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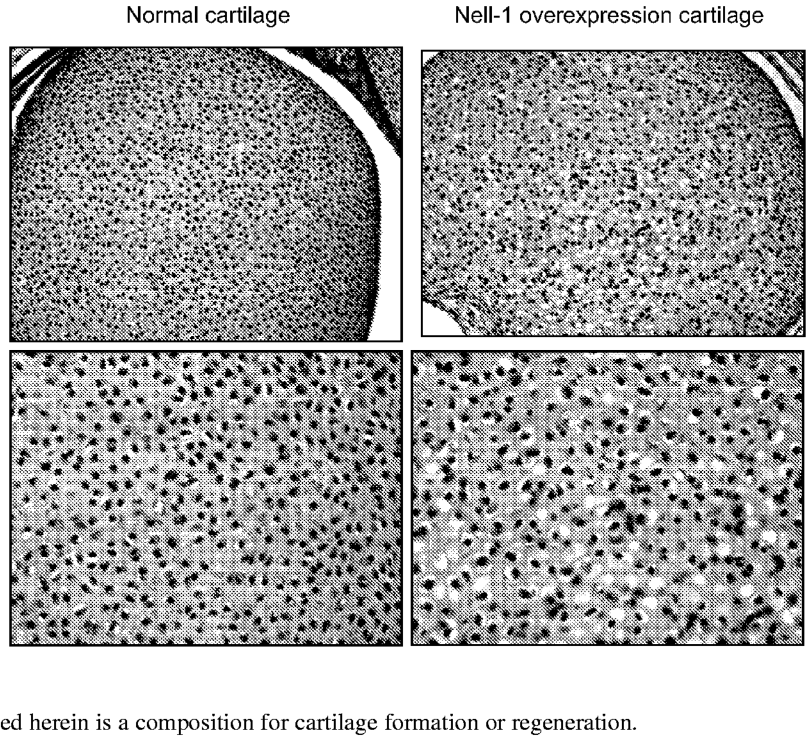

(57) **Abstract:** Provided herein is a composition for cartilage formation or regeneration.

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COMPOSITION FOR CARTILAGE

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STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. application Serial No. 10/527,786, filed on September 28, 2005, which is a U.S. National Phase of international application No. PCT/US2003/29281, filed on September 15, 2003, which claims priority to U.S. provisional application No. 60/410,846, filed on September 13, 2002. This application is also a continuation-in-part of U.S. Application Serial No. 10/544,553, filed on August 5, 2005, which is a U.S. National Phase of PCT application PCT/US2004/003808, filed on February 9, 2004, which claims priority to U.S. provisional application No. 60/445,672, filed on July 2, 2003, and PCT/US2003/29281, filed on September 15, 2003, the teachings of which are incorporated herein by reference. This application is also a continuation-in-part of international application No. PCT/US2006/005473, filed on February 16, 2006, which claims priority to U.S. Provisional Application No. 60/653,722 filed on February 16, 2005. This application is also a continuation-in-part of U.S. application No. 11/392,294, filed on March 28, 2006, which is a continuation application of U.S. application No. 09/912,297, filed on October 5, 1999, issued as U.S. Patent No. 7,052,856. The teachings of all the copending applications are incorporated hereto by reference in their entirety.

FIELD OF THE INVENTION

The invention generally relates to a composition for cartilage formation or regeneration.

BACKGROUND OF THE INVENTION

Growth factors are substances, such as peptides, which affect the growth and differentiation of defined populations of cells *in vivo* or *in vitro*.

Cartilage is a type of dense connective tissue. It is composed of chondrocytes which are dispersed in a firm gel-like matrix. Cartilage is avascular (contains no blood vessels) and nutrients are diffused through the matrix. Cartilage is found in the joints, the rib cage, the ear, the nose, in the throat and between intervertebral disks. There are three main types of cartilage: hyaline (e.g., costal cartilages, the cartilages of the nose, trachea, and bronchi, and the articular cartilages of joints), elastic (e.g., external ear, external auditory meatus, part of the Eustachian tube, epiglottis, and in some of the laryngeal cartilages) and fibrocartilage [e.g. meniscus (e.g., wrist triangular fibrocartilage complex, knee meniscus), intervertebral discs, temporomandibular joint disc, the pubic symphysis, and in some tendons and ligaments at their attachment to bones, . One of the main purposes of cartilage is to provide a framework upon which bone deposition could begin (i.e., during endochondral ossification). Another important purpose of cartilage is to provide smooth surfaces for the movement of articulating bones. For example, articular cartilage, most notably that which is found in the knee joint, is generally characterized by very low friction, high wear resistance, and poor regenerative qualities. It is responsible for much of the compressive resistance and load bearing qualities of the knee joint and, without it, walking is painful to impossible. Yet another important purpose of cartilage is to provide, firm, yet flexible support (e.g., nasal cartilage, spinal discs, tracheal cartilage, knee meniscus, bronchial cartilage). For instance, cartilage such as the meniscus plays a crucial role in joint stability, lubrication, and force transmission. Under a weight bearing load, the meniscus maintains the balanced position of the femur on the tibia and distributes the compressive forces by increasing the surface contact area, thereby decreasing the average stress two to three times. Additionally, the menisci interact with the joint fluid to produce a coefficient of friction that is five times as slick as ice on ice. In another example, the intervertebral disc has several important functions, including functioning as a spacer, as a shock absorber, and as a motion unit. The gelatinous central portion of the disc is called the nucleus pulposus. It is composed of 80 - 90% water. The solid portion of the nucleus is Type II collagen and non-aggregated proteoglycans. The outer ligamentous ring around the nucleus pulposus is called the annulus fibrosus, which hydraulically seals the nucleus, and allows intradiscal pressures to rise as the disc is loaded. The annulus has overlapping radial bands, not unlike the plies of a radial tire, and this allows torsional stresses to be distributed through the annulus under normal loading without rupture. The disc functions as a hydraulic cylinder. The annulus interacts with the nucleus. As the nucleus is pressurized, the annular fibers serve a containment function to prevent the nucleus from bulging or herniating.

Cartilage can be damaged by wear, injury or diseases. As we age, the water and protein content of the body's cartilage changes. This change results in weaker, more fragile and thin cartilage. Osteoarthritis is a common condition of cartilage failure that can lead to limited range of motion, bone damage and invariably, pain. Due to a combination of acute stress and chronic fatigue, osteoarthritis directly manifests itself in a wearing away of the articulating surface and, in extreme cases, bone can be exposed in the joint. In another example, loss of the protective stabilizing meniscus leads to increased joint laxity or abnormal motions that lead to joint instability. The excessive motion and narrowed contact area promotes early arthritic changes. At the cellular level, there is initially a loss of cells from the superficial layer of the articular cartilage followed by cartilage splitting, subsequent thinning and erosion occurs, and finally protrusion of the underlying raw bone. The earliest arthritic changes have been noted three weeks after loss of the entire meniscus. In yet another example, because both the discs and the joints that stack the vertebrae (facet joints) are partly composed of cartilage, these areas are subject to wear and tear over time (degenerative changes). As the inner nucleus dehydrates, the disc space narrows, and redundant annular ligaments bulge. With progressive nuclear dehydration, the annular fibers can crack and tear. Loss of normal soft tissue tension may allow the spinal segment to sublux (e.g. partial dislocation of the joint), leading to osteophyte formation (bone spurs), foraminal narrowing, mechanical instability, and pain. If the annular fibers stretch or rupture, allowing the pressurized nuclear material to bulge or herniate and compress neural tissues, pain and weakness may result. This is the condition called a pinched nerve, slipped disc, or herniated disc. Radiculopathy refers to nerve irritation caused by damage to the disc between the vertebrae. Mechanical dysfunction may also cause disc degeneration and pain (e.g. degenerative disc disease). For example, the disc may be damaged as the result of some trauma that overloads the capacity of the disc to withstand increased forces passing through it, and inner or outer portions of the annular fibers may tear. These torn fibers may be the focus for inflammatory response when they are subjected to increased stress, and may cause pain directly, or through the compensatory protective spasm of the deep paraspinal muscles.

There are several different repair options available for cartilage damage or failure. Osteoarthritis is the second leading cause of disability in the elderly population in the United States. It is a degenerative disorder that generally starts off relatively mild and escalates with time and wear. For those patients experiencing mild to moderate symptoms, the disorder can be dealt with by several non-surgical treatments. The use of braces and drug therapies, such as anti-inflammatories (ex. diclofenac, ibuprofen, and naproxen), COX-2 selective inhibitors, hydrocortisone, glucosamine, and chondroitin sulfate, have been shown to alleviate the pain caused by cartilage deficiency and some claim they can slow the degenerative process.

Most surgical treatments for articular cartilage, short of total joint replacement, can be divided into various treatment groups. Treatments that remove the diseased and undermined cartilage with an aim to stop inflammation and pain include shaving (chondrectomy) and debridement. Another group of treatments consists of a range of abrasive procedures aimed at triggering cartilage production, such as drilling, microfracture surgery, chondroplasty, and spongialization. Abrasion, drilling, and microfracture originated 20 years ago. They rely on the phenomenon of spontaneous repair of the cartilage tissue following vascular injury to the subchondral plate of the bone. Laser assisted treatments, currently experimental, compose another category; they combine the removal of diseased cartilage with cartilage reshaping and also induce cartilage proliferation. Additional treatments include autologous cartilage implants (e.g., Carticel by Genzyme).

Other treatments, more applicable to meniscal cartilage, include early surgical intervention and suture repair of torn structures or allograft meniscus transplantation in severe injury cases.

Although the overwhelming majority of patients with a herniated disc and sciatica heal without surgery, if surgery is indicated procedures include removal of the herniated disc with laminotomy (producing a small hole in the bone of the spine surrounding the spinal cord), laminectomy (removal of the bony wall adjacent to the nerve tissues), by needle technique through the skin (percutaneous discectomy), disc- dissolving procedures (chemonucleolysis), and others. For patients with mechanical pain syndrome, unresponsive to conservative treatment, and disabling to the individual's way of life, the problem can be addressed by spinal fusion, intradiscal electrothermal coagulation (or annuloplasty), posterior dynamic stabilization, artificial disc technologies, or still experimental disc regeneration therapies using various molecular based therapies delivered using proteins, peptides, gene therapies, or nucleotides. Although numerous methods have been described for treatment of cartilage problems, it is clear that many are artificial or mechanically based solutions that do not seek to recreate normal cartilage tissue biology. Therefore, there is a need for methods for stimulating cartilage formation.

The embodiments described below address the above identified issues and needs.

SUMMARY OF THE INVENTION

The present invention is related to agents and methods for inducing cartilage formation or repair using a NELL peptide or related agent (collectively referred as "agent"). The composition can include a NELL peptide, a Nell-like molecule, and optionally at least one other active agent, cells, and biocompatible material implanted for the purpose of cartilage repair (i.e., hyaline cartilage, elastic cartilage, or fibrocartilage).

In some embodiments, the present invention provides a composition that contains an effective amount of at least one agent for either directly or indirectly promoting the generation of cartilage for treating, preventing or ameliorating a cartilage related medical condition. One of the agents for direct promotion of cartilage generation can be NELL peptides or NELL-based gene therapy or NELL-gene product enhancers applied to chondrogenic cells such as, but not limited to, chondroblasts, chondrocytes, or chondroprogenitor cells, adult and embryonic stem cells, bone marrow cells, bone marrow stromal cells, mesenchymal cells, a fibroblast, or adipose derived cells. The agent for indirect promotion of cartilage generation (e.g., through inducing chondroblast/chondrocyte differentiation) can be, e.g., one of NELL peptide, or agonists of NELL peptide receptors.

In some embodiments, the composition can include, e.g., one or more inhibitors or antagonists of NELL peptide receptors, high dose NELL peptides, or combinations thereof. Such a composition is effective for inhibition of chondrogenic differentiation by inhibiting potential or committed chondrogenic cells such as, but not limited to, osteoblasts, osteoprogenitor cells, stem cells, bone marrow cells, fibroblastic cells, dural cells, periosteal cells, pericytes, and/or muscle cells.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows increased cartilage maturation and hypertrophy in femoral head cartilage of NELL1 overexpression mice compared with wild type littermate. On the left is wild type newborn femoral head cartilage demonstrating small, less mature chondrocytes in the femoral head. On the right is the NELL1 over-expression transgenic mice demonstrating well differentiated, more mature, hypertrophic chondrocytes present throughout the femoral head with large nuclei and vacuoles present.

Figures 2A-2F show increased meniscus development in E18 NELL1 overexpression mice compared with wild type littermate. Figures 2A and 2B with arrows pointing at the meniscus between the femoral and tibial cartilage head in wild type (Figure2A) and NELL1 overexpression (Figure 2B) animals. Figures 2C and 2D are higher magnification views of Figures 2A and 2B. Figure 2E is a higher magnification of the wild type control shown in 2C demonstrating less differentiated chondrocytes with minimal hypertrophy. Figure 2F is a higher magnification of the NELL1 overexpression animal shown in 2D demonstrating significantly more differentiated chondrocyte in the cartilage matrix. Vacuoles in the hypertrophic chondrocytes are observed indicating well differentiation of chondrocyte in the meniscus.

Figures 3A and 3B show adenovirus transduction of goat primary chondrocytes isolated from auricular cartilage. Figure 3A shows the efficiency of adenoviral (Ad) transduction with significant number of positively stained cells expressing beta-galactosidase. Figure 3B is a Western gel demonstrating significant NELL1 protein expression in the AdNELL1 transduced goat chondrocytes (relative to beta-actin controls) and no NELL1 protein expression in Ad BMP2 or AdLacZ (control) transduced goat chondrocytes.

Figures 4A and 4B show gross appearance of AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 4 weeks after implantation/injection into nude mice. NELL1 transduced samples were significantly larger than control by both inspection (Figure4A) and weight (Figure4B). In addition, NELL1 transduced samples did not demonstrate the discoloration present in the BMP2 transduced samples.

Figures 5A-C show micro computed tomography (CT) examination of the samples shown in Figure 4. Figure 5A demonstrates undesirable mineralization (red coloring) in the AdBMP2 transduced specimens but not AdNELL1 or AdLacZ specimens. Figure 5B demonstrates that NELL1 induces significantly more cartilage mass than AdLacZ controls.

Figure 5C demonstrates that AdBMP2 significantly increased density (another indicator of mineralization) in the specimens.

Figure 6 shows histologic appearance of AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 2 weeks after implantation/injection into nude mice. Hematoxylin and eosin (H&E) staining (1st row) shows evidence of increased cartilage formation in the AdNELL1 and AdBMP2 transduced specimens relative to AdLacZ controls. Alcian blue staining which stains cartilage (2nd row) also demonstrates increased cartilage formation in the AdNELL1 and AdBMP2 transduced specimens relative to AdLacZ controls. Type X collagen (ColX) immunostaining which stains more mature cartilage cells (3rd row) demonstrates increased staining in the AdNELL1 and AdBMP2 transduced specimens.

Figure 7 shows histologic appearance of AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 4 weeks after implantation/injection into nude mice. H&E staining (1st row) shows significant cartilage formation in the AdNELL transduced samples with no evidence of bone formation, while AdBMP2 samples show significant bone formation. A small amount of cartilage formation is seen the AdLacZ controls. Alcian blue staining (2nd row) also demonstrates significant cartilage formation in the AdNELL transduced samples with no evidence of bone formation, while AdBMP2 samples show significant bone formation and minimal cartilage formation. A small amount of immature cartilage formation is seen the AdLacZ controls.

Figure 8 shows immunostaining for bone marker Cbfa1/Runx2 and cartilage markers ColX and tenascin in AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 4 weeks after implantation/injection into nude mice. Tenascin is intimately associated with the development of articular cartilage and other permanent cartilages whereas absence or reduced amounts of this matrix protein characterize transient cartilages which undergo maturation and are replaced by bone (Pacifici, M., M. Iwamoto, et al. Tenascin is associated with articular cartilage development. Dev Dyn 198(2): 123-34, 1993). Cbfa1/Runx2 is minimally expressed in cartilaginous AdNELL1 or control AdLacZ transduced samples and moderately expressed in bony AdBMP2 transduced samples (1st row). ColX is highly expressed and localized largely to cells in cartilaginous AdNELL1 samples without evidence of bone formation, while ColX is largely associated with the extracelluar matrix rather than cells in the AdBMP2 treated samples (2nd row). Tenascin is highly expressed in AdNELL1 samples and minimally present in AdBMP2 and control AdLacZ samples (3^{rd} row).

