	159	0	159	162	174	165	4
<i>Lamc1</i>	109	125	119	117	5	130	131	126	129	1	104	90	101	98	4
<i>Agrn</i>	112	116	111	113	2	45	42	42	43	1	36	33	32	34	1
<i>Col4a2</i>	108	113	97	106	5	43	45	46	44	1	44	37	42	41	2
<i>Nid2</i>	93	107	102	100	4	167	163	165	165	1	37	49	54	46	5
<i>Lama5</i>	90	105	100	98	4	47	49	46	47	1	61	61	62	61	0
<i>Nid1</i>	89	105	95	96	4	38	37	28	34	3	31	31	32	31	0
<i>Col8a1</i>	74	85	74	77	4	34	34	32	34	1	26	19	16	20	3
<i>Col12a1</i>	58	72	66	65	4	46	45	46	46	0	25	31	30	29	2
<i>Col6a1</i>	65	56	65	62	3	47	44	52	47	2	56	50	48	51	2
<i>Col3a1</i>	55	54	52	54	1	46	49	48	48	1	57	51	51	53	2
<i>Col9a2</i>	45	39	40	41	2	48	51	49	49	1	70	62	51	60	5
<i>Colla2</i>	37	40	40	39	1	37	40	39	39	1	41	39	37	39	1
<i>Col27a1</i>	40	34	39	38	2	35	40	36	37	1	49	46	41	45	2
<i>Col13a1</i>	38	31	38	36	2	38	38	35	37	1	50	44	40	45	3
<i>Col2a1</i>	38	35	36	36	1	35	38	38	37	1	49	43	46	46	2
<i>Colla1</i>	37	32	36	35	2	34	38	37	36	1	42	39	37	39	2
<i>Col23a1</i>	39	31	36	35	2	36	39	42	39	2	60	46	46	50	5
<i>Col16a1</i>	36	29	32	33	2	33	31	33	32	1	41	38	33	37	2
<i>Col19a1</i>	29	36	32	33	2	68	65	73	68	2	49	53	53	52	1
<i>Coll1a2</i>	33	26	31	30	2	35	35	35	35	0	49	45	40	44	2
<i>Col6a2</i>	32	31	28	30	1	32	31	29	31	1	38	32	35	35	2
<i>Col7a1</i>	32	27	30	30	2	31	32	32	32	1	40	38	38	39	1
<i>Col25a1</i>	33	27	24	28	3	40	40	40	40	0	50	57	53	53	2
<i>Lamb3</i>	27	26	28	27	1	24	26	24	25	1	26	27	25	26	1
<i>Col5a3</i>	27	24	30	27	2	33	39	35	36	2	41	38	34	38	2
<i>Col9a1</i>	24	25	25	25	0	27	25	26	26	1	35	31	27	31	2
<i>Lamc3</i>	25	22	26	24	1	25	23	25	24	1	33	27	24	28	3
<i>Col5a1</i>	24	21	24	23	1	24	24	24	24	0	31	28	24	28	2
<i>Col17a1</i>	22	22	22	22	0	21	23	22	22	1	29	29	24	27	2
<i>Col4a5</i>	22	20	24	22	1	24	24	24	24	0	28	29	24	27	1

<i>Col20a1</i>	22	20	23	21	1	23	23	23	23	0	23	23	22	23	0
<i>Lamc2</i>	21	19	19	19	1	33	30	28	31	1	24	25	25	25	0
<i>Col15a1</i>	21	16	21	19	2	21	21	21	21	0	26	26	25	26	0
<i>Col24a1</i>	22	19	17	19	2	21	22	22	22	0	31	31	23	28	3
<i>Col8a2</i>	22	18	18	19	1	22	22	21	22	0	31	29	32	30	1
<i>Col4a4</i>	20	16	19	18	1	19	19	19	19	0	20	20	23	21	1
<i>Col4a3</i>	18	15	17	17	1	17	18	18	18	0	21	20	22	21	1
<i>Col6a3</i>	18	15	17	17	1	19	19	19	19	0	21	20	20	20	0
<i>Bgn</i>	17	17	15	16	1	17	16	13	15	1	20	24	23	22	1
<i>Col11a1</i>	18	16	16	16	1	16	18	18	17	1	22	22	19	21	1
<i>Tnn</i>	15	14	15	15	0	15	15	15	15	0	15	17	15	16	1
<i>Col14a1</i>	15	14	15	15	1	15	15	15	15	0	19	16	15	17	1
<i>Col28a1</i>	18	14	15	15	1	18	19	17	18	0	24	25	18	22	2
<i>Tnxb</i>	12	12	15	13	1	15	15	15	15	0	20	17	16	18	1
<i>Col4a6</i>	15	12	13	13	1	15	15	14	15	0	20	17	15	17	2
<i>Lama1</i>	13	11	12	12	1	13	12	12	12	0	14	13	13	14	0
<i>Col10a1</i>	11	13	13	12	0	13	15	12	13	1	14	13	16	14	1
<i>Tnf</i>	9	11	13	11	1	13	13	13	13	0	13	11	17	13	2
<i>Lama3</i>	11	11	11	11	0	11	11	10	10	0	12	11	12	12	0
<i>Vtn</i>	9	10	11	10	1	11	11	11	11	0	12	16	11	13	1
<i>Dcn</i>	9	8	8	9	0	8	8	8	8	0	9	8	12	10	1
<i>Lama4</i>	8	8	8	8	0	9	9	8	8	0	9	10	8	9	1

Replicates are from primary myoblasts in proliferation (Prol.) and differentiation (diff.).

AV=Average, SE=Standard error.

The expression pattern of FN and other ECM components by myogenic cells were determined using an additional gene expression analysis on prospectively isolated quiescent satellite cells (Quie.), versus established proliferating satellite cell-derived myoblasts (Prol.), and differentiated myotubes (2d and 5d diff.) (Figure 8F, Table 4).

Table 4: Affymetrix microarray probe signal intensity of ECM components synthesized by myogenic cells.

Gene	Quie.	Prol.	2d diff.	5d diff.
Vtn	1953.1	11.5	13.4	14.7
Bgn	1618.3	18.2	17	25.7
Dcn	1323.8	9.7	9	12
Hspg2	1130.8	181.8	200.3	167.4
Lama2	1093.8	178	178.6	188
Lamc1	1028.3	135.1	150.5	109.7
Nid1	873.2	115.5	39.8	36.2
Lamb2	577.4	187.1	384.8	497.9
Tnxb	521.8	13.4	17.4	20.5
Col6a1	447.8	67.1	50.1	55.1
Col3a1	357.6	400	74.2	38.6
Col15a1	354.3	21	22.9	28.9
Fn1	331	884.4	266.6	69.9
Col6a3	297.9	18.5	21.5	24.6
Col4a1	286.2	184.4	55.8	50.6
Col4a2	250.3	125.5	51.4	48.4
Col6a2	229.5	35.7	38.5	45.3

Lamb1	212	510.2	95.7	35.1
Col1a2	206.1	46.3	45.5	44.8
Col1a1	174.4	37.7	39.5	44.8
Lama4	158.9	8.2	9.5	9.5
Nid2	158.8	114.5	187.4	53.7
Aggrn	148.1	128.5	49.8	40.3
Lama5	135	117.5	54.4	70
Col8a1	130.2	91.6	38.4	22.2
Lama3	127	11.3	11.4	13.7
Col4a3bp	122.8	408.6	769.4	403.7
Col5a1	109.2	67	57	64.6
Col5a2	95.6	380.4	155.9	64
Col12a1	71.7	77.6	54.5	32.1
Col5a3	68.2	30.4	41.4	43.1
Col18a1	64.4	367.2	76.7	54.1
Lamc3	55.5	27.5	27.7	34.1
Col19a1	49.5	37.9	81.7	62.2
Col20a1	44.2	22.8	25	26
Tnc	42.5	446.5	45	12
Col27a1	38.1	42	42.2	52.7
Col16a1	34.9	36.1	36.1	43.9
Col6a6	34.8	32.9	35.8	42.4
Col11a2	31.3	37	43	55.6
Col2a1	31.3	44	44.3	56
Col9a3	30.7	53	55.3	75.4
Col5a1	30.6	29.6	29.5	36.2
Col14a1	30.4	16.9	17	20.7
Col9a2	29.5	46.5	56.6	70.8
Col7a1	28.3	33.9	35.9	46.2
Col23a1	25.7	41.8	45.9	62.1
Col25a1	23.9	31.5	45.2	61.7
Col17a1	23.7	23.1	23.4	30.3
Col22a1	22.8	26.8	28.4	37.1
Col13a1	22.5	41.3	43.3	55.9
Col9a1	20.6	24.3	24.9	32.3
Lamc2	20.4	21.1	34.7	26.6
Col4a5	20.2	23.3	25.3	30
Col4a3	20.1	19.1	20.1	24.8
Col4a4	20.1	20.7	21.8	23.6
Col11a1	19.3	19.3	20.1	25.9
Col6a4	18.2	19.5	21.1	28.9

Col24a1	17.3	20.2	23.6	30.3
Lamb3	15.6	30.1	26	29.4
Tnf	15.6	12.6	14.7	15.4
Col28a1	15.6	17.1	20.2	25.9
Col6a6	15.2	14.3	14	14.8
Col10a1	13.4	13.2	14.9	15.7
Tnn	12.5	14.3	14.9	16.6
Col4a6	12.1	14.6	18	21.2
Col8a2	11.5	17.8	21	29.8
Lama1	10.7	11.3	11.9	13.8

Several probes, including Vitronectin (Vtn), Biglycan (Bgn), Decorin (Dcn), Perlecan (HSPG2), Laminin subunits (Lama2 and Lamc1) and Nidogen (Nid1) showed a high hybridization signal in quiescent satellite cells when compared to primary myoblasts or differentiated myotubes. In proliferating primary myoblasts the probe for FN (Fn1) showed a strong hybridization signal, which was 60-70% lower in quiescence or differentiation. These data indicate that proliferating myogenic progenitors are a potential source of FN within the satellite cell niche.

To confirm that satellite cells express FN single fibers from mouse EDL muscles were isolated. Quiescent satellite cells on fibers that were immediately fixed after isolation showed marginal immunostaining with FN antibodies (Figure 8B). However, activated proliferating satellite cells found on fibers that were cultured under free floating conditions for 42 hours stained strongly for FN.

Numerous cell types have been noted to express FN including fibroblasts, chondrocytes, endothelial cells, macrophages, as well as certain epithelial cells (Hynes and Yamada, 1982). Low levels of FN expression have been described in the interstitium and in capillaries of adult skeletal muscle (Peters *et al.*, 1996). Satellite cells reside closely juxtaposed to muscle fibers in a niche between the sarcolemma and the basal lamina (Charge and Rudnicki, 2004).

FN expression dynamics during regeneration were studied: the TA muscle was injured by injection of CTX and analyzed at several time-points after injury. In contrast to the unrelated ECM component Laminin (LM), FN in muscle cross sections peaked at five days post injury and declined to baseline thereafter (Figure 8C). Immunostaining performed with antibodies directed to Pax7 and FN revealed that the satellite cell niche does not contain detectable levels of FN in resting tibialis anterior (TA) muscle. However, FN staining was

present in ring-like structures reminiscent of capillaries (Figure 8E). In contrast, five days after acute cardiotoxin (CTX) muscle injury, satellite cells were embedded in a extracellular milieu containing high levels of FN.

Quantitative real-time PCR (qPCR) using whole muscle lysates confirmed that maximal FN expression after injury correlated with Pax7 expression and therefore with tissue satellite cell content (Figure 8D). These results suggested that satellite cells are a source of FN during muscle regeneration.

FN expression in activated satellite cells was determined. Quiescent satellite cells on freshly isolated single myofibers (0h) or activated satellite cells on cultured fibers for 42h were stained with anti-FN antibody (Figure 21A). FN was barely detectable in quiescent satellite cells, but was upregulated in activated satellite cells at 42h in culture. After 72h of culture, the majority of satellite cells on single fibers were identified by high-level FN expression (Figure 21B).

Activated satellite cells incubated with FN antibody before permeabilization showed that a large fraction of FN protein was extracellularly localized (Figure 21C). FN expression by satellite cells on isolated myofibers was not induced by cultivation. Isolated muscle fibers with activated satellite cells from mice that had been injured for five days with cardiotoxin (CTX) showed detectable FN expression in discrete domains around activated satellite cells within their niche beneath the intact basal-lamina (Figure 21D).

The FN expression in Pax7⁺/YFP⁻ satellite stem cells versus Pax7⁺/YFP⁺ satellite myogenic cells was assessed by analyzing asymmetric satellite cell divisions found on cultured individual myofibers at 42h after isolation. This experiment showed that FN expression was markedly up regulated in Pax7⁺/YFP⁺ satellite myogenic cells relative to Pax7⁺/YFP⁻ satellite stem cells (Figure 21E). Stringent washing conditions used during the staining procedure enriched intracellular FN in the secretory pathway and allowed for the quantification of protein levels in doublets resulting from asymmetric cell divisions (Figure 22A).

Immunostaining grey values from >10 randomly selected asymmetric doublets were quantitated using non-saturating concentrations of FN antibody and revealed that Pax7⁺/YFP⁻ cells contain about 60% of the FN levels found in Pax7⁺/YFP⁺ cells (Figure

22B). In addition, FACS-purified Pax7⁺/YFP⁻ primary cells expressed 66% of FN mRNA compared to Pax7⁺/YFP⁺ cells and contained lower levels of protein (Figure 22C and 21F).

The observation that Pax7⁺/YFP⁺ satellite myogenic cells expressed elevated levels of FN relative to Pax7⁺/YFP⁻ satellite stem cells indicated that Wnt7a signaling is primed in satellite stem cells by FN originating from satellite myogenic cells following an asymmetric division.

EXAMPLE 6

SDC4 IS AN FN RECEPTOR ON SATELLITE CELLS

Background

Syndecan 4 (Sdc4) and the related syndecan 3 (Sdc3) are known to be important for myogenesis (Cornelison *et al.*, 2001). Syndecans are highly glycosylated single transmembrane proteins which have been reported to act as co-receptors for Integrins and the FGF receptor (Murakami *et al.*, 2008; Xian *et al.*, 2010). Several ECM proteins, including FN, Tenascin-c, Vitronectin, Fibrillin-1 and Thrombospondin-1 can bind to Syndecans through their heparin-binding sites (Xian *et al.*, 2010). Protein kinase C (PKC) binds directly to the cytoplasmic tail of Sdc4 to modulate small GTPases (Lim *et al.*, 2003; Xian *et al.*, 2010).

In *Xenopus laevis*, Sdc4 is required for convergent extension movement and influences PCP signaling by binding to Fzd7 and Dishevelled (Davidson *et al.*, 2006; Munoz *et al.*, 2006). Sdc4 is highly expressed in myogenic cells.

Results

No Integrin (Itg) subunits involved in FN binding showed a high signal in proliferating myogenic cells in the microarray data (Figure 9A; Table 3). The Lm binding $\alpha 7\beta 1$ Itg appeared to be present in substantial levels. However, a strong signal was obtained for the high affinity FN receptor Sdc4. qPCR subsequently confirmed that Sdc4 expression was substantially higher than the classic FN receptor Itg subunit $\alpha 5$ (Figure 9B). In addition, the expression level between Sdc4 and Itg $\alpha 5$ was maintained through differentiation of myoblasts into myofibers. Immunostaining of 42 hour activated satellite cells on free floating fiber cultures showed a co-localization of FN with Sdc4 (Figure 9C). Itg $\beta 1$ was not observed to colocalize with FN (Figure 9D).

The data demonstrated that the Fzd7/Sdc4 receptor complex exists in mammalian muscle cells.

Table 3

Gene Name	Prol. 1	Prol. 2	Prol. 3	Av Prol.	SE
<i>Sdc4</i>	1274	1273	1177	1240	32
<i>Itgb1</i>	1072	1174	1056	1099	37
<i>Itga7</i>	629	815	705	712	54
<i>Itgb4</i>	508	556	516	526	15
<i>Sdc2</i>	305	342	364	336	17
<i>Itgav</i>	284	358	331	323	22
<i>Sdc3</i>	260	310	250	272	19
<i>Itga3</i>	172	222	188	193	15
<i>Sdc1</i>	189	187	177	184	3
<i>Itga6</i>	125	136	123	128	4
<i>Itgb5</i>	102	114	106	107	4
<i>Itgb6</i>	77	91	82	83	4
<i>Itga5</i>	74	84	80	79	3
<i>Itgb1</i>	42	46	47	45	2
<i>Itgb8</i>	30	37	32	33	2
<i>Itgb4</i>	37	26	28	30	3
<i>Itgad</i>	27	25	25	26	1
<i>Itga4</i>	24	28	26	26	1
<i>Itga2b</i>	22	22	20	22	1
<i>Itga10</i>	17	19	18	18	0
<i>Itgb7</i>	16	16	16	16	0
<i>Itgb3</i>	15	14	16	15	1
<i>Itgb21</i>	16	12	15	14	1
<i>Itga2</i>	12	14	12	13	1
<i>Itgad</i>	11	11	13	12	0
<i>Itga8</i>	11	11	11	11	0
<i>Itga1</i>	12	10	12	11	0
<i>Itga11</i>	11	11	11	11	0
<i>Itga9</i>	15	9	9	11	2
<i>Itgax</i>	10	10	11	10	0
<i>Itgb2</i>	11	9	9	10	1
<i>Itgb11</i>	10	9	9	10	0
<i>Itgal</i>	11	11	8	10	1
<i>Itgae</i>	9	9	8	9	0
<i>Itgam</i>	10	7	7	8	1

Replicates are from primary myoblasts in proliferation (Prol.). AV=Average, SE=Standard error.

EXAMPLE 7

SDC4 FORMS A COMPLEX WITH THE SATELLITE STEM CELL RECEPTOR FZD7

The inventors previously identified Fzd7 and its ligand Wnt7a as components for the symmetric expansion of the Pax7 positive and Myf5-Cre-ROSA-YFP negative (Pax7⁺/YFP⁻) satellite stem cell pool (Le Grand *et al.*, 2009).

Mouse Fzd7 immunoprecipitated with mouse Sdc4 in mammalian myogenic cells. Immunoprecipitation of transfected Flag-tagged Fzd7 from primary myoblasts coprecipitated transfected YFP-tagged Sdc4 (Figure 9E and Figure 19A). Endogenous Fzd7 and Sdc4 were also found to form a receptor complex in satellite cells using an *in-situ*

proximity ligation assay (PLA) (Fredriksson *et al.*, 2002; Pisconti *et al.*, 2010). PLA detection of endogenous Fzd7 and Sdc4 with antibodies resulted in a strong signal in activated satellite cells on cultured myofibers (Figure 19B). This signal was abolished by knocking down Sdc4 with siRNA (siSdc4). These data indicated that Pax7⁺/YFP⁻ satellite stem cells contain a Fzd7/Sdc4 receptor complex that integrates Wnt and FN signals.

Cultured Pax7⁺/YFP⁻ cells contained lower levels of FN protein and mRNA when compared to committed Pax7⁺/YFP⁺ cells (Figure 9F, Figure 16A). Pax7⁺/YFP⁻ satellite stem cells divide asymmetrically to give rise to a committed Pax7⁺/YFP⁺ daughter cell (Kuang *et al.*, 2007). Dividing asymmetric doublets on 42 hour fiber cultures were immunostained to confirm that satellite stem cells express lower levels of FN (Figure 9G). These results indicated that Pax7⁺/YFP⁻ satellite stem cells were responsive to FN that is released from Pax7⁺/YFP⁺ committed cells.

Fzd7 is expressed abundantly in Pax7⁺/YFP⁻ satellite stem cells and only marginal transcript levels are detected in Pax7⁺/YFP⁺ satellite myogenic cells (Le Grand *et al.*, 2009). Sdc4 on the other hand was expressed at relatively high levels throughout differentiation. Sdc4 is a high affinity receptor for fibronectin (FN) (Lyon *et al.*, 2000; Woods *et al.*, 2000). PLA was used to assess the binding of FN to Sdc4 in satellite cells, and similarly detected a strong signal in satellite cells on cultured myofibers (Figure 19C). PLA reactivity of Sdc4 and FN antibodies on satellite cells was completely abrogated by siSdc4 treatment. Therefore, the inventors concluded that Sdc4 binds FN on activated satellite cells.

To determine whether binding of Wnt7a to Fzd7 in primary myoblasts was dependent on the presence of Sdc4 as a co-receptor, co-immunoprecipitation experiments were performed. Immunoprecipitation of Flag-tagged Fzd7 from primary myoblasts co-precipitated FN and this interaction was lost following siRNA knockdown of endogenous Sdc4 (Figure 19D). In addition, immunoprecipitation of YFP-tagged Sdc4 co-precipitated overexpressed Wnt7a-HA, and this interaction was lost following siRNA knockdown of endogenous Fzd7 (Figure 19E). These data indicated that Fzd7/Sdc4 co-receptor complex binds both Wnt7a and FN.

In addition, this data indicated that Fzd7 was a limiting factor for the specific function of the Fzd7/Sdc4 receptor complex in satellite stem cells. Moreover, Pax7⁺/YFP⁻ satellite stem cells produced lower amounts of FN than committed Pax7⁺/YFP⁺ satellite

myogenic cells. This further indicated that satellite stem cells were more sensitive to exogenous FN and that the bulk of satellite cell derived FN during muscle regeneration was released by proliferating committed cells.

Rac1 is associated with Sdc4 and is activated by FN binding (Bass *et al.*, 2007). Rac1 is also a known effector of the PCP pathway (Seifert and Mlodzik, 2007). FN stimulation of Sdc4 facilitated Fzd7 dependent Rac1 activation. Fzd7 overexpression, or stimulation with FN resulted in increased levels of active Rac1 in primary myoblasts (Figure 19F). In addition, FN stimulation of cells over-expressing Fzd7 resulted in markedly increased levels of Rac1 activation. These data show that Fzd7/Sdc4-Rac1 coreceptor complex integrated Wnt7a and FN signals to activate PCP signaling.

EXAMPLE 8

FN AND WNT7A SIGNAL THROUGH THE FZD7/SDC4 COMPLEX TO STIMULATE SATELLITE STEM CELL SYMMETRIC DIVISIONS

Co-activation of the Fzd7/Sdc4 receptor complex by FN and Wnt7a was determined by applying FN and Wnt7a to Pax7⁺/YFP⁻ satellite stem cells in culture.

Both plasma and cellular FN contain the Hep II domain for binding to Sdc4 (Singh *et al.*, 2010; Woods *et al.*, 2000). Standard fiber medium contains 20% Fetal bovine serum (FBS) resulting in a final concentration around 5-15 µg/ml in the medium (Hayman and Ruoslahti, 1979; Sochorova *et al.*, 1983). The medium was supplemented with an additional 25 µg/ml FN to determine the effect of FN on Pax7⁺/YFP⁻ satellite stem cells. As a control, the concentration of the ECM component Collagen (COL) was similarly increased. Neither FN nor COL alone significantly affected Pax7⁺/YFP⁻ satellite stem cells in 42 hour fiber cultures (Figure 10A).

It was previously described that the COL control in combination with Wnt7a (COL&Wnt7a) lead to an increase in the number of Pax7⁺/YFP⁻ satellite stem cells (Le Grand *et al.*, 2009). After 42h of culture, addition of Wnt7a with COL (COL&Wnt7a) resulted in a 73% increase in the number of Pax7⁺/YFP⁻ satellite stem cells (Figure 10A), and a 108% increase in the proportion of symmetric cell divisions when compared to COL alone (Figure 10B). Surprisingly, FN applied together with Wnt7a (FN&Wnt7a) lead to a synergistic increase in the number of Pax7⁺/YFP⁻ satellite stem cells that was significantly higher than

that observed for COL&Wnt7a: a 147% increase in the number of satellite stem cells (Figure 10A). This synergistic effect was confirmed by scoring a 163% increase in the proportion of symmetric Pax7⁺/YFP⁻ cell divisions (Figure 10B).

By 72h of culture, FN&Wnt7a treatment resulted in 156% increase in numbers of satellite stem cells relative to COL&Wnt7a treatment (Figure 10C). Strikingly, FN&Wnt7a treatment resulted in the formation of large homogeneous clusters of Pax7⁺/YFP⁻ satellite stem cells after 72h of myofiber culture (Figure 10D). Again, neither FN nor COL alone had a significant effect on satellite cells after 72 hours of fiber culture (Figure 16B). In addition, numbers of Pax7⁺/YFP⁺ cells were unchanged under all conditions at 42 hours and slightly increased by ~38% at 72 hours in the FN&Wnt7a condition (Figure 20A and 20B).

Unusually large clusters of Pax7⁺/YFP⁻ satellite stem cells were found on FN&Wnt7a treated fibers after 72 hours of culture (Figure 10D). To confirm that a functional Fzd7/Sdc4 receptor complex was required for Wnt7a mediated expansion of the Pax7⁺/YFP⁻ satellite stem cell pool Sdc4 was blocked with an anti-Sdc4 antibody (Cornelison *et al.*, 2004). When compared to an unspecific IgG in combination with Wnt7a (IgG&Wnt7a), Sdc4 antibody and Wnt7a (α Sdc4&Wnt7a) led to a 30% decrease in the numbers of Pax7⁺/YFP⁺ satellite myogenic cells, and a 64% decrease in Pax7⁺/YFP⁻ satellite stem cells after 42h of myofiber culture (Figure 10E and 10F). Moreover, blocking of FN binding to Sdc4 with Tenascin-C (TEN) (Huang *et al.*, 2001) selectively impaired the ability of Wnt7a to stimulate the expansion of the Pax7⁺/YFP⁻ satellite stem cell pool on myofibers cultured for 42h (Figure 10G) without any observed effect on Pax7⁺/YFP⁺ satellite myogenic cells (Figure 20C). However, the effect of α Sdc4&Wnt7a was pronounced for Pax7⁺/YFP⁻ satellite stem cells.

The data showed that the Fzd7/Sdc4 receptor complex exists in mammalian cells and that Wnt7a signaling through Fzd7 occurs through ligation of FN to its receptor Sdc4. In particular embodiments, the present invention contemplates, that other Sdc4 ligands, *e.g.*, FGF, co-activate the Fzd7/Sdc4 receptor complex and further synergistically activate the PCP pathway in satellite stem cells.

EXAMPLE 9

FN PLAYS A ROLE IN THE MAINTENANCE OF THE SATELLITE CELL POOL

The foregoing examples indicate that Fzd7 and Sdc4 are co-receptors, and that Wnt7a signaling through Fzd7 requires ligation of FN to its receptor Sdc4. Therefore, activated satellite cells upregulate FN to remodel their niche and FN expression provides feedback to modulate Wnt7a-induced PCP signaling in satellite cells.

The cell-autonomous role of satellite cell-derived FN was examined. Satellite cells were prospectively isolated; an *ex-vivo* siRNA knockdown of FN was performed; the cells were transplanted back into muscle; and repopulation of the satellite cell niche was enumerated. Quiescent satellite cells were FACS purified from Pax7- zsGreen reporter mice (Bosnakovski *et al.*, 2008) and transfected with a validated duplexed silencer select siRNA for FN (siFN) (Daley *et al.*, 2009; Daley *et al.*, 2011) or with a scrambled siRNA (siSCR) for three hours on ice. After washing, 15,000 transfected satellite cells were either injected into the TA of immunosuppressed mice that had received a CTX injury two days previously, or cultured for three days for qPCR validation of knockdown efficiency. Three weeks after transplantation, mice were sacrificed and the engraftment of Pax7 and zsGreen double-positive (Pax7⁺/zsGreen⁺) cells was assessed by immunostaining of muscle sections (Figure 23A).

Ex-vivo siRNA knockdown of FN in prospectively isolated satellite cells resulted in a 65% reduction of their engraftment three weeks following injection (Figure 23B). Transfection of siRNA reduced FN by 50% after three days in culture (Figure 24A). In addition, resident satellite cells in the injected TA muscle displayed no significant change in their numbers (Figure 24B). Direct injection of self-delivering FN siRNA into the TA muscles at three days after CTX injection resulted in a 59% reduction in satellite cell numbers relative to siSCR injected muscles when examined 10 days after injury (Figure 23C and 24C). Injection of siRNA into whole muscle reduced FN levels by 58% after 5 days (Figure 24D). Taken together, these results demonstrate that cell-autonomous expression of FN by activated satellite cells within their niche plays a significant role in the homeostatic regulation of the satellite cell pool size during regenerative myogenesis.

