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Degenerative Pathology

# Spinal Degeneration Process and Aging

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# OBJECTIVES

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Degenerative Pathology

# Spinal Degeneration Process and Aging

- To describe the natural degenerative changes that occur over time in the spine.
- To explain how these degenerative changes can become the source of a pathology and symptoms.
- To define the difference between the normal aging process and pathologic processes that lead to symptoms.

# CONTENTS

# 1. INTRODUCTION

## Overview

As the number of elderly persons continues to increase, and as this population continues to age, there will be an associated increase in age-related diseases, such as degenerative disorders of the lumbar spine .

Our systems and organs begin a maturity process at birth, as do our body and mental functions, which take several years to reach their maximum potential.

A degenerative process also begins after the first ten years of life. As stated in the medical dictionary (Navarro-Beltrán, 2004, 271), this process represents changes in tissue and organs by the loss of structural and functional characteristics, which has a major effect on the spine.

As in all human tissue, aging of the structural components of the spine can be associated with genetic viability of the cells and/or a lifetime of tissue exposure to mechanical stress and loads. Recent research indicates that heredity can be a decisive factor in the disc degeneration process.

The influence of genetics in these processes has been confirmed since 1998 by the identification of various genes associated with intervertebral disc degeneration. This research has paved the way for a greater understanding of the biological mechanisms involved.

Today, many researchers unanimously agree that the development of disc degeneration appears to be similar to the development of other complex diseases. The etiology of these diseases is influenced by the environment and genetics, each of which contributes in its own way and poses its own relative risk (Zhang, Sun, Liu and Guo, 2008). Regardless of the mechanism of origin, aging will lead to degenerative changes that often remain asymptomatic; it is the symptomatic patients that require workup and treatment.

This degenerative cycle and its biochemical consequences progressively modify the functional anatomy. On certain occasions it generates painful syndromes such as imbalance and instability (Benoist, 2009).


In painful degenerative processes, it is extremely important to be certain of the origin of the lesion in order to arrive at a correct diagnosis and subsequent treatment. In other words, a match must be sought between the pain and its source.

# 2. THE YOUNG SPINE

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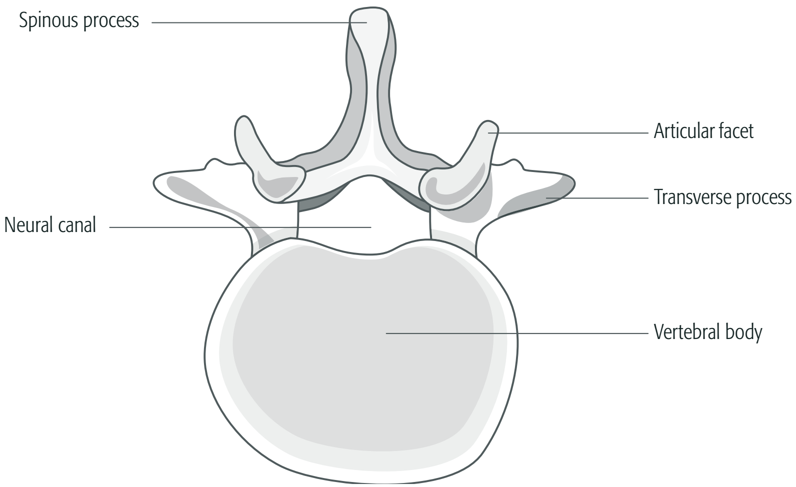
## Anatomical Structures

The spine is formed by alternating vertebral bodies (rigid structures) interconnected by intervertebral discs made of fibrocartilage (structures that permit movement and load support), as well as posterior diarthrodial facet joints.