Figure 9 shows immunostaining for endochondral ossification associated angiogenic growth factor, vascular endothelial growth factor (VEGF), and bone marker osteocalcin (OCN) in AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 4 weeks after implantation/injection into nude mice. Both VEGF and OCN are not expressed in cartilaginous AdNELL1 or control AdLacZ transduced samples and moderately expressed in bony AdBMP2 transduced samples.

Figure 10 shows the histology of long bone cartilage in NELL-1 over expression mice. NELL1 is expressed throughout the tibia during endochondral bone formation including both articular cartilage region (Upper panel) and also the long bone formation region (lower panel). Upper panel demonstrates that NELL1 can modulate and increase cartilage differentiation in the articular cartilage region. Accordingly, these data show that increased NELL peptide activity directly (e.g., through addition of NELL peptides or increased NELL peptide expression) or indirectly (e.g., through addition of NELL peptide enhancers and/or NELL peptide receptor agonists and/or activators) promotes cartilage formation. In the lower panel, in the long bone shaft region where bone formation originated, increased NELL1 causes cartilage formation and then hypertrophy and increased bone formation through endochondral ossification.

DETAILED DESCRIPTION

The present invention is related to agents and methods for inducing cartilage formation or repair using a NELL peptide or related agent (collectively referred as "agent"). The composition can include a NELL peptide, a Nell-like molecule, and optionally at least one other active agent, cells, and biocompatible material implanted for the purpose of articular cartilage repair.

In some embodiments, the present invention provides a composition that contains an effective amount of at least one agent for either directly or indirectly promoting the generation of cartilage for treating, preventing or ameliorating a cartilage related medical condition. One of the agents for direct promotion of cartilage generation can be NELL peptides applied to chondrogenic cells such as, but not limited to, chondroblasts, chondrocytes, or chondroprogenitor cells, stem cells, bone marrow cells, a bone marrow stromal cells, a fibroblast, or adipose derived cells. The agent for indirect promotion of cartilage generation (e.g., through inducing chondroblast/chondrocyte differentiation) can be, e.g., one of NELL peptide, or agonists of NELL peptide receptors.

In some embodiments, the present invention includes a systemic or local application of the composition described herein to a mammalian subject (e.g., a human being) to promote cartilage formation or regeneration.

In some embodiments, the composition can include, e.g., one or more inhibitors or antagonists of NELL peptide receptors, high dose NELL peptides, or combinations thereof. Such a composition is effective for inhibition of chondrogenic differentiation by inhibiting potential or committed chondrogenic cells such as, but not limited to, osteoblasts, osteoprogenitor cells, stem cells, bone marrow cells, fibroblastic cells, dural cells, periosteal cells, pericytes, and/or muscle cells.

The effectiveness of the present invention for cartilage formation or regeneration are shown in Figures 1-10.

Figure 1 shows increased cartilage maturation and hypertrophy in femoral head cartilage of NELL1 overexpression mice compared with wild type littermate. On the left is wild type newborn femoral head cartilage demonstrating small, less mature chondrocytes in the femoral head. On the right is the NELL1 over-expression transgenic mice demonstrating well differentiated, more mature, hypertrophic chondrocytes present throughout the femoral head with large nuclei and vacuoles present. Note the absence of mineralization in the hypertrophied cartilage. These studies demonstrate that NELL1 increases chondrocyte maturation, hypertrophy without necessarily inducing mineralization.

Figures 2A-2F show increased meniscus development in E18 NELL1 overexpression mice compared with wild type littermate. Figures 2A and 2B with arrows pointing at the meniscus between the femoral and tibial cartilage head in wild type (Figure2A) and NELL1 overexpression (Figure 2B) animals. Figures 2C and 2D are higher magnification views of Figures 2A and 2B. Figure 2E is a higher magnification of the wild type control shown in 2C demonstrating less differentiated chondrocytes with minimal hypertrophy. Figure 2F is a higher magnification of the NELL1 overexpression animal shown in 2D demonstrating significantly more differentiated chondrocyte in the cartilage matrix. Vacuoles in the hypertrophic chondrocytes are observed indicating well differentiation of chondrocyte in the meniscus. This data indicates that Nell-1 can promote meniscus formation and differentiation.

Figures 3A and 3B show adenovirus transduction of goat primary chondrocytes isolated from auricular cartilage. Figure 3A shows the efficiency of adenoviral (Ad) transduction with significant number of positively stained cells expressing beta-galactosidase. Figure 3B is a Western gel demonstrating significant NELL1 protein expression in the AdNELL1 transduced goat chondrocytes (relative to beta-actin controls) and no NELL1 protein expression in Ad BMP2 or AdLacZ (control) transduced goat chondrocytes. These studies demonstrate that there is efficient adenoviral transduction and that AdNELL1, but not AdBMP2, increases NELL1 protein expression.

Figures 4A and 4B show gross appearance of AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 4 weeks after implantation/injection into nude mice. NELL1 transduced samples were significantly larger than control by both inspection (Figure4A) and weight (Figure4B). In addition, NELL1 transduced samples did not demonstrate the discoloration present in the BMP2 transduced samples. These studies unexpectedly demonstrate that although BMP2 induces a larger tissue mass, the appearance of the induced mass is not consistent with a purely cartilaginous phenotype.

Figures 5A-C show micro computed tomography (CT) examination of the samples shown in Figure 4. Figure 5A demonstrates undesirable mineralization (red coloring) in the AdBMP2 transduced specimens but not AdNELL1 or AdLacZ specimens. Figure 5B demonstrates that NELL1 induces significantly more cartilage mass than AdLacZ controls. Figure 5C demonstrates that AdBMP2 significantly increased density (another indicator of mineralization) in the specimens. These studies quantitatively demonstrate that although BMP2 induces a larger tissue mass, the induced mass is largely mineralized and is not consistent with a purely cartilaginous phenotype.

Figure 6 shows histologic appearance of AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 2 weeks after implantation/injection into nude mice. Hematoxylin and eosin (H&E) staining (1st row) shows evidence of increased cartilage formation in the AdNELL1 and AdBMP2 transduced specimens relative to AdLacZ controls. Alcian blue staining which stains cartilage (2nd row) also demonstrates increased cartilage formation in the AdNELL1 and AdBMP2 transduced specimens relative to AdLacZ controls. Type X collagen (ColX) immunostaining which stains more mature cartilage cells (3rd row) demonstrates increased staining in the AdNELL1 and AdBMP2 transduced specimens. Collectively, these data indicate that both AdNELL1 and AdBMP2 induce comparable cartilage formation and maturation at 2 weeks.

Figure 7 shows histologic appearance of AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 4 weeks after implantation/injection into nude mice. H&E staining (1st row) shows significant cartilage formation in the AdNELL transduced samples with no evidence of bone formation, while AdBMP2 samples show significant bone formation. A small amount of cartilage formation is seen the AdLacZ controls. Alcian blue staining (2nd row) also demonstrates significant cartilage formation in the AdNELL transduced samples with no evidence of bone formation, while AdBMP2 samples show significant bone formation and minimal cartilage formation. A small amount of immature cartilage formation is seen the AdLacZ controls. Collectively, these data indicate that by 4 weeks, AdNELL1 can continue to induce and maintain a cartilaginous phenotype, while AdBMP2 goes on to form bone and is unable to maintain a cartilaginous phenotype in chondrogenic cells.

Figure 8 shows immunostaining for bone marker Cbfa1/Runx2 and cartilage markers ColX and tenascin in AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 4 weeks after implantation/injection into nude mice. Tenascin is intimately associated with the development of articular cartilage and other permanent cartilages whereas absence or reduced amounts of this matrix protein characterize transient cartilages which undergo maturation and are replaced by bone (Pacifici, M., M. Iwamoto, et al. Tenascin is associated with articular cartilage development. Dev Dyn 198(2): 123-34, 1993). Cbfa1/Runx2 is minimally expressed in cartilaginous AdNELL1 or control AdLacZ transduced samples and moderately expressed in bony AdBMP2 transduced samples (1st row). ColX is highly expressed and localized largely to cells in cartilaginous AdNELL1 samples without evidence of bone formation, while ColX is largely associated with the extracelluar matrix rather than cells in the AdBMP2 treated samples (2nd row). Tenascin is highly expressed in AdNELL1 samples and minimally present in AdBMP2 and control AdLacZ samples (3rd row). These studies show NELL1 is able to induce molecules (e.g., tenascin) associated with development of articular cartilage and other permanent cartilages.

Figure 9 shows immunostaining for endochondral ossification associated angiogenic growth factor, vascular endothelial growth factor (VEGF), and bone marker osteocalcin (OCN) in AdNELL1, AdBMP2, or AdLacZ (control) transduced goat primary chondrocytes 4 weeks after implantation/injection into nude mice. Both VEGF and OCN are not expressed in cartilaginous AdNELL1 or control AdLacZ transduced samples and moderately expressed in bony AdBMP2 transduced samples. These data show that

NELL1 does not promote angiogenesis and that NELL1 may inhibit angiogenesis in cartilaginous samples.

Figure 10 shows the histology of long bone cartilage in NELL-1 over expression mice. NELL1 is expressed throughout the tibia during endochondral bone formation including both articular cartilage region (Upper panel) and also the long bone formation region (lower panel). Upper panel demonstrates that NELL1 can modulate and increase cartilage differentiation in the articular cartilage region. Accordingly, these data show that increased NELL peptide activity directly (e.g., through addition of NELL peptides or increased NELL peptide expression) or indirectly (e.g., through addition of NELL peptide enhancers and/or NELL peptide receptor agonists and/or activators) promotes cartilage formation. In the lower panel, in the long bone shaft region where bone formation originated, increased NELL1 causes cartilage formation and then hypertrophy and increased bone formation through endochondral ossification. Accordingly, these data show that increased NELL peptide activity directly or indirectly promotes cartilage formation, cartilage hypertrophy and endochondral ossification. The absence of NELL1 associates with less differentiated articular chondroblast/chondrocyte phenotype and less hypertrophy which is important to prevent articular cartilage replaced by bone. Accordingly, the inhibition of NELL peptide activity directly (through decreased NELL peptide expression or use of NELL peptide inhibitors) or indirectly (through NELL peptide receptor antagonists and/or inhibitors) can prevent cartilage hypertrophy and endochondral ossification and promote maintenance of a less differentiated or hypertrophied cartilage phenotype. Overall, these data are not intended to be limiting, but rather to show that NELL has broad effects on osteochondroprogenitor cell types and that the exact phenotype induced by NELL depends on a complex interplay between the amount and timing of NELL application, the exact cell type, cell differentiation state, and the microenvironment.

Definitions

The term “cartilage” is understood to encompass hyaline, elastic and fibrocartilage and can refer to any cartilaginous component of a mammal. For instance, spinal disc and knee meniscus are fibrocartilaginous structures that are included in the definition of cartilage.

The terms “polypeptide”, “peptide” and “protein” can be used interchangeably herein to refer to a polymer of amino acid residues. The terms can apply to amino acid polymers in which one or more amino acid residue is an artificial chemical analogue of a corresponding naturally occurring amino acid, as well as to naturally occurring amino acid polymers.

The term “NELL” refers to “NELL1 and NELL2 peptide. A NELL1 peptide is a protein which can be expressed by the NELL1 gene or cDNA and includes SEQ ID NO: 2, 4, and 6. The NELL1 peptide can include a NELL1 peptide fragment that retains the ability to induce chondrogenic cell differentiation for cartilage formation. A NELL2 peptide is a protein which can be expressed by the NELL2 gene or cDNA and includes SEQ ID NO: 8, 10, 12 and 14. The NELL2 peptide can include NELL2 peptide fragments that retain similar activity to the full NELL2 peptide sequence. Nell-1, Nell-2, etc. intact proteins, completely or partially glycosylated, fragments, deletions, additions, amino acid substitutes, mutations and modifications that retain the biological characteristics of the naturally occurring agents. Small molecules containing Nell active domains and Nell binding sites.

In some embodiments, the term “NELL peptide” can include a fragment of a NELL1 or NELL2 related polypeptide.

In some embodiments, the term “NELL peptide” can include a NELL related agent. For example, a NELL peptide related agent can include any polypeptide with significant homology to a NELL peptide or a fragment thereof. Significant homology can be a homology of higher than about 50% homology to a NELL peptide, e.g., higher than about 60% homology to a NELL peptide, higher than about 70% homology to a NELL peptide, or higher than about 80% homology to a NELL peptide.

The NELL peptides can be natural and/or recombinant NELL peptides with a non-mutated wild-type sequence or recombinant NELL peptides with a mutated wild-type sequence that still contains significant homology to NELL peptides. In addition, NELL peptides can be derived from, but not limited to, an organism such as human cells, bacteria, yeast, or insect or plant cells. In some embodiments, the term “NELL peptide” includes structural, functional or conformational equivalents of NELL peptide. As used herein, a structural equivalent of a NELL peptide refers to a protein or peptide including a structure equivalent or substantially similar to that of a NELL peptide or of a functional domain of a NELL peptide. A functional equivalent of a NELL peptide refers to a protein or peptide having a function equivalent or substantially similar to that of a NELL peptide or of a functional domain of a NELL peptide. A conformational equivalent of a NELL peptide refers to a protein or peptide having a conformation equivalent or substantially similar to that of a NELL peptide or of a functional domain of a NELL peptide.

In some embodiments, the NELL peptide described herein can be a derivative of the NELL peptide. The term "derivative" as used herein, refers to any chemical or biological compounds or materials derived from a NELL peptide, structural equivalents thereof, or conformational equivalents thereof. For example, such a derivative can include any pro-drug form, PEGylated form, or any other form of a NELL peptide that renders the NELL peptide more stable or to have a better osteo philicity or lipophilicity. In some embodiments, the derivative can be a NELL peptide attached to poly(ethylene glycol), a poly(amino acid), a hydrocarbyl short chain having C1-C20 carbons, or a biocompatible polymer. In some embodiments, the term "derivative" can include a NELL peptide mimetics. Synthesis of mimetics of a peptide is well document in the art. The following describes an example of the basic procedure for the synthesis of a peptide, including a peptide mimetics:

Before the peptide synthesis starts, the amine terminus of the amino acid (starting material) can protected with FMOC (9-fluoromethyl carbamate) or other protective groups, and a solid support such as a Merrifield resin (free amines) is used as an initiator. Then, step (1) through step (3) reactions are performed and repeated until the desired peptide is obtained: (1) a free-amine is reacted with carboxyl terminus using carbodiimide chemistry, (2) the amino acid sequence is purified, and (3) the protecting group, e.g., the FMOC protecting group, is removed under mildly acidic conditions to yield a free amine. The peptide can then be cleaved from the resin to yield a free standing peptide or peptide mimetics.

In some embodiments, the peptide derivative described herein includes a physically or chemically modified NELL peptide. Physically modified peptide can be modification by, for example, modification by ionic force such as forming an ionic pair with a counterion, modification by hydrogen bonding, modification by modulation of pH, modulation by solvent selection, or modification by using different protein folding/unfolding procedures, which can involve selection of folding/unfolding temperature, pH, solvent, and duration at different stage of folding/unfolding.

In some embodiments, the peptide derivative can include a chemically modified NELL peptide. For example, a short hydrocarbon group(s) (e.g. methyl or ethyl) can be selectively attached to one or multiple sites on the NELL peptide molecule to modify the chemical and/or physical properties of the peptide. In some embodiments, a mono-, oligo- or poly(ethylene glycol) (PEG) group(s) can be selectively attached to one or multiple sites on the NELL peptide molecule to modify the chemical and/or physical properties of the peptide by commonly known protein PEGylation procedures (see, e.g., Mok, H., et al., Mol. Ther., 11(1):66-79 (2005)).

The terms "NELL1 cDNA" can refer to SEQ ID NO:1, 3 and 5, and "NELL2 cDNA" can refer to SEQ ID NO:7, 9, 11 and 13.

The term "antibody" refers to any antibody that specifically binds to a NELL peptide or a related agent. The term can include various forms of modified or altered antibodies, such as an intact immunoglobulin, an Fv fragment containing only the light and heavy chain variable regions, an Fv fragment linked by a disulfide bond, a Fab or (Fab)'2 fragment containing the variable regions and parts of the constant regions, a single-chain antibody and the like. An antibody can include intact molecules as well as fragments thereof, such as, Fab and F(ab')$^{2'}$, and/or single-chain antibodies (e.g. scFv) which can bind an epitopic determinant. An antibody can be of animal (such as mouse or rat) or human origin or can be chimeric or humanized. Antibodies can be polyclonal or monoclonal antibodies ("mAb's"), such as monoclonal antibodies with specificity for a polypeptide encoded by a NELL1 or NELL 2 protein.