EXAMPLE 10

FN AND WNT7A SYNERGIZE *IN-VIVO*

To elucidate whether increased FN levels were capable of boosting the satellite stem cell pool or modulating the satellite stem cell response to Wnt7a stimulation *in-vivo*, Wnt7a-HA and/or FN plasmids were electroporated into TA muscle fibers of Myf5-nLacZ mice and the number of satellite cells was quantified after seven days. Similar to Myf5-Cre-ROSA-YFP, the Myf5-nLacZ allele was used to detect satellite stem cells as Pax7⁺/β-Gal⁻. The nuclear localization of β-Gal allowed for superior staining for satellite stem cells on muscle cross sections.

The electroporation (EP) caused significant electro-damage and most muscle fibers were centralized post EP. β-Gal antibody-staining revealed that CMV-FN plasmid alone did not significantly change numbers of Pax7⁺/β-Gal⁻ satellite cells (Figure 11A). However, CMV-Wnt7a increased numbers Pax7⁺/β-Gal⁻ satellite cells by 289%. Importantly, the combination CMV-FN and CMV-Wnt7a plasmid lead to a 654% increase in the number of Pax7⁺/β-Gal⁻ satellite cells. Pax7⁺/β-Gal⁻ satellite cells were evenly distributed throughout the muscle cross-sections and we did not observe focal accumulation around Wnt7a-HA expressing fibers (Figure 11B).

FN activated the Fzd7/Sdc4 receptor complex in conjunction with Wnt7a leading to a synergistic expansion of the Myf5 negative satellite stem cell pool. This result indicated that Wnt7a and FN stimulate PCP signaling to drive the symmetric expansion of satellite stem cells during regenerative myogenesis. The present invention contemplates, in part, that a high tissue content of satellite stem cells facilitates the generation of committed daughter cells through asymmetric divisions. In a particular embodiment, the satellite stem cell pool is synergistically expanded by transient exposure to FN and Wnt7a.

EXAMPLE 11

DECREASING FN LEVELS ARE REQUIRED FOR

LINEAGE PROGRESSION AND DIFFERENTIATION

In 72 hour fiber cultures, a subset of YFP⁺ satellite cells ceased to express Pax7 (Pax7/YFP⁺). Downregulation of Pax7 was indicative of terminal differentiation. It was observed that Pax7/YFP⁺ cells almost exclusively decreased FN protein levels (Figure

12A). Moreover, qPCR confirmed that differentiating myoblasts dramatically downregulate FN expression (Figure 12B).

Satellite cell derived primary myoblasts were plated on FN or COL to determine the effect of sustained FN levels on differentiation. Myoblasts that were differentiated for 2 days on FN displayed impaired fusion and retained mononuclear cells (Figure 12C). The fraction of MHC positive (MHC⁺) cells per total nuclei was strongly decreased on FN when compared to COL (Figure 12D). Mononuclear MHC⁻ cells were indicative of an anti-differentiation effect of FN.

To test whether MRF levels are higher in cells that were differentiated on FN we determined the expression of Myf5 and MyoD. Myf5 and MyoD were expressed at significantly lower levels in cells differentiated on FN when compared to COL (Figure 12E). We concluded that, in contrast to its beneficial effects for Pax7⁺/YFP⁻ satellite stem cells, FN had negative effects on terminal differentiation which were due to the conversion of myoblasts into a non-myogenic MHC⁻ and MRF⁻ cell type.

siRNA knockdown of FN (siFN) in primary myoblasts prior to differentiation, accelerated the formation of MHC⁺ myotubes and increased the fusion index when compared to a scrambled siRNA (siSCR) (Figure 12F&G), and confirmed these observations.

In advanced stages of regeneration, the majority of committed satellite cells downregulated FN expression which allowed them to differentiate and to become fusion competent. The data showed that differentiating primary myoblasts in the presence of FN become MHC⁻ mononuclear cells.

EXAMPLE 12

SUSTAINED LEVELS OF FN FORCE SATELLITE CELLS INTO THE MYOFIBROBLAST LINEAGE

It was determined that sustained levels of FN have anti-myogenic effects *in-vivo*. After 21 days of EP with FN&Wnt7a-HA, a dramatic fibrosis was observed in the proximity of targeted fibers when compared to Wnt7a-HA alone (Figure 13A). Mononuclear cells which were Pax7 negative and positive for the myofibroblast marker alpha smooth muscle actin (Pax7⁻/α-SMA⁺) accumulated in the FN rich fibrotic areas in the periphery of electroporated fibers (Figure 13B&C). None of these mononuclear cells stained positive for CD11b, excluding macrophages, granulocytes or killer cells (Figure 17).

We used Pax7-Cre-ERT-ROSA-tdTomato mice to determine whether prolonged exposure to FN may force satellite cells into an alternative Pax7/ α -SMA⁺ lineage.

Tamoxifen injection of these mice leads to active Cre recombinase which irreversibly labels all Pax7 expressing satellite cells with the fluorescent protein tdTomato (Figure 18A). In order to lineage trace satellite cells upon EP with FN&Wnt7a-HA we induced Pax7-Cre-ER-ROSA-tdTomato mice 1 week prior to EP with Tamoxifen and analyzed the mice 21 days after the plasmid transfer (Figure 13D).

Electrodamage of the EP satellite cells having a recombined ROSA locus fused with myofibers induced regeneration and activation of satellite cells and lead to tdTomato expression from the new myonuclei (Figure 18B). Therefore, in muscle cross sections most muscle fibers were brightly labeled with tdTomato after EP (Figure 13E). In addition, most of the Pax7/ α -SMA⁺ cells that accumulated in fibrotic areas around FN&Wnt7a-HA expressing fibers were also positive for the Pax7-tdTomato lineage tracer. This data suggested that prolonged exposure of satellite cells to FN drives them into an alternative, non-myogenic myofibroblast lineage.

Pax7-tdTomato lineage tracing and the local accumulation of α -SMA positive cells in the fibrotic FN rich periphery of fibers after long-term EP, demonstrated that the sustained exposure of differentiating myogenic cells to FN prevents fusion and forces the cells into an alternative non-myogenic fibroblast lineage.

EXAMPLE 13

CHRONICALLY HIGH FN LEVELS MIGHT TRIGGER SATELLITE CELL PATHOLOGY IN MUSCULAR DYSTROPHY

Background

Fibrosis is the formation of excess fibrous connective tissue, and is a common pathologic phenomenon in several forms of muscular dystrophy (Mann *et al.*, 2011). Fibrosis and the accumulation of mononuclear inflammatory cells are a frequent problem in muscular dystrophy and anti-fibrotic drugs have been demonstrated to be beneficial for dystrophic muscle (Mann *et al.*, 2011; Zhou and Lu, 2010). Many muscular dystrophies preferentially affect distinct muscle groups (Dalkilic and Kunkel, 2003). Moreover, it has been reported that in mdx mice, the mouse model for Duchenne muscular dystrophy, that certain muscle

types contain unequal levels of hydroxyproline, a marker for fibrosis (Morrison *et al.*, 2000). Intriguingly, the fibrotic phenotype of mdx mice is generally mild and the regenerative capacity of their muscles is almost unimpaired and superior to other muscular dystrophy mouse models such as Laminin- $\alpha 2$ deficient d^{yw} mice (Dangain and Vrbova, 1984; Kuang *et al.*, 1998; Torres and Duchen, 1987). In the mdx mouse sequential phases of de- and regeneration occur while degeneration in d^{yw} mice is progressive.

Results

Immunostaining for FN on cross sections of the slow Soleus (Sol) when compared to the mixed TA muscle was performed to determine whether FN content also varies between different muscles in the mdx mouse. Stronger immunostaining was observed for FN on cross sections of the slow Sol when compared to the mixed TA muscle (Figure 14A). Due to the ongoing de- and regeneration of muscle fibers in mdx mice leading to sustained satellite cell activation, FN staining in both muscle types was not confined only to blood-vessels.

Western blot analysis and qPCR confirmed the differential FN content of Sol and TA (Figure 14B&C). In addition, it was found that the high FN content of the dystrophic mdx Sol had an effect on MRF expression when compared to the TA: lower MyoD transcript levels in the Sol were indicative of the antimyogenic FN effect (Figure 14C). Further, lower numbers of Pax7⁺/MyoD⁺ satellite cells were found by immunostaining in mdx Sol cross sections when compared to TA (Figure 14D). These results indicated that, similar to its effects in the *in-vitro* and EP paradigm, increased FN fibrosis in muscular dystrophy leads to negative effects on the differentiation of committed myogenic cells.

The amount of Pax7⁺/ α -SMA⁺/Vimentin⁺ (Pax7⁺/ α -SMA⁺/Vim⁺) in cross sections of mdx Sol and TA muscles was quantified to determine whether the increased FN content of the dystrophic muscles also triggered to a myofibroblast lineage deviation of satellite cells. Indeed, it was determined that the FN-rich Sol contained a higher number of Pax7⁺/ α -SMA⁺/Vim⁺ myofibroblasts (Figure 14E).

The FN rich Sol muscle in mdx mice contained a lower number of MyoD⁺ satellite cells and more myofibroblasts than the less fibrotic TA muscle. These results indicated that, due to its high FN content, satellite cells in the mdx Sol have a lower potential for myogenic differentiation when compared to the TA.

These results suggested that linear degeneration of muscle leads to chronically high levels of FN-fibrosis which constantly impairs satellite cell function. However, in mdx mice phases with low myonecrosis allowed committed satellite cells to proliferate and differentiate under conditions of low tissue FN content. It could be therapeutically beneficial to pharmacologically treat fibrotic muscle pathology in intervals. Such treatment would simulate both physiological states of muscle regeneration, fibrotic conditions triggering satellite stem cell expansion, and lower levels of FN fostering lineage progression and the differentiation of myoblasts. Moreover, this therapeutic approach should theoretically reduce lineage switching of differentiating satellite cells into the myofibroblast state.

EXAMPLE 14

METHODS

Plasmid Electroporation

pcDNA3.1 plasmids containing CMV-Wnt7a CT (lacks N-terminal domain), CMV-Wnt7a FL (a full-length Wnt7a), or CMV-Wnt7a NT (lacks C-terminal domain) or LacZ were transformed into OmniMax2 T1r competent cells (Invitrogen, Löhne, Germany). The DNA was extracted from 100mL of an overnight bacterial culture using the MidiPrep Plasmid extraction kit (Invitrogen) DNA was dissolved in saline (0.9% NaCl). 17.5µg of plasmid solution was injected into the right tibialis anterior (TA) muscle of 6 week old C57BL6 mice (Charles River Laboratories, Boston, MA), followed by five 20ms rounds of 100V electrical impulse to optimize plasmid uptake by muscle fibers. Mice were sacrificed using CO₂ asphyxiation 6 days following electroporation and the TA muscle was excised and weighed. Muscles were divided in two, with one half frozen in a 2:1 solution of Tissue-Tek OCT (Optimal Cutting Temperature compound, Sakura Finetek, Torrance, CA): 30% sucrose using liquid nitrogen, and the other half was crushed with a pellet pastel and frozen in Protease Inhibitor cocktail (1 Complete Mini Protease Inhibitor Cocktail Tablet per 20mL ddH₂O, Roche Scientific, Mannheim, Germany).

Cryosections and Immunohistochemistry (Examples 1-4)

Frozen muscles were sectioned at 12µm using a Leica CM 1850 Cryostat and mounted on Fisher brand slides (Waltham, MA). Cryosections were fixed with 4% PFA (paraformaldehyde). Sections were permeabilized with 0.1% Triton in PBS (Roche), and

blocked in PBS containing 5% horse serum (Invitrogen) for 1hr. Primary antibodies were applied overnight in the same blocking solution, followed by 1hr incubation of fluorophore-conjugated secondary antibodies. Table 1 includes a complete list of the antibodies used.

Table 1: Antibodies

Primary antibodies	Secondary antibodies
Anti-laminin rabbit IgG (Sigma L9393)	Alexa488 anti-rabbit IgG (Invitrogen)
Anti-HA mouse IgG1 (Sigma H9658)	Alexa568 anti-mouse IgG1 (Invitrogen)
Anti- α -Tubulin, mouse monoclonal IgG1 (DM1A) (Sigma T9026)	Goat anti-rabbit IgG (H+L)-HRP Conjugate (Bio-Rad, Hercules, CA)
Bis-benzimide-Hoechst 33342 (Sigma B2261)	Goat anti-mouse IgG (H+L)-HRP Conjugate (Bio-Rad, Hercules, CA)
	Goat pAb to chk IgY (HRP) (Abcam ab6877-1)

Nuclei were counter-stained with Hoechst for 5 min. and coverslips (VWR International, Randor, PA) were mounted using Dako Fluorescent Mounting Medium (Glostrup, Denmark). Images of stained muscle sections were uploaded to ImageJ, which was used in measuring the average diameter of muscle fibers. The distance measured was the shortest, or ferret distance, which accounts for any variations in mounting.

Western Blotting (Examples 1-4)

Muscle lysate protein concentrations were analyzed using Bradford Microassay and 50 μ g of protein was loaded per lane on a 10% 1.5mm SDS-Polyacrylamide gel and run at 115mA. Samples were transferred to a PVDF (polyvinylidene fluoride) membrane (Millipore, Billerica, MA) for 1.5hrs. Blocking and staining was performed using 5% skim milk powder in PBS-T (PBS-Tween 20, Roche) and primary and secondary antibody titers of 1/1000 (for a list of antibodies, see Table 1). Detection was done using Immobilon Western Chemiluminescent HRP Substrate (Millipore) on Kodak BioMax Film (Kodak, Rochester, NY).

Plasmids

A 6xHis-TEV-3xFLAG (HF) epitope was derived from pBRIT-TAP and added to the C-terminus of mouse Fzd7 (Invitrogen). EYFP derived from pEYFP-N1 (Clontech) was added to the C-terminus of mouse Sdc4 (Open Biosystems). Full length

plasma fibronectin (Open Biosystems) was subcloned into pcDNA3. All expression constructs were either in the pEYFP-N1 or pcDNA3 backbone.

Cloning

Plasmids carrying the Coding Sequence (CDS) of Wnt7a variants were obtained. A C-terminal HA tag was added to the Wnt7a coding sequences through PCR amplification using the following primers:

5' ATATGGATCCACCATGAACCGGAAAGC 3' (SEQ ID NO: 8), and

5' ATATCTCGAGTCAGGCGTAGTCAGGCACGTCGTATGGATACT
TGCACGTGTACATC 3' (SEQ ID NO: 9).

Protein truncation was carried out using the following set of primers:

SEQ ID NO:	Primer	Sequence
9	Wnt7a SP sense	5' ATATAAGCTTATGAACCGGAAAGCGC 3'
10	Wnt7a SP antisense	5' ATATGGATCCAGCTACCACTGAGGAG 3'
11	Wnt7a NT sense	5' ATATGGATCCCTGGGCGCAAGCATCA 3'
12	Wnt7a NT antisense	5' ATATCTCGAGTCAGGCGTAGTCAGGCAC GTCGTATGGATACTTGGTGGTGCACGAG 3'
13	Wnt7a CT sense	5' ATATGGATCCACGTGCTGGACCACACTGCC 3'
14	Wnt7a CT antisense	5' ATATCTCGAGTCAGGCGTAGTCAGGCACGTCGTA TGGATACTTGCACGTGTACATC 3'
15	Wnt7a FL sense	5' ATATGGATCCCTGGGCGCAAGCATCA 3'
16	Wnt7a FL antisense	5' ATATCTCGAGTCAGGCGTAGTCAGGCACGTCGTA TGGATACTTGCACGTGTACATC 3'

PCR amplification was done at denaturing, annealing and extension temperatures of 95°C, 65°C and 72°C respectively, and amplicons were introduced into pcDNA3.1 vector using BamHI and XhoI restriction endonucleases (New England Biolabs). Ligation mixtures were transformed in OmniMax2 T1r Competent Cells (Invitrogen), which were plated in Ampicillin-LB Agar plates overnight.

Immunostaining and Antibodies (Examples 5-13)

Muscles frozen in liquid nitrogen-cooled isopentane were cut into 12 μ m cross sections. Cross-sections were fixed with 4% PFA for 5 min, permeabilized with 1% Triton/PBS for 20 min, washed with 100 mM glycine/PBS for 10 min, blocked with 5% goat serum and 2% BSA in PBS for several hours, and incubated with specific primary antibody in blocking buffer overnight at 4°C. Samples were subsequently washed with PBS and stained with appropriate fluorescently labeled secondary antibodies for 1 hr at room temperature. After washing with PBS, samples were mounted with Permafluor (Fisher). For FN antibody staining 2% BSA in PBS without serum was used overnight at 4°C. To enrich for intracellular FN in asymmetric satellite cell doublets, 0.5% Triton was kept in all solutions during the staining procedure. The PLA (proximity ligation assay) was performed using the Duolink II Detection Reagents Red according to the instructions provided by the manufacturer (Olink). Primary antibodies were directly coupled to the PLA oligonucleotides using the Duolink II Probemaker (Olink). Antibodies are as follows: Rabbit anti-Fibronectin (Abcam, ab23750), rabbit anti-Laminin (Sigma, L9393), rabbit anti-HA (Millipore, 07-221), rabbit anti-zsGreen (Clontech, 632474), rabbit anti-MyoD (Santa Cruz, sc-304), Chicken anti-Sdc4 (Cornelison *et al.*, 2004), chicken anti-GFP (Abcam, ab13970), chicken anti- β Gal (Abcam, ab9361), rat anti-CD29 (BD biosciences, 550531), rat anti-Laminin B2 (Millipore, 05-206), rat anti-CD11b (eBioscience, 25-0112-82), mouse anti-Pax7 (DSHB), mouse anti-GFP (Roche, 11814460001), mouse anti-FLAG (Sigma, F3165), mouse anti-GAPDH (Ambion, AM4300), mouse anti-HA (Roche, 1583816), mouse anti-Myosin (DSHB), mouse anti- α SMA (Sigma, A2547).

qPCR and PCR for the detection of FN splice variants

Total RNA was isolated (NucleoSpin RNA II, Macherey-Nagel). Reverse transcription was carried out using a mixture of oligodT and random hexamer primers (iScript cDNA Synthesis Kit, Bio-Rad). Sybr Green, real-time PCR analysis (iQ SYBR Supermix, Bio-Rad) was performed using Mx300P real time thermocycler (Stratagene). The following primers were used:

SEQ ID NO:	Primer	Sequence
17	Pax7 sense	5' TCTTACTGCCCCACCCACCTA 3'
18	Pax7 antisense	5' CACGTTTTTGGCCAGGTAAT 3'
19	Fn1 sense	5' GGCCACACCTACAACCAGTA 3'
20	Fn1 antisense	5' TCGTCTCTGTCAGCTTGCAC 3'
21	Itga5 sense	5' AATCCTCAAGACCAGCCTCA 3'
22	Itga5 antisense	5' TAGAGGAGCTGTTGGCCTTC 3'
23	Myf5 sense	5' TGAGGGAACAGGTGGAGAAC 3'
24	Myf5 antisense	5' CTGTTCTTTCGGGACCAGAC 3'
25	MyoD sense	5' GGCTACGACACCGCCTACTA 3'
26	MyoD anti-sense	5' GTGGAGATGCGCTCCACTAT 3'
27	Sdc4 sense	5' AACCACATCCCTGAGAATGC 3'
28	Sdc4 anti-sense	5' AGGAAAACGGCAAAGAGGAT 3'
29	β -actin sense	5' CAGCTTCTTTGCAGCTCCTT 3'
30	β -actin anti-sense	5' GCAGCGATATCGTCATCCA 3'
31	GAPDH sense	5' ACCCAGAAGACTGTGGATG 3'
32	GAPDH anti-sense	5' ACACATTGGGGGTAGGAACA 3'
33	Fn1 EIIB sense	5' CGAGATGGCCAGGAGAGA 3'
34	Fn1 EIIB anti-sense	5' AAGGTTGGTGAGGGTGATGG 3'
35	Fn1 EIIIA sense	5' AAGGTTGGTGAGGGTGATGG 3'
36	Fn1 EIIIA anti-sense	5' CCAGTTTCCATCAATTATAAAACAGAA 3'
37	Fn1 IIICS sense	5' CCCTGAAGAACAATCAGAAGAG 3'
38	Fn1 IIICS anti-sense	5' TGAAATGACCACTGCCAAAG 3'

Western blotting and Immunoprecipitation (Examples 5-13)

For co-immunoprecipitation (Co-IP) experiments and Rac1 activation assay satellite cell derived primary myoblasts were transfected with Lipofectamine 2000 according to the manufacturer's instructions. For Co-IP the cells were treated with disuccinimidyl suberate crosslinker prior to lysis (Pierce). Cell extracts were obtained by RIPA buffer lysis in the presence of protease inhibitor cocktail (Nacalai). GFP-Trap beads (Allele Biotechnology) or anti-flag M2 beads (Sigma) were used were used for Co-IP according to the manufacturer's recommendations. Whole muscle extracts for western blotting and grey value densitometry of western blots were performed as previously described (Bentzinger *et al.*, 2008). Denaturing SDS-PAGE was performed using standard molecular biology techniques. Rac1 activation assay was performed according to the manufacturer's instructions (Pierce).

Tissue and satellite cell siRNA knockdown

For FN knockdown in satellite cells and subsequent transplantation, cells were FACS purified from Pax7-zsGreen mice by gating for zsGreen and Hoechst (Bosnakovski *et al.*, 2008). Directly after isolation, the cells were lipofected with a validated duplexed silencer select siRNA for FN (Daley *et al.*, 2009; Daley *et al.*, 2011) for three hours on ice. Silencer select FN siRNA was: Sense (5-->3): CCGUUUUCAUCCAACAAGA(TT) (SEQ ID NO: 45) and anti-sense (3-->5): UCUUGUUGGAUGAAAACGG(GT) (SEQ ID NO: 46). After siRNA transfection satellite cells were washed several times with FACS buffer. 15,000 cells for each condition were resuspended in 0.9% NaCl and transplanted into muscles of FK506 immunosuppressed mice that had been injured two days before. Scd4 was knocked down in satellite cells in fiberculture as previously described (Le Grand *et al.*, 2009). Silencer select Sdc4 siRNA was: Sense (5-->3): GUUACGACUUGGGCAAGAA(TT) (SEQ ID NO: 47) and anti-sense (3-->5): UUCUUGCCCAAGUCGUAAC(TG) (SEQ ID NO: 48). siRNA to Fzd7 has been previously described (Le Grand *et al.*, 2009). In all siRNA knockdown experiments, except for the *in-vivo* knockdown (Figure 23C, 23D and 23E), scrambled siRNA Silencer Select Negative Control No. 1 was used as a control (Ambion). For tissue knockdown the validated FN siRNA sequence was modified to the Accell self-delivering format (Dharmacon). 100µg Accell siRNA was injected into muscles two days after CTX injury. FN Accell siRNA was: Sense (5-->3):

CCGUUUUCAUCCAACAAGA(dGdT) (SEQ ID NO: 49) and anti-sense (3-->5): (dTdG)GGCAAAGUAGGUUGUUCU(5'-P) (SEQ ID NO: 50). A similarly modified scrambled sequence was used as a negative control.

Mice and Animal Care

6–8 week old Myf5-Cre-ROSA-YFP mice were obtained by crossing Myf5-Cre mice with ROSA26-YFP reporter mice (Srinivas *et al.*, 2001; Tallquist *et al.*, 2000). zsGreen and Myf5-nLacZ mice were generated as described (Bosnakovski *et al.*, 2008; Tajbakhsh *et al.*, 1996). Pax7-Cre-ERTROSA-tdTomato were generated by crossing the Pax7-Cre-ERT allele with ROSAtdTomato mice (Madisen *et al.*, 2010; Nishijo *et al.*, 2009). To irreversibly label Pax7 expressing cells, Pax7-Cre-ERT-ROSA-tdTomato were intraperitoneally injected for 5 subsequent days with 200 µL Tamoxifen in corn oil (20 mg/mL). mdx mice were obtained from the Jackson Laboratory. All mice were maintained inside a barrier facility, and experiments were performed following the University of Ottawa regulations for animal care and handling.

Myofiber Isolation and Culture

Single myofibers were isolated from the EDL muscles as previously described (Rosenblatt *et al.*, 1995). Isolated myofibers were cultured in suspension in horse serum coated dishes (Kuang *et al.*, 2006). Fiber medium contained 20% FBS (Hyclone) and 1% chick embryo extract (CEE, Accurate Chemicals) and DMEM with 2% L-glutamine, 4,5% glucose, and 110 mg/ml sodium pyruvate. For Wnt stimulation, recombinant Wnt7a added to the fiber medium to a final concentration of 100 ng/ml (R&D Systems). To expose the fibers to increased FN or COL levels, human plasma fibronectin (BD biosciences) or rat tail collagen in PBS (VWR) were added to increase the concentration in the medium to 25 µg/ml. For inhibition of FN binding to Sdc4 in fibercultures, 5 µg/ml Tenascin-C (R&D Systems) was added to the fiber medium. For inhibition of Sdc4, 20 µg/ml chicken anti-Sdc4 (Cornelison *et al.*, 2004) was added to the fiber medium.

Primary myoblast isolation and culture

Pax7⁺/YFP⁺, Pax7⁺/YFP⁻ and total satellite cells were isolated from hind limb muscles and staining was performed as previously described (Kuang *et al.*, 2006; Le Grand *et*

al., 2009). Cells were separated on a MoFlo cytometer (DakoCytomation) equipped with three lasers. Dead cells and debris were excluded by Hoescht staining and by gating on forward and side scatter profiles. For myoblast culture, satellite cells were sorted and plated on COL or FN coated dishes (BD biosciences) in Ham's F10 medium supplemented with 20% FBS and 5 ng/ml of basic FGF (Millipore).

Affymetrix microarray analysis

For microarrays, cells were obtained from six week old BALB/c mice. Total RNA was isolated from freshly FACS isolated quiescent satellite cells that were pooled from nine mice, or in triplicates from established mouse primary myoblasts and differentiated myotubes using the RNeasy mini kit (Qiagen). The purity of RNA was analyzed by Bioanalyzer (Agilent Technologies, Santa Clara, CA). Samples with an RNI > 9.0 were used for subsequent labeling and hybridization with Mouse Gene 1.0 ST Arrays (Affymetrix). Expression data was processed using Gene Expression Consol (Affymetrix).

Electroporation and muscle injury

40 µg of plasmid DNA in 0.9 % NaCl was injected into the TA muscle of anesthetized mice through the skin. Similar amounts of individual plasmids were used for all conditions. For comparison of single plasmids with co-electroporated plasmids an empty stuffer plasmid was added to equalize the amount of DNA in each transfection. Immediately after injection, electric stimulation was applied to the TA by a pulse generator (ECM 830, BTX) of 100-150 volts for 6 pulses, with a fixed duration of 20 ms and an interval of 200 ms using 5 mm needle electrodes (BTX). For CTX-induced muscle regeneration, 25ul of 10 µM cardiotoxin (Sigma) was directly injected into the TA muscle through the skin.

Statistical analysis

Densitometry of grey values from western blots and FN staining in asymmetric doublets was performed with the Image-J software. Compiled data are expressed as mean ± standard error of the mean (SEM). Compiled data were expressed as mean ± SEM. Experiments were done with a minimum of three replicates. For statistical comparisons of two conditions, the Student's t- test was used. The level of significance is indicated as follows: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Abbreviations Used

DMD: Duchenne Muscular Dystrophy

mdx: Duchenne Muscular Dystrophy mouse model

PCP: Planar Cell Polarity

CMV: cytomegalovirus

TA: Tibialis Anterior

HA: Hemagglutinin

β -Gal: β -Galactosidase

CDS: Coding Sequence

SP: signal peptide

NT: N-terminal domain (of Wnt7a)

CT: C-terminal domain (of Wnt7a)

FL: Full length Wnt7a

EP: electroporation

In general, in the following claims, the terms used should not be construed to limit the claims to the specific embodiments disclosed in the specification and the claims, but should be construed to include all possible embodiments along with the full scope of equivalents to which such claims are entitled. Accordingly, the claims are not limited by the disclosure.