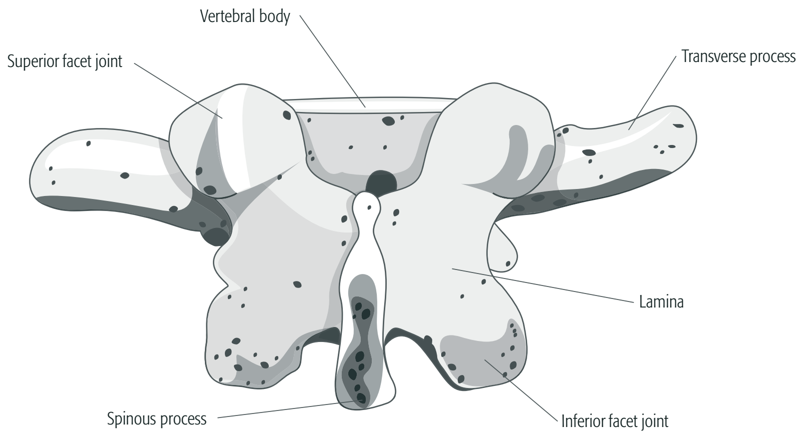
The total number of vertebrae is 33 (7 cervical, 12 thoracic, 5 lumbar, 5 sacral and between 3 and 4 in the coccyx).

Except for the 2 first vertebrae (atlas and axis), all the vertebral bodies consist of an anterior vertebral body that is more or less cylindrical and a posterior arch consisting of pedicles and laminae at each side and ending in a spinous process at the furthest posterior point.




*Axial view of a normal vertebral body*

The transverse processes are found at each side of the posterior arch, as well as a superior and inferior synovial facet joint that articulate with the overlying or underlying vertebra.




*Posterior view of a normal lumbar vertebral body*

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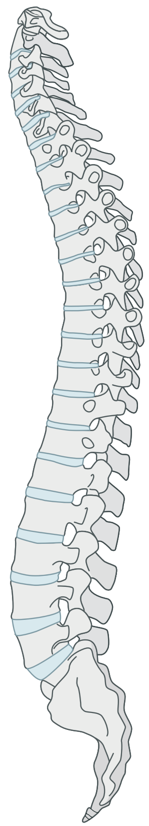
The purpose of the spinous and transverse processes is to provide leverage and attachment points for the muscle groups distributed along the spine.

Although only limited range movements are allowed in the adjacent vertebrae, the sum of these movements provide the spine with a high degree of mobility. The differences in the range of mobility in different sections of the spine are primarily due to the presence of the rib cage in the area of the thoracic vertebrae (markedly limiting motion) and to the difference in size and shape of the joints and transverse processes of the cervical and lumbar vertebrae (Fergusson and Steffen, 2003).

At birth, the overall shape of the spine is convex (kyphotic), during the first year of development as upright posture is assumed, holding the head and standing up, the cervical and lumbar vertebrae develop their lordotic shape.



*Normal spine*

During development towards adulthood and taking on the orthostatic position, human beings need to modify the position of the sacrum between the pelvic bones, gradually increasing their inclination in the sagittal plane. This development gradually changes the height and size of the vertebral bodies and discs.

This progressive increase in size of the vertebrae from the cranial segment to the caudal segment is due to an increase in weight and the load supported by the successive segments.

The vertebrae of the sacrum and coccyx fuse into a solid base in the shape of a wedge that transmits the axial load of spine weight onto the pelvic bones and hips, towards the pelvic extremities.

The upright position increases the load on the lumbar vertebrae joints and, despite the adaptations that the human skeleton has undergone over the course of thousands of years, there are still imperfections that predispose this particular region to undergo degeneration.

An important role of the spine is to support load. Approximately 75% to 80% of the axial load is supported by the anterior spine. The structures that carry out this work primarily are the vertebral bodies, their platforms and the intervertebral bodies (Fergusson and Steffen, 2003).

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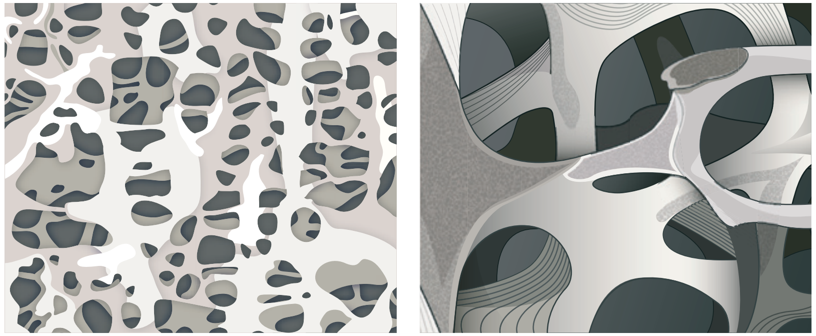
## Vertebral Body

The architecture of the young spine consists of an internal, highly porous trabecular bone (cancellous) and an external solid and dense (cortical) layer of bone that is approximately 0.4 mm thick. This layer is practically indistinguishable from the trabecular layer; however, between both there is a meshwork of trabecular structures in young adults that make up a solid compact bone with smooth and even external shapes.