The term "capture agent" can refer to molecules that specifically bind other molecules to form a binding complex such as antibody-antigen, lectin-carbohydrate, nucleic acid-nucleic acid, biotin-avidin, and the like.

The term "specifically binds" can refer to a biomolecule (e.g., protein, nucleic acid, antibody, etc.), refers to a binding reaction which is determinative of the presence biomolecule in heterogeneous population of molecules (e.g., proteins and other biologics). Thus, under designated conditions (e.g. immunoassay conditions in the case of an antibody or stringent hybridization conditions in the case of a nucleic acid), the specified ligand or antibody can bind to its particular "target" molecule and can not bind in a significant amount to other molecules present in the sample.

The terms "nucleic acid" or "oligonucleotide" can refer to at least two nucleotides covalently linked together. A nucleic acid of the present invention can be single-stranded or double stranded and can contain phosphodiester bonds, although in some cases, nucleic acid analogs can be included that can have alternate backbones, comprising, for example, phosphoramide, phosphorothioate, phosphorodithioate, omethylphophoroamidite linkages, and/or peptide nucleic acid backbones and linkages. Analog nucleic acids can have positive backbones and/or non-ribose backbones. Nucleic acids can also include one or more carbocyclic sugars. Modifications of the ribose-phosphate backbone can be done to facilitate the addition of additional moieties such as labels, or to increase the stability and half-life of such molecules in physiological environments, for example.

The term “specific hybridization” can refer to the binding, duplexing, or hybridizing of a nucleic acid molecule preferentially to a particular nucleotide sequence under stringent conditions, including conditions under which a probe can hybridize preferentially to its target subsequence, and can hybridize to a lesser extent to other sequences.

The term “inhibitor of NELL peptides” refers to a chemical or biological compound capable of inhibiting the activity of NELL peptides. The term also includes a chemical or biological compound capable of suppressing the expression of NELL peptides. Inhibitors of NELL peptides can interact directly or indirectly with NELL peptide transcripts or translational products. As examples, methods of interactions can include but are not limited to decreased transcription or translation of NELL peptides, decreased stability of NELL peptide transcripts or protein products, decreased activity of NELL peptide transcripts or protein products, and increased degradation of NELL peptide transcript or protein products. The term “enhancer of NELL peptides” refers to a chemical or biological compound capable of enhancing the activity of NELL peptides. The term also includes a chemical or biological compound capable of enhancing the expression of NELL peptides. As examples, methods of interactions can include but are not limited to increased transcription or translation of NELL peptides, increased stability of NELL peptide transcripts or protein products, increased activity of NELL peptide transcripts or protein products, and decreased degradation of NELL peptide transcript or protein products.

The term “modulator of NELL peptide receptors” refers to a chemical or biological compound capable of facilitating or inhibiting the binding of NELL peptide receptors to or by NELL peptides or to a chemical or biological compound capable of modulating NELL peptide receptor activity irrespective of the presence or the absence of NELL peptide. The modulator that facilitates the binding and/or activation of NELL peptide receptors to or by NELL peptides is referred to as an “agonist” of the receptor, and the modulator that inhibits the binding and/or activation of NELL peptide receptors to or by NELL peptides is referred to as an "antagonist" of the receptor. The modulator that facilitates the activation of NELL peptide receptors irrespective of NELL peptides is referred to as an "activator" of the receptor, and the modulator that inhibits activation of NELL peptide receptors irrespective of NELL peptides is referred to as an "inhibitor" of the receptor.

The term "NELL peptide," "NELL related agent," "inhibitor of NELL peptide" or "modulator of NELL peptide receptor(s)" can also be referred to as an "agent" throughout the specification.

The term "delivery vehicle" refers to any delivery vehicle used in the art of biochemistry. Some examples of common delivery vehicle are a naked DNA type vehicle, an RNA type vehicle, a virus type vehicle. Some further examples are e.g., a polymer or a peptide, sustained release carriers, synthetic scaffolds, natural scaffolds, allograft or xenograft scaffolds.

The term "mammalian subject" or "mammal" refers to any mammals, examples of which include human beings and animals such as horse.

Cartilage Formation

Cartilage formation generally proceeds via chondrification process. Chondrification is the process in which cartilage is formed from condensed mesenchyme tissue, which differentiates into chondrocytes and begins secreting the materials that form the matrix. Cartilage can undergo mineralization. Adult hyaline articular cartilage, for example, is progressively mineralized at the junction between cartilage and bone. A mineralization front advances through the base of the hyaline articular cartilage at a rate dependent on cartilage load and shear stress. Intermittent variations in the rate of advance and mineral deposition density of the mineralizing front lead to multiple tidemarks in the articular calcified cartilage.

Adult articular calcified cartilage is penetrated by vascular buds, and new bone produced in the vascular space in a process similar to endochondral ossification at the physis. A cement line demarcates articular calcified cartilage from subchondral bone. Two types of growth can occur in cartilage: appositional and interstitial. Appositional growth results in the increase of the diameter or thickness of the cartilage. The new cells derive from the perichondrium and occur on the surface of the cartilage model. Interstitial growth results in an increase of cartilage mass and occurs from within. Chondrocytes undergo mitosis within their lacuna but remain imprisoned in the matrix, which results in clusters of cells called isogenous groups.

Cartilage can also be formed via endochondral ossification. The mammalian skeleton develops through both endochondral and intramembranous bone formation processes. Embryologically, During skeletal development, the establishment of a layer of cartilage at the ends of certain bones is intimately linked to the process of endochondral ossification. The cartilaginous portion of endochondral bone formation involves chondroblast/chondrocyte differentiation, maturation, hypertrophy with or without mineralization depending on the location of the cartilage. Non-mineralizing cartilage formation includes but is not limited to formation of articular cartilage, temporomandibular joint, wrist, knee, and intervertebral disc fibrocartilages.

Endochondral ossification or long bone formation is related to bone formation, which permits functional stresses to be sustained during skeletal growth and is well demonstrated in the development of the long bones. In this process, a small model of the long bone is first formed in solid hyaline cartilage which undergoes mainly appositional growth to form an elongated, dumb-bell shaped mass of cartilage consisting of a shaft (diaphysis) and future articular portions (epiphysis) surrounded by perichondrium (see, e.g., Wheater, P. R. and H. G. Burkitt (1987). Functional histology : a text and colour atlas. Edinburgh ; New York, Churchill Livingstone; Beaupre, G. S., S. S. Stevens, et al., J Rehabil Res Dev 37(2): 145-51) (2000)).

Within the shaft of the cartilage model then chondrocytes enlarge greatly, resorbing the surrounding cartilage so as to leave only slender perforated trabeculae of cartilage ,matrix. This cartilage matrix then calcifies and the chondrocytes degenerate leaving large, interconnecting spaces. During this period the perichondrium of the shaft develops chondrogenic potential and assumes the role of periosteum. The periosteum then lays down a thin layer of bone around the surface of the shaft and primitive mesenchymal cells and blood vessels invade the spaces left within the shaft after degeneration of the chondrocytes. The primitive mesenchymal cells differentiate into osteoblasts and blood-forming cells on the surface of the calcified remnants of the cartilage matrix and commence the formation of irregular, woven bone (Wheater and Burkitt, 1987, *supra*). In the cartilage model described in Wheater and Burkitt, 1987, *supra*, the ends of the original cartilage model have then become separated by a large site of primary ossification in the shaft. The cartilaginous ends of the model, however, continue to grow in diameter. Meanwhile, the cartilage at the ends of the shaft continues to undergo regressive changes followed by ossification so that the developing bone now consists of an elongated, bony diaphyseal shaft with a semilunar cartilage epiphysis at each end. The interface between the shaft and each epiphysis constitutes a growth or epiphyseal plate. Within the growth plate, the cartilage proliferates continuously, resulting in progressive elongation of the bone. At the diaphyseal aspect of each growth plate, the chondrocytes mature and then die, the degenerating zone of cartilage being replaced by bone. Thus the bony diaphysis lengthens and the growth plates are pushed further and further apart. On reaching maturity, hormonal changes inhibit further cartilage proliferation and the growth plates are replaced by bone causing fusion of the diaphysis and epiphysis (Wheater and Burkitt, 1987, *supra*). In the meantime, in the center of the mass of cartilage of each developing epiphysis, regressive changes and bone formation similar to that in the diaphyseal cartilage occur along with appositional growth of cartilage over the whole external surface of the epiphysis. This conversion of central epiphyseal cartilage to bone is known as secondary ossification. A thin zone of hyaline cartilage always remains at the surface as the articular cartilage (Wheater and Burkitt, 1987, *supra*).

Thus, endochondral bone formation and growth is achieved in part by the proliferation and maturation of cartilage cells (chondroblasts, chondrocytes) with or without cartilage cell mineralization. Cartilage formation or regeneration can be achieved by controlling cartilage cell mineralization. Without being bound by a particular theory, cartilage cell mineralization can be controlled by controlling factors such as: a) location, b) cell type, c) cell differentiation state, d) microenvironment, and e) bioimechanical forces. For example, the mineralization of a cartilage cell can be controlled by placing the cartilage cell near an epiphyseal growth plate in which mineralization generally occurs or near an articular surface in which mineralization generally does not occur. It is known in the art that chondrocyte hypertrophy and up-regulated matrix calcification are dissociable states (see, e.g., Johnson, van Etten et al. 2003) (see, e.g., Johnson, K. A., D., et al., J Biol Chem 278(21):18824-32 (2003)). For example, the formation of endochondral bone can be evaluated by chondroblast hypertrophy as viewed by an increase in hypertrophic and apoptotic chondroblasts, elucidated by TUNEL staining. In another example, the formation of cartilage can be evaluated also by chondroblast hypertrophy without necessarily apoptosis or mineralization.

Cartilage regeneration

Cartilage contains a significant amount of water. For instance, articular cartilage is comprised of mostly water (60-80 wt%) and the remaining ECM comprises mostly type II collagen (50-90% dry mass) and proteoglycans (5-10%). Other collagens and minor ECM molecules have been identified in small quantities. It is organization of the ECM into distinct zones, and the interaction between water and the ECM in the various zones that provide the toughness that is required for the absorption and transmission of biomechanical forces across joints, and simultaneously the frictionless articulating surfaces that are needed for joint motion. Stresses as high as 4 and 20 MPa have been reported in human hip joints during routine walking and jumping, respectively! As amazing as the articular cartilage is, it exhibits unfortunately minimal capacity for repair. Over 20 million Americans suffer from osteoarthritis and degenerative joint diseases with an associated annual healthcare burden of over $60 billion. A wide array of scaffolds, cytokines, and growth factors have been investigated for cartilage tissue engineering (see, e.g., Frenkel, S.R., et al., Ann. Biomed. Eng. 32:26-34 (2004); Tuli, R., et al., Arthritis Res. Ther. 5:235-238 (2003); and Ashammakhi, N. and Reis, RL. Topics in Tissue Engineering, Vol. 2, 2005). The role of static vs. dynamic compression, shear stress, hydrostatic pressure, fluid flow, electrical streaming potentials, bioreactors, and complex loading on chondrocyte biological response and tissue remodeling have been investigated extensively and the mechanotransduction pathways reviewed Ashammakhi, N. and Reis, RL. Topics in Tissue Engineering, Vol. 2, 2005) (see Figures 7A-D therein)

Accordingly, in a further aspect of the present invention, the composition provided herein includes at least a NELL peptide or an agonist of the receptor of NELL peptides in an amount effective for inducing chondroblast and chondrocyte to form cartilage. NELL proteins, peptides, DNA, RNA, and NELL agonists, and antagonist inhibitors can be used alone or in conjunction with scaffolds with and without cells, with or without mechanical stimulation, in the presence or absence of additional growth factors. For example, in one embodiment, the composition can be effective in regenerating or repairing or augmenting cartilage in intervertebral disc, temporomandibular disc, knee and wrist fibrocartilage, and articular surfaces. In another embodiment, the composition can be effective in forming cartilage via ex vivo gene therapy and protein application to cells with or without scaffold in tissue engineering.

Depending on the delivery method and the local environment, a composition including a NELL peptide (e.g., a NELL1 peptide) can be used to induce an chondrogenic cell, as such as a chondrocyte or chondroblast, to differentiate and form cartilage only. For example, in an articular cartilage defect, the composition described herein can induce an chondrogenic cell such as chondrocyte/blast to form cartilage only. The composition can be applied to the defected cartilage area as a scaffold/carrier. In some embodiments, the composition can optionally include cells (stem cells, chondroblast etc). In some embodiments, the composition can be applied as gene therapy.

In some embodiments, as used herein, the cells can be, e.g., differentiated chondrocytes; differentiated cells (e.g. skeletal muscle cells, fibroblasts) that are de-differentiated after implantation, or prior to implantation; adult stem cells that are differentiated after implantation, or prior to implantation; embryonic stem cells that are differentiated after implantation, or prior to implantation; human; modified by nucleic acid, protein, small molecules, siRNA, antibodies.

In some yet embodiments, the composition can be used in cartilage tissue engineering. For example, when chondroblasts are cultured on an "oscillating", intermittent stress tension environment, NELL1 peptide can include the chondroblast cells to differentiate and form cartilage. In these embodiments, the duration of application of the oscillating stress also plays an important role. For example, if the oscillating force is applied continuously, the composition having a NELL1 peptide can induce endochondral bone formation. Therefore, in the application of the oscillating stress shall be intermittently such that the differentiation of an chondrogenic cell (e.g., chondrocyte/blast) can stop at the cartilage stage and thus prevent the cell from differentiating into endochondral bone formation.

Therefore, in some embodiments, the composition described herein can be used to regenerate/repair cartilage, e.g., for disc repair in articular cartilage and intervertebral disc.

Other exemplary cartilage conditions that can be treated, prevented, or ameliorated by a composition disclosed herein include, but are not limited to, chondrocalcinosis, osteoarthritis, and/or other diseases characterized by pathological cartilage degeneration.

In one embodiment, a method of increasing endochondral bone formation can include increasing the concentration of a NELL1 gene product in a region where bone formation is desired; optionally applying a second agent to the region where bone formation is desired and at least inducing hypertrophy of chondroblast in the region where bone formation is desired.

The method can include increasing the concentration of a NELL1 gene product by applying a NELL1 peptide to the location where bone formation is desired, and the NELL1 peptide can be selected from the group comprising: SEQ ID NO:2, SEQ ID NO: 4, or SEQ ID NO:6, or any portion of the NELL peptide which is effective in increasing endochondral bone formation, which involves both cartilage and bone.

The second agent can include, but is not limited to TGF-beta, BMP2, BMP4, BMP7, bFGF , insulin like growth factor (IGF), Sox9, collagen, chondrogenic cells, bone, bone matrix, tendon matrix, ligament matrix. The second agent can be selected to have a complimentary or synergistic effect with NELL1 in inducing endochondral bone formation. Other agents are described below.

Inhibition of angiogenesis and cartilage formation/regeneration

As specified in Shukunami et al., cartilage forms a template for most of the bony skeleton in embryonic development (Shukunami, C., Y. Oshima, et al., Biochem Biophys Res Commun 333(2): 299-307) (2005)). Cartilage is not directly converted to bone but is gradually replaced through the actions of osteoclasts and osteoblasts, which are brought to the ossification center of cartilage with vascular invasion (endochondral bone formation). Thus, the vascular invasion of cartilage can be crucial for bone formation at an appropriate stage of development. Cartilage acquires an anti-angiogenic nature upon chondrogenesis and quickly loses it, as chondrocytes mature to become hypertrophic and calcified prior to vascular invasion, suggesting that cartilage undergoes a dynamic switching of the anti-angiogenic phenotype. Undoubtedly pro-angiogenic factors act as a driving force for vascular invasion into tissues. VEGF-A is a key regulator of angiogenesis during endochondral bone formation: VEGF-A is expressed in hypertrophic cartilage, but not in resting or proliferating cartilage.