CLAIMS

1. A composition for increasing the symmetric expansion of a stem cell comprising a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5.
2. A composition for increasing the symmetric expansion of a stem cell comprising an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3.
3. A composition comprising a polynucleotide encoding a Wnt7a polypeptide according to claim 1 or claim 2.
4. The composition of claim 3, wherein the polynucleotide comprises an expression vector.
5. The composition of any of claims 1 to 4, further comprising a stem cell or a population of stem cells.
6. The composition of any of claim 1 to 5, further comprising one or more stem cell modulators.
7. The composition of claim 6, wherein the modulator further increases the rate of stem cell division.
8. The composition of claim 7, wherein the modulator comprises FGF.
9. The composition of any of claims 1 to 8, wherein the stem cell is an adult stem cell.

10. The composition of claim 9, wherein the adult stem cell is a satellite stem cell.
11. The composition of any of claims 1 to 10 for promoting tissue formation, regeneration, maintenance or repair.
12. The composition of any of claim 11, wherein the tissue is muscle.
13. The composition of any of claim 12, wherein the muscle is skeletal.
14. A composition for enhancing tissue formation, regeneration or repair in a mammal comprising as an active agent (a) a Wnt7a polypeptide comprising the amino acid sequence set forth in SEQ ID NO: 3 and further comprising an N-terminal deletion of 210 to 219 amino acids, or (b) a polynucleotide encoding a Wnt7a polypeptide comprising the amino acid sequence set forth in (a).
15. A composition for enhancing tissue formation, regeneration or repair in a mammal comprising as an active agent (a) a Wnt7a polypeptide fragment comprising the amino acid sequence set forth in SEQ ID NO: 5, or (b) a polynucleotide encoding a Wnt7a polypeptide comprising the amino acid sequence set forth in SEQ ID NO: 5.
16. The composition of any of claims 1 to 15, comprising a physiologically acceptable carrier or diluent.
17. The composition of any of claims 1 to 16, formulated for injection.
18. The composition of claim 17, formulated for one or more of intravenous injection, intramuscular injection, intracardiac injection, subcutaneous injection, or intraperitoneal injection.

19. The composition of any one of claims 1 to 18, for promoting formation, maintenance, repair or regeneration of skeletal muscle in a human subject in need thereof.

20. The composition of claim 19, wherein the subject has, is suspected of having, or is at risk of having, a degenerative disease.

21. The composition of claim 20, wherein the degenerative disease is a muscular dystrophy.

22. The composition of claim 21, wherein muscular dystrophy selected from Duchenne muscular dystrophy (DMD), Becker muscular dystrophy (BMD), Emery-Dreifuss muscular dystrophy, Landouzy-Dejerine muscular dystrophy, facioscapulohumeral muscular dystrophy (FSH), Limb-Girdle muscular dystrophies, von Graefe-Fuchs muscular dystrophy, oculopharyngeal muscular dystrophy (OPMD), Myotonic dystrophy (Steinert's disease) and congenital muscular dystrophies.

23. The composition of claim 20, wherein the subject has, is suspected of having, or is at risk of having a disease or condition affecting muscle.

24. The composition of claim 23, wherein the disease or condition affecting muscle is a wasting disease (*e.g.* cachexia, which may be associated with an illness such as cancer or AIDS), muscular attenuation or atrophy (*e.g.* sarcopenia, which may be associated with aging), ICU-induced weakness, prolonged disuse (*e.g.* coma, injury, paralysis), surgery-induced weakness (*e.g.* following hip or knee replacement), or a muscle degenerative disease (*e.g.* muscular dystrophy).

25. The composition of claim 20, wherein the subject has, is suspected of having, or is at risk of developing muscle wasting or atrophy associated with injury or illness.

26. A composition for synergistically increasing the symmetric expansion of a stem cell comprising:

(a) a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3;

(b) a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5; or

(c) a Wnt7a polypeptide fragment having an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; and

(d) a fibronectin polypeptide.

27. A composition comprising a polynucleotide encoding a Wnt7a polypeptide according to claim 26 and a polynucleotide encoding a fibronectin polypeptide according to claim 26.

28. The composition of claim 27, wherein each polynucleotide comprises an expression vector.

29. The composition of any of claims 26 to 28, further comprising a stem cell or a population of stem cells.

30. The composition of claim 29, wherein the stem cell is an adult stem cell.

31. The composition of claim 30, wherein the adult stem cell is a satellite stem cell.

32. The composition of claim 31 for promoting tissue formation, regeneration, maintenance or repair.

33. The composition of claim 32, wherein the tissue is muscle.
34. The composition of claim 33, wherein the muscle is skeletal.
35. The composition of any of claims 26 to 34, comprising a physiologically acceptable carrier or diluent.
36. The composition of any of claims 26 to 35, formulated for injection.
37. The composition of claim 36, formulated for one or more of intravenous injection, intramuscular injection, intracardiac injection, subcutaneous injection, or intraperitoneal injection.
38. The composition of any one of claims 26 to 37, for promoting formation, maintenance, repair or regeneration of skeletal muscle in a human subject in need thereof.
39. The composition of claim 38, wherein the subject has, is suspected of having, or is at risk of having, a degenerative disease.
40. A method for increasing the symmetric expansion of a stem cell comprising contacting the stem cells with a composition comprising a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5, or an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3.
41. A method for increasing the symmetric expansion of a stem cell comprising contacting the stem cells with a composition comprising a polynucleotide encoding Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5, or an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3.

42. The method of claim 41, wherein the polynucleotide comprises an expression vector.
43. The method of any of claims 40 to 42, wherein the composition further comprises a population of stem cells.
44. The method of any of claims 40 to 43, wherein the composition is administered to a subject in need thereof.
45. The method of claim 43 or claim 44, wherein the stem cells are adult stem cells
46. The method of claim 45, wherein the adult stem cells comprise satellite stem cells.
47. The method of any of claims 40 to 46, wherein the composition comprises a physiologically acceptable carrier or diluent.
48. The method of claim 47, wherein the composition is formulated for injection.
49. The method of any of claims 40 to 48, for promoting tissue formation, regeneration maintenance, or repair.
50. The method of any of claim 49, wherein the tissue is muscle.
51. The method of any of claim 50, wherein the muscle is skeletal muscle.
52. The method of any of claims 40 to 51, for promoting formation, maintenance, repair or regeneration of skeletal muscle in a human subject in need thereof.

53. The method of claim 52, wherein the subject has a degenerative disease.

54. The method of claim 53, wherein the degenerative disease is a muscular dystrophy.

55. A method for promoting muscle formation, regeneration, maintenance or repair in a mammal comprising administering to the mammal a therapeutically effective amount of a composition as defined in any of claims 1 to 25.

56. A method for preventing muscle wasting, atrophy or degeneration in a subject in need thereof comprising administering to the subject a therapeutically effective amount of a composition as defined in any of claims 1 to 25.

57. A method for expanding a population of satellite stem cells *in vivo*, *ex vivo*, or *in vitro* comprising contacting the stem cells with an effective amount of a composition as defined in any of claims 1 to 25.

58. A method for synergistically increasing the symmetric expansion of a stem cell comprising contacting the stem cells with a composition comprising:

(a) a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3;

(b) a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5; or

(c) a Wnt7a polypeptide fragment having an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; and

(d) a fibronectin polypeptide.

59. A method for synergistically increasing the symmetric expansion of a stem cell comprising contacting the stem cells with a composition comprising:

(a) a polynucleotide encoding a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3;

(b) a polynucleotide encoding a Wnt7a polypeptide fragment having the amino acid sequence set forth in SEQ ID NO: 5; or

(c) a polynucleotide encoding a Wnt7a polypeptide fragment having an N-terminal deletion of 210 to 219 amino acids of a Wnt7a polypeptide having the amino acid sequence set forth in SEQ ID NO: 3; and

(d) a polynucleotide encoding a fibronectin polypeptide.

60. The method of claim 59, wherein each polynucleotide comprises an expression vector.

61. The method of any of claims 58 to 60, wherein the composition further comprises a population of stem cells.

62. The method of any of claims 58 to 61, wherein the composition is administered to a subject in need thereof.

63. The method of claim 62 or claim 62, wherein the stem cells are adult stem cells

64. The method of claim 63, wherein the adult stem cells comprise satellite stem cells.

65. The method of any of claims 58 to 64, wherein the composition comprises a physiologically acceptable carrier or diluent.

66. The method of claim 65, wherein the composition is formulated for injection.

67. The method of any of claims 58 to 66, for promoting tissue formation, regeneration maintenance, or repair.

68. The method of any of claim 67, wherein the tissue is muscle.

69. The method of any of claim 68, wherein the muscle is skeletal muscle.

70. The method of any of claims 58 to 69, for promoting formation, maintenance, repair or regeneration of skeletal muscle in a human subject in need thereof.

71. The method of claim 70, wherein the subject has a degenerative disease.

72. The method of claim 71, wherein the degenerative disease is a muscular dystrophy.

73. A method for promoting muscle formation, regeneration, maintenance or repair in a mammal comprising administering to the mammal a therapeutically effective amount of a composition as defined in any of claims 26 to 39.

74. A method for preventing muscle wasting, atrophy or degeneration in a subject in need thereof comprising administering to the subject a therapeutically effective amount of a composition as defined in any of claims 26 to 39.

75. A method for expanding a population of satellite stem cells *in vivo*, *ex vivo*, or *in vitro* comprising contacting the stem cells with an effective amount of a composition as defined in any of claims 26 to 39.

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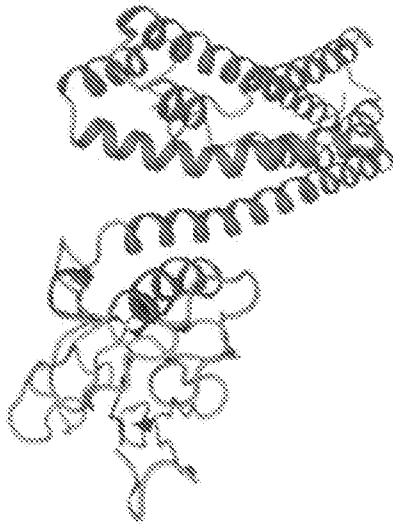
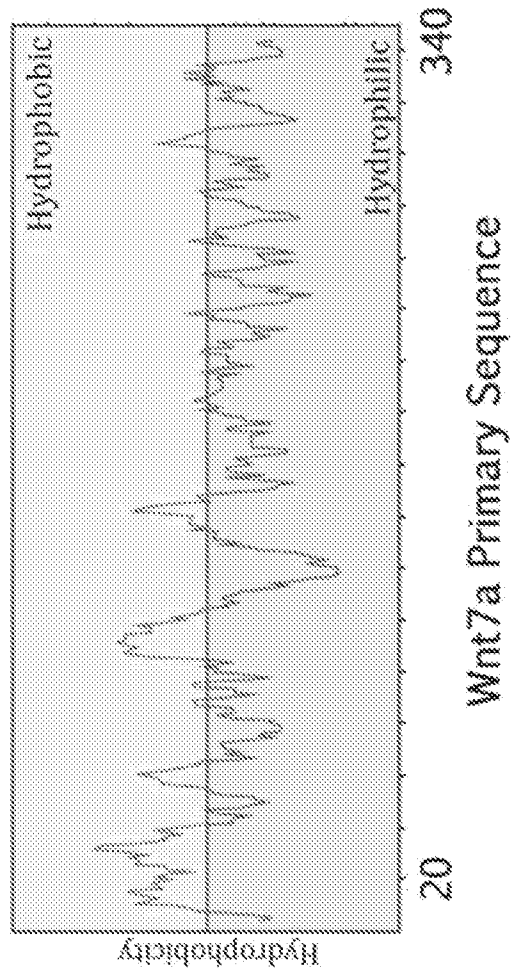


FIG. 1B

FIG. 1A

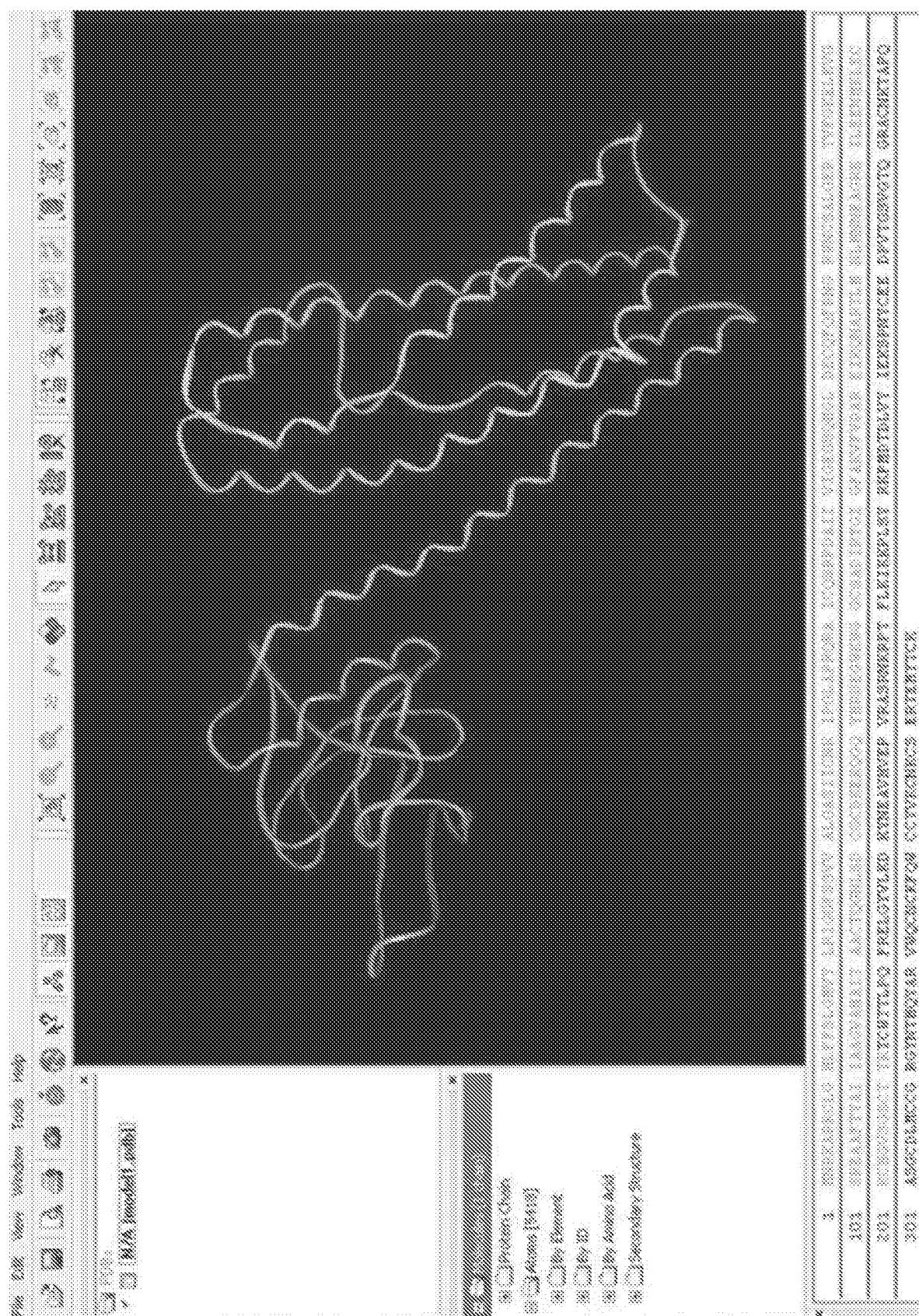


FIG. 2

WEIGHT (G) OF ELECTROPORATED TIBIALIS ANTERIOR
(TA) MUSCLE

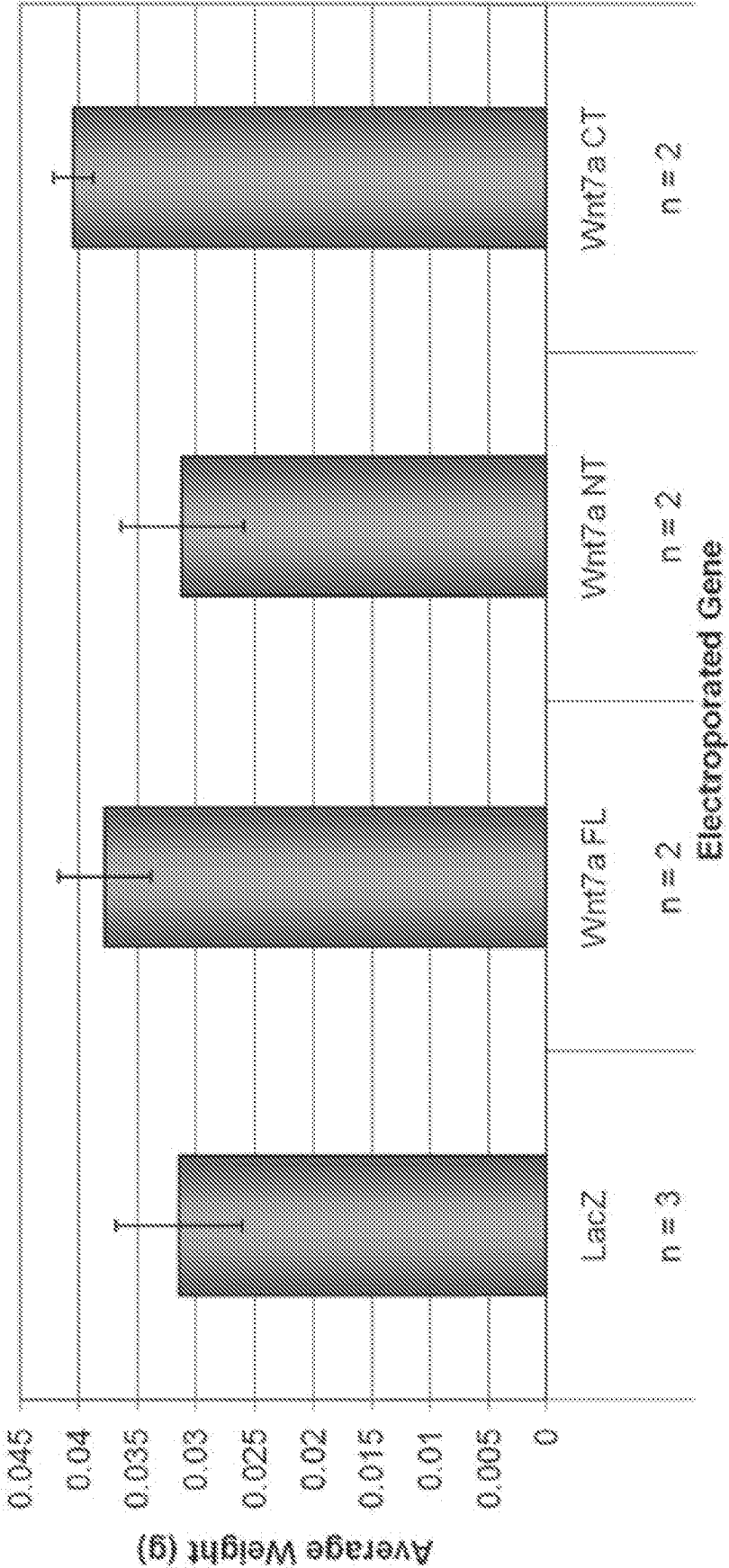


FIG. 3A

AVERAGE FIBER DIAMETER IN PLASMID
ELECTROPORATED MOUSE TA MUSCLE

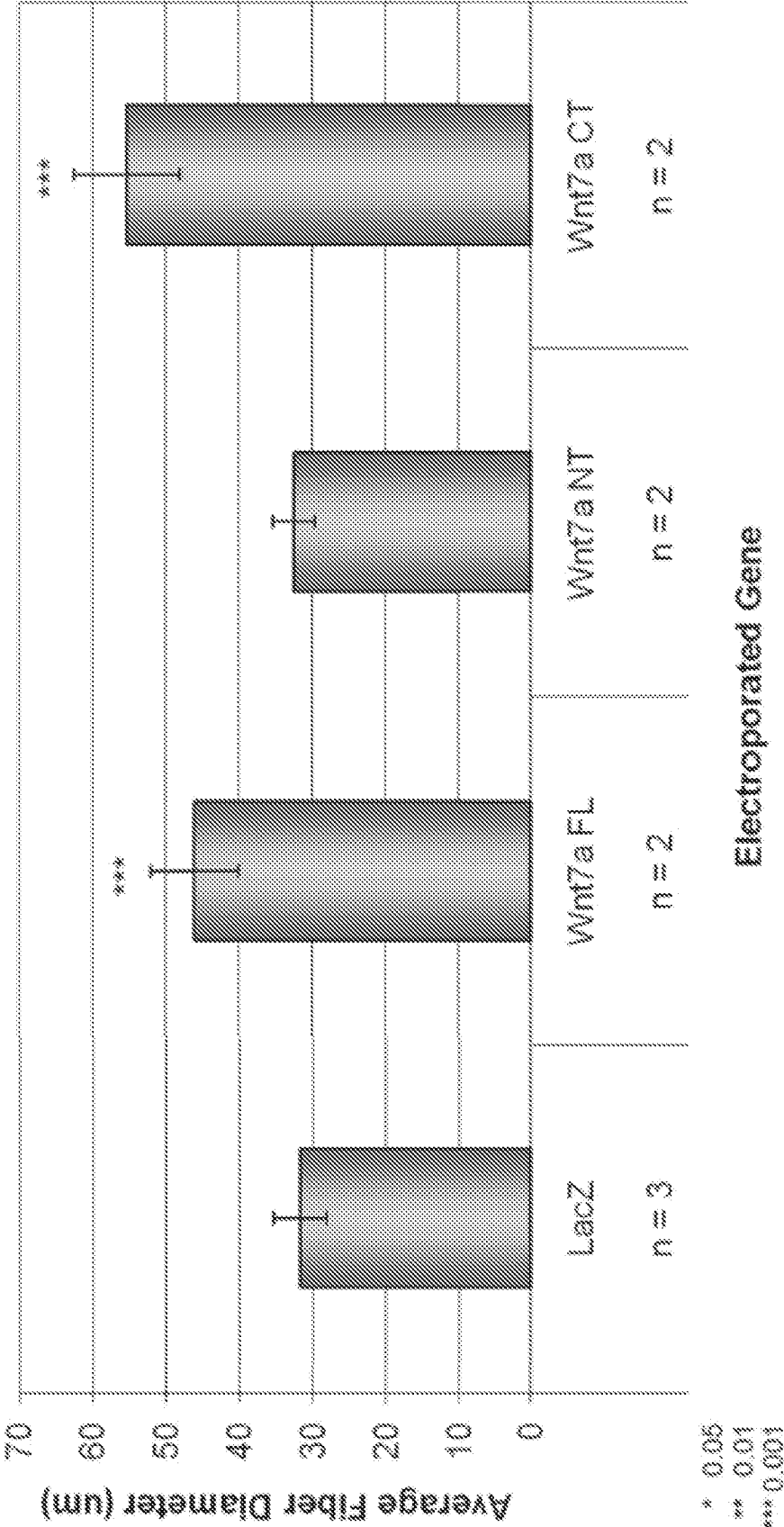
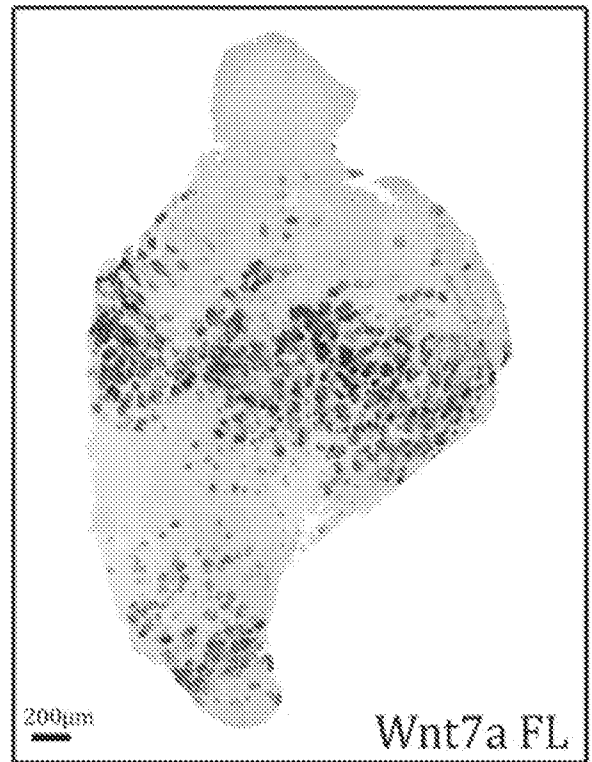
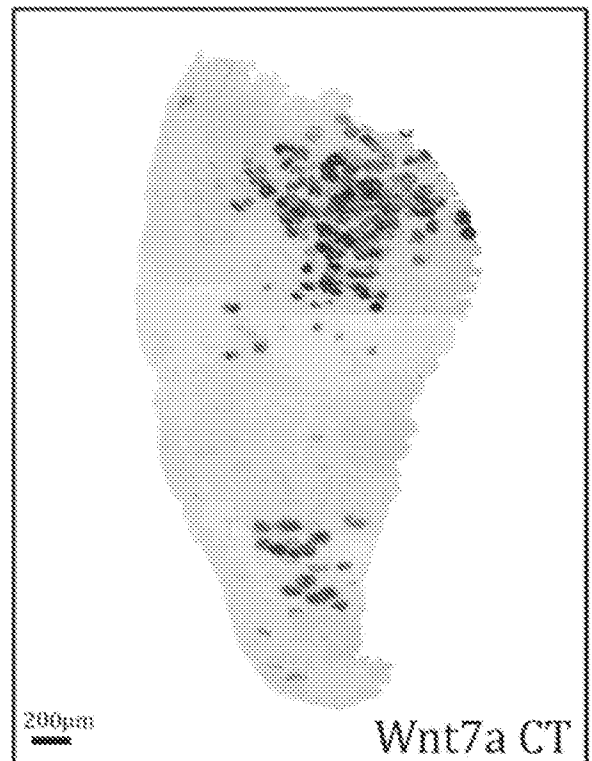


FIG. 3B

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*FIG. 4A**FIG. 4B**FIG. 4C**FIG. 4D*