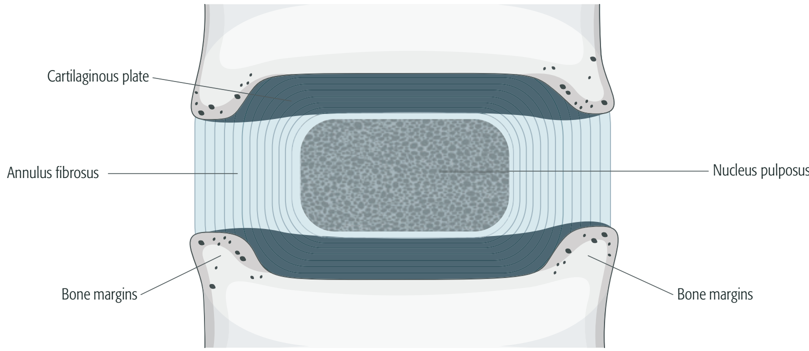


*Trabeculation of a vertebral body at lower and higher magnification*

Bone density varies greatly: from 0.05 g/cm3 to 0.30 g/cm3. This may vary between individuals, with changes at different levels, depending mainly on age and gradually diminishing from the age of forty onwards (Benoist, 2009; Fergusson and Steffen, 2003).

## The Intervertebral Endplate

The intervertebral endplate is a structure that separates the intervertebral disc from the center of the spongy bone of the vertebral body. It consists of a thin layer of semi-porous subchondral bone that is approximately 0.5 mm thick, covered by a layer of cartilage of similar thickness.




*Intervertebral disc*

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The primary functions of the intervertebral endplate are as follows:

- to prevent disc extrusion towards the vertebral body;
- to distribute loads and weight towards and throughout the vertebral body evenly

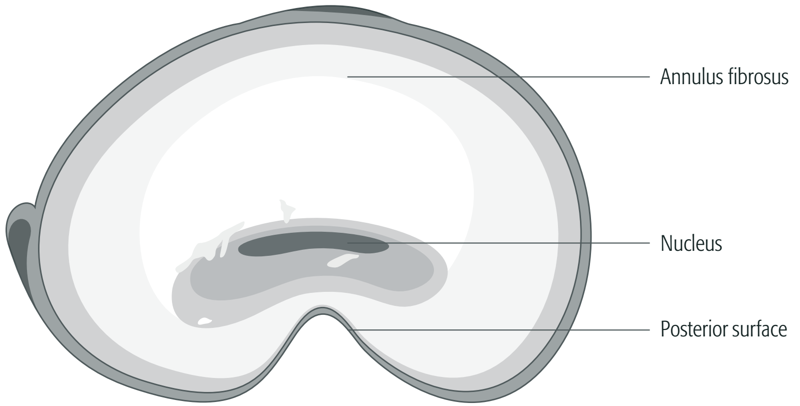
The dense layer of cartilage in the intervertebral endplate also acts as a semi-permeable interface that allows water and salts to pass through but prevents the loss of large hydrophilic proteoglycan molecules. Lastly, the dense subchondral bone of the intervertebral endplate provides a secure anchor for the collagen network of the intervertebral disc.

Intervertebral endplate thickness varies, with thicker bone found under the annulus fibrosus than under the nucleus pulposus. The top plate is usually thinner than the bottom plate and there is a positive correlation between plate thickness and the proteoglycan content of the disc. This may be the result of the remodeling process, by which the intervertebral endplate responds to greater hydrostatic pressure on the discs with a higher content of proteoglycans.

## Intervertebral Disc

The intervertebral disc is primarily in charge of spine mobility and allows for complex movements.

The disc owes this load capacity to its unique structure, in which the nucleus pulposus, similar to gelatin, is surrounded by a thick annulus fibrosus with highly oriented fibers.