Matrix metalloproteinases (MMPs) can influence bone development, which involves matrix-remodeling during vascular invasion (e.g., MMP-9, MMP-13, MMP-14). In mice lacking MMP-9, vascular invasion and subsequent ossification were delayed, causing progressive lengthening of the growth plate. The delay in ossification appeared to be secondary to a diminished vascular invasion of cartilage probably because MMP-9-deficient hypertrophic cartilage fails to release normal levels of pro-angiogenic activity to stimulate vessel formation and to recruit osteo/chondroclasts. Targeted inactivation of MMP-14 (membrane type 1 MMP: MT1-MMP) causes severe defects in both endochondral and intramembranous bone formation in mice. These results indicate that MMPs play a regulatory role in angiogenic switching of the cartilage phenotype. Thus, an important part of cartilage formation and regeneration can involve differential regulation of pro-angiogenic factors such as MMP-9, MMP-13, MMP-14, and VEGF and anti-angiogenic factors such as chondromodulin-I (ChM-I), thrombospondin (TSP)-1, TSP-2, tissue inhibitor of metalloproteinase (TIMP)-2, TIMP-3. Specifically, pro-angiogenic factors can be relatively more prominent in areas of cartilage undergoing ossification, and anti-angiogenic factors may be relatively more prominent in areas of cartilage not undergoing ossification. These results also indicate that the transcription factor Cbfa1/Runx2 can be involved in the control of angiogenic switching in cartilage: Cbfa1/ Runx2 null mice are defective in hypertrophic cartilage differentiation, vascular invasion of cartilage rudiments, and VEGF expression, and exhibit a sustained expression of the ChM-I gene. In Cbfa1/Runx2 null mice expressing the Cbfa1/Runx2 transgene in non hypertrophic chondrocytes, vascular invasion, and cartilage remodeling was restored with the upregulation of VEGF and concomitant downregulation of ChM-I gene expression.

Without being bound by a particular theory, NELL1 can have a role in the angiogenic switching in cartilage, since NELL1 is a direct downstream effector of Cbfa1/Runx2 effects. In addition without being bound by a particular theory, NELL1's role in cartilage formation can also relate to potential anti-angiogenic effects of NELL1--as NELL1 also contains a NH_2-terminal thrombospondin-like module.

Other agents

In one embodiment, the composition for cartilage formation and regeneration described herein can include one or more other agents. Such agents can be chondroprotective agents, anti-pain and/or anti-inflammatory agents, growth factors, anti-angiogenic agents, or combinations thereof.

The chondroprotective agents can be, for example, (1) antagonists of receptors for the interleukin-1 family of proteins, including, for example, IL-1.beta., IL-17 and IL-18; (2) antagonists of the tumor necrosis factor (TNF) receptor family, including, for example, TNF-R1; (3) agonists for interleukin 4, 10 and 13 receptors; (4) agonists for the TGF-.beta. receptor superfamily, including, for example, BMP-2, BMP-4 and BMP-7; (5) inhibitors of COX-2; (6) inhibitors of the MAP kinase family, including, for example, p38 MAP kinase; (7) inhibitors of the matrix metalloproteinases (MMP) family of proteins, including, for example, MMP-3 and MMP-9; (8) inhibitors of the NF-.kappa.B family of proteins, including, for example, the p50/p65 dimer complex with I.kappa.B; (9) inhibitors of the nitric oxide synthase (NOS) family, including, for example, iNOS; (10) agonists and antagonists of integrin receptors, including, for example, agonists of $\alpha_V\beta_3$ integrin; (11) inhibitors of the protein kinase C (PKC) family; (12) inhibitors of the protein tyrosine kinase family, including, for example, the src subfamily; (13) modulators of protein tyrosine phosphatases; and (14) inhibitors of protein src homology 2 (SH2) domains. Additional chondroprotective agents include other growth factors, such as by way of example insulin-like growth factors (e.g., IGF-1) and fibroblast growth factors (e.g., bFGF). Other chondroprotective agents are described in USPN 7,067,144, the teachings of which are incorporated herein by reference. These chondroprotective agents can be used alone or in combination along with a NELL peptide or related agent. In some embodiments, the composition described herein can specifically exclude any of the above described chondroprotective agents.

The anti-pain and/or anti-inflammatory agents can be, e.g., (1) serotonin receptor antagonists; (2) serotonin receptor agonists; (3) histamine receptor antagonists; (4) bradykinin receptor antagonists; (5) kallikrein inhibitors; (6) tachykinin receptor antagonists, including neurokinin.sub.1 and neurokinin.sub.2 receptor subtype antagonists; (7) calcitonin gene-related peptide (CGRP) receptor antagonists; (8) interleukin receptor antagonists; (9) inhibitors of enzymes active in the synthetic pathway for arachidonic acid metabolites, including (a) phospholipase inhibitors, including PLA.sub.2 isoform inhibitors and PLC isoform inhibitors, (b) cyclooxygenase inhibitors, and (c) lipooxygenase inhibitors; (10) prostanoid receptor antagonists including eicosanoid EP-1 and EP-4 receptor subtype antagonists and thromboxane receptor subtype antagonists; (11) leukotriene receptor antagonists including leukotriene B.sub.4 receptor subtype antagonists and leukotriene D.sub.4 receptor subtype antagonists; (12) opioid receptor agonists, including μ-opioid, δ-opioid, and .kappa.-opioid receptor subtype agonists; (13) purinoceptor antagonists including P_2X receptor antagonists and P_2Y receptor antagonists; and (14) calcium channel antagonists. Each of the above agents functions either as an anti-inflammatory agent and/or as an anti-nociceptive (i.e., anti-pain or analgesic) agent. The selection of agents from these classes of compounds is tailored for the particular application. These anti-pain and/or anti-inflammatory agents can be used alone or in combination along with a NELL peptide or related agent. In some embodiments, the composition described herein can specifically exclude any of the above described anti-pain and/or anti-inflammatory agents.

The growth factors can be, e.g., FGF-2, FGF-5, IGF-1, TGF-.beta., BMP-2, BMP-7, PDGF, VEGF, OP1, OP2, OP3, BMP2, BMP3, BMP4, BMP5, BMP6, BMP9, BMP10, BMP11, BMP12, BNP15, BMP16, DPP, Vgl, 60A protein, GDF-1, GDF3, GDF5, GDF6, GDF7, GDF8, GDF9, GDF10 and GDF11. Some other growth factors are described in U.S. Patent Nos. 7,067,123, and 7,041,641, the teachings of which are incorporated herein by reference. These growth factors can be used alone or in combination along with a NELL peptide or related agent. In some embodiments, the composition described herein can specifically exclude any of the above described growth factors.

The anti-angiogenic agents can be, e.g., anti-angiogenic factors, including for example Anti-Invasive Factor, retinoic acids and their derivatives, paclitaxel including analogues and derivatives thereof, Suramin, Tissue Inhibitor of Metalloproteinase-1, Tissue Inhibitor of Metalloproteinase-2, Plasminogen Activator Inhibitor-1 and Plasminogen Activator Inhibitor-2, and lighter "d group" transition metals. Similarly, a wide variety of polymeric carriers may be utilized, representative examples of which include poly(ethylene-vinyl acetate) (40% cross-linked), poly(D,L-lactic acid) oligomers and polymers, poly(L-lactic acid) oligomers and polymers, poly(glycolic acid), copolymers of lactic acid and glycolic acid, poly(caprolactone), poly(valerolactone), poly(anhydrides), copolymers of poly(caprolactone) or poly(lactic acid) with polyethylene glycol, and blends thereof. Within certain preferred embodiments, the compositions comprise a compound which disrupts microtubule function, such as, for example, paclitaxel, estramustine, colchicine, methotrexate, curacin-A, epothilone, vinblastine or tBCEV. Within other preferred embodiments, the compositions comprise a polymeric carrier and a lighter d group transition metal (e.g., a vanadium species, molybdenum species, tungsten species, titanium species, niobium species or tantalum species) which inhibits the formation of new blood vessels (as specified in USP 20060240113), inhibitors of VEGF (as specified in USP 20060241084), other inhibitors of angiogenesis (as specified in USP 20060235034, 7,122,635), chondromodulin-I or tenomodulin (Shukunami, et al., 2005, supra), or other endogenous or exogenous anti-angiogenic factors well known to those in the art.

Formulations

The composition described herein can be formulated into any desired formulation. The composition can include materials and carriers to effect a desired formulation. For example, the composition can include an injectable or moldable material that can set within a pre-defined period of placement. Such a pre-defined period can be, e.g., 10 minutes, 30 minutes, one hour, two hours, etc.

In some embodiments, the composition can include a chemical gel that includes primary bonds formed due to changes in pH, ionic environment, and solvent concentration. Examples of such chemical gels can be, but are not limited to, polysaccharides such as chitosan, chitosan plus ionic salts such as beta-glycerophosphates, aginates plus Ba2+, Sr 2+, Ca2+, Mg2+, collagen, fibrin, plasma or combinations thereof.

In some embodiments, the composition can include a physical gel that include secondary bonds formed due to temperature changes. Examples of such physical gels can be, but are not limited to, alginate, poly(ethylene glycol)-poly(lactic acid-co-glycolic acid)-poly(ethylene glycol) (PEG-PLGA-PEG) tri-block copolymers, agarose, and celluloses. In some embodiments, physical gels that can be used in the composition described herein can include physical gels that are liquid under high shear but gels to solid at low shear. Examples of such physical gels include, but are not limited to, hyaluronic acid, or polyethylene oxides. The physical gels can have pre-formed materials with pre-defined dimensions and shape.

In some embodiments, the composition described herein can include a material that degrade or release active agents in response to a stimulus. Some examples of such stimuli are mechanical stimuli, light, temperature changes, pH changes, change of ionic strength, or electromagnetic field. Such materials are know in the art. some examples of such materials are chitosan, alginates, pluronics, methyl cellulose, hyaluronic acids, and polyethylene oxides. . Other examples are described by Brandl F, Sommer F, Goepferich A. “Rational design of hydrogels for tissue engineering: Impact of physical factors on cell behavior “in Biomaterials. Epub 2006 Sep 29.

In some embodiments, the composition described herein can include a gel containing any of hydroxyapatites, apatites, tricalcium phostphates, calcium phosphates, bioactive glass, human allograft bone and cartilage, bovine bone and cartilage, or their mixtures thereof.

In some embodiments, the composition described herein including any of the gels described above can further include a crosslinker to further tailor degradation kinetics and controlled release. Alternatively, in some embodiments, the composition described herein can include an interpenetrating phase composite or interpenetrating network (IPN) that includes any of the above described gels. Some examples of the crosslinker includes, but are not limited to, common crosslinking agents (polyalkylene oxide, ethylene dimethacrylate, N,N'-methylenebisacrylamide, methylenebis(4-phenyl isocyanate), ethylene dimethacrylate, divinylbenzene,allyl methacrylate, carbodiimidazole, sulfonyl chloride, chlorocarbonates, n-hydroxysuccinimide ester, succinimidyl ester, epoxides, aryl halides, sulfasuccinimidyl esters, and maleimides); PEG based crosslinkers (e.g. MAL-dPEGx-NHS-esters, MAL-dPEGx acid, Bis-MAL-dPEGx, etc.) and photo/light activated crosslinkers, N-hydroxysuccinimide-based crosslinkers, dilysine, trilysine, and tetralysine.

The composition described herein can include a carrier. The carrier can be a polymeric carrier or non-polymeric carrier. In some embodiments, the carrier can be biodegradable, such as degradable by enzymatic or hydrolytic mechanisms. Examples of carriers include, but are not limited to synthetic absorbable polymers such as such as but not limited to poly(α-hydroxy acids) such as poly (L-lactide) (PLLA), poly (D, L-lactide) (PDLLA), polyglycolide (PGA), poly (lactide-co-glycolide (PLGA), poly (-caprolactone), poly (trimethylene carbonate), poly (p-dioxanone), poly (-caprolactone-co-glycolide), poly (glycolide-co-trimethylene carbonate) poly (D, L-lactide-co-trimethylene carbonate), polyarylates, polyhydroxybutyrate (PHB), polyanhydrides, poly (anhydride-co-imide), propylene-co-fumarates, polylactones, polyesters, polycarbonates, polyanionic polymers, polyanhydrides, polyester-amides, poly(amino-acids), homopolypeptides, poly(phosphazenes), poly (glaxanone), polysaccharides, and poly(orthoesters), polyglactin, polyglactic acid, polyaldonic acid, polyacrylic acids, polyalkanoates; copolymers and admixtures thereof, and any derivatives and modifications. See for example, U. S. Patent 4,563,489, and PCT Int. Appl. No. WO/03024316, herein incorporated by reference. Other examples of carriers include cellulosic polymers such as, but not limited to alkylcellulose, hydroxyalkylcellulose, methylcellulose, ethylcellulose, hydroxyethylcellulose, hydroxypropylcellulose, hydroxypropyl-methylcellulose, carboxymethylcellulose, and their cationic salts. Other examples of carriers include synthetic and natural bioceramics such as, but not limited to calcium carbonates, calcium phosphates, apatites, bioactive glass materials, and coral-derived apatites. See for example U.S. Patent Application 2002187104; PCT Int. Appl. WO/9731661; and PCT Int. Appl. WO/0071083, herein incorporated by reference.

In one embodiment, the carrier can further be coated by compositions, including bioglass and or apatites derived from sol-gel techniques, or from immersion techniques such as, but not limited to simulated body fluids with calcium and phosphate concentrations ranging from about 1.5 to 7-fold the natural serum concentration and adjusted by various means to solutions with pH range of about 2.8-7.8 at temperature from about 15-65 degrees C. See, for example, U.S. Patents 6,426,114 and 6,013,591; and PCT Int. Appl. WO/9117965 herein incorporated by reference.

Other examples of carriers include, collagen (e.g. Collastat, Helistat collagen sponges), hyaluronan, fibrin, chitosan, alginate, and gelatin. See for example, PCT Int. Appls. WO/9505846; WO/02085422, herein incorporated by reference.

In one embodiment, the carrier can include heparin-binding agents; including but not limited to heparin-like polymers e.g. dextran sulfate, chondroitin sulfate, heparin sulfate, fucan, alginate, or their derivatives; and peptide fragments with amino acid modifications to increase heparin affinity. See for example, Journal of Biological Chemistry (2003), 278(44), p. 43229-43235, herein incorporated by reference.

In one embodiment, the composition can be in the form of a liquid, solid or gel. In one embodiment, the substrate can include a carrier that is in the form of a flowable gel. The gel can be selected so as to be injectable, such as via a syringe at the site where cartilage formation is desired. The gel can be a chemical gel which can be a chemical gel formed by primary bonds, and controlled by pH, ionic groups, and/or solvent concentration. The gel can also be a physical gel which can be formed by secondary bonds and controlled by temperature and viscosity. Examples of gels include, but are not limited to, pluronics, gelatin, hyaluronan, collagen, polylactide-polyethylene glycol solutions and conjugates, chitosan, chitosan & b-glycerophosphate (BST-gel), alginates, agarose, hydroxypropyl cellulose, methyl cellulose, polyethylene oxide, polylactides/glycolides in N-methyl-2-pyrrolidone. See for example, Anatomical Record (2001), 263(4), 342-349, herein incorporated by reference.

In one embodiment, the carrier can be photopolymerizable, such as by electromagnetic radiation with wavelength of at least about 250 nm. Example of photopolymerizable polymers include polyethylene (PEG) acrylate derivatives, PEG methacrylate derivatives, propylene fumarate-co-ethylene glycol, polyvinyl alcohol derivatives, PEG-co-poly(-hydroxy acid) diacrylate macromers, and modified polysaccharides such as hyaluronic acid derivatives and dextran methacrylate. See for example, U.S. Patent 5,410,016, herein incorporated by reference.

In one embodiment, the substrate can include a carrier that is temperature sensitive. Examples include carriers made from N-isopropylacrylamide (NiPAM), or modified NiPAM with lowered lower critical solution temperature (LCST) and enhanced peptide (e.g. NELL1) binding by incorporation of ethyl methacrylate and N-acryloxysuccinimide;

or alkyl methacrylates such as butylmethacrylate, hexylmethacrylate and dodecylmethacrylate. PCT Int. Appl. WO/2001070288; U.S. Patent 5,124,151 herein incorporated by reference.

In one embodiment, where the carrier can have a surface that is decorated and/or immobilized with cell adhesion molecules, adhesion peptides, and adhesion peptide analogs which can promote cell-matrix attachment via receptor mediated mechanisms, and/or molecular moieties which can promote adhesion via non-receptor mediated mechanisms binding such as, but not limited to polycationic polyamino-acid-peptides (e.g. poly-lysine), polyanionic polyamino-acid-peptides, Mefp-class adhesive molecules and other DOPA-rich peptides (e.g. poly-lysine-DOPA), polysaccharides, and proteoglycans. See for example, PCT Int. Appl. WO/2004005421; WO/2003008376; WO/9734016, herein incorporated by reference.