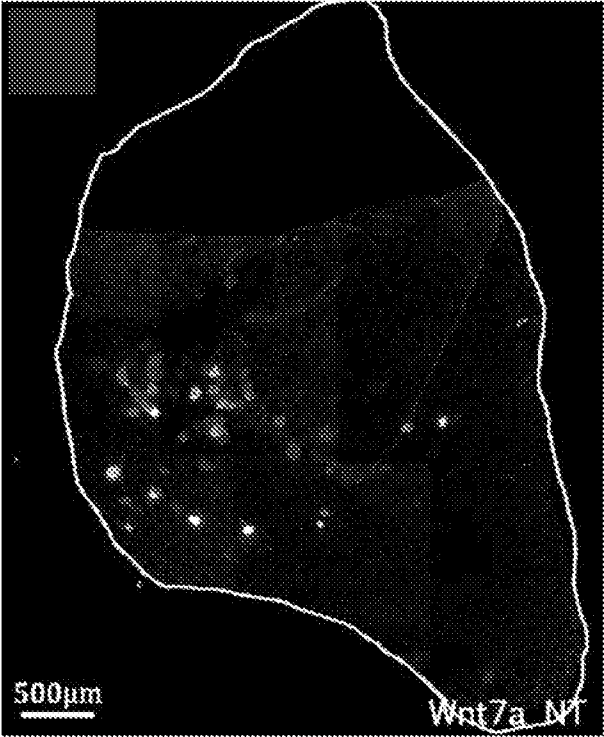


FIG. 5A

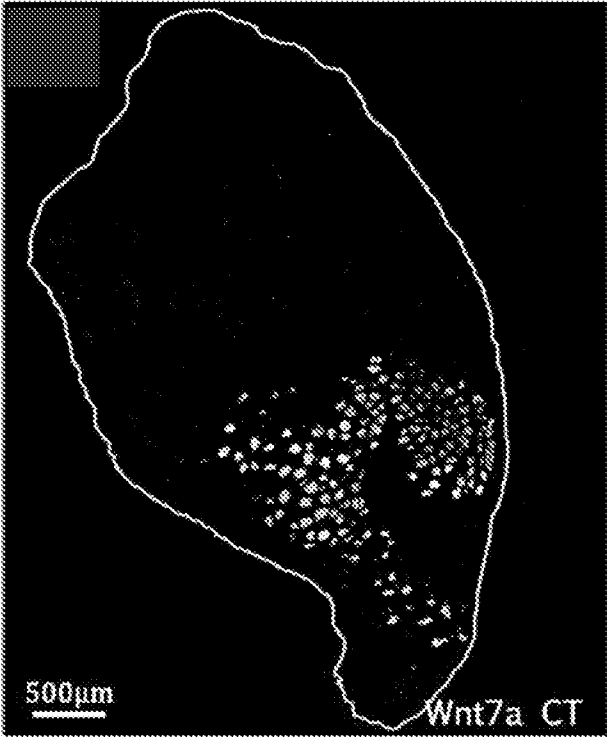


FIG. 5B

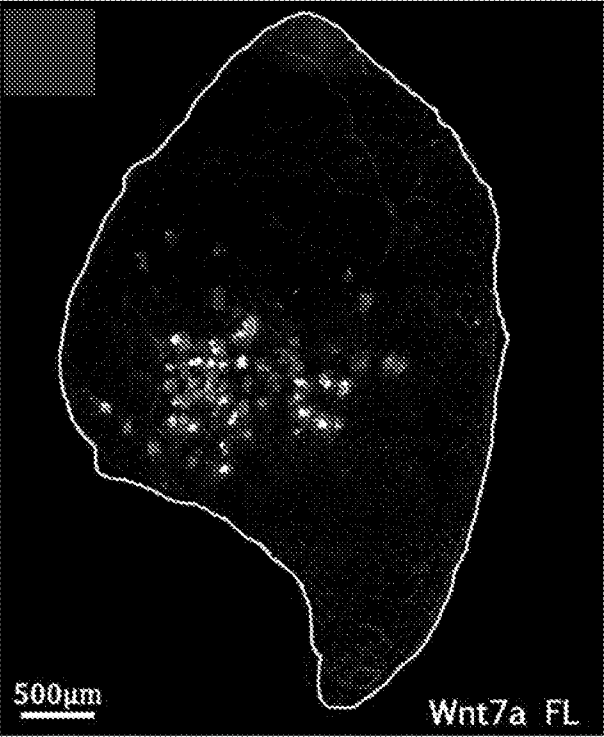


FIG. 5C

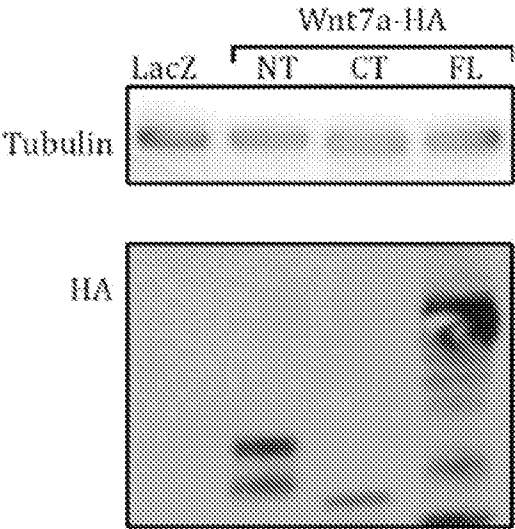


FIG. 5D

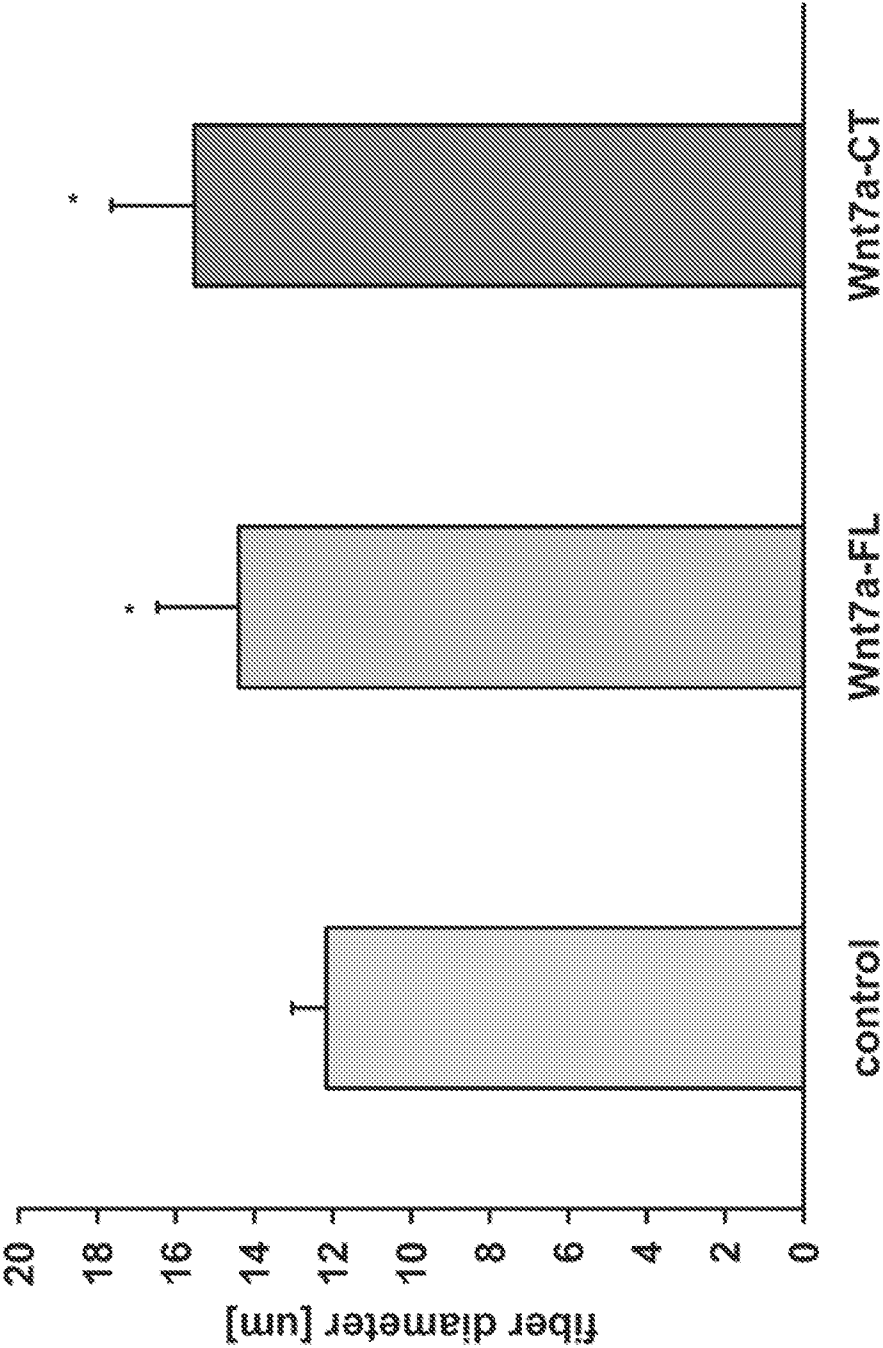


FIG. 6

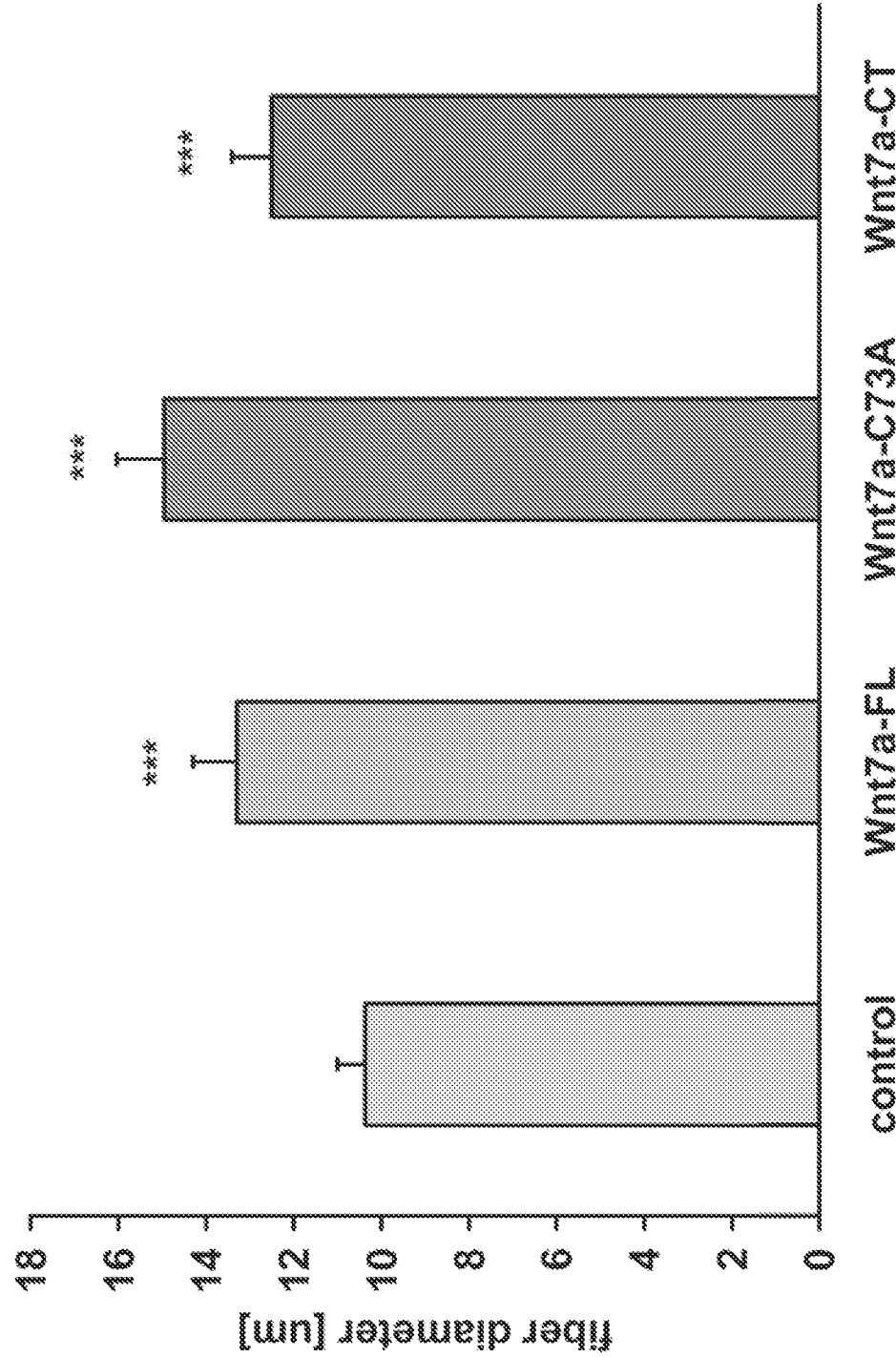


FIG. 7

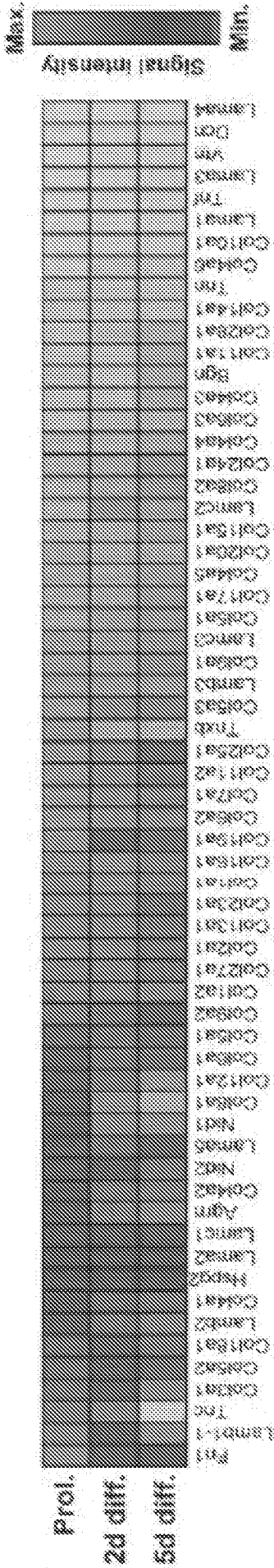


FIG. 8A

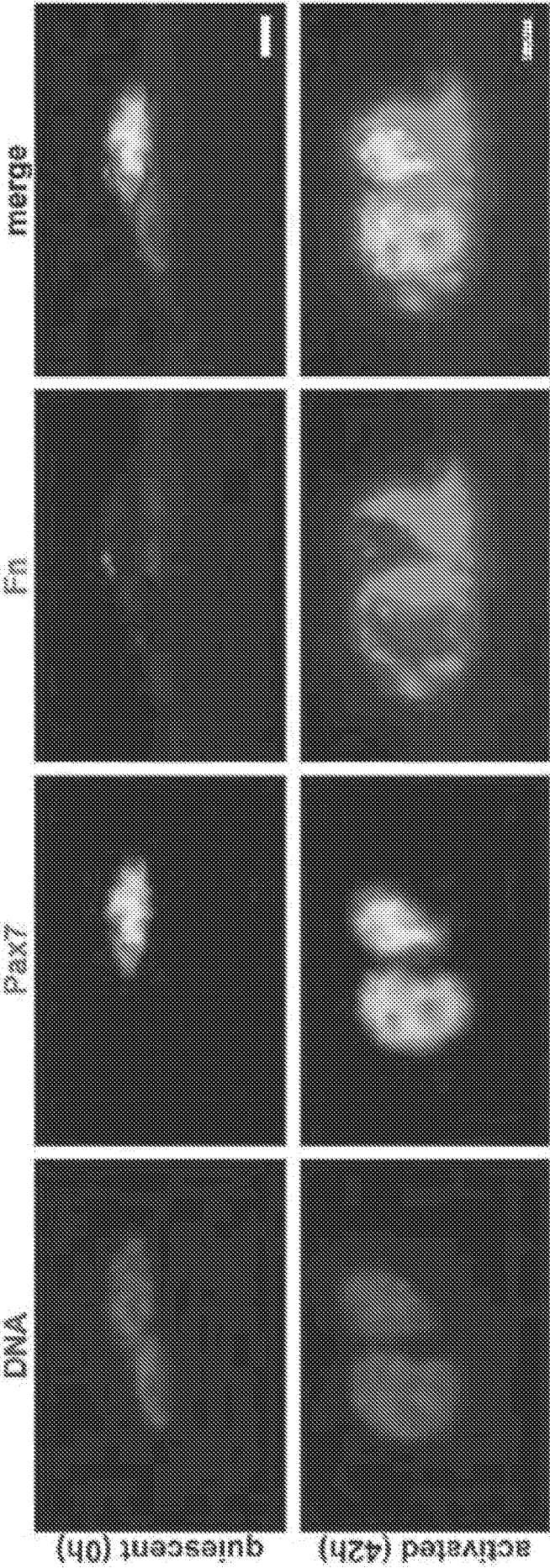


FIG. 8B

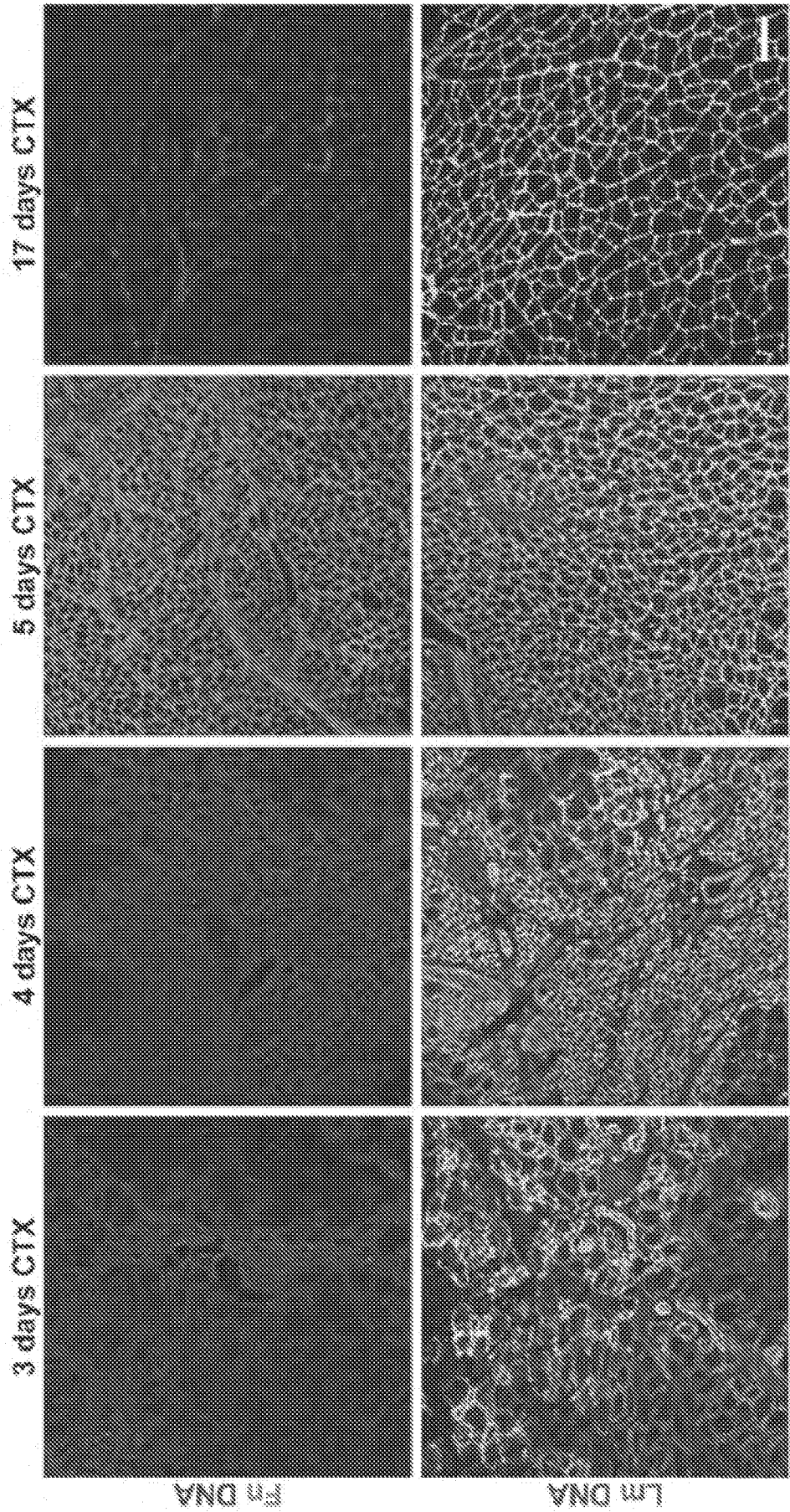


FIG. 8C

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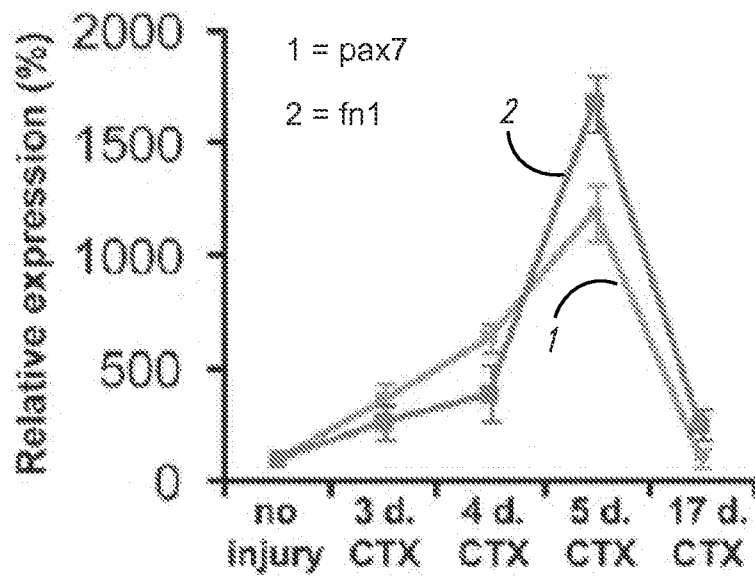


FIG. 8D

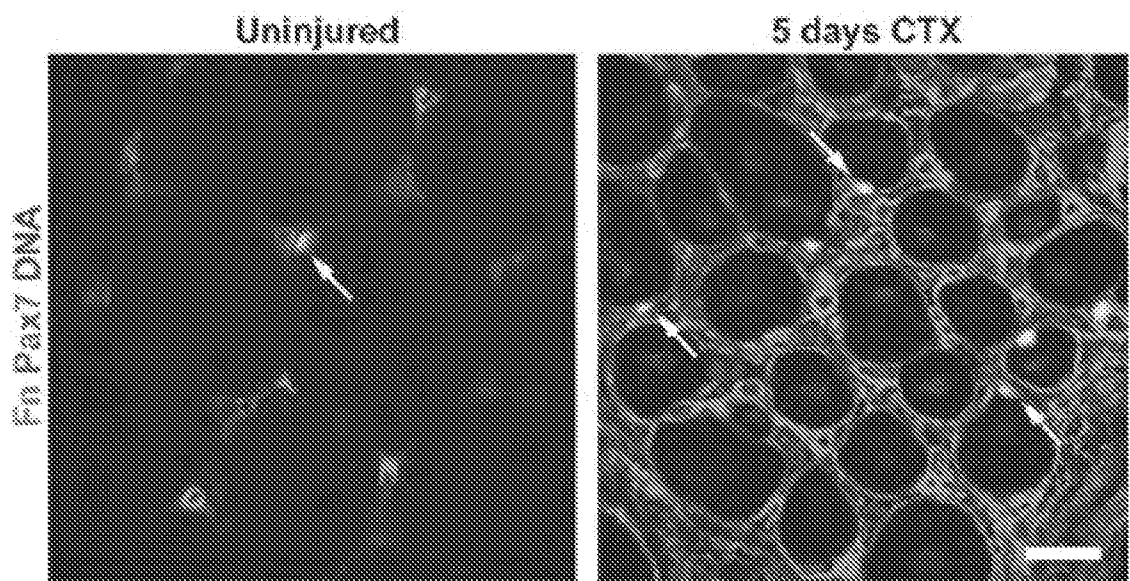


FIG. 8E

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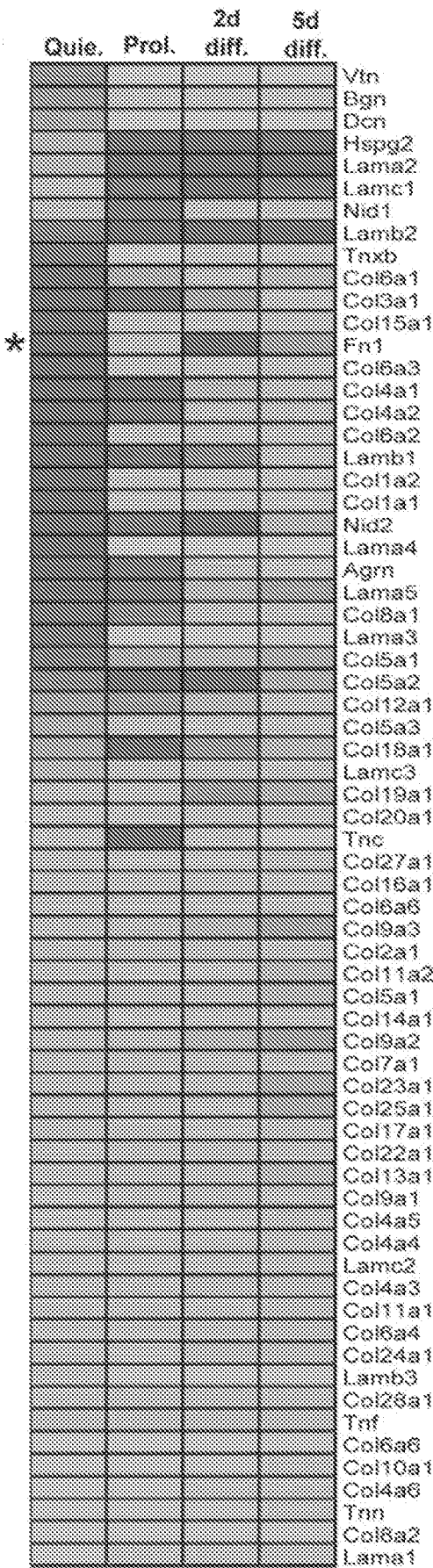


FIG. 8F

Signal intensity
Max. Min.