*Intervertebral disc*

During load bearing, the intervertebral disc of the young adult develops hydrostatic pressure within the nucleus contained by the strong fibers of the annulus fibrosus and the loads are distributed evenly through the underlying vertebra (Fergusson and Steffen, 2003).

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# Appearance in Imaging Studies

## Radiography

The most common X-rays to be requested are for basic views: antero-posterior (AP) and lateral.

According to Hardacker (1997), the radiological characteristics of simple, normal X-rays are as follows:

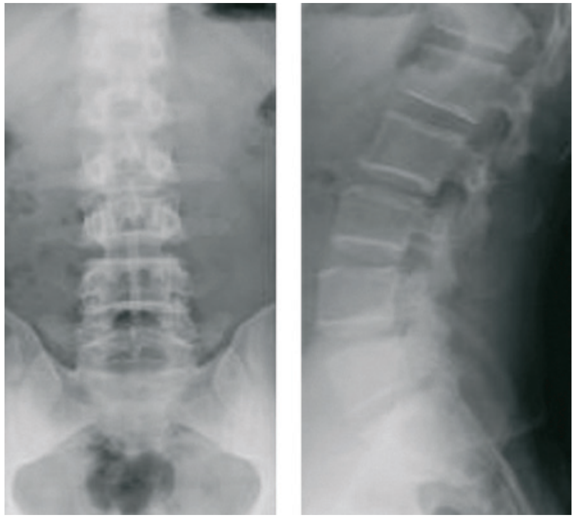
- The frontal (AP) view shows smooth regular bone margins, free of subluxations. Joint surfaces are not rough and evenly separated.
- In the lateral views, the spine presents normal lordosis and kyphosis curves with symmetrical, regular disc spacing, without tissue damage.

## Spinography

This study, which is also called a panoramic or scoliosis study, presents a view from the base of the skull to the pelvis. Its usefulness lies in the capacity to show a complete view of the spine, including the following views:

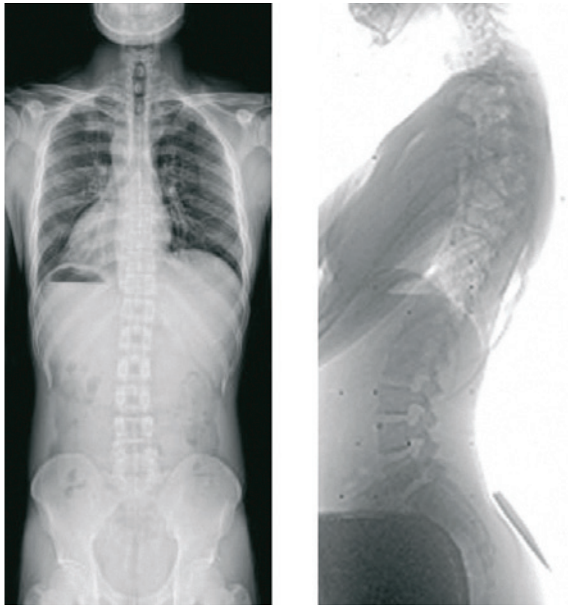
- cervical lordosis curves (40° +/- 9.7°)
- horacic kyphosis (20° to 50°)
- lumbar lordosis (31° to 79°)

This is the most adequate view for the determination of sagittal balance, defined as “alignment from C7 to the sacral promontory with a difference in plumb line of +/- 2 cm” (Knight et al., 2001, 2).



Anteroposterior view. Lateral view.

*X-rays of normal lumbar spine*



*Normal spinography*

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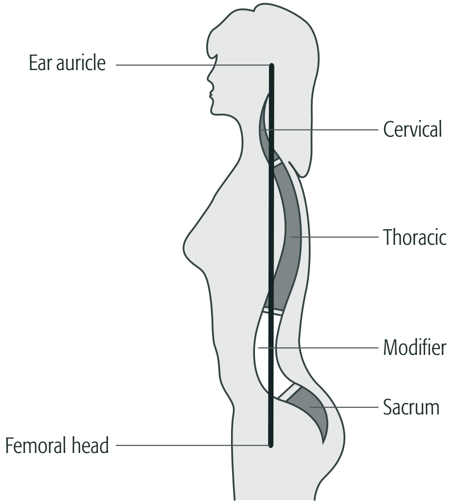