In one embodiment, the carrier can include various naturally occurring matrices or their components such as devitalized cartilage matrix, demineralized bone matrix, or other components derived from allograft, xenograft, or any other naturally occurring material derived from Monera, Protista, Fungi, Plantae, or Animalia kingdoms.

In one embodiment, the carrier can include comprised of sequestering agents such as, but not limited to, collagen, gelatin, hyaluronic acid, alginate, poly(ethylene glycol), alkylcellulose (including hydroxyalkylcellulose), including methylcellulose, ethylcellulose, hydroxyethylcellulose, hydroxypropylcellulose, hydroxypropyl-methylcellulose, and carboxymethylcellulose, blood, fibrin, polyoxyethylene oxide, calcium sulfate hemihydrate, apatites, carboxyvinyl polymer, and poly(vinyl alcohol). See for example, United States Patent 6,620,406, herein incorporated by reference.

In one embodiment, the carrier can include surfactants to promote NELL1 stability and/or distribution within the carrier materials such as, but not limited to polyoxyester (e.g. polysorbate 80, polysorbate 20 or Pluronic F-68).

In one embodiment, the carrier can include buffering agents such as, but not limited to glycine, glutamic acid hydrochloride, sodium chloride, guanidine, heparin, glutamic acid hydrochloride, acetic acid, succinic acid, polysorbate, dextran sulfate, sucrose, and amino acids. See for example, U.S. Patent 5,385,887, herein incorporated by reference. In one embodiment, the carrier can include a combination of materials such as those listed above. By way of example, the carrier can a be PLGA/collagen carrier membrane. The membrane can be soaked in a solution including NELL1 peptide.

In one embodiment, an implant for use in the human body can include a substrate including NELL1 in an amount sufficient to induce cartilage formation or repair proximate to the implant.

In one embodiment, an implant for use in the human body can include a substrate having a surface including NELL1 in an amount sufficient to induce cartilage formation or repair proximate to the implant.

In one embodiment, an implant for use in the human body can include a substrate having a surface including chondrogenic cells, and NELL1 in an amount sufficient to induce cartilage formation or repair. In one embodiment, the implant can be seeded with cells, including but not limited to autologous cells, chondrogenic or osteoblastic cells, cells expressing NELL1 or another chondrogenic molecule.

An implant can include a substrate formed into the shape of a mesh, pin, screw, plate, or prosthetic joint. By way of example, a substrate can be in a form of a dental or orthopedic implant, and NELL1 can be used to enhance integration in bone in proximity to the implant. An implant can include a substrate that is resorbable, such as a substrate including collagen.

The NELL1 peptide can be combined with a acceptable carrier to form a pharmacological composition. Acceptable carriers can contain a physiologically acceptable compound that acts, for example, to stabilize the composition or to increase or decrease the absorption of the agent. Physiologically acceptable compounds can include, for example, carbohydrates, such as glucose, sucrose, or dextrans, antioxidants, such as ascorbic acid or glutathione, chelating agents, low molecular weight proteins, compositions that reduce the clearance or hydrolysis of the anti-mitotic agents, or excipients or other stabilizers and/or buffers.

Other physiologically acceptable compounds include wetting agents, emulsifying agents, dispersing agents or preservatives which are particularly useful for preventing the growth or action of microorganisms. Various preservatives are well known and include, for example, phenol and ascorbic acid. One skilled in the art would appreciate that the choice of a carrier, including a physiologically acceptable compound depends, for example, on the route of administration.

The compositions can be administered in a variety of unit dosage forms depending upon the method of administration. For example, unit dosage forms suitable can include powder, or injectable or moldable pastes or suspension.

The compositions of this invention can comprise a solution of the NELL1 peptide dissolved in a pharmaceutically acceptable carrier, such as an aqueous carrier for water-soluble peptides. A variety of carriers can be used, e.g., buffered saline and the like. These solutions are sterile and generally free of undesirable matter. These compositions can be sterilized by conventional, well known sterilization techniques. The compositions can contain pharmaceutically acceptable auxiliary substances as required to approximate physiological conditions such as pH adjusting and buffering agents, toxicity adjusting agents and the like, for example, sodium acetate, sodium chloride, potassium chloride, calcium chloride, sodium lactate and the like.

The concentration of NELL1 peptide in these formulations can vary widely, and will be selected primarily based on fluid volumes, viscosities, body weight and the like in accordance with the particular mode of administration selected and the patient's needs.

The dosage regimen will be determined by the clinical indication being addressed, as well as by various patient variables (e.g. weight, age, sex) and clinical presentation (e.g. extent of injury, site of injury, etc.).

However, a therapeutically effective dose of a NELL1 peptide or agent useful in this invention is one which has a positive clinical effect on a patient or desired effect in cells as measured by the ability of the agent to enhance chondrogenic differentiation for cartilage formation or repair, as described above. The therapeutically effective dose of each peptide or agent can be modulated to achieve the desired clinical effect, while minimizing negative side effects. The dosage of the peptide or agent can be selected for an individual patient depending upon the route of administration, severity of the disease, age and weight of the patient, other medications the patient is taking and other factors normally considered by an attending physician, when determining an individual regimen and dose level appropriate for a particular patient.

Device

The composition can be formulated into an injectable or implantable device in any desired form. Some exemplary devices can be for intervertebral disc nucleus replacement, knee meniscus replacement, wrist triangular fibrocartilage replacement, temporomandibular joint replacement, articular cartilage replacement and can consist of, porous scaffold with preformed shape and attachment features to anchor to underlying bone; viscous gel with preformed shape that can be re-shaped by manual manipulation and the cured to new shape by the application of light; or low viscosity liquid that can polymerize in situ. For example, the composition can be formulated into a single mixture (or a simple mixture) for cartilage formation.

In some embodiments, the composition can be formulated into a single device containing specifically designed layers that are tissue-specific, e.g. it may be desirable to have a bone layer to anchor to the hard tissues, and then a cartilage layer immediately adjacent to the bone layer.

In some embodiments, the composition can be formulated into a single mixture allowing multiple tissues formation and self-assembly, such as . polymers or monomers with amphiphilic functional groups can self-assemble into macroscopic structures.

In some embodiments, where a device including a composition described herein having a cell(s), the device can be subjected to pre-implantation stimulation. For example, the device can be placed in a mechanical bioreactor with controlled mechanical stimulation (frequency, duty cycle, amplitude, etc.); Frequency in the range of 0.01 Hz to 10,000 Hz, duty cycle above 10%; and amplitude in the range of 0.1-100% strain have reported enhanced cellular function. In some embodiments, the device described herein can be placed in a mechanical bioreactor with controlled microfluidic flow and shear stresses, which arise when at least one flow path or channel has one dimension less than 1 mm. In some embodiments, a device described herein can be implanted in a human being via direct implantation immediately following cell harvesting.

In some embodiments, the composition provided herein can form any of the following examples of devices, which illustrate, but shall not be construed to limit the claimed invention:

An injectable/implantable device containing NELL protein (with or without cells) that can be directly injected/implanted into spinal discs to promote cartilage formation;

A disc nucleus replacement device impregnated with NELL that is designed to replace the inner portion of the vertebral disc (the nucleus) or both the inner and outer portion of the disc;

An injectable/implantable device containing NELL (with or without cells) that can be directly injected into the various joint spaces (e.g., knee, temporomandibular joint, wrist) or implanted arthroscopically or openly into various joint spaces;

An injectable/implantable device containing NELL nucleic acids (with or without delivery vehicle such as a virus) (with or without cells) that can be directly injected/implanted into spinal discs to promote cartilage formation;

A disc nucleus replacement device impregnated with NELL nucleic acids (with or without delivery vehicle such as a virus) that is designed to replace the inner portion of the vertebral disc (the nucleus) or both the inner and outer portion of the disc;

An injectable/implantable device containing NELL nucleic acids (with or without delivery vehicle such as a virus) (with or without cells) that can be directly injected into the various joint spaces (e.g., knee, temporomandibular joint, wrist) or implanted arthroscopically or openly into various joint spaces;

An injectable/implantable device containing NELL protein (with or without cells) and other factors that can be directly injected/implanted into spinal discs to promote cartilage formation;

A disc nucleus replacement device impregnated with NELL and other factors that is designed to replace the inner portion of the vertebral disc (the nucleus) or both the inner and outer portion of the disc;

An injectable/implantable device containing NELL and other factors (with or without cells) that can be directly injected into the various joint spaces (e.g., knee, temporomandibular joint, wrist) or implanted arthroscopically or openly into various joint spaces;

An injectable/implantable device containing NELL nucleic acids and other factors (with or without delivery vehicle such as a virus) (with or without cells) that can be directly injected/implanted into spinal discs to promote cartilage formation;

A disc nucleus replacement device impregnated with NELL nucleic acids (with or without delivery vehicle such as a virus) that is designed to replace the inner portion of the vertebral disc (the nucleus) or both the inner and outer portion of the disc;

An injectable/implantable device containing NELL nucleic acids (with or without delivery vehicle such as a virus) (with or without cells) that can be directly injected into the various joint spaces (e.g., knee, temporomandibular joint, wrist) or implanted arthroscopically or openly into various joint spaces.

Dosages

Dosages of NELL peptides and other agents can be determined according to methods known in the art based on type of agent, the disease, and other factors such as age and gender.

In one embodiment, the dosage of NELL peptide for cartilage formation or repair generally ranges from 0.001 pg/mm^2 to 1 pg/mm^2, or more preferably from 0.001 ng/mm^2

to 1 ng/mm^2, or more preferably from 0.001 μg/mm^2 to 1μg/mm^2, or more preferably from 0.001 mg/mm^2 to 1 mg/mm^2, or more preferably from 0.001 g/mm^2 to 1 g/mm^2, with or without a particular carrier or scaffold. In another embodiment, the dosage of NELL peptide for cartilage formation or repair generally ranges from 0.001 pg/ml to 1 pg/ml, or more preferably from 0.001 ng/ml to 1 ng/ml, or more preferably from 0.001 μg/ml to 1μg/ml, or more preferably from 0.001 mg/ml to 1 mg/ml, or more preferably from 0.001 g/ml to 100 g/ml, with or without a particular carrier or scaffold. In yet another embodiment, the dosage of NELL peptide for cartilage formation or repair generally ranges from 0.001 pg/kg to 1 pg/kg, or more preferably from 0.001 ng/kg to 1 ng/kg, or more preferably from 0.001 μg/kg to 1μg/kg, or more preferably from 0.001 mg/kg to 1 mg/kg, or more preferably from 0.001 gm/kg to 1 gm/kg, more preferably from 0.001 kg/kg to 1 kg/kg with or without a particular carrier or scaffold. Furthermore, it is understood that all dosages can be continuously given or divided into dosages given per a given timeframe. Examples of timeframes include but are not limited to every 1 hour, 2 hour, 4 hour, 6 hour, 8 hour, 12 hour, 24 hour, 48 hour, or 72 hour, or every week, 2 weeks, 4 weeks, or every month, 2 months, 4 months, and so forth.

However, because NELL peptides can have effects on *in vitro* osteoblast apoptosis (Zhang, X., et al., J Bone Miner Res, 2003. 18(12): p. 2126-34), NELL dosages (e.g., NELL1 dosages) that are significantly above an optimal range can not increase cartilage formation or repair. Accordingly, even more preferable dosages of NELL peptide shall not be significantly above the optimal dosage range. The even more preferable optimal dosage ranges of NELL peptides can vary according to factors such as the type, the age, the location, and the gender of a mammalian subject; the carrier or scaffold material employed; and the purity and potency of different NELL peptides. In one embodiment, the even more preferable optimal dosage ranges of NELL peptides includes but are not limited to 1 ng/mm^2 to 100 ng/mm^2, or even more preferably from 100 ng/mm^2 to 1000 ng/mm^2, or even more preferably from 1 μg/mm^2 to 100 μg/mm^2, or even more preferably from 100 μg/mm^2 to 1000 μg/mm^2. In another embodiment, the even more preferable optimal dosage ranges of NELL peptides includes but are not limited to 1 ng/ml to 100 ng/ml, or even more preferably from 100 ng/ml to 1000 ng/ml, or even more preferably from 1 μg/ml to 100 μg/ml, or even more preferably from 100 μg/ml to 1000 μg/ml. In yet another embodiment, even more preferable optimal dosage ranges of NELL peptide for cartilage formation or repair generally ranges from 1 μg/kg to 100 μg/kg, or even more preferably from 100 μg/kg to 1000 μg/kg, or even more preferably from 1 mg/kg to 100 mg/kg with or without a particular carrier or scaffold. Furthermore, it is understood that all dosages can be continuously given or divided into dosages given per a given timeframe. Examples of timeframes include but are not limited to every 1 hour, 2 hour, 4 hour, 6 hour, 8 hour, 12 hour, 24 hour, 48 hour, or 72 hour, or every week, 2 weeks, 4 weeks, or every month, 2 months, 4 months, and so forth. As used herein, the term "significantly above the optimal range" means, e.g., about 1% to about 50%, about 5% to about 50%, about 10% to about 50%, about 20% to about 50%, about 30% to about 50%, or about 40% to 50% over the optimal range.

The dosage for inhibitors of NELL peptides varies according to the type of the inhibitor, the bone or cartilage condition to be treated, prevented, or ameliorated, and the age, the location, and the gender of the mammalian subject receiving the composition containing the inhibitor. Generally, the dosage for inhibitors of NELL peptides ranges from but at not limited to: 0.001 pg/mm^2 to 1 pg/mm^2, or more preferably from 0.001 ng/mm^2 to 1 ng/mm^2, or more preferably from 0.001 μg/mm^2 to 1μg/mm^2, or more preferably from 0.001 mg/mm^2 to 1 mg/mm^2, or more preferably from 0.001 g/mm^2 to 1 g/mm^2, with or without a particular carrier or scaffold. In another embodiment, the dosage for inhibitors of NELL peptides generally ranges from 0.001 pg/ml to 1 pg/ml, or more preferably from 0.001 ng/ml to 1 ng/ml, or more preferably from 0.001 μg/ml to 1μg/ml, or more preferably from 0.001 mg/ml to 1 mg/ml, or more preferably from 0.001 g/ml to 100 g/ml, with or without a particular carrier or scaffold. In yet another embodiment, the dosage for inhibitors of NELL peptides generally ranges from 0.001 pg/kg to 1 pg/kg, or more preferably from 0.001 ng/kg to 1 ng/kg, or more preferably from 0.001 μg/kg to 1μg/kg, or more preferably from 0.001 mg/kg to 1 mg/kg, or more preferably from 0.001 gm/kg to 1 gm/kg, more preferably from 0.001 kg/kg to 1 kg/kg with or without a particular carrier or scaffold. Furthermore, it is understood that all dosages can be continuously given or divided into dosages given per a given timeframe. Examples of timeframes include but are not limited to every 1 hour, 2 hour, 4 hour, 6 hour, 8 hour, 12 hour, 24 hour, 48 hour, or 72 hour, or every week, 2 weeks, 4 weeks, or every month, 2 months, 4 months, and so forth.

The dosage for modulators of receptors of NELL peptides varies according to the type of the inhibitor, the type of receptor, the bone or cartilage condition to be treated, prevented, or ameliorated, and the age, the location, and the gender of the mammalian subject receiving the composition containing the modulators of receptors of NELL peptides. Generally, the dosage for modulators of receptors of NELL peptides ranges from but at not limited to: 0.001 pg/mm^2 to 1 pg/mm^2, or more preferably from 0.001 ng/mm^2 to 1 ng/mm^2, or more preferably from 0.001 μg/mm^2 to 1μg/mm^2, or more preferably from 0.001 mg/mm^2 to 1 mg/mm^2, or more preferably from 0.001 g/mm^2 to 1 g/mm^2, with or without a particular carrier or scaffold. In another embodiment, the dosage for modulators of receptors of NELL peptides generally ranges from 0.001 pg/ml to 1 pg/ml, or more preferably from 0.001 ng/ml to 1 ng/ml, or more preferably from 0.001 μg/ml to 1μg/ml, or more preferably from 0.001 mg/ml to 1 mg/ml, or more preferably from 0.001 g/ml to 100 g/ml, with or without a particular carrier or scaffold. In yet another embodiment, the dosage for modulators of receptors of NELL peptides generally ranges from 0.001 pg/kg to 1 pg/kg, or more preferably from 0.001 ng/kg to 1 ng/kg, or more preferably from 0.001 μg/kg to 1μg/kg, or more preferably from 0.001 mg/kg to 1 mg/kg, or more preferably from 0.001 gm/kg to 1 gm/kg, more preferably from 0.001 kg/kg to 1 kg/kg with or without a particular carrier or scaffold. Furthermore, it is understood that all dosages can be continuously given or divided into dosages given per a given timeframe. Examples of timeframes include but are not limited to every 1 hour, 2 hour, 4 hour, 6 hour, 8 hour, 12 hour, 24 hour, 48 hour, or 72 hour, or every week, 2 weeks, 4 weeks, or every month, 2 months, 4 months, and so forth.