13/48

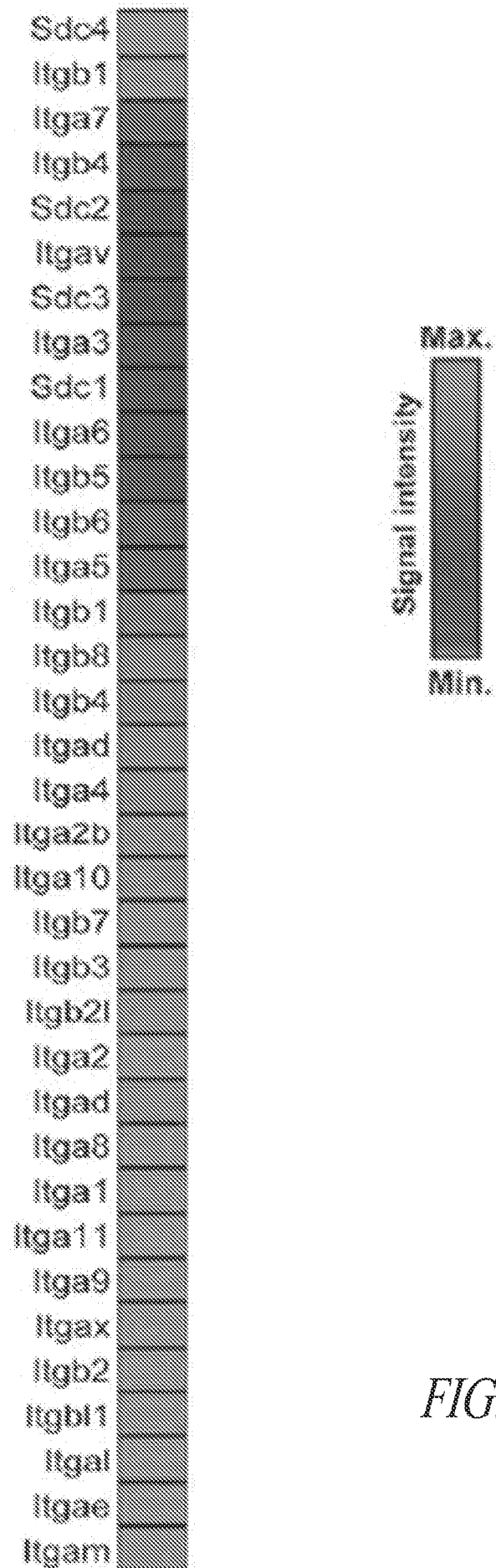


FIG. 9A

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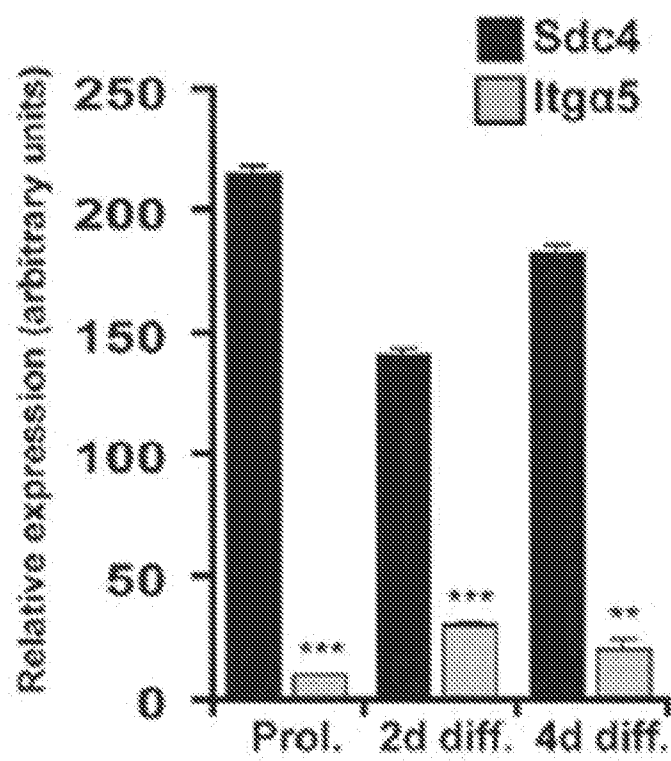
*FIG. 9B*

FIG. 9C

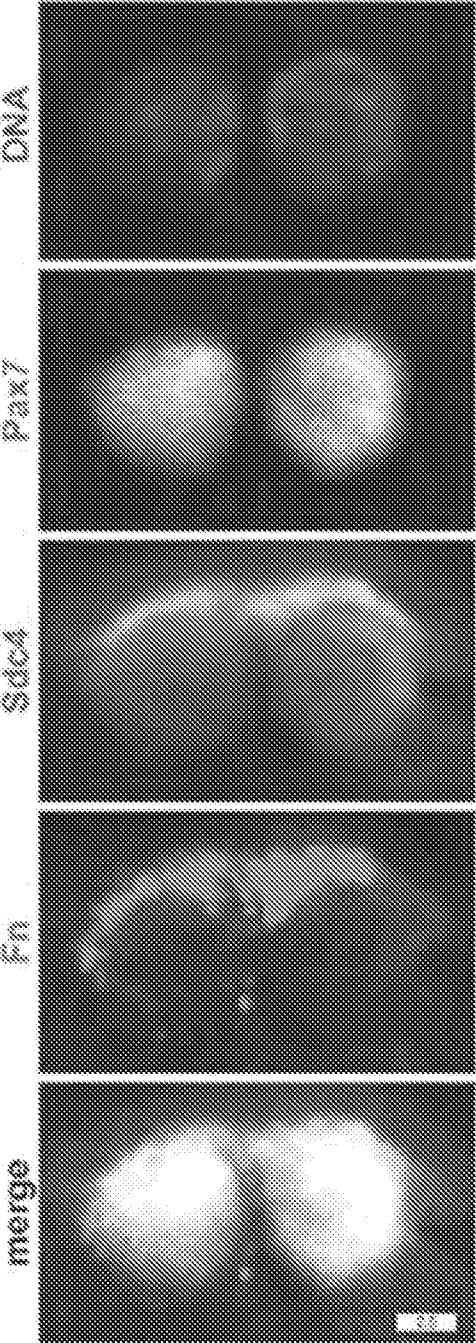
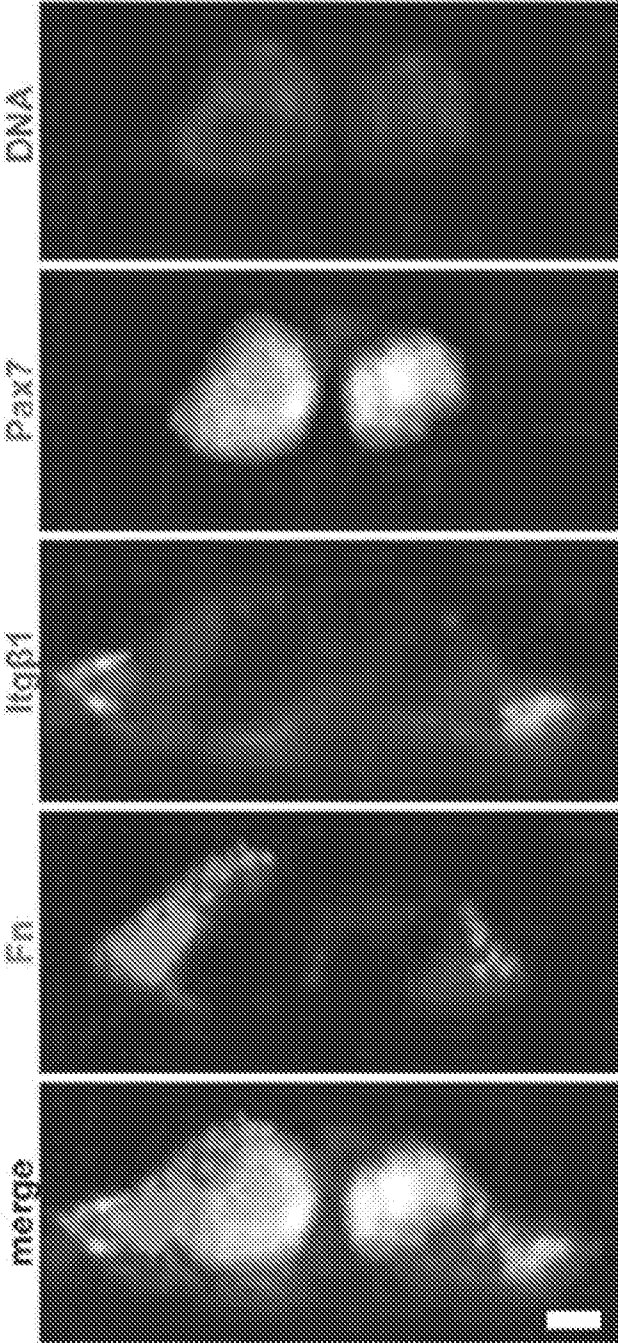
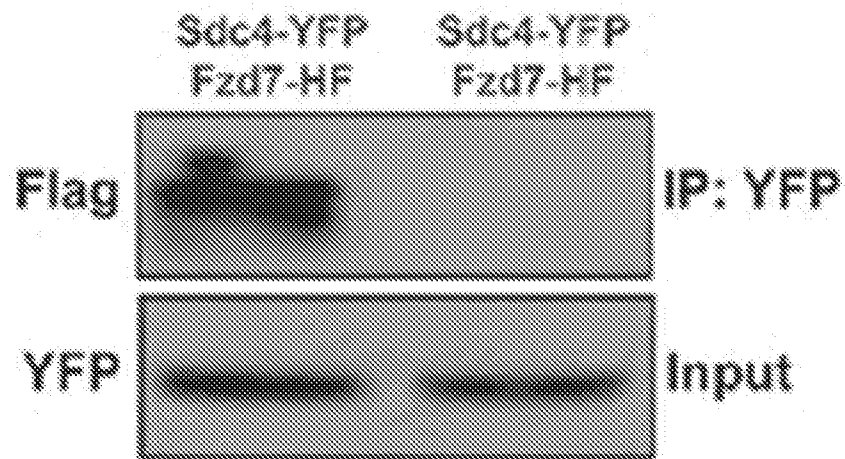
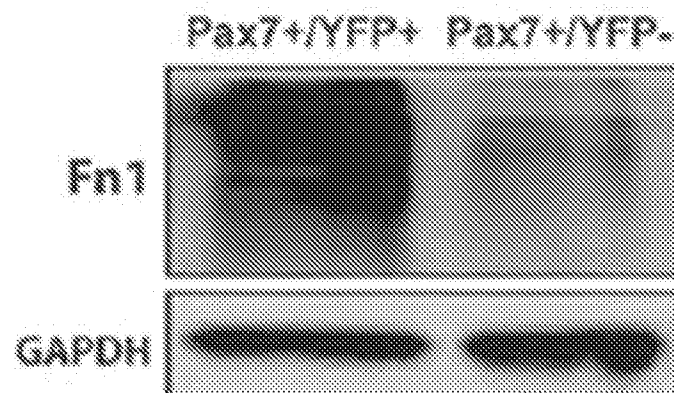


FIG. 9D



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*FIG. 9E**FIG. 9F*

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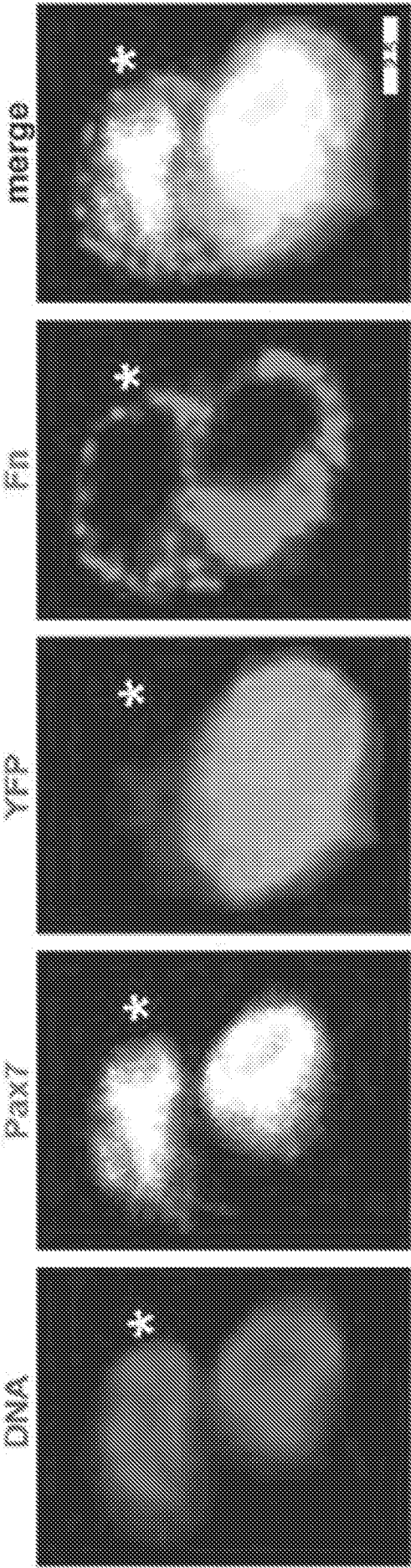


FIG. 9G

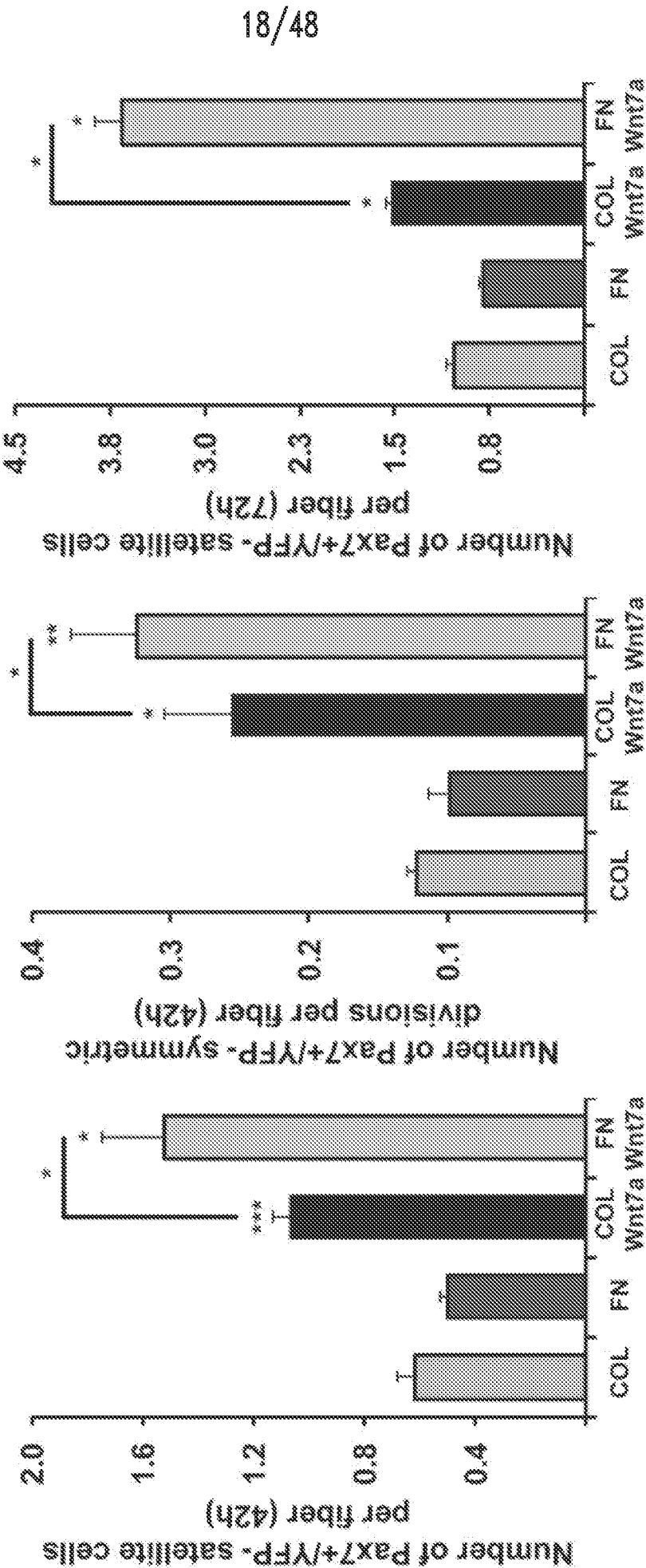


FIG. 10A

FIG. 10B

FIG. 10C

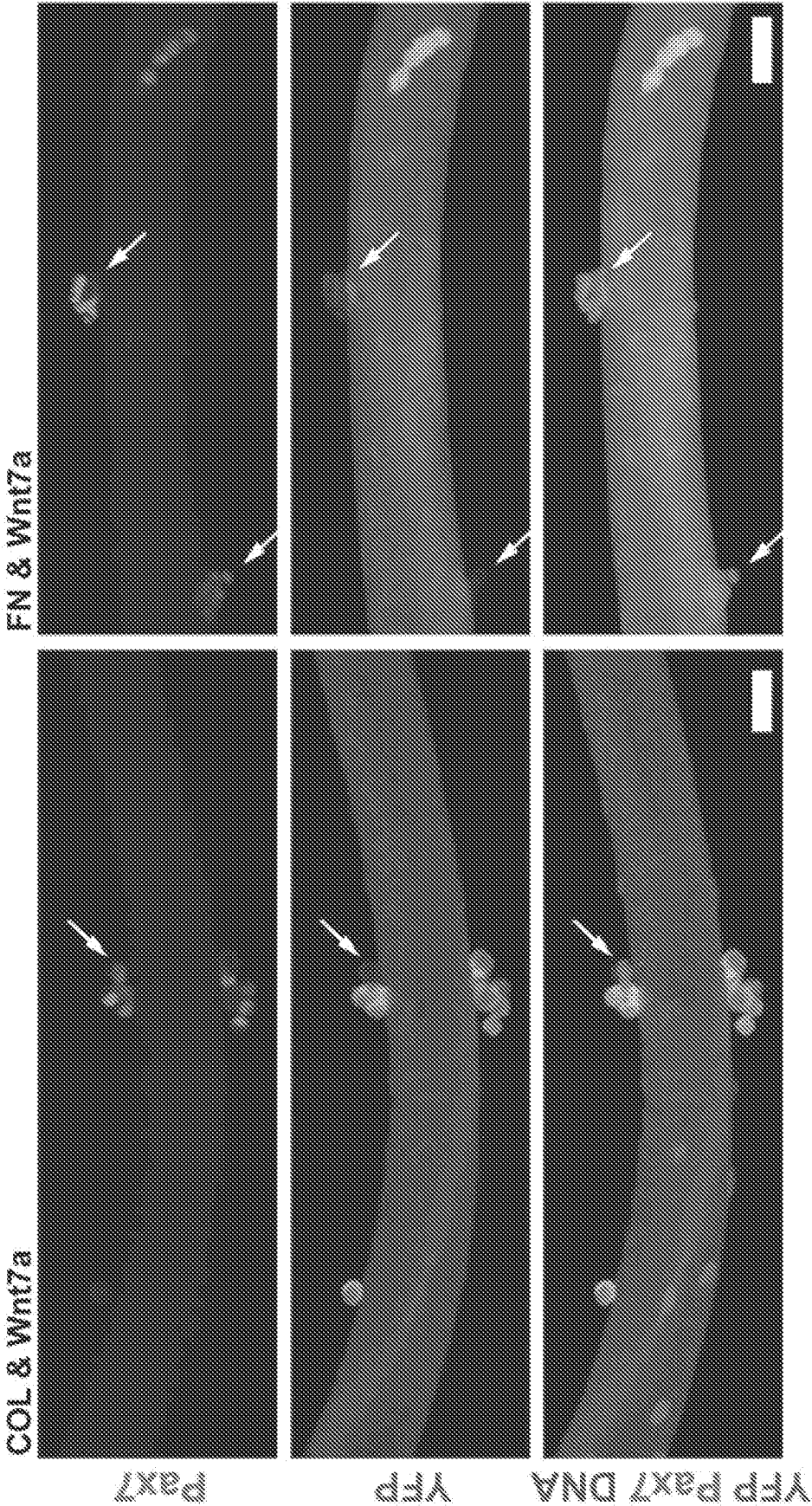


FIG. 10D

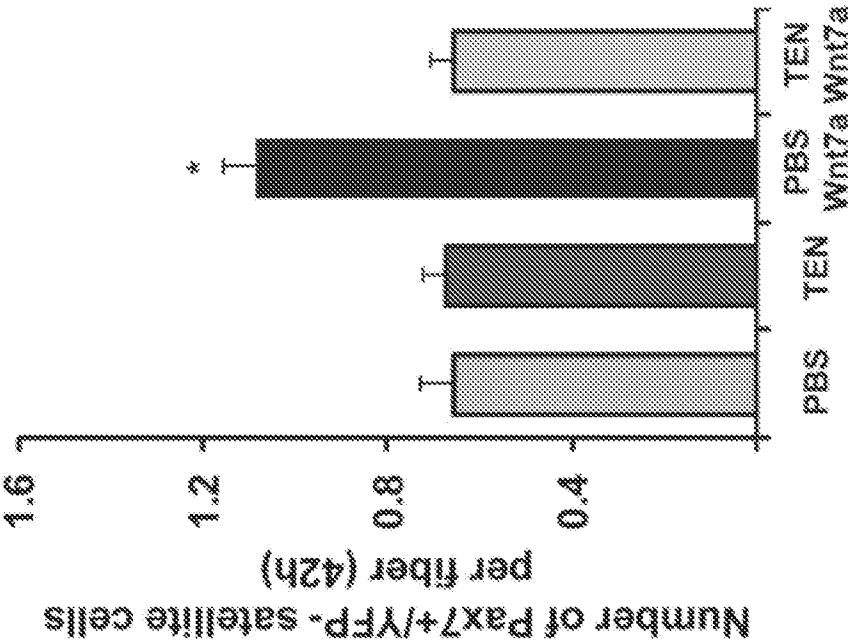


FIG. 10G

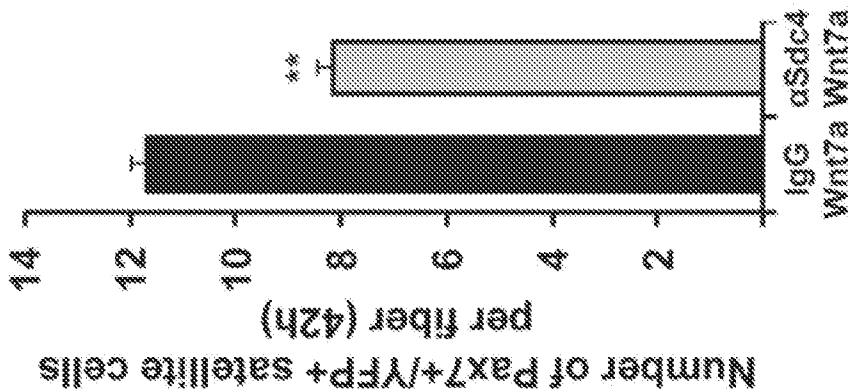


FIG. 10F

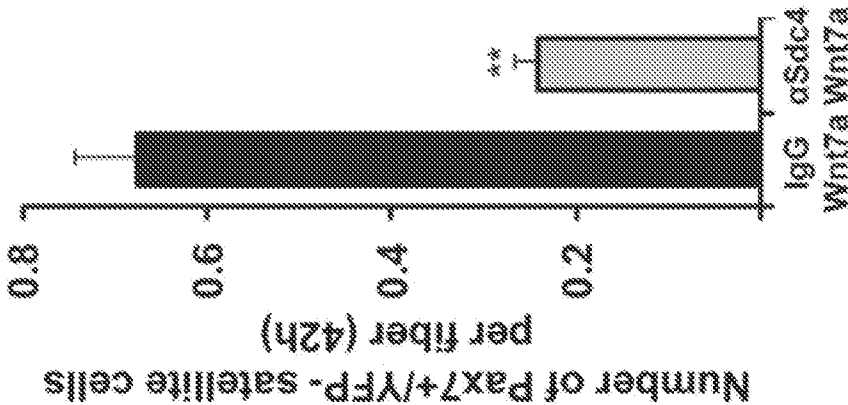


FIG. 10E

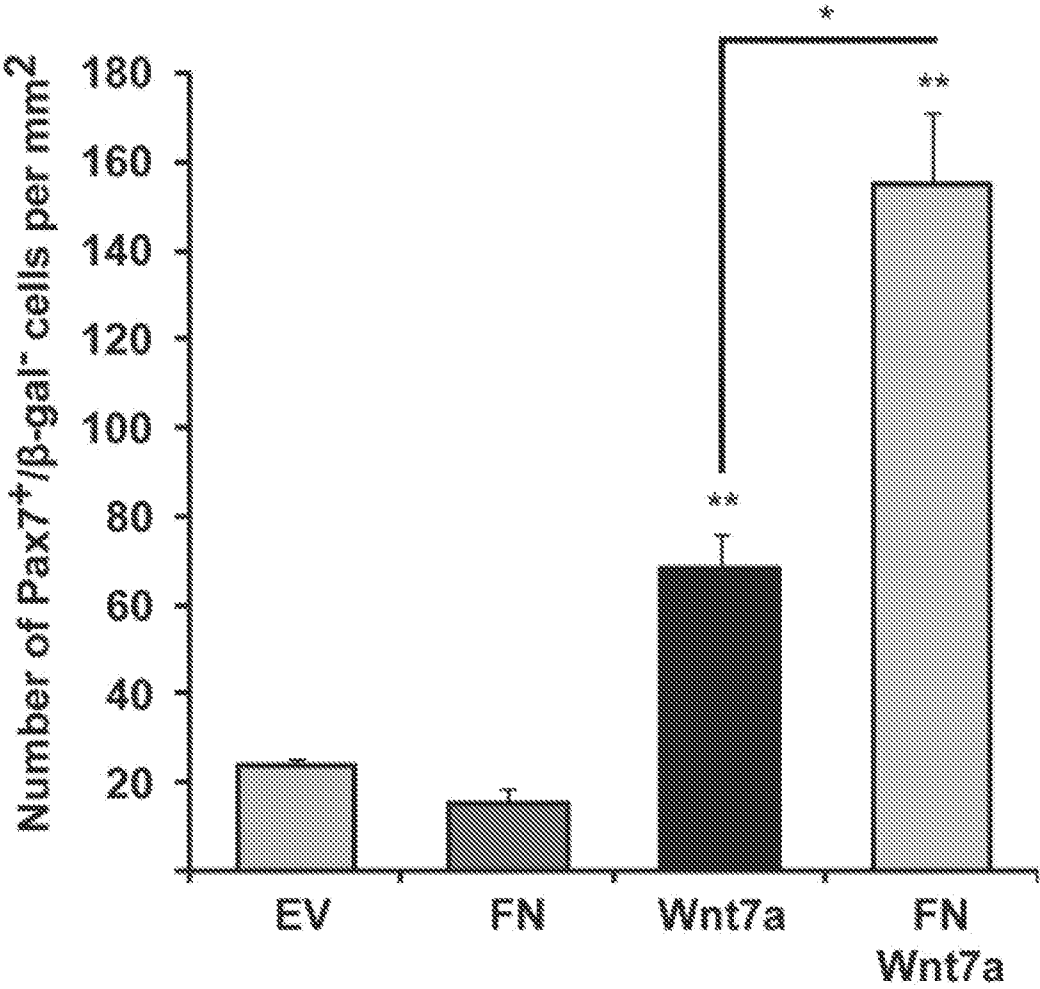


FIG. 11A

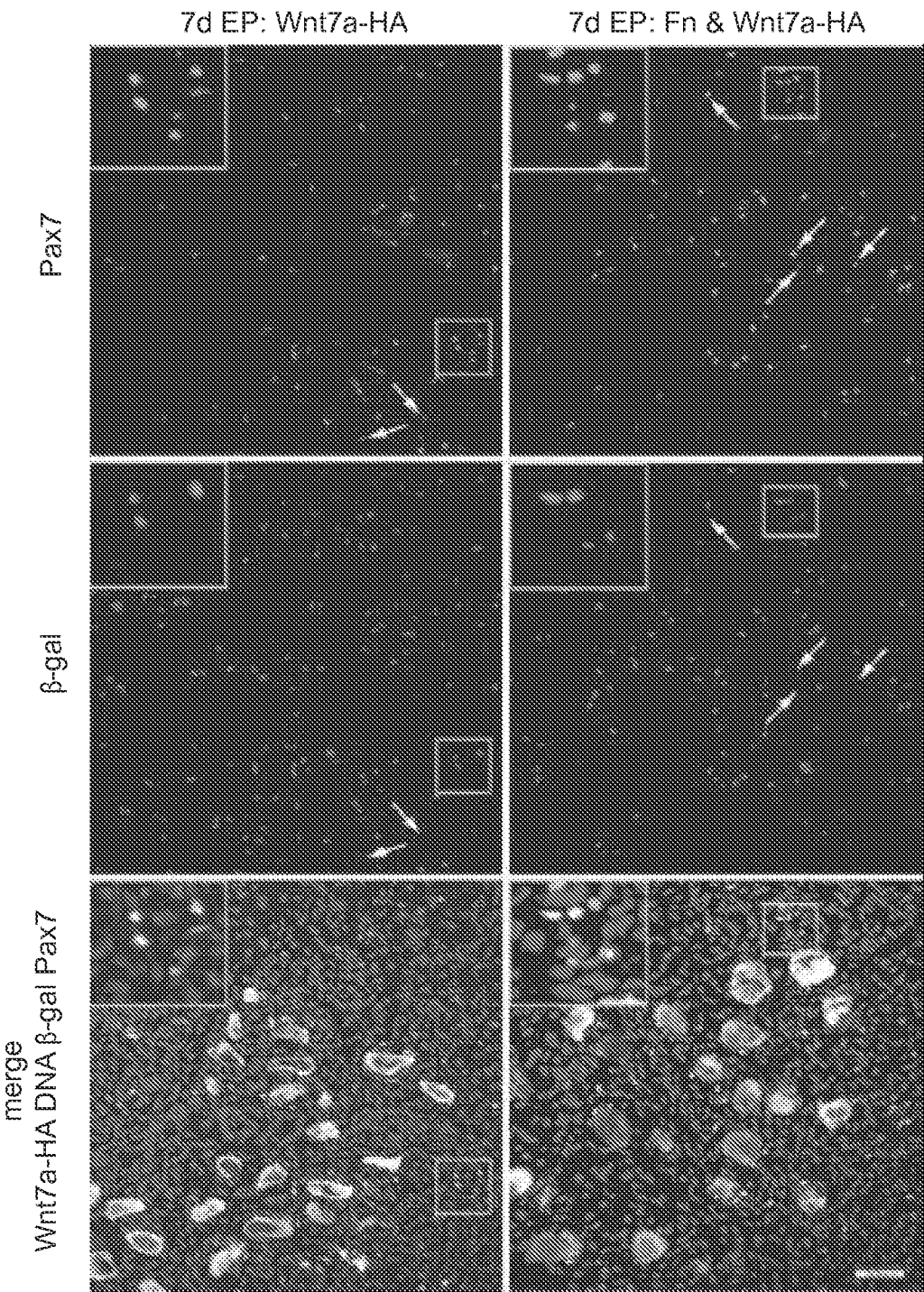


FIG. 11B

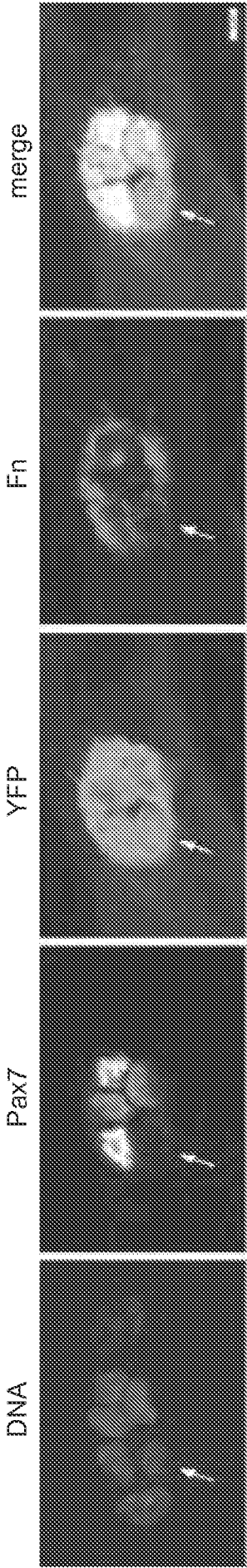


FIG. 12A

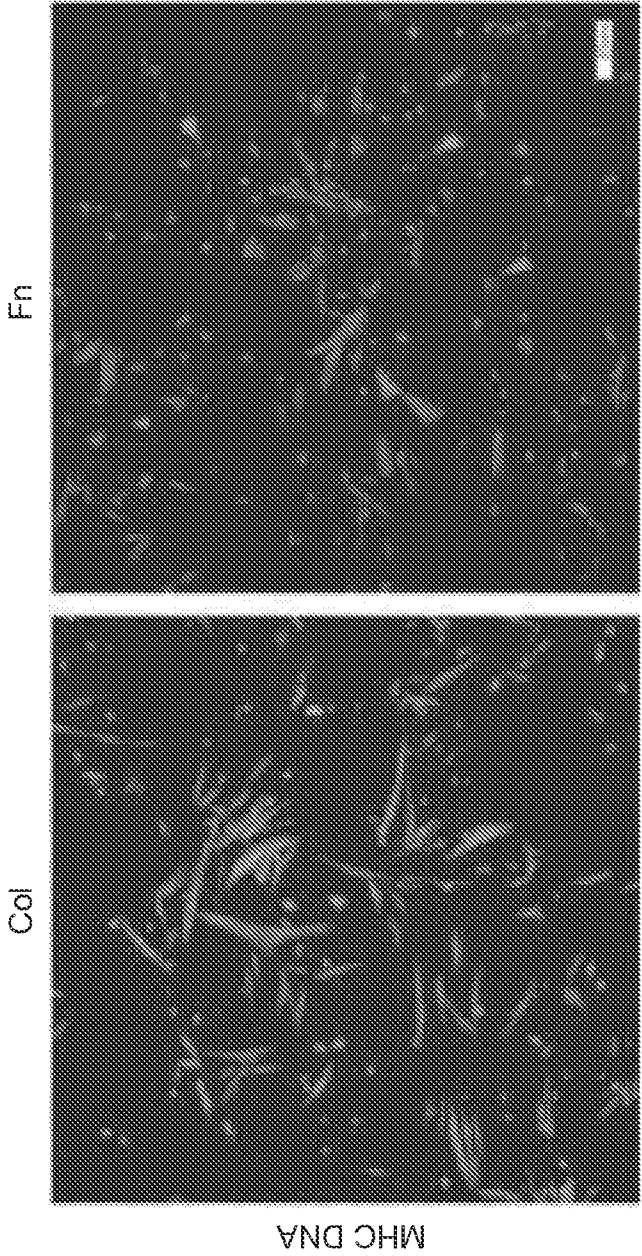


FIG. 12C

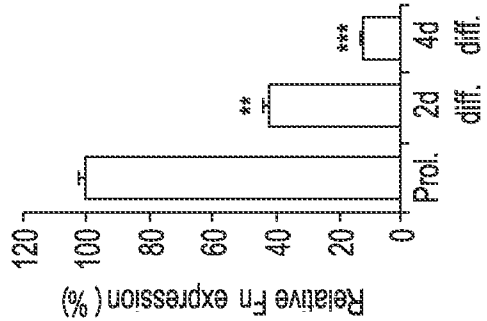


FIG. 12B

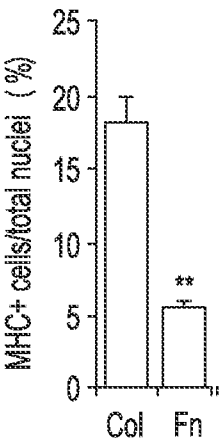


FIG. 12D

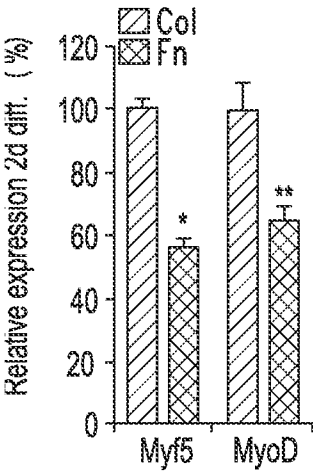


FIG. 12E

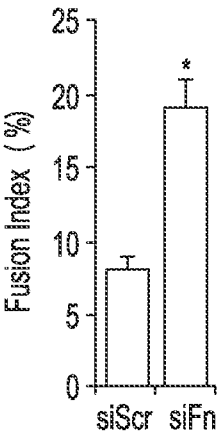


FIG. 12G

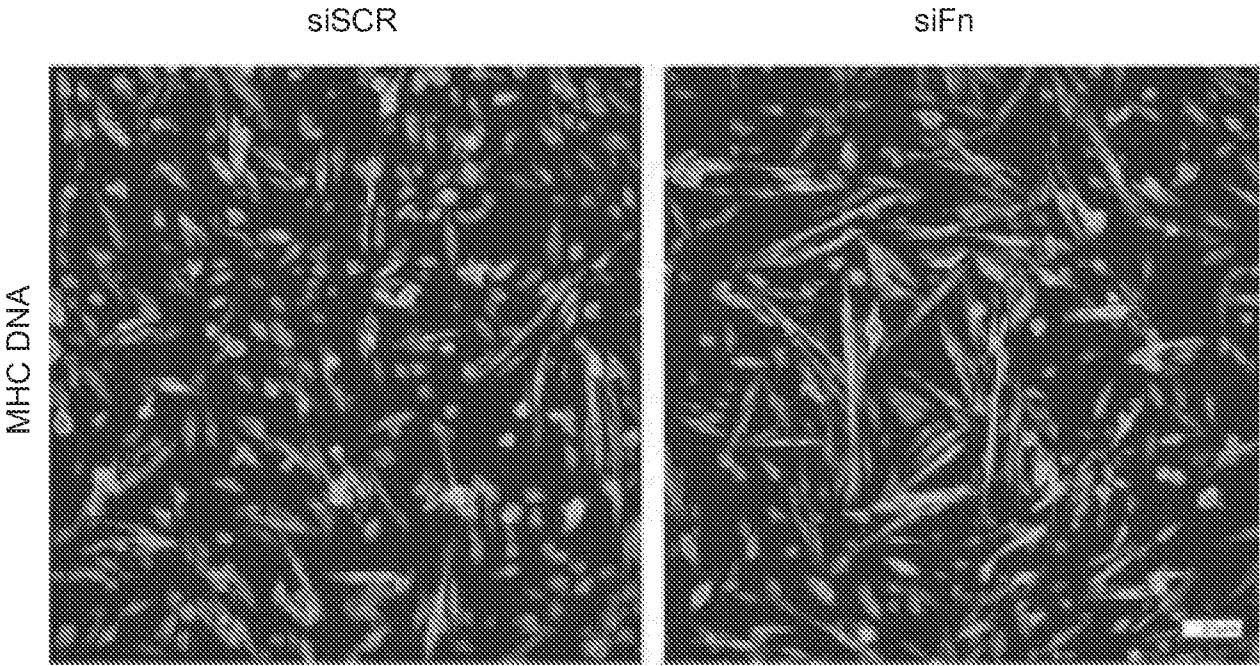


FIG. 12F

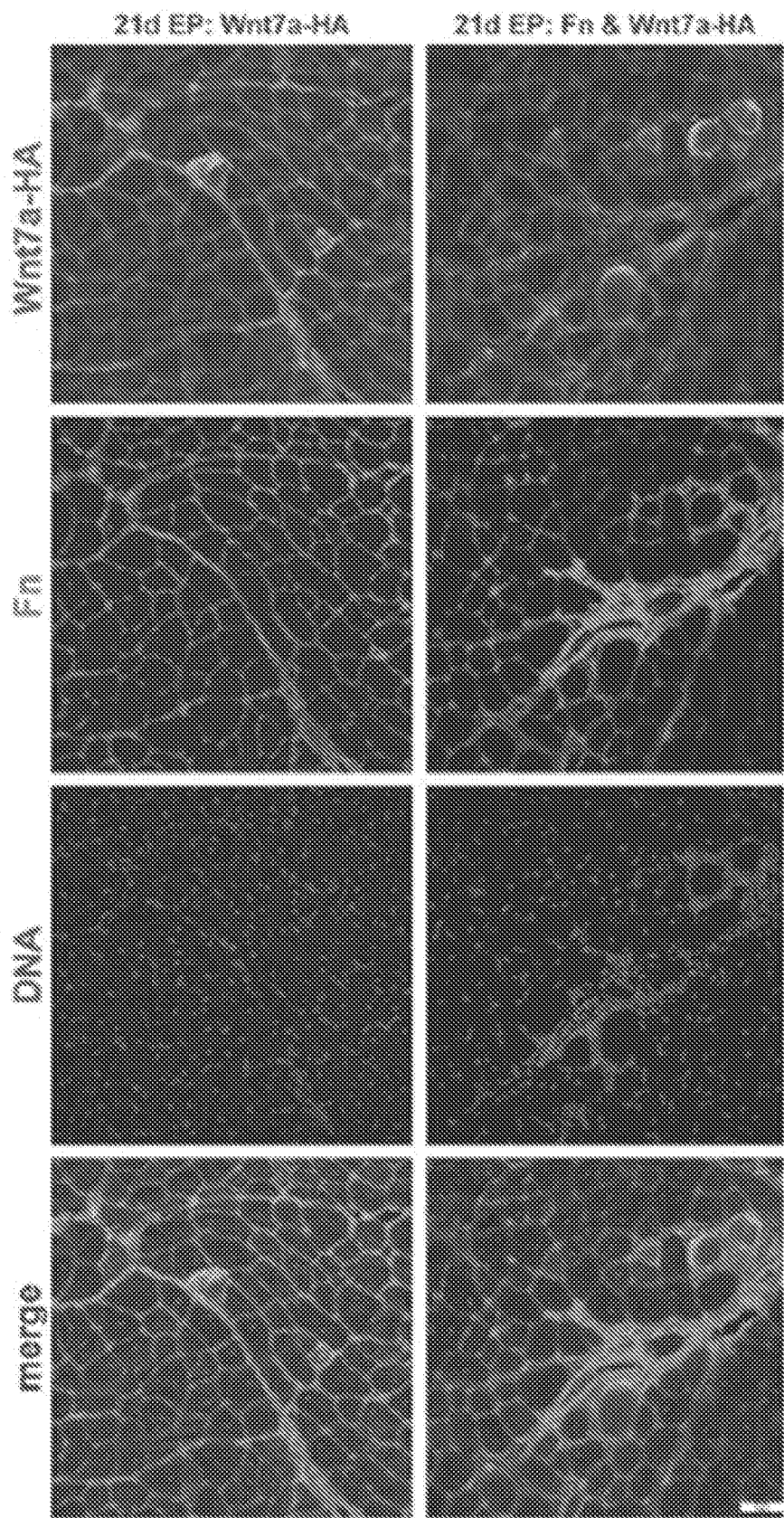


FIG. 13A

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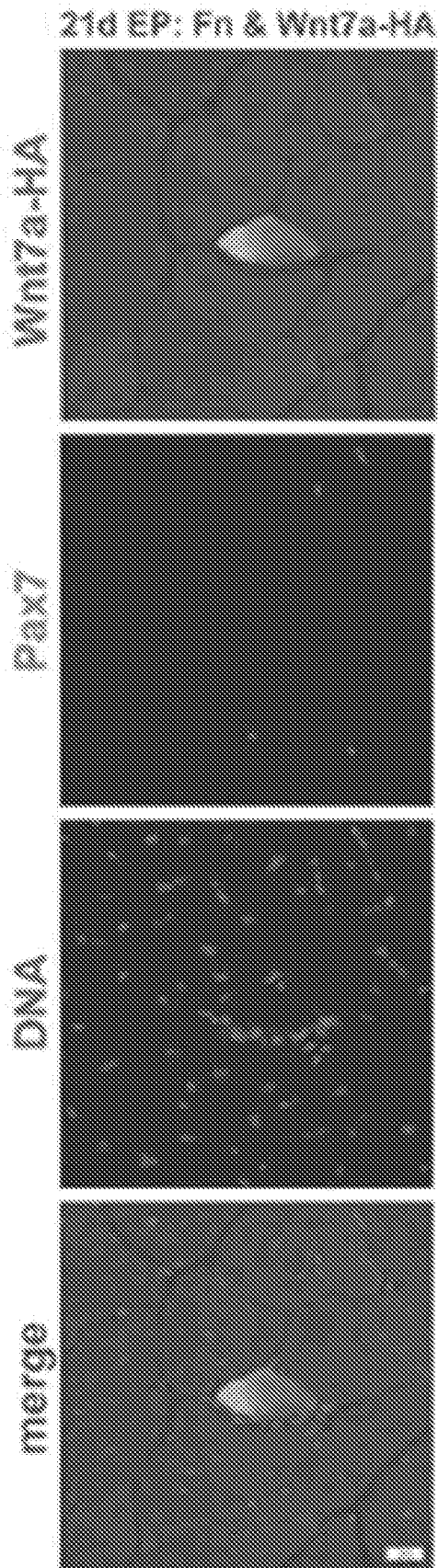


FIG. 13B

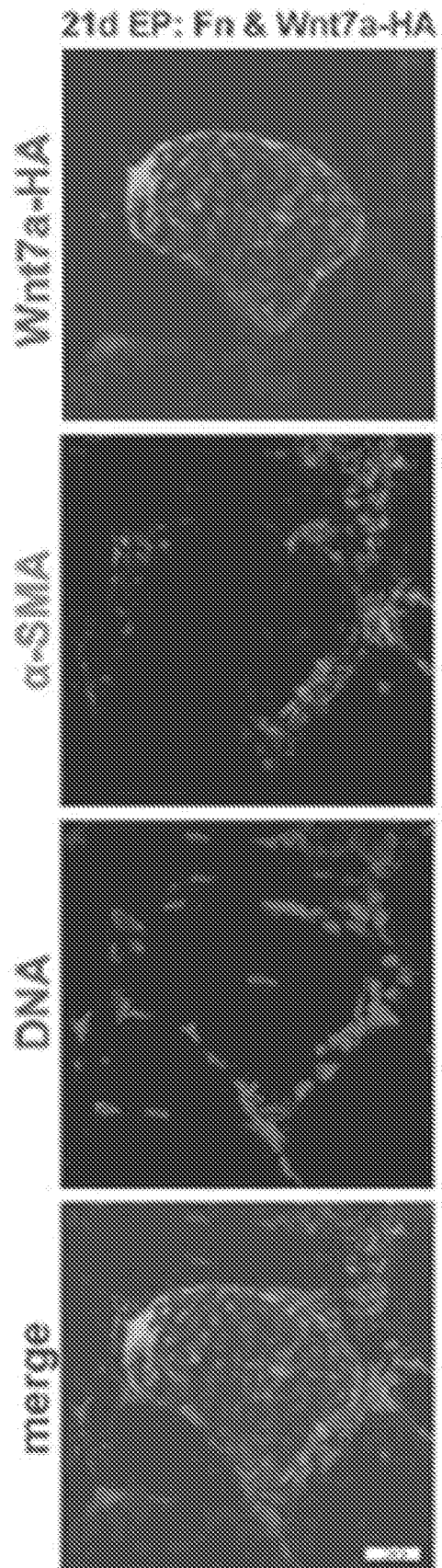


FIG. 13C

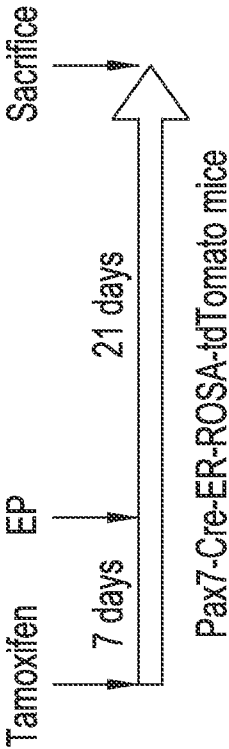


FIG. 13D

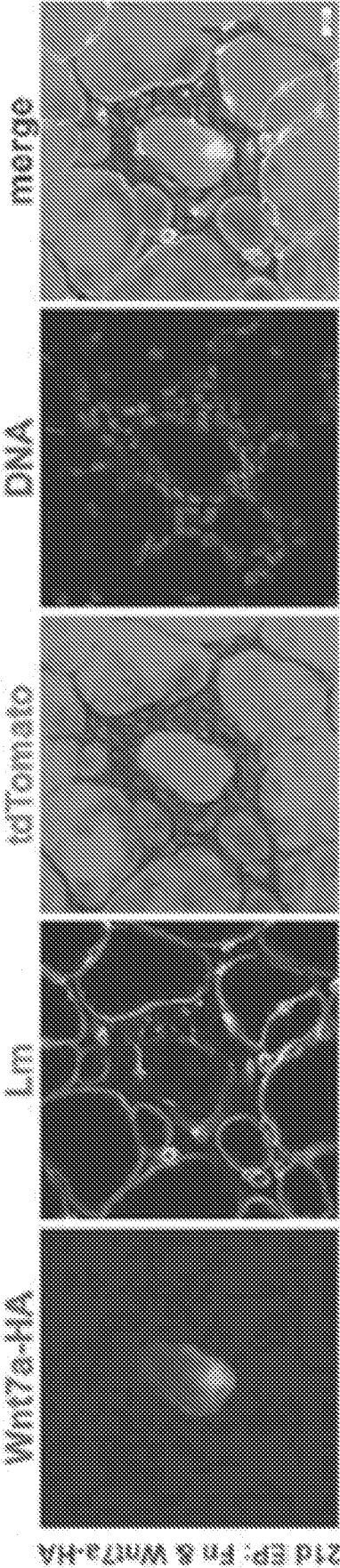


FIG. 13E

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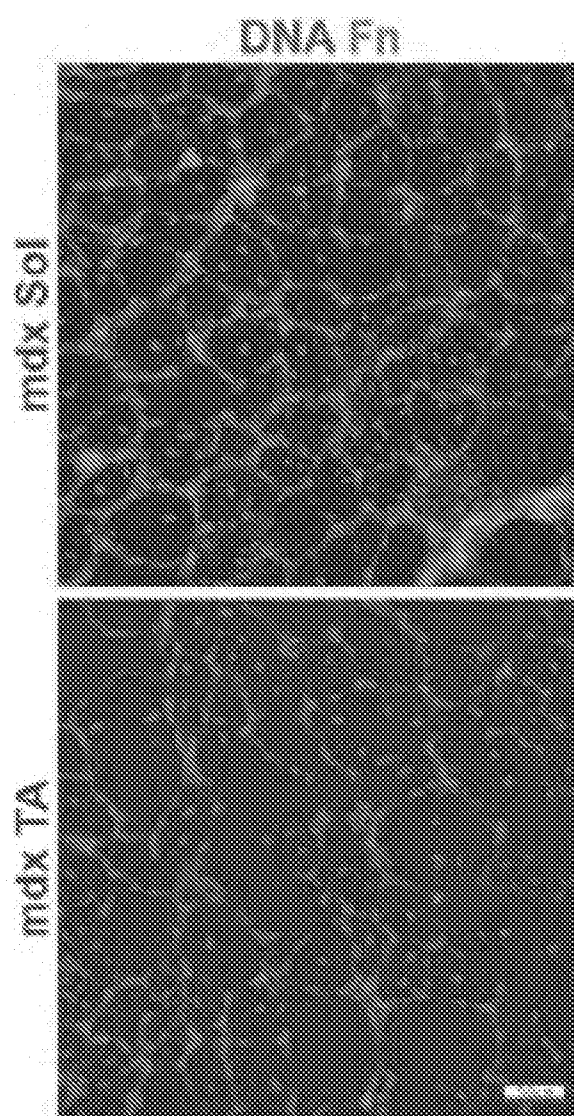


FIG. 14A

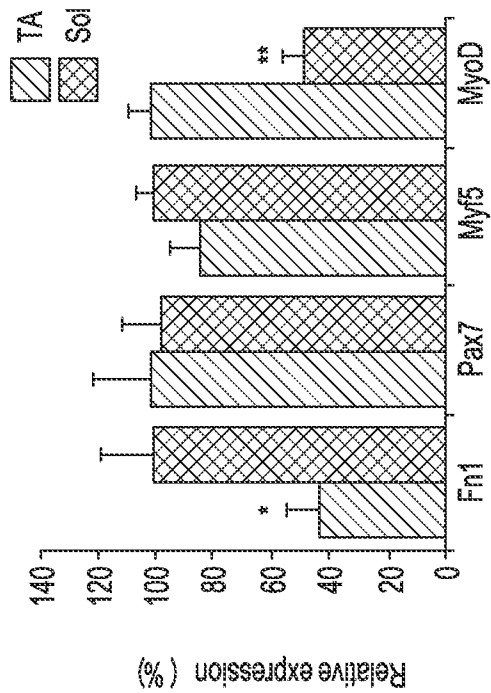


FIG. 14C

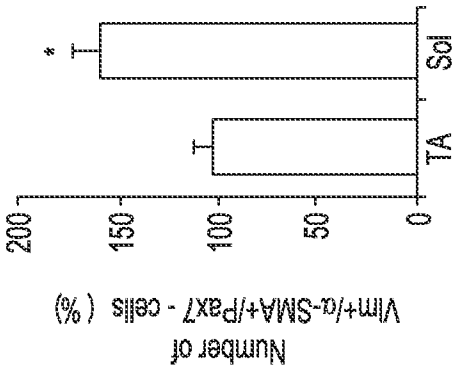


FIG. 14E

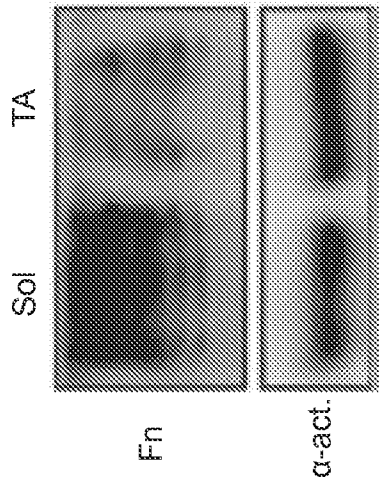


FIG. 14B

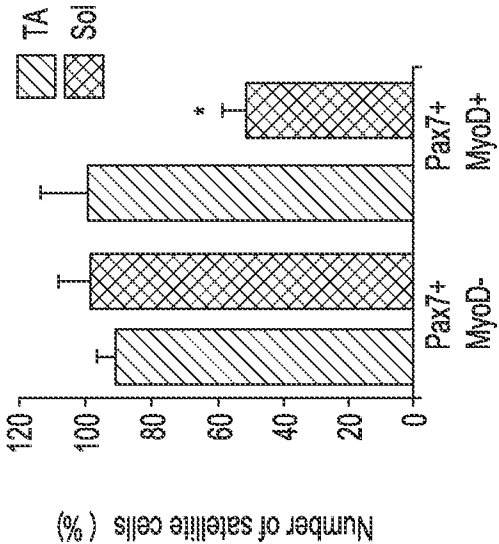
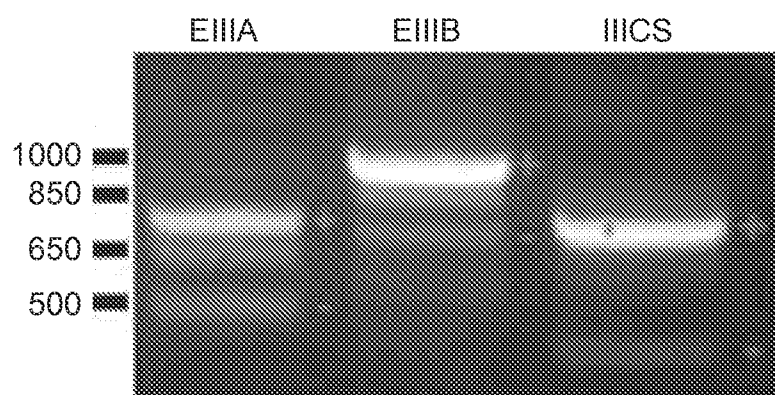