Dosage Form

The therapeutically effective dose of an agent included in the dosage form can be selected by considering the type of agent selected and the route of administration. The dosage form can include a agent in combination with other inert ingredients, including adjutants and pharmaceutically acceptable carriers for the facilitation of dosage to the patient, as is known to those skilled in the pharmaceutical arts.

In one embodiment, the invention can include a method of treating a patient to induce cartilage formation, comprising administering NELL1 peptide at a therapeutically effective dose in an effective dosage form at a selected interval to enhance cartilage formation or repair. The method of can further comprise administering at least one secondary agent in the region where cartilage formation or repair is desired, including but not limited to TGF- beta, BMP2, BMP4, BMP7, bFGF, VEGF, PDGF, collagen, bone, bone matrix, tendon matrix or ligament matrix, chondrogenic or osteoblastic cells.

In one embodiment, a method of treating a patient to induce cartilage formation or repair can include harvesting mammalian chondrogenic cells, increasing the concentration of expression of NELL1 peptide in contact with the chondrogenic cells and administering the chondrogenic cells to a region where cartilage formation or repair is desired.

EXAMPLES

The following examples are offered to illustrate, but not to limit the claimed invention.

An injectable device containing NELL (with or without cells) that can be directly injected into spinal discs to promote cartilage formation. A disc nucleus replacement device impregnated with NELL is designed to replace the inner portion of the vertebral disc (the nucleus) or both the inner and outer portion of the disc. An injectable device containing NELL (with or without cells) that can be directly injected into the various joint spaces (e.g., knee, temporomandibular joint, wrist) or implanted arthroscopically or openly into various joint spaces.

Example 2. Cartilage differentiation, maturation and hypertrophy without necessarily mineralization

NELL1 transgenic overexpression mice were created with the rationale was that NELL1 overexpression transgenic mice would exhibit altered intramembranous or endochondral bone formation. The invention was tested with F2 progeny from NELL1 transgenic mice. Histology from various forms of NELL1 overexpression mice has demonstrated increased cartilage differentiation, maturation, and hypertrophy without necessarily mineralization in both hyaline cartilage areas (Figure 1) and fibrocartilage areas (Figures 2A-2F).

Goat auricular cartilage was minced to 1 x 3 mm pieces and digested with 0.25% trypsin/1mM EDTA at room temperature for 30 min, followed by 3mg/ml collagenase II (Sigma, St Louis, MO, USA) digestion with shaking at 37C for 6 h. The cell suspension was filtered through a 70 mm strainer and the chondrocytes were then pelleted by centrifugation. After washing with PBS, the cells were cultured in DMEM (Gibco BRL, Grand Island, NY, USA) plus 10% fetal calf serum (Hyclone, Logan, UT, USA), 100 U/ml penicillin and 100 mg/l streptomycin at 37 °C with 5% CO2. The cells were then treated/transduced with AdNELL1, AdBMP2, or AdLacZ. The *in vitro* transduction efficiency was assessed by staining for beta galactosidase (Figure 3). The cells were combined with pluronic F127 (Sigma) as a common carrier for nude mice subcutaneous injection/or implantation and then examined at 2 weeks (Figure 6) or 4 weeks (Figures 4,5,7-9). A total of 8 million cells were injected/implanted per site.

High-resolution micro-computed tomography (microCT), which utilized 9–20 μm resolution technology from μCT40 (Scanco Medical, Basserdorf, Switzerland) was performed on 4 week samples (Figure 5). MicroCT data were collected at 55 kVp and 145 μA and reconstructed using the cone-beam algorithm supplied with the microCT scanner by Scanco. Visualization and reconstruction of the data were performed using the μCT Ray T3.3 and μCT Evaluation Program V5.0 provided by Scanco Medical.

Harvested samples were processed and embedded in paraffin wax. Six micron-thick sections, using a microtome (McBain Instruments, Chatsworth, CA), were placed on poly-L-lysine-coated Polysine microscope slides (Erie Scientific Company, Portsmouth, NH) and baked at 37°C overnight. Samples were hematoxylin and eosin (H&E) stained. Additional analysis utilized alcian blue staining. Sections were stained with alcian blue solution for 30 min followed by washing in 3% glacial acetic acid followed by water. Sections were then counterstained with nuclear fast red solution and rinsed in distilled water. Finally, sections were dehydrated in alcohol and cleared in xylenes before mounting in permount (Figures 6 and 7).

Six-micron-thick sections were dewaxed in xylenes and rehydrated in ethanol baths. Sections were enzyme-treated for antigen retrieval with 20 μg/ml Proteinase K at 37°C for 10 min and then blocked with 5% horse serum for 2 h at room temperature. Sections were incubated with appropriate primary antibodies at 4°C overnight then incubated with a biotinylated anti-rabbit IgG secondary antibody (Vector Laboratories, Burlingame, CA) for 1 h at room temperature. Positive immunoreactivity was detected using Vectastain ABC reagents and AEC chromagen (both from Vector Laboratories) according to the manufacturer's instructions. Controls for each antibody consisted of incubation with secondary antibody in the absence of primary antibody. Sections were counterstained with hematoxylin for 2 min followed by 10 min in running water. Aqueous mounting medium was used with cover slips.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that changes and modifications can be made without departing from this invention in its broader aspects. Therefore, the appended claims are to encompass within their scope all such changes and modifications as fall within the true spirit and scope of this invention.

We claim

1. A composition for promoting cartilage formation or repair, comprising a NELL peptide or a NELL related agent, wherein the NELL peptide or NELL related agent is in an effective amount for cartilage formation or repair.

2. The composition of claim 1, wherein the NELL peptide is a NELL1 peptide.

3. The composition of claim 1, wherein the NELL related agent is a NELL gene product.

4. The composition of claim 1, further comprising a second agent.

5. The composition of claim 1, further comprising a second agent selected from the group consisting of chondroprotective agents, anti-pain and/or anti-inflammatory agents, growth factors, cytokines, small molecules, anti-angiogenic factors and combinations thereof.

6. The composition of claim 1, further comprising a pharmaceutically acceptable carrier.

7. The composition of claim 4, further comprising a pharmaceutically acceptable carrier.

8. The composition of claim 1, further comprising a material that comprises a chemical gel, a physical gel, an interpenetrating network, or a crosslinker.

9. The composition of claim 1 in an injectable or moldable formulation that sets upon application to a site in a body part of a human being.

10. The composition of claim 1, further comprising a material that degrades or releases the NELL peptide or NELL related agent in response to a stimulus.

11. The composition of claim 10, wherein the stimulus is selected from mechanical stimuli, light, electromagnetic field, or temperature changes, pH changes, changes of ionic strength.

12. The composition of claim 1, further comprising an osteochondroprogenitor cell.

13. The composition of claim 1, further comprising an osteochondroprogenitor cell selected from mesenchymal cells, fetal embryonic cells, stem cells, bone marrow cells, adipose stem cells, fibroblasts, or combinations thereof.

14. The composition of claim 1, further comprising a chondrogenic cell.

15. The composition of claim 1, wherein cartilage formation or repair is formation or repair of hyaline or tracheal cartilage, elastic cartilage, or fibrocartilage.

16. The composition of claim 1, formulated into a device.

17. The composition of claim 1, wherein the NELL peptide or NELL related agent is in an amount effective for treating, preventing or ameliorating a cartilage related disorder.

18. The composition of claim 17, wherein the cartilage related disorder is arthropathies of various joints, arthritis of various joints, internal cartilage derangements of various joints, or spinal joint and disc-related disorders.

19. An implant for use in the human body comprising a substrate having a surface, wherein at least a portion of the surface includes a composition according to claim 1.

20. An implant for use in the human body comprising a substrate having a surface, wherein at least a portion of the surface includes a composition according to claim 4.

21. An implant for use in the human body comprising a substrate having a surface, wherein at least a portion of the surface includes a composition according to claim 5.

22. An implant for use in the human body comprising a substrate having a surface, wherein at least a portion of the surface includes a composition according to claim 6.

23. An implant for use in the human body comprising a substrate having a surface, wherein at least a portion of the surface includes a composition according to claim 7.

24. An implant for use in the human body comprising a substrate having a surface, wherein at least a portion of the surface includes a composition according to claim 12.

25. The implant of claim 19, wherein the substrate is resorbable.

26. The implant of claim 19, wherein the substrate comprises collage.

27. The implant of claim 20, wherein the substrate is resorbable.

28. The implant of claim 20, wherein the substrate comprises collagen

29. The implant of claim 19, which is a device selected from:

an injectable/implantable device containing NELL protein with or without cells that can be directly injected or implanted into spinal discs to promote cartilage formation;

a disc nucleus replacement device impregnated with NELL that is designed to replace the inner portion of the vertebral disc or both the inner and outer portion of the disc;

an injectable/implantable device containing NELL with or without cells that can be directly injected into the various joint spaces or implanted arthroscopically or openly into various joint spaces;

an injectable/implantable device containing NELL nucleic acids with or without delivery vehicle with or without cells that can be directly injected/implanted into spinal discs to promote cartilage formation;

a disc nucleus replacement device impregnated with NELL nucleic acids with or without delivery vehicle that is designed to replace the inner portion of the vertebral disc (the nucleus) or both the inner and outer portion of the disc;

an injectable/implantable device containing NELL nucleic acids with or without delivery vehicle with or without cells that can be directly injected into the various joint spaces or implanted arthroscopically or openly into various joint spaces;

an injectable/implantable device containing NELL protein with or without cells and other factors that can be directly injected/implanted into spinal discs to promote cartilage formation;

a disc nucleus replacement device impregnated with NELL and other factors that is designed to replace the inner portion of the vertebral disc or both the inner and outer portion of the disc;

an injectable/implantable device containing NELL and other factors with or without cells that can be directly injected into the various joint spaces or implanted arthroscopically or openly into various joint spaces;

an injectable/implantable device containing NELL nucleic acids and other factors with or without delivery vehicle with or without cells that can be directly injected/implanted into spinal discs to promote cartilage formation;

a disc nucleus replacement device impregnated with NELL nucleic acids with or without delivery vehicle that is designed to replace the inner portion of the vertebral disc or both the inner and outer portion of the disc; or

an injectable/implantable device containing NELL nucleic acids with or without delivery vehicle with or without cells that can be directly injected into the various joint spaces or implanted arthroscopically or openly into various joint spaces.

30. A method of increasing cartilage formation or repair comprising:

increasing the concentration of a NELL gene product in a region where cartilage formation or repair is desired;

optionally applying an agent to the region where cartilage formation or repair is desired; and

at least inducing hypertrophy of chondroblast in the region where cartilage formation or repair is desired.

31. The method of claim 30, wherein cartilage formation or repair includes bone healing or bone regeneration.

32. The method of claim 30, wherein the increasing the concentration of a NELL1 gene product comprises applying a NELL peptide or a NELL related agent to the region where cartilage formation or repair is desired.

33. The method of claim 30, wherein the agent is selected from chondroprotective agents, anti-pain and/or anti-inflammatory agents, growth factors, cytokines, small molecules, anti-angiogenic factors, or combinations thereof.

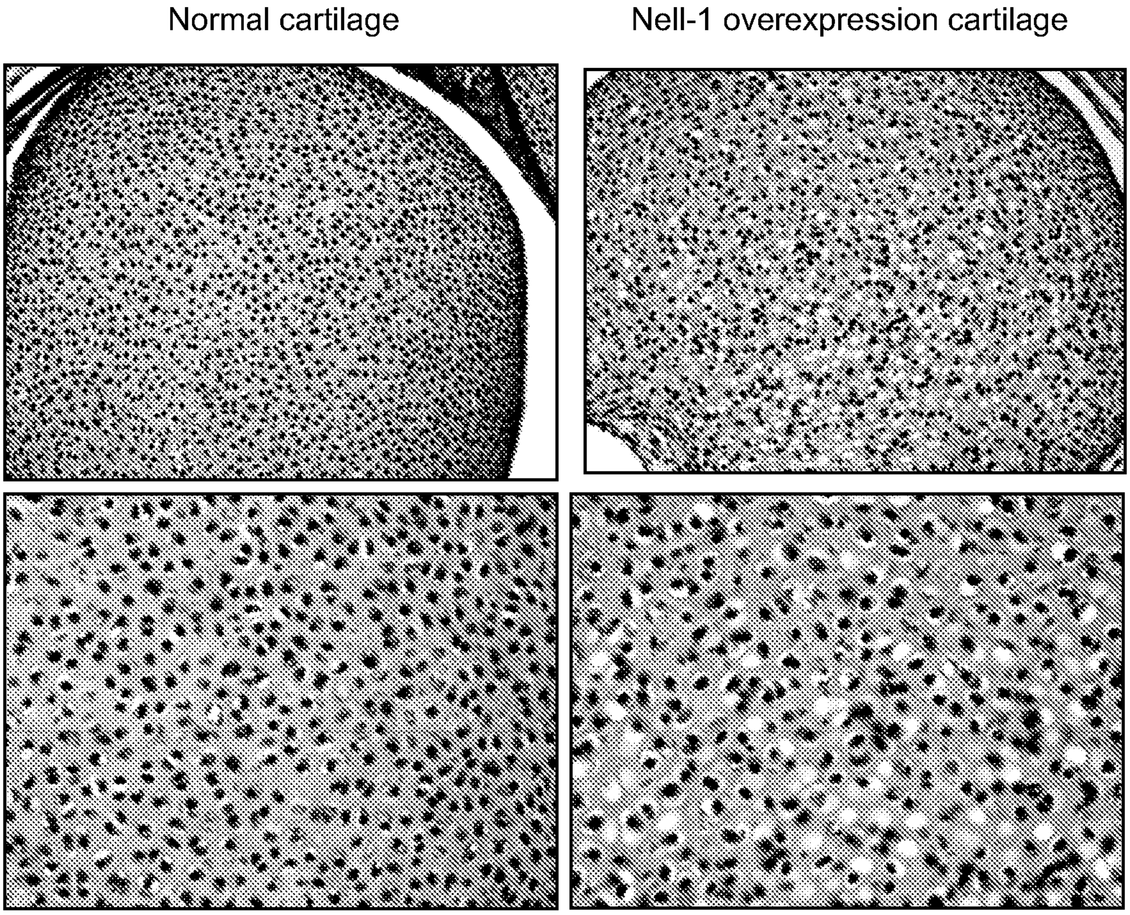
34. The method of claim 30, wherein the agent is selected from collagen, bone matrix, ligament matrix, tendon matrix, chondrogenic cells or osteochondroprogenitor cells.

35. A method of treating, preventing or ameliorating a cartilage related condition, comprising applying to a site in a mammalian subject a composition according to claim 1.

36. A method of treating, preventing or ameliorating a cartilage related condition, comprising applying to a site in a mammalian subject a composition according to claim 4.

37. A method of treating, preventing or ameliorating a cartilage related condition, comprising applying to a site in a mammalian subject an implant according to claim 19.

38. A method of treating, preventing or ameliorating a cartilage related condition, comprising applying to a site in a mammalian subject an implant according to claim 21.