FIG. 14D

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*FIG. 15*

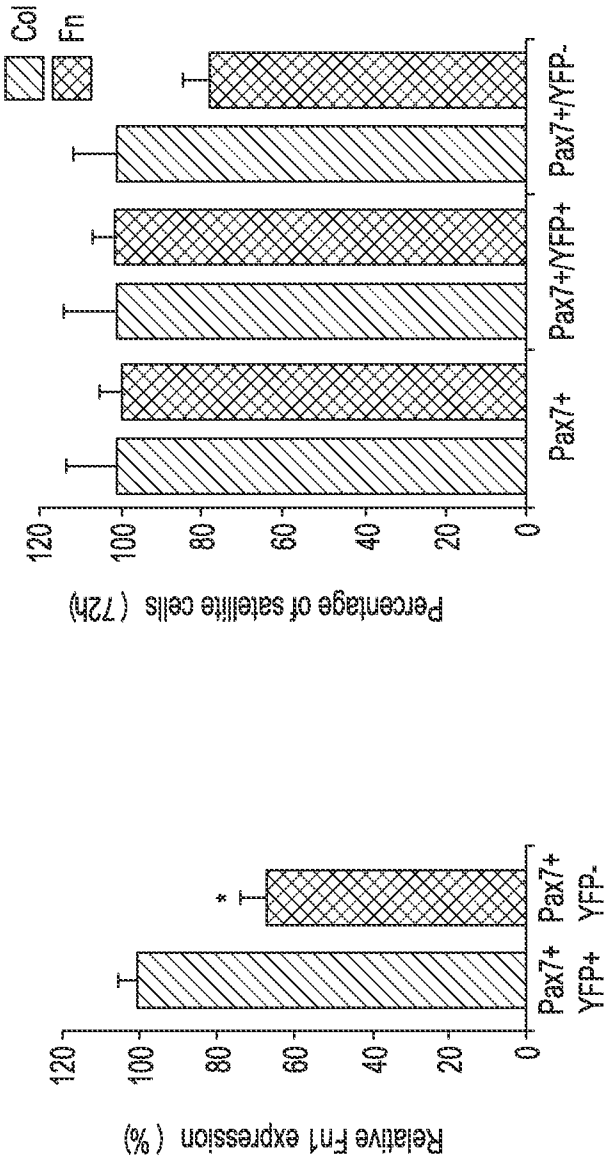


FIG. 16B

FIG. 16A

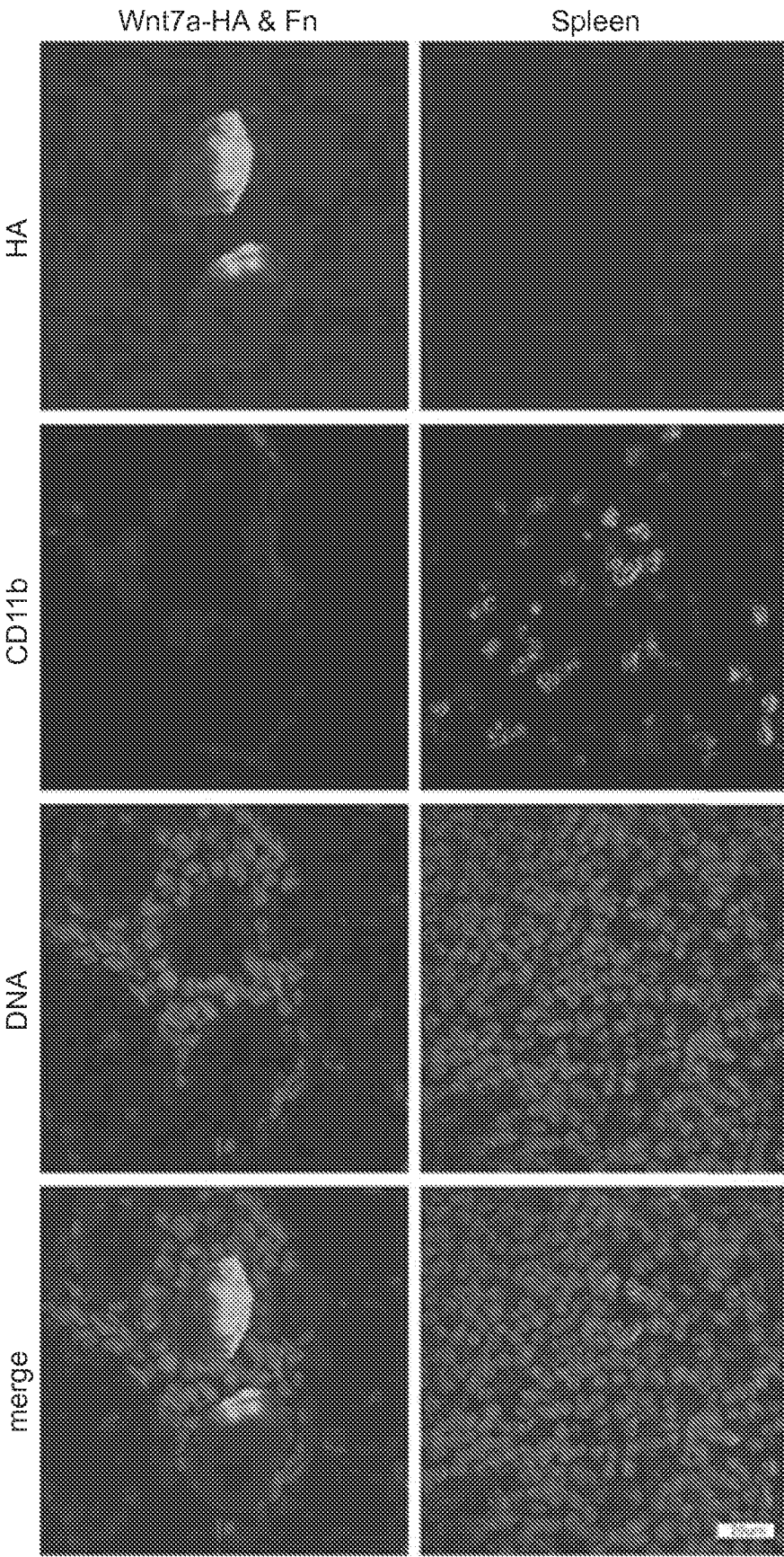


FIG. 17

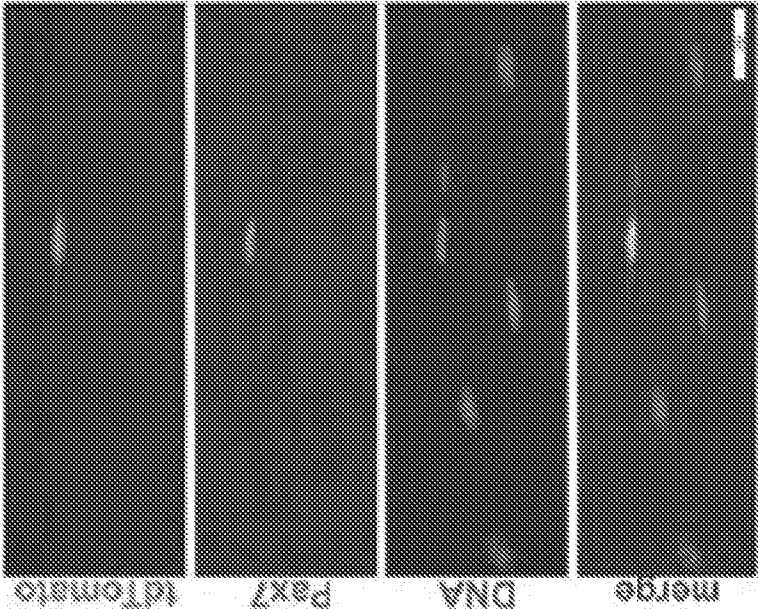


FIG. 18A

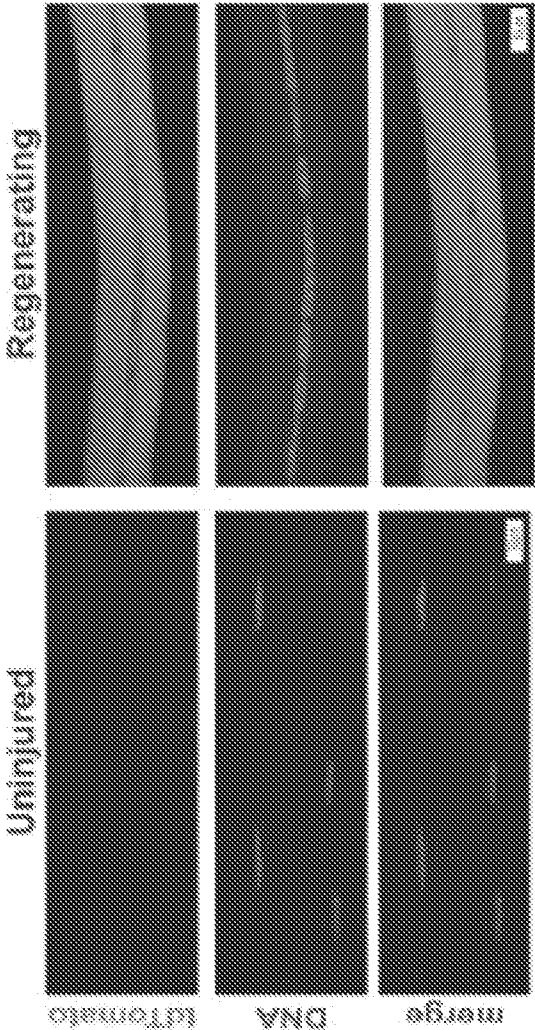


FIG. 18B

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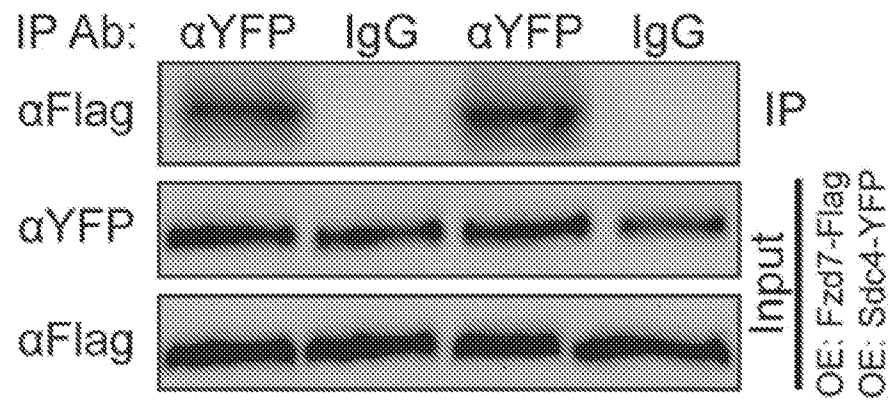


FIG. 19A

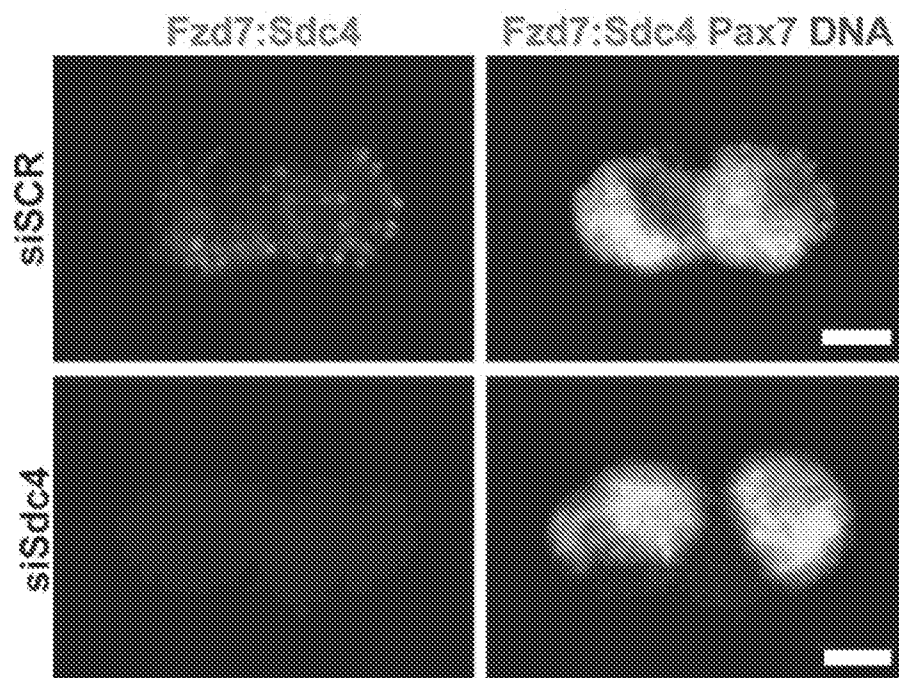


FIG. 19B

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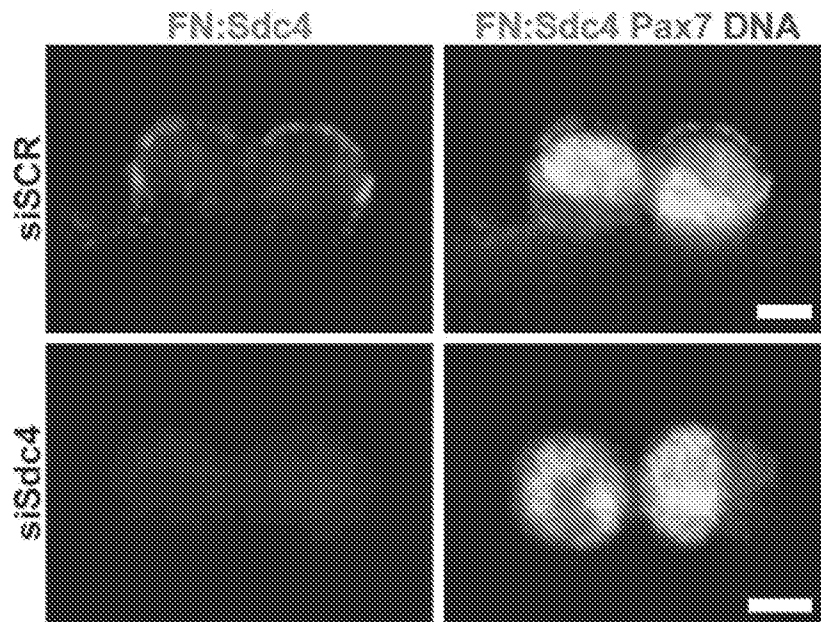


FIG. 19C

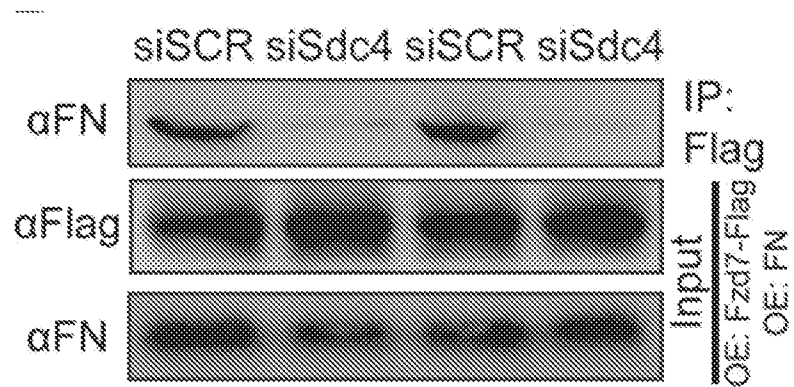


FIG. 19D

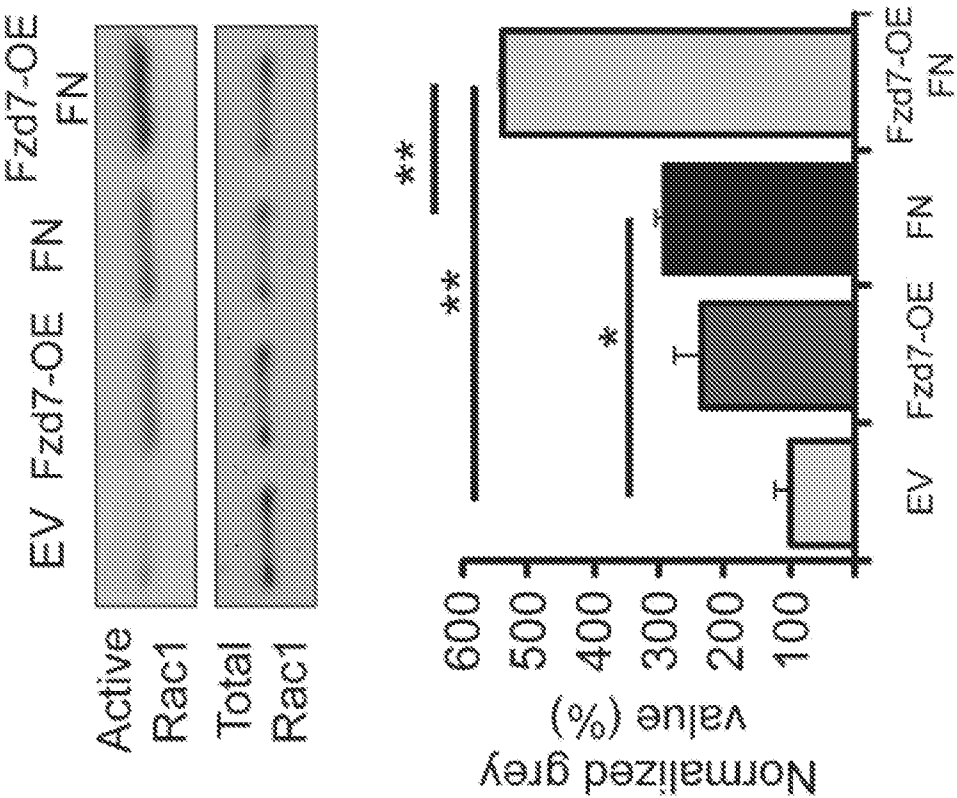


FIG. 19F

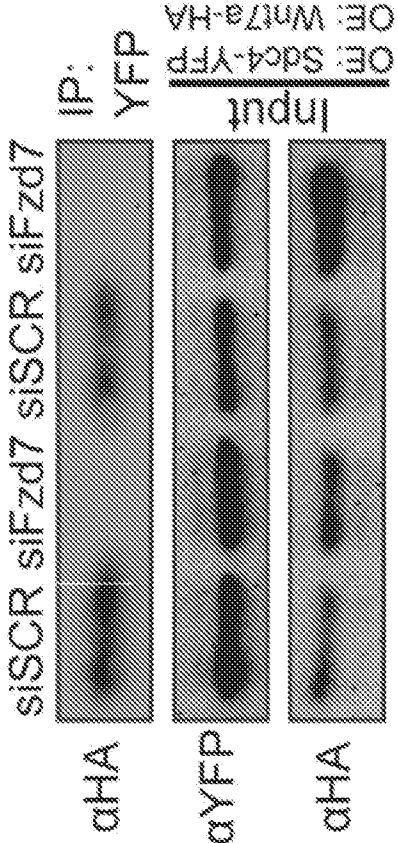


FIG. 19E

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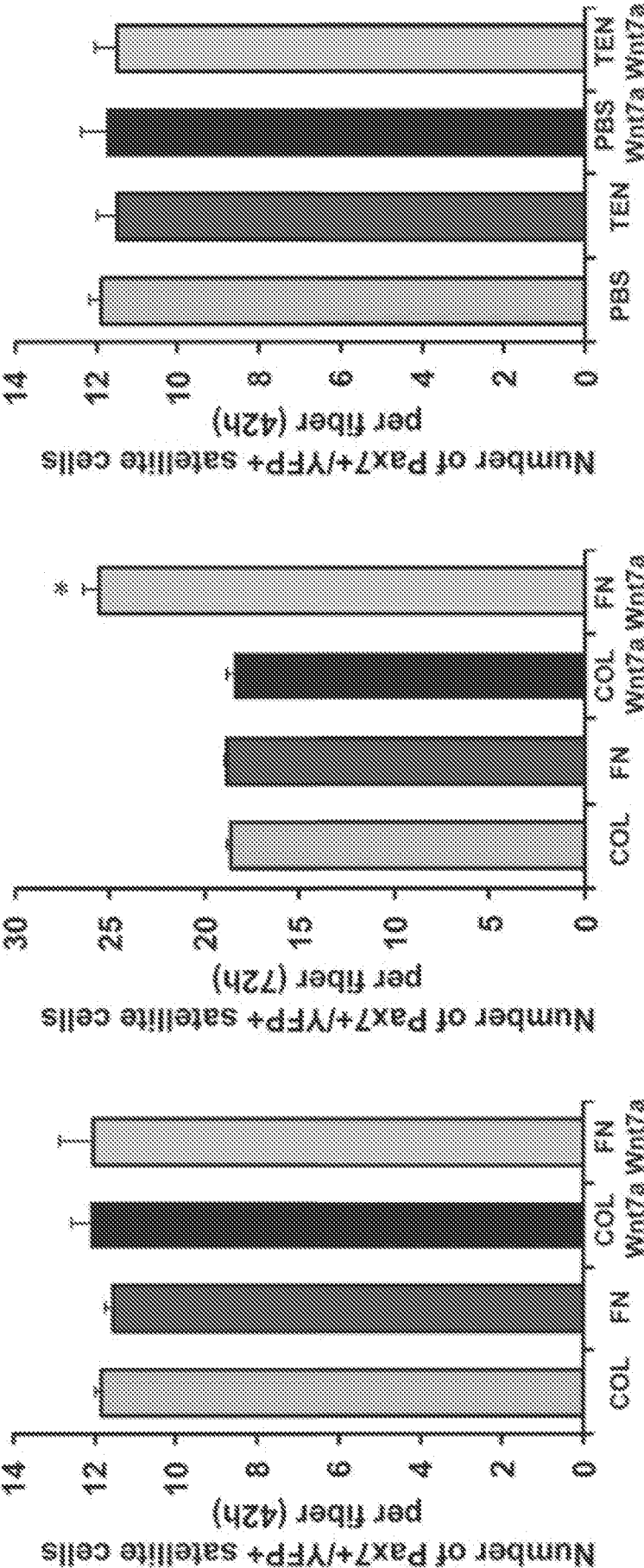