Normal cartilage

Nell-1 overexpression cartilage

FIG. 1

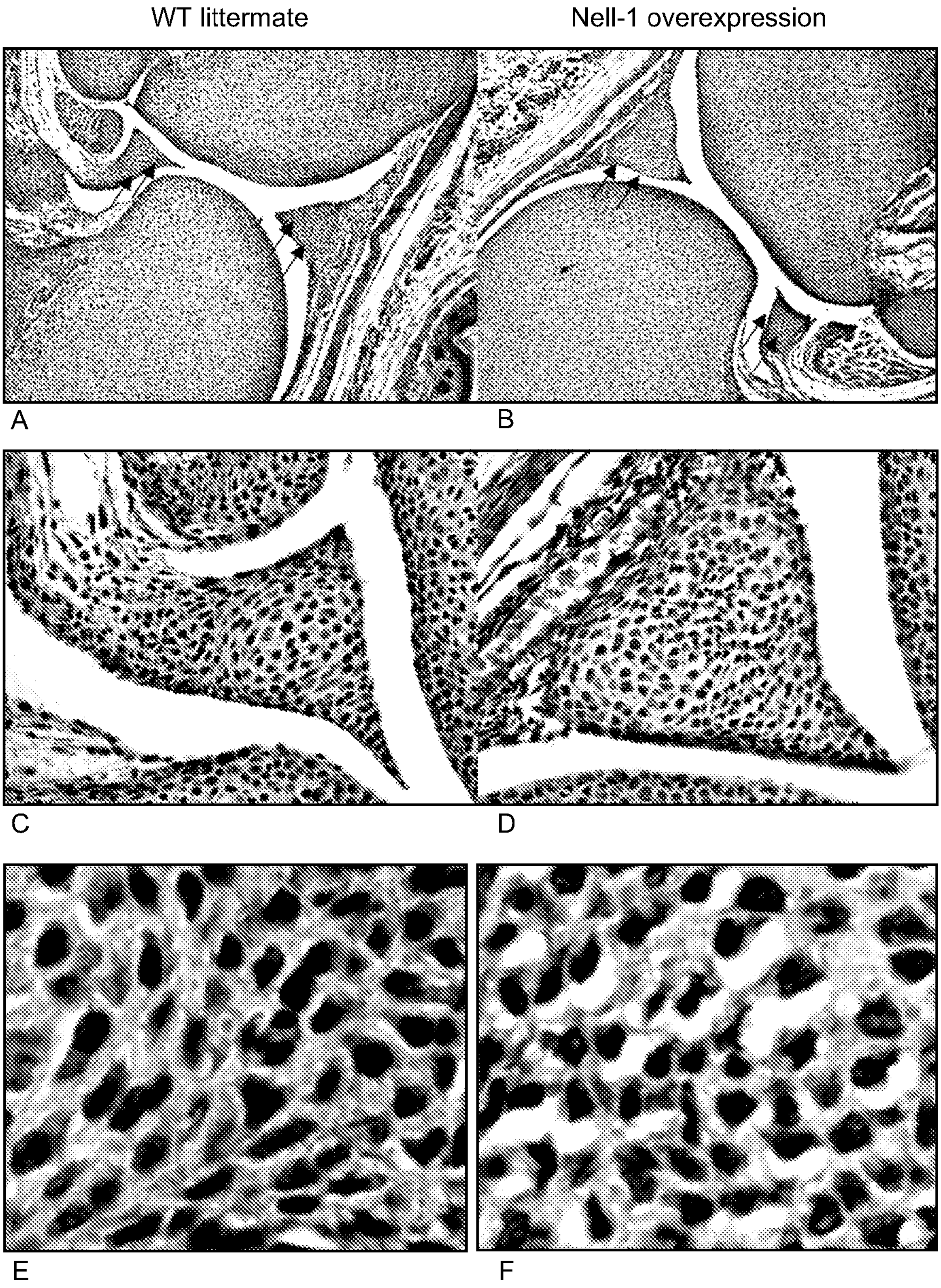


FIG. 2

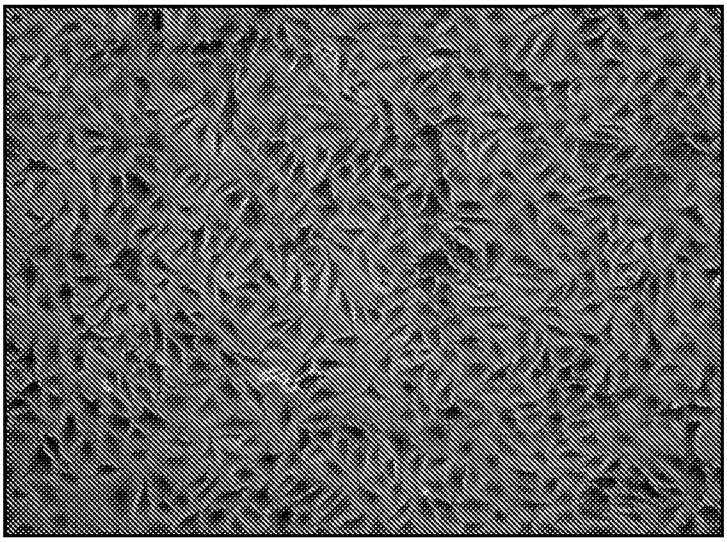


FIG. 3A

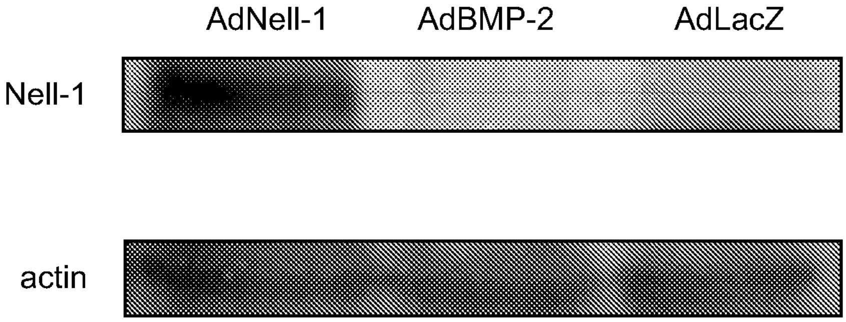


FIG. 3B

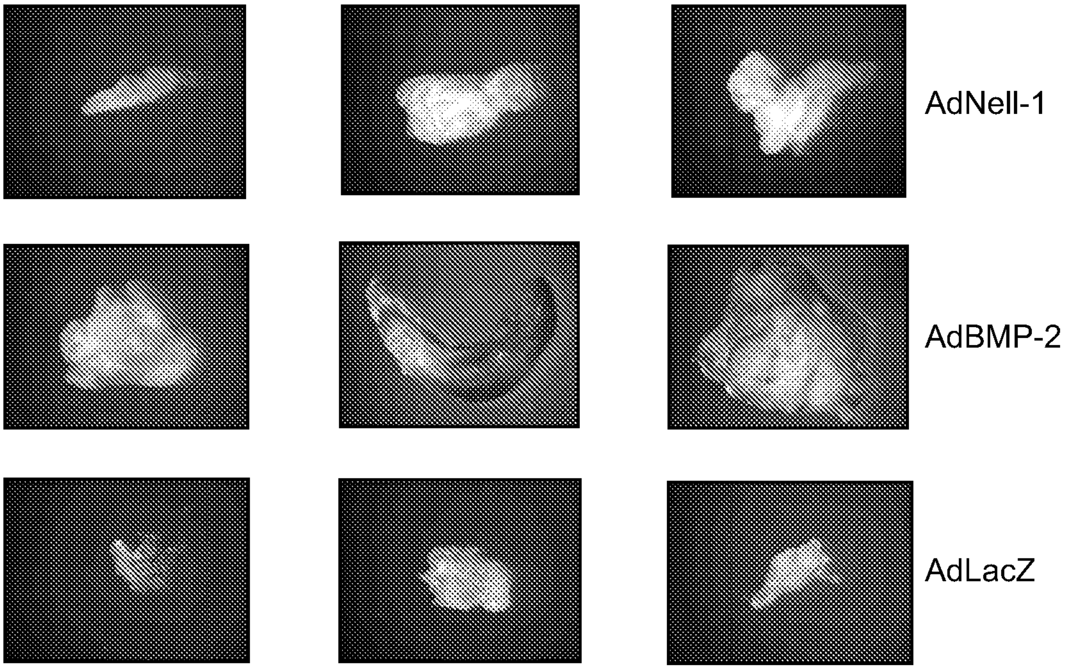

AdNell-1
AdBMP-2
AdLacZ

FIG. 4A

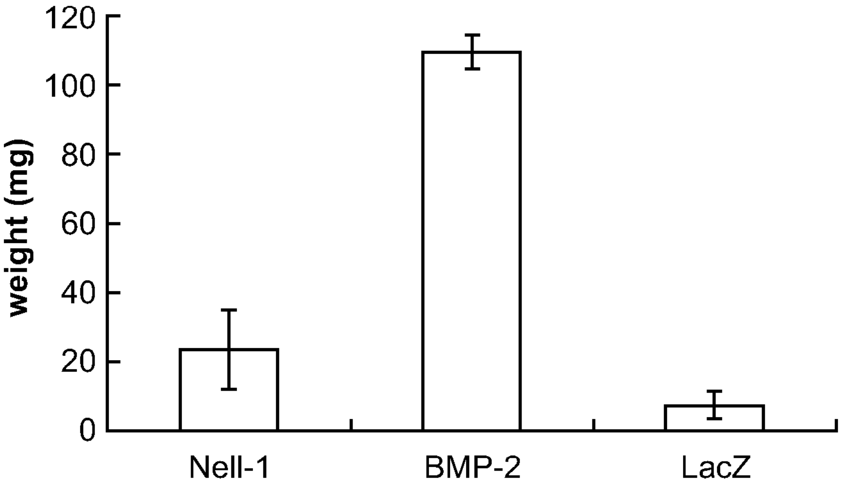

weight (mg)
120
100
80
60
40
20
0
Nell-1
BMP-2
LacZ

FIG. 4B

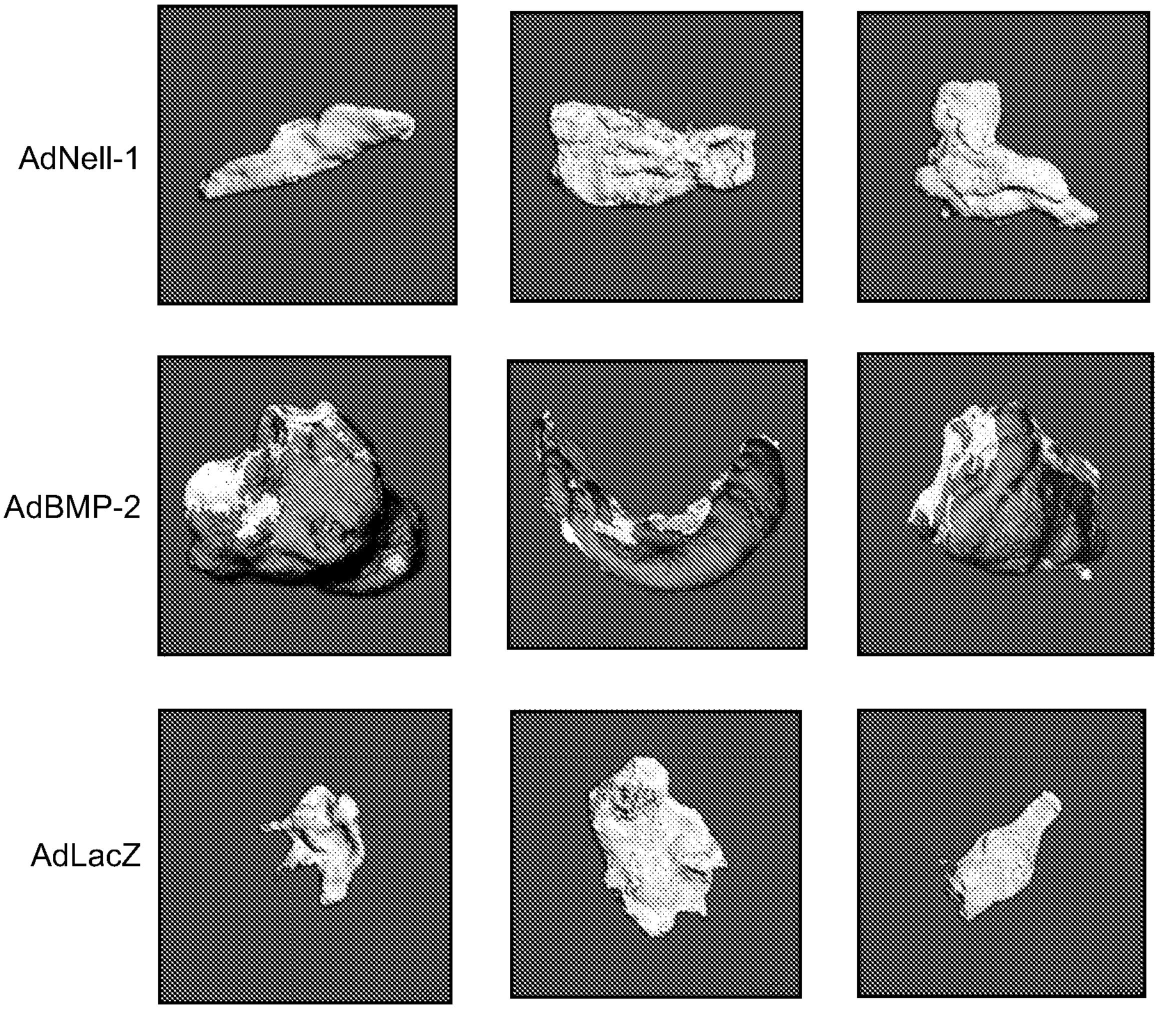


FIG. 5A

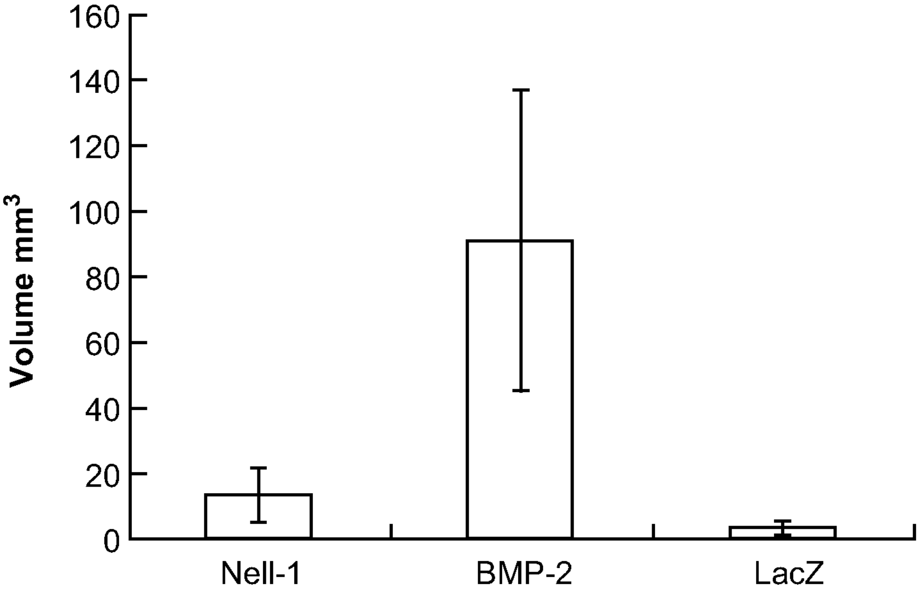

Volume mm^3
160
140
120
100
80
60
40
20
0
Nell-1
BMP-2
LacZ

FIG. 5B

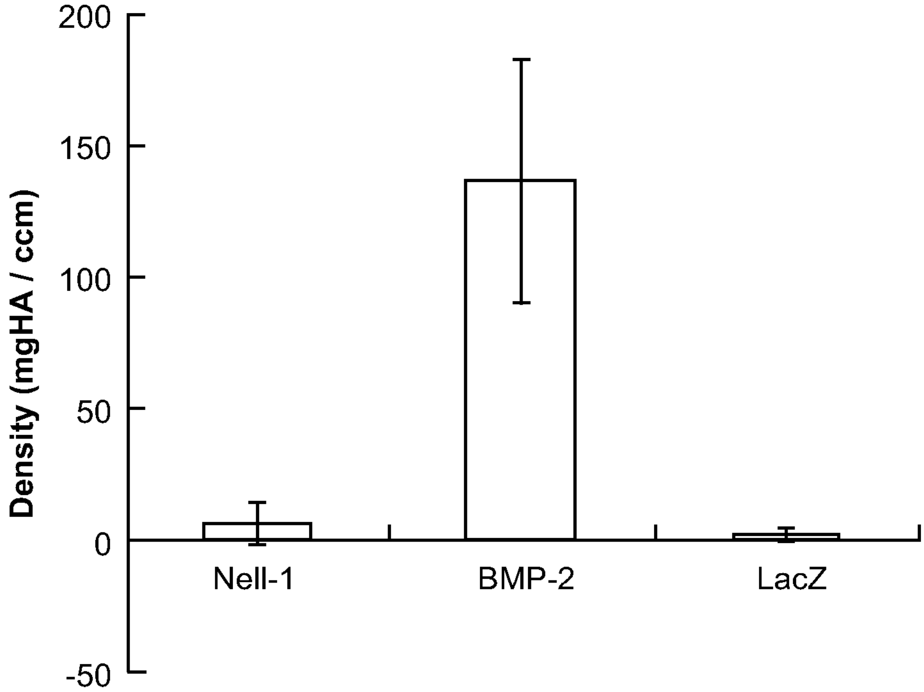

Density (mgHA / ccm)
200
150
100
50
0
-50
Nell-1
BMP-2
LacZ

FIG. 5C

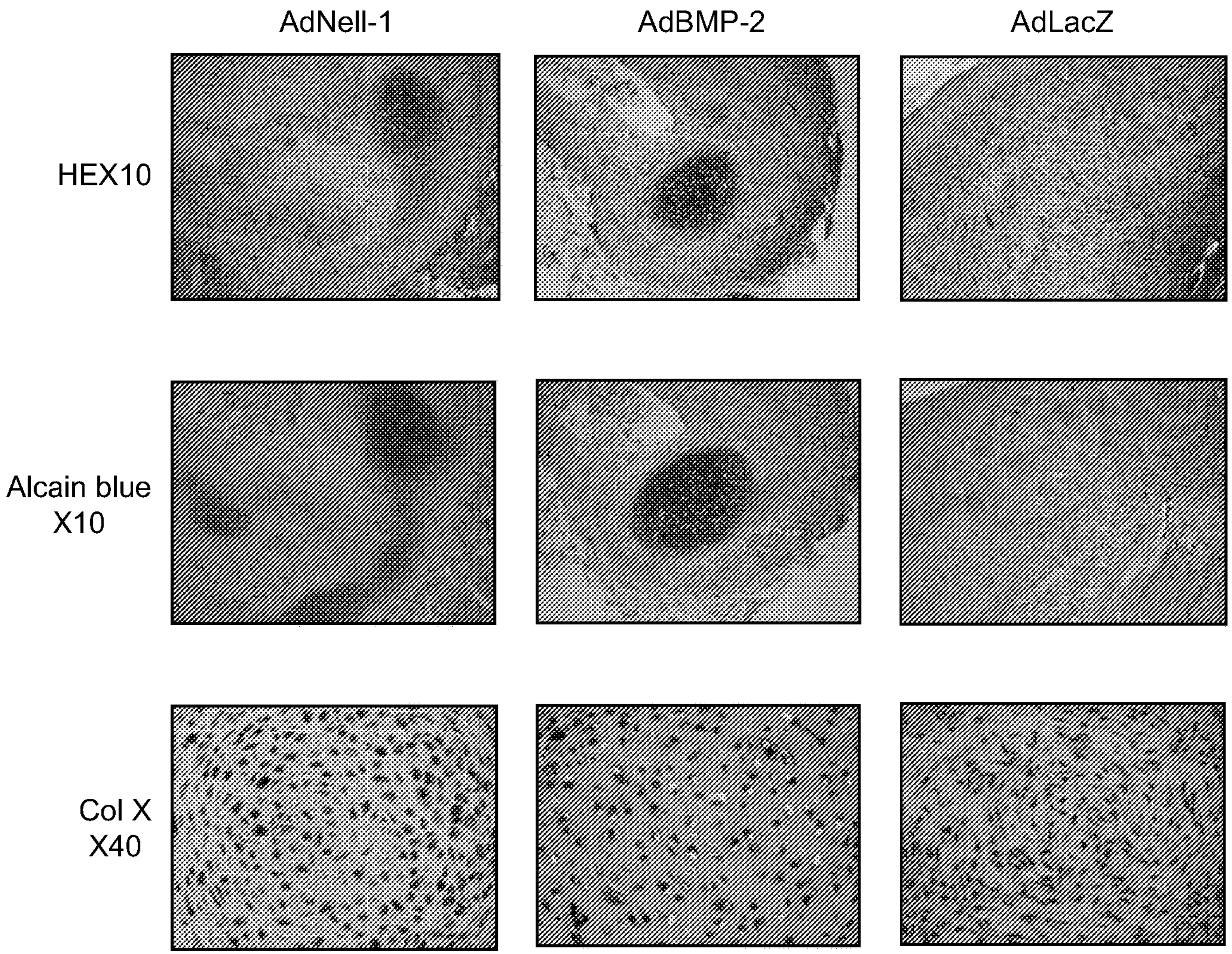


FIG. 6

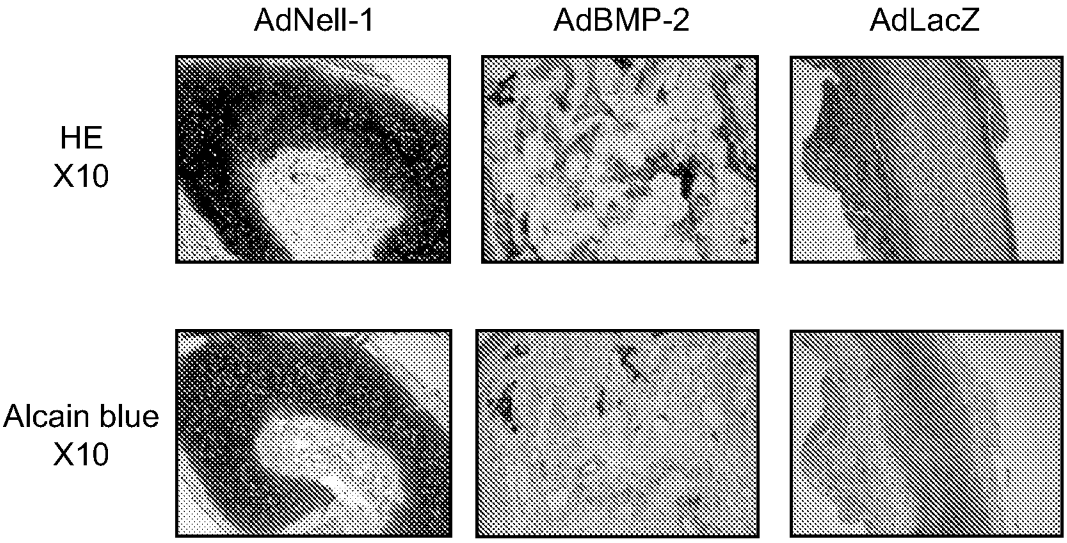


FIG. 7

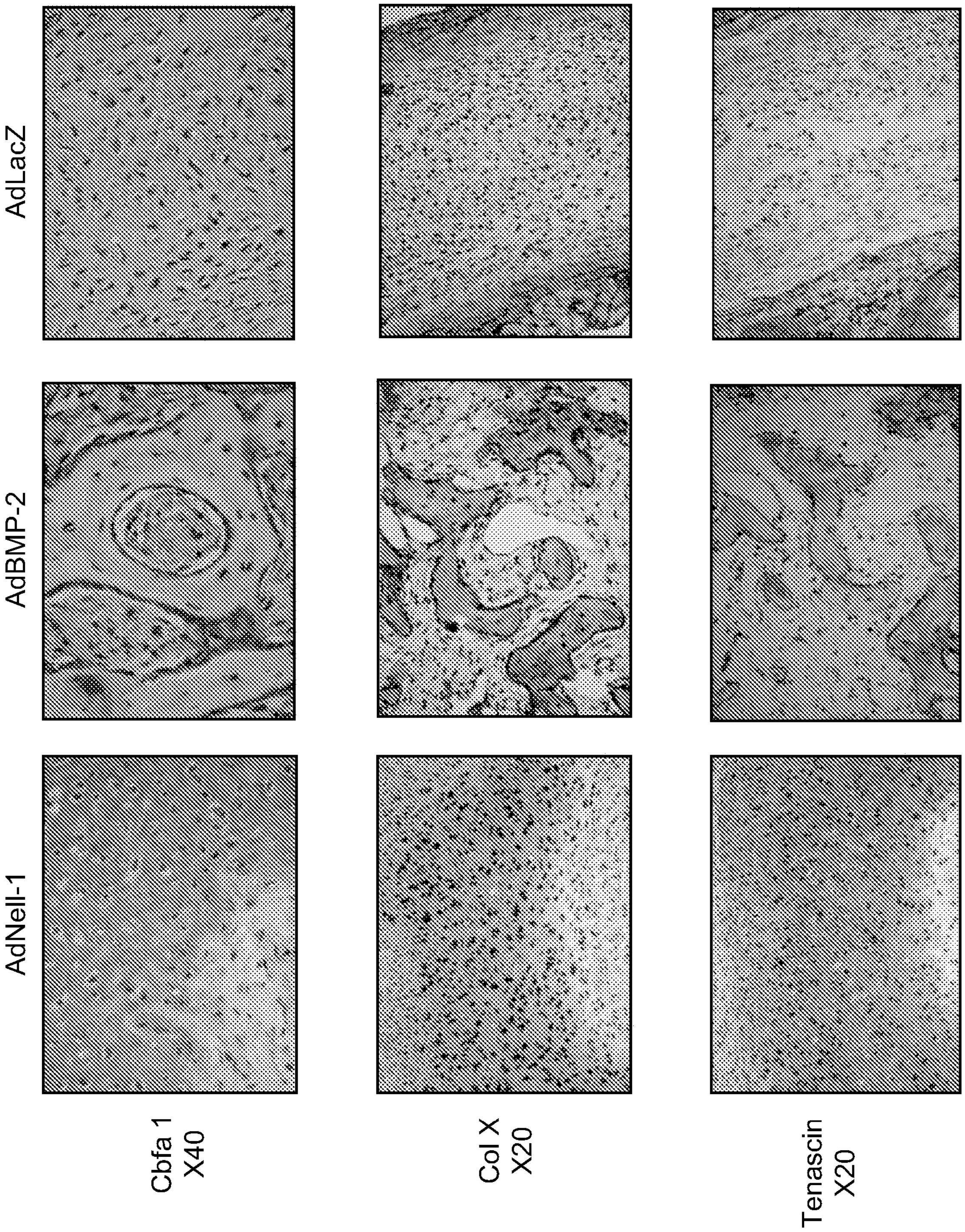


FIG. 8

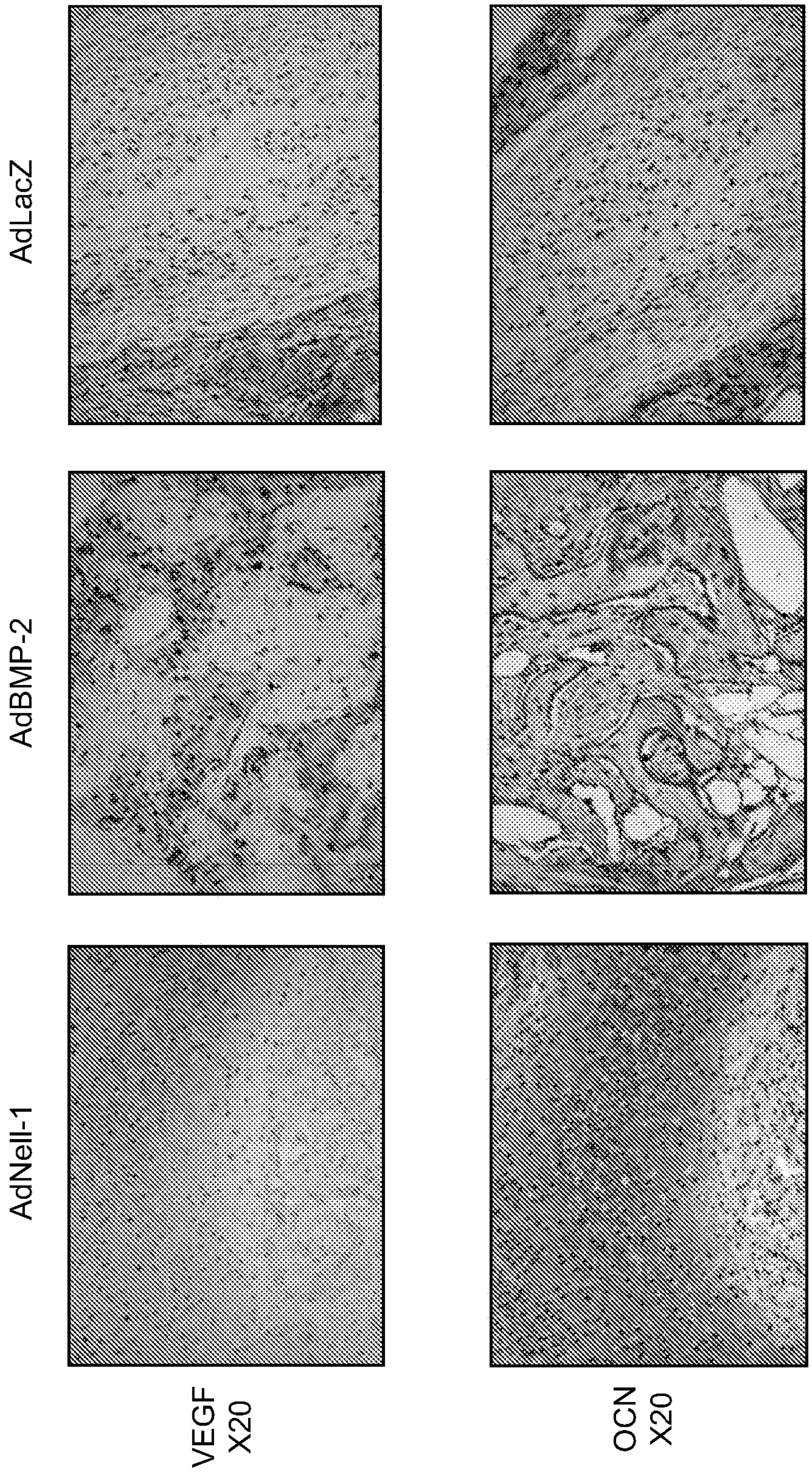
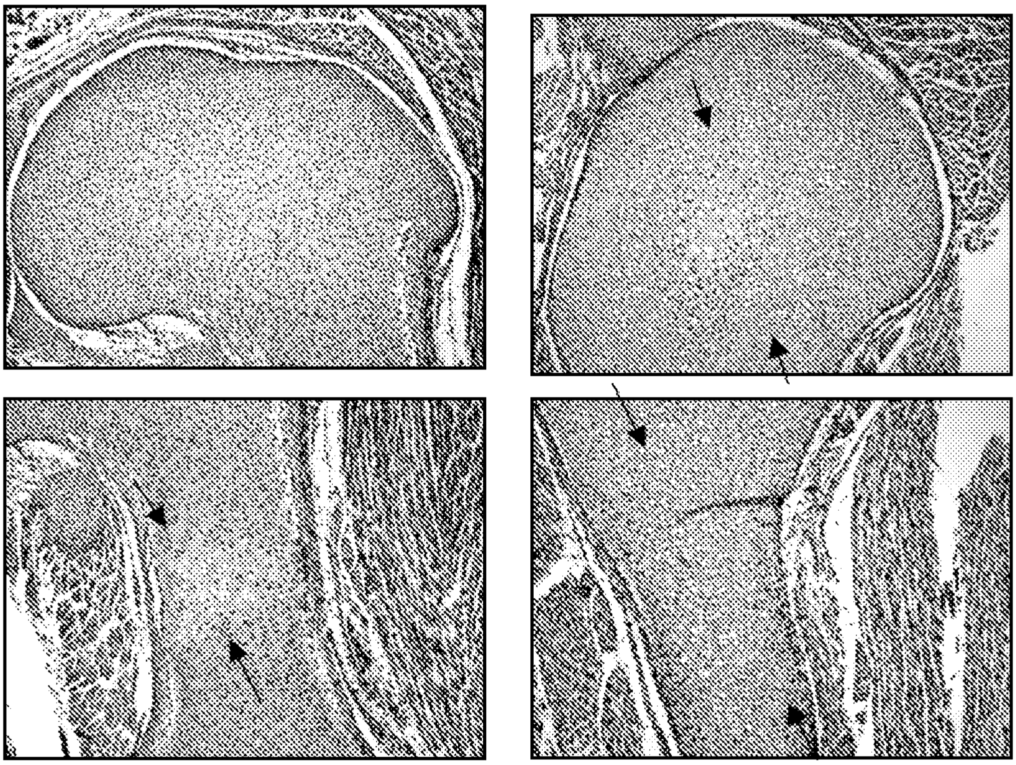


FIG. 9



Control Nell-1

FIG. 10