FIG. 20C

FIG. 20B

FIG. 20A

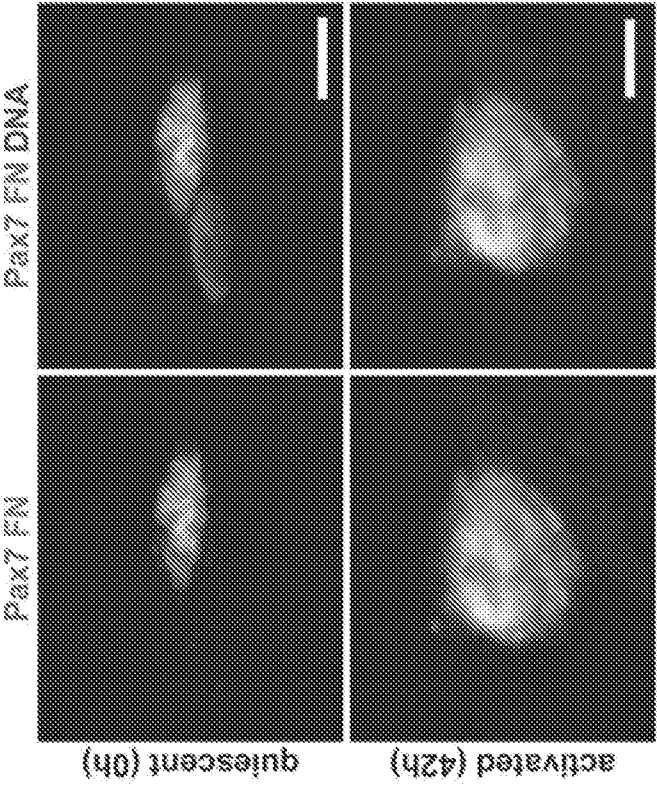


FIG. 21A

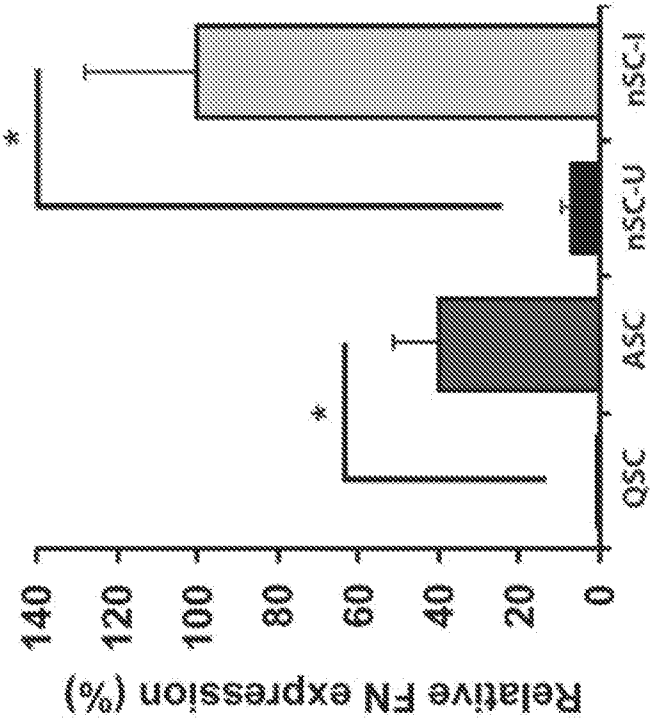


FIG. 21B

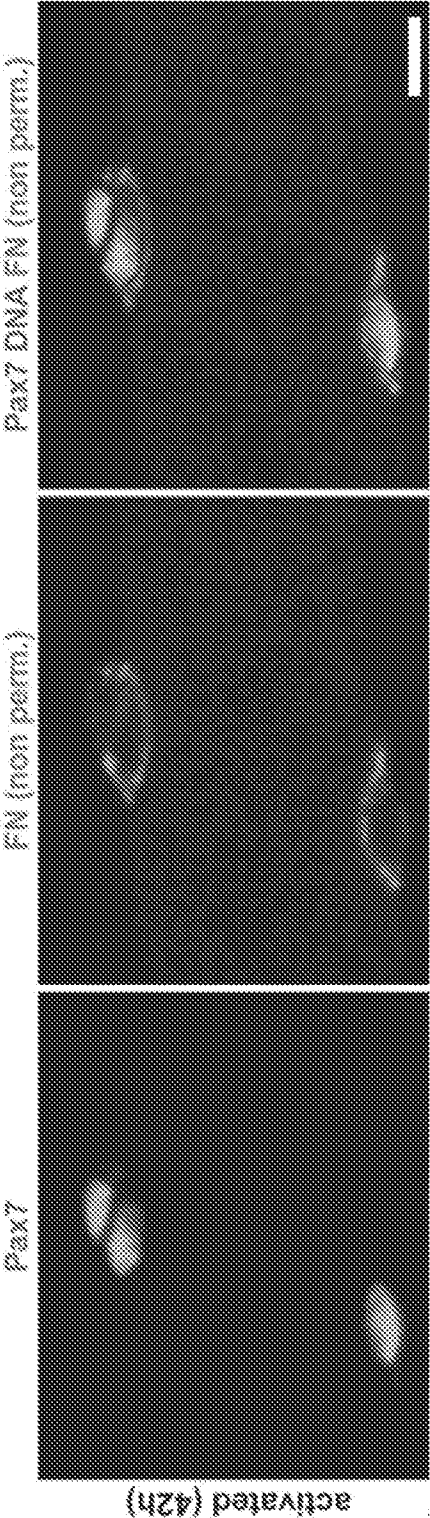


FIG. 21C



FIG. 21D

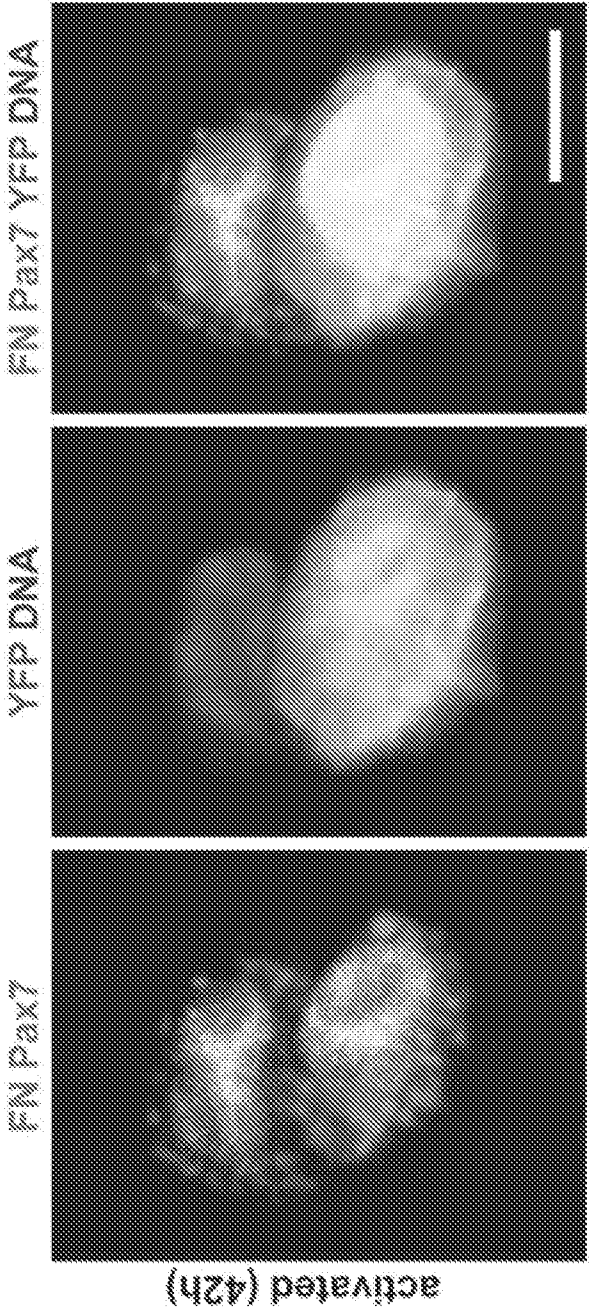


FIG. 21E

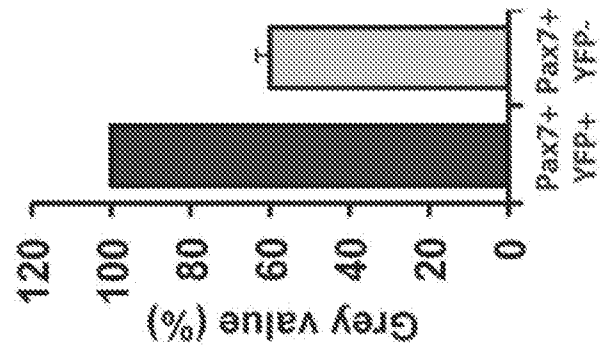


FIG. 21F

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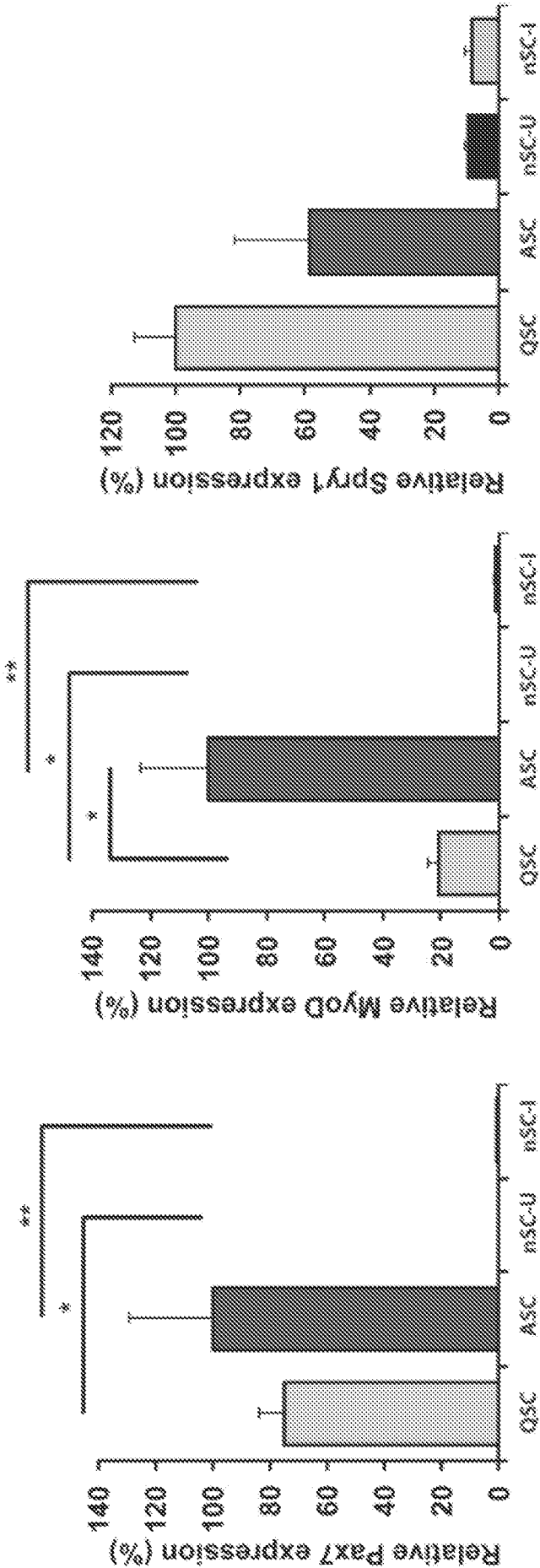
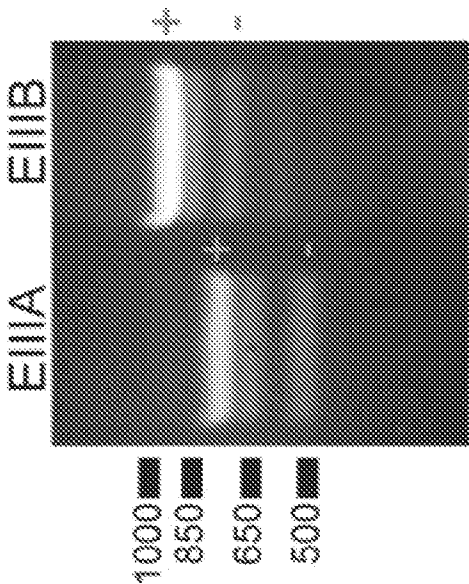
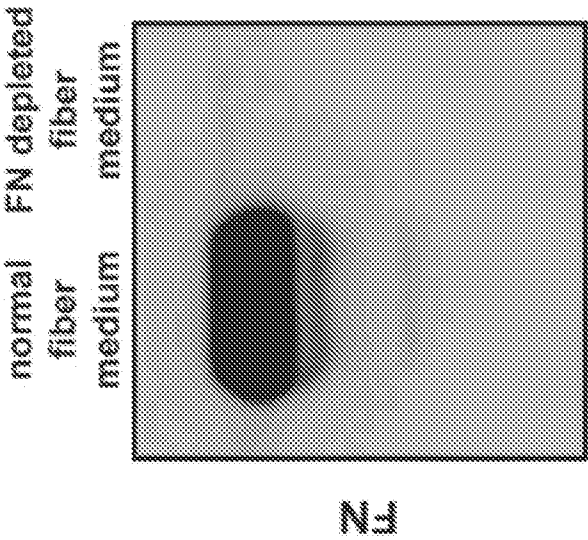
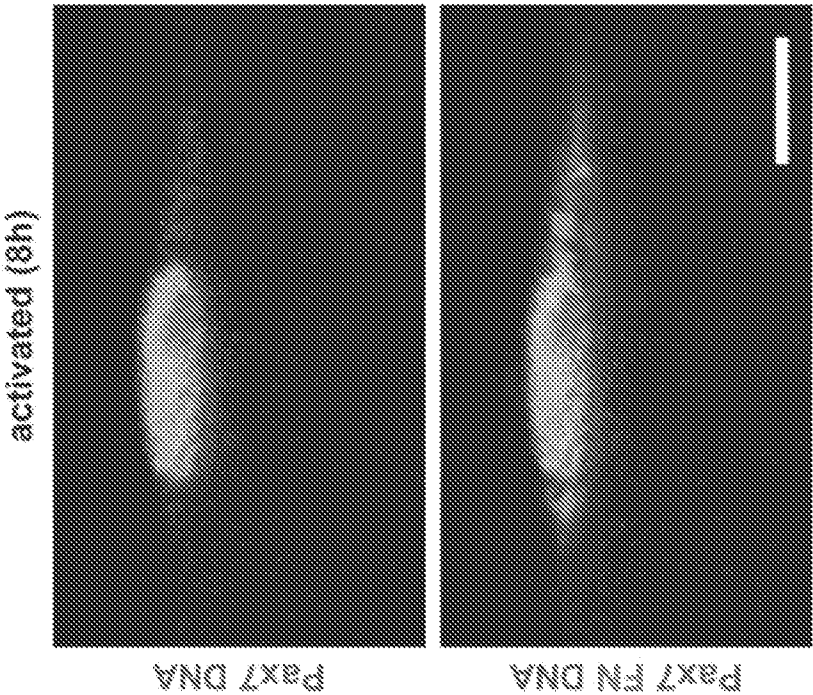


FIG. 22A

FIG. 22B

FIG. 22C

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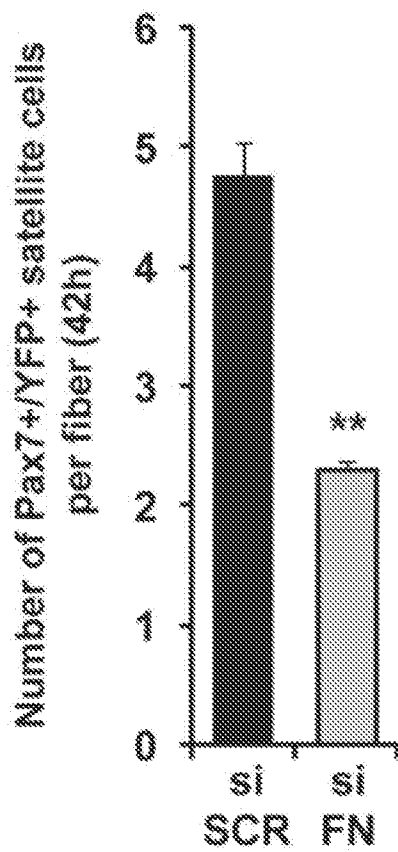


FIG. 23A

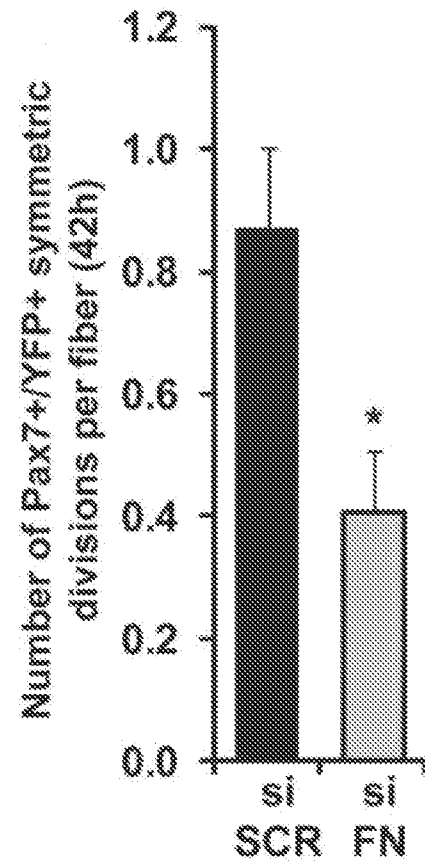


FIG. 23B

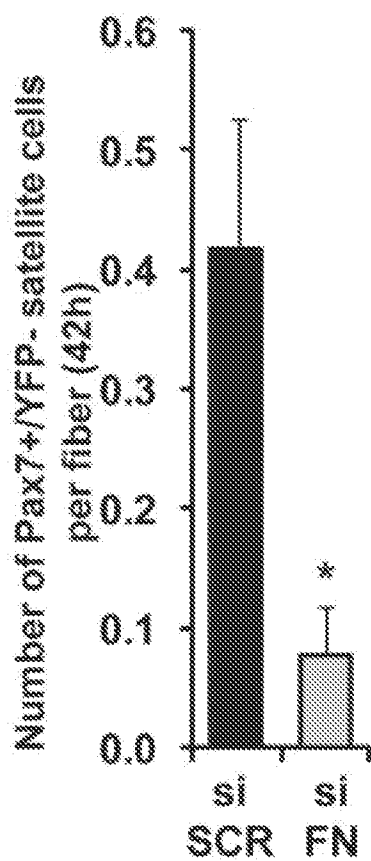


FIG. 23C

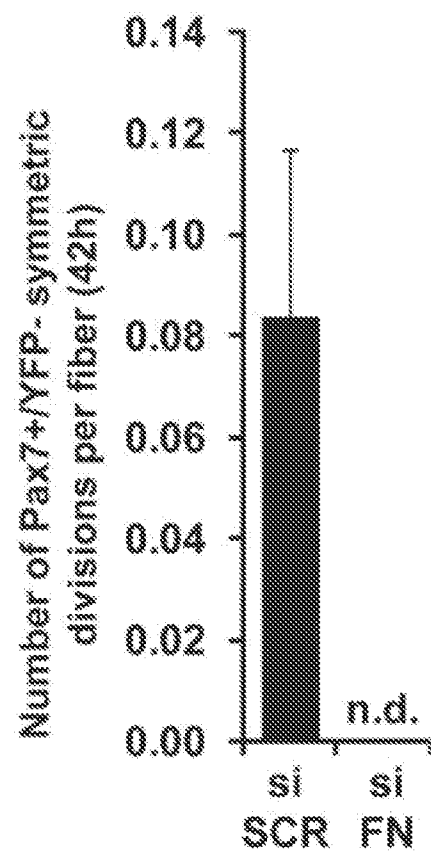


FIG. 23D

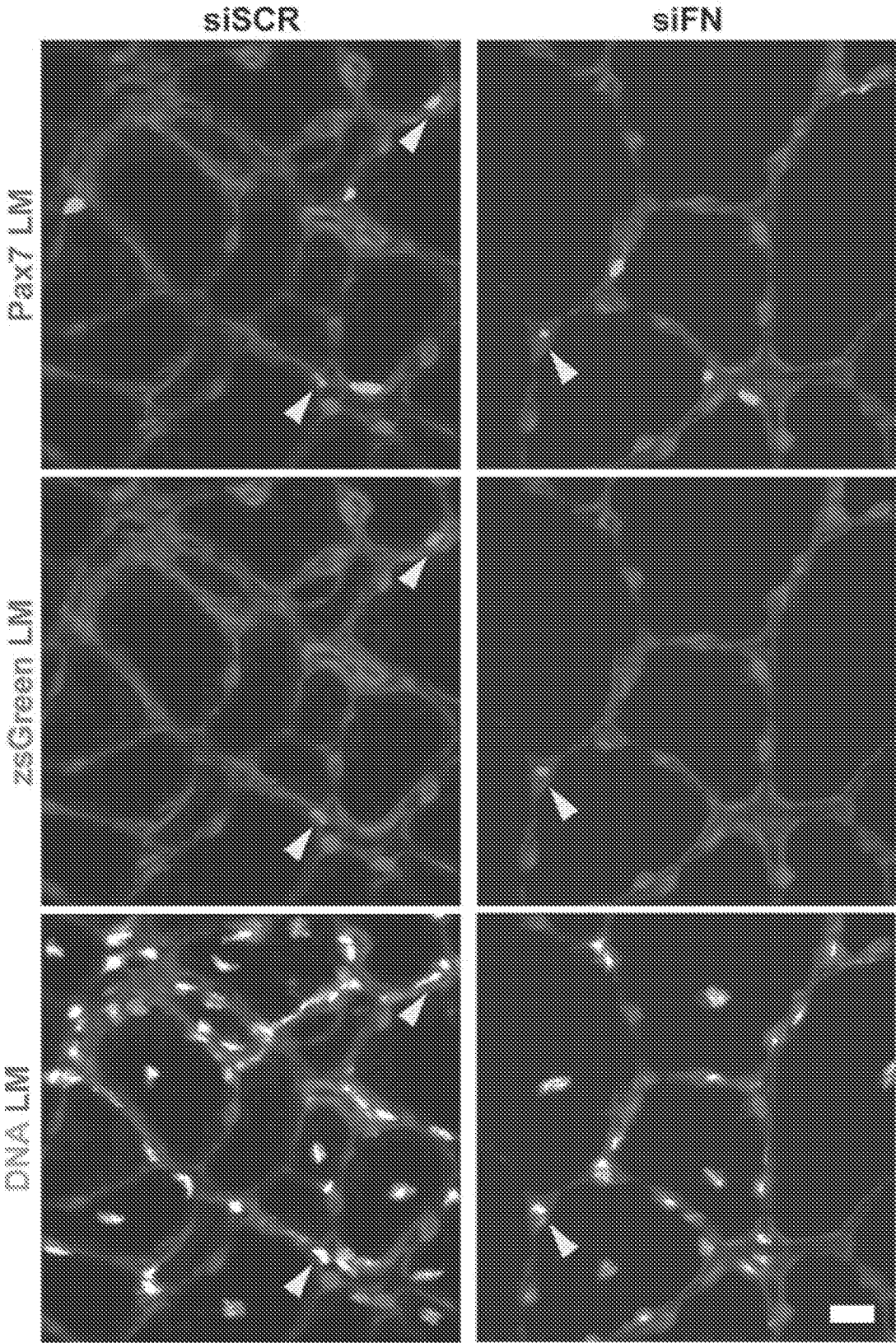
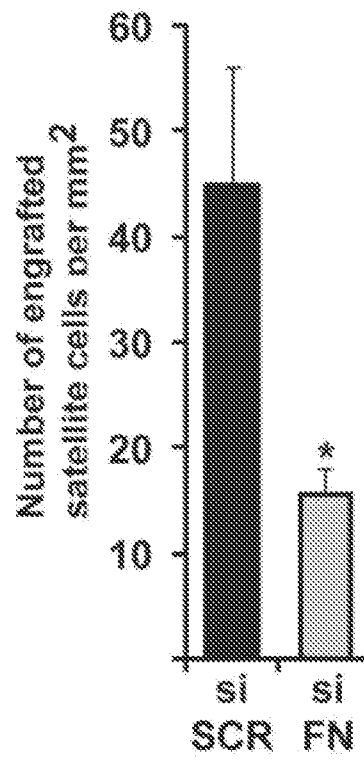
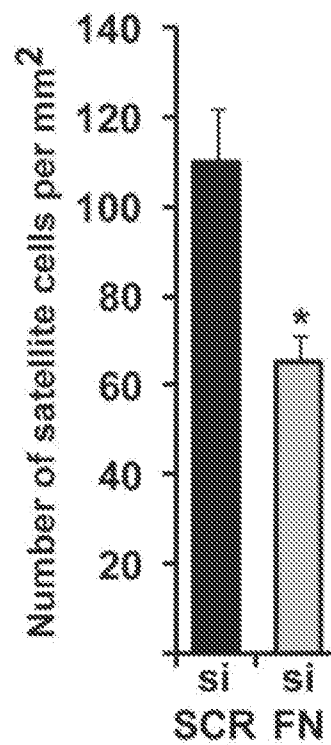


FIG. 23E

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*FIG. 23F**FIG. 23G*

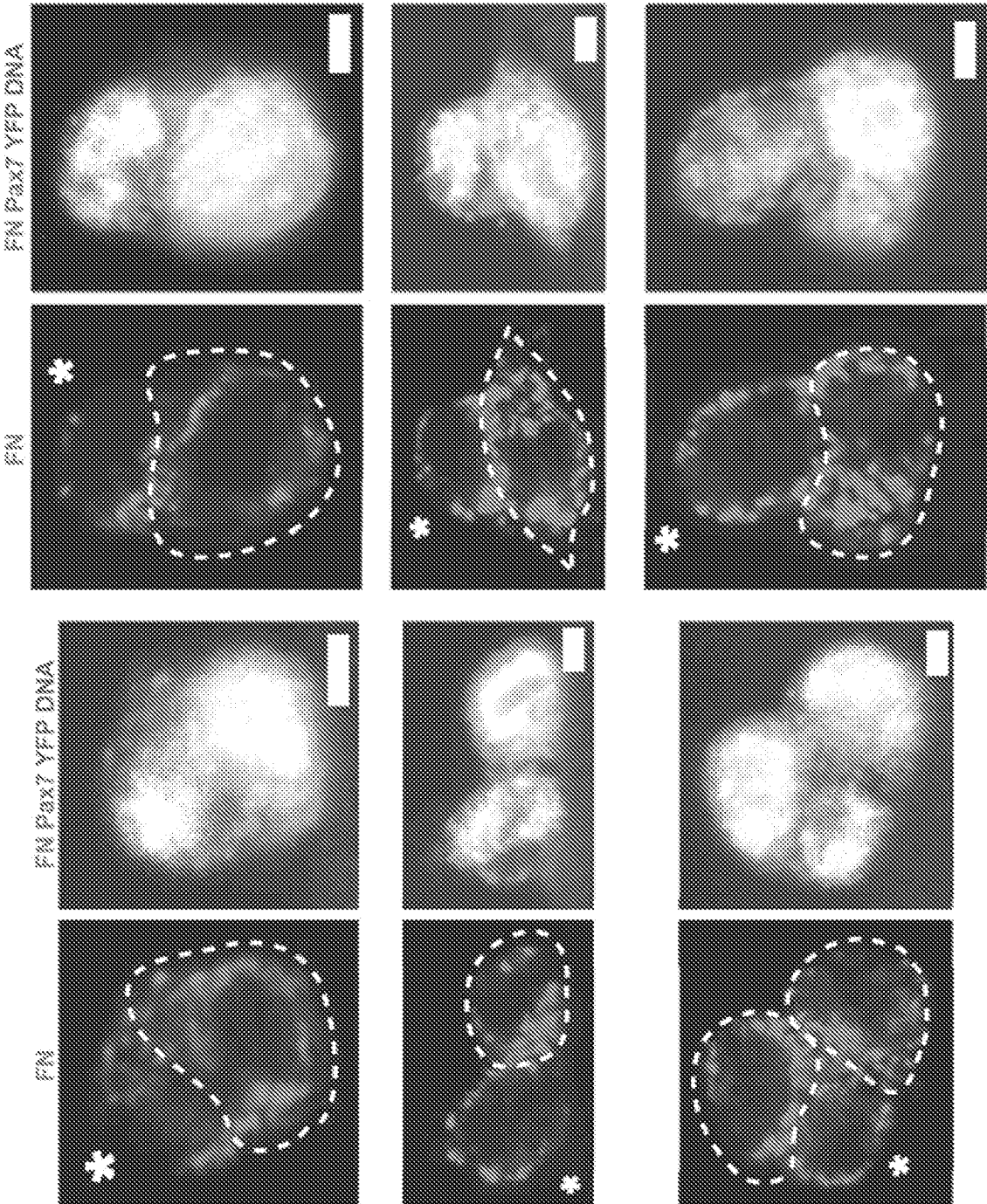


FIG. 24A

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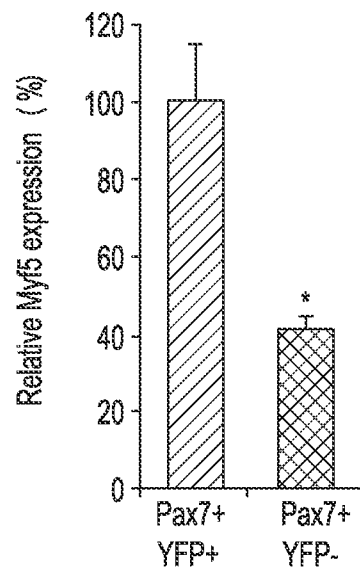


FIG. 24B

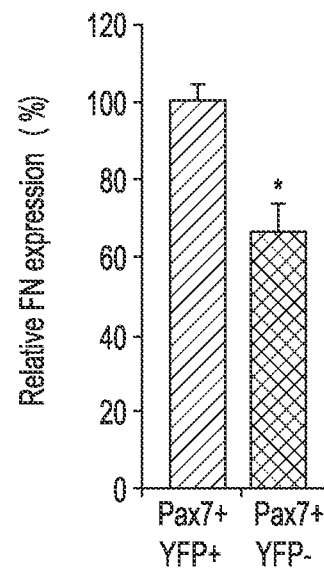


FIG. 24C

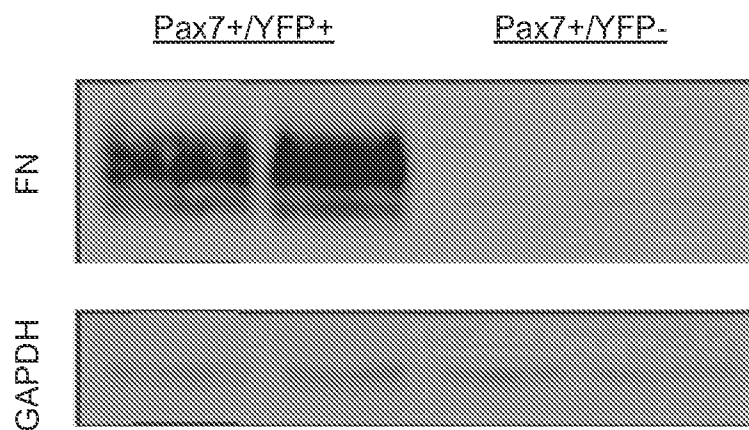
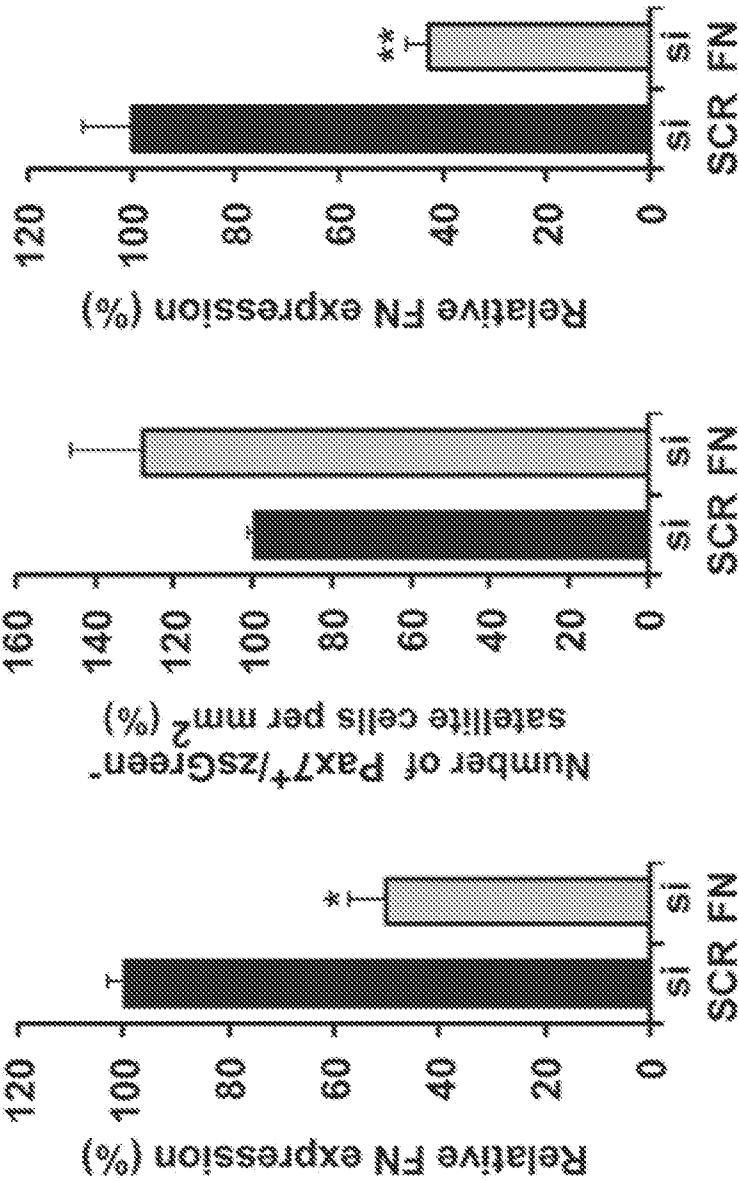


FIG. 24D



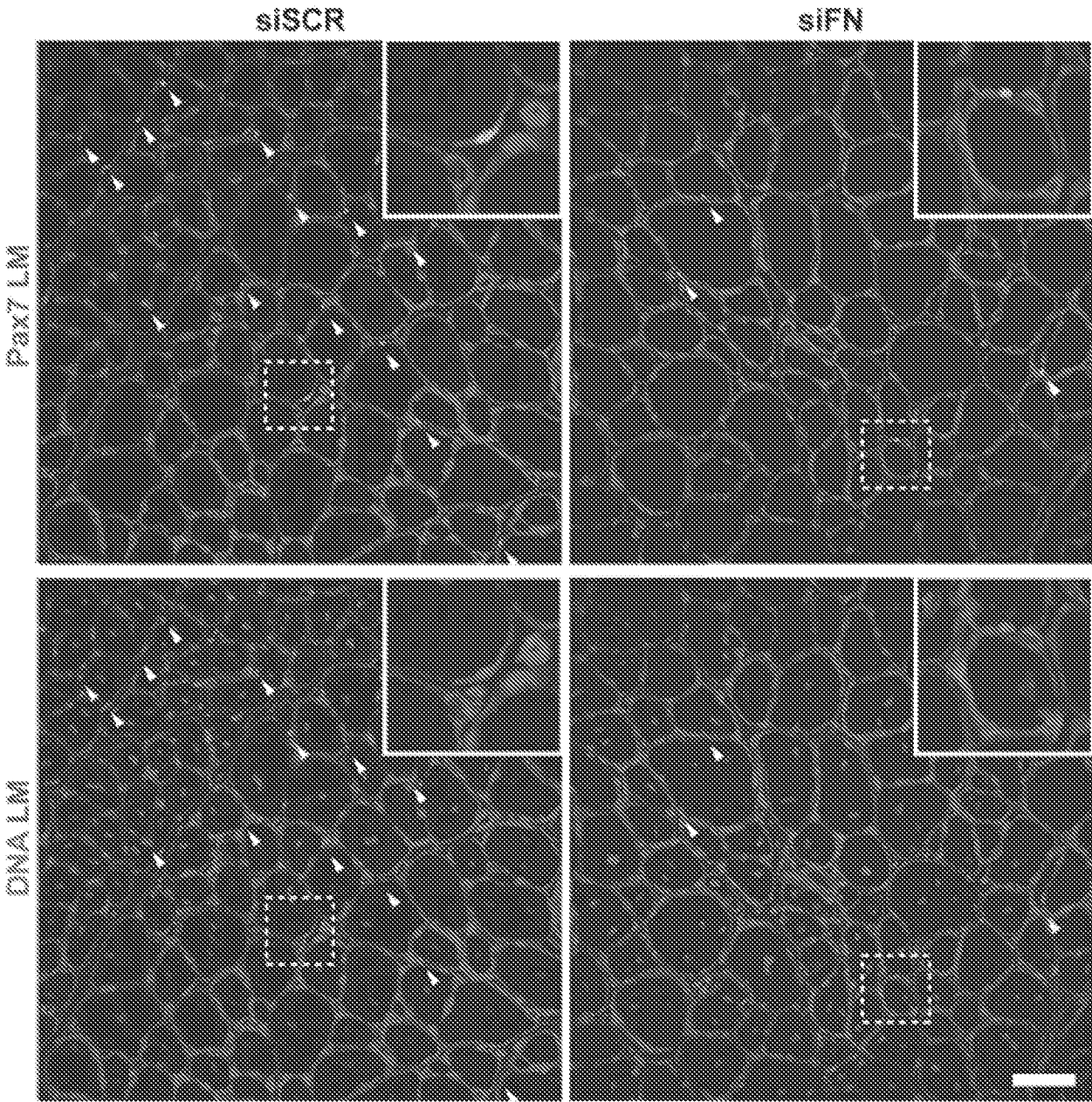


FIG. 25D