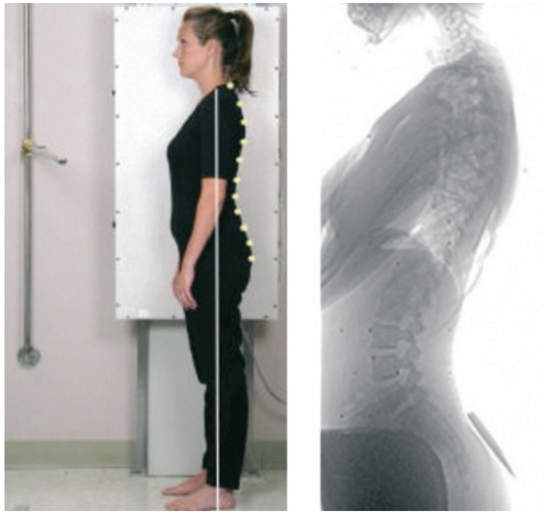

*Sagittal balance (Jackson, 2003)*

## Magnetic Resonance Imaging (MRI)

An MRI is a study that emits a magnetic field from a powerful magnet and receives a radiofrequency signal from excited hydrogen atoms to take digital images of the spine.

Hydrogen is abundant in the human body as it is present in approximately 2/3 of the atoms in the body. T1- and T2-weighted parameters represent different forms of hydrogen proton relaxation.

**T1**

Used to view the anatomy.

*T1-weighted normal lumbar MRI*

**T2**

Used for improved viewing of pathological disorders.

*T2-weighted normal lumbar MRI*

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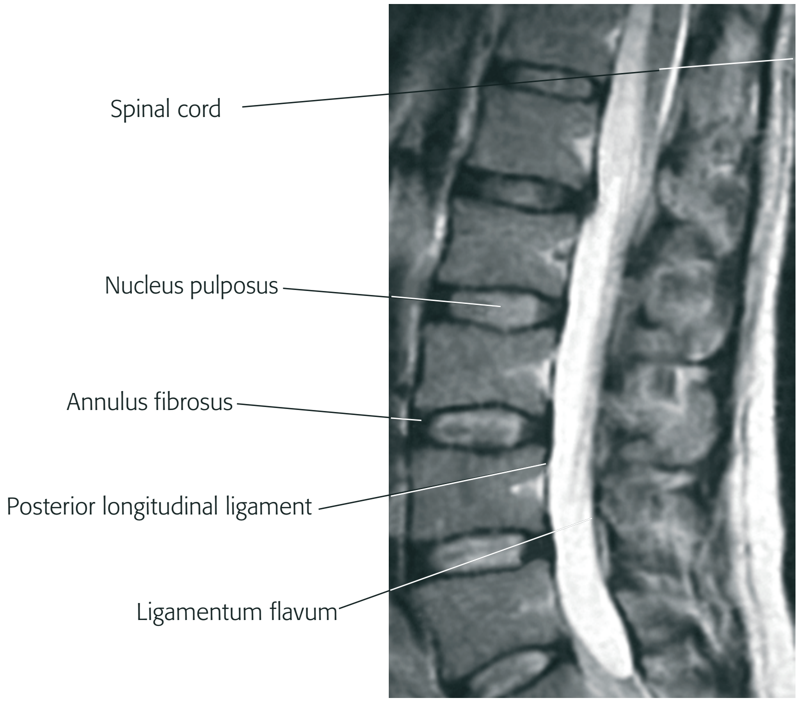
According to Pfirrmann, Metzdorf, Zanetti, Hodler and Boos (2001), normal MRI imaging presents the following characteristics:

- normal spine curves
- spine alignment
- disc height (this should be symmetrical)
- disc hydration (shown by the presence of fluid, a whitish color in T2-weighted images)
- appearance of vertebral bodies (normally smooth and even)
- diameter of the neural tube
- exit of the nerve roots




*Normal lumbar discs*

Summary:

## THE YOUNG SPINE

The spine of the young adult is mainly characterized by the symmetry of its curves and the congruent sagittal balance on the lateral plane (primarily due to proper disc hydration), as well as normal morphology of the vertebral bodies, smooth surfaces free of irregular edges and symmetrical posterior joints.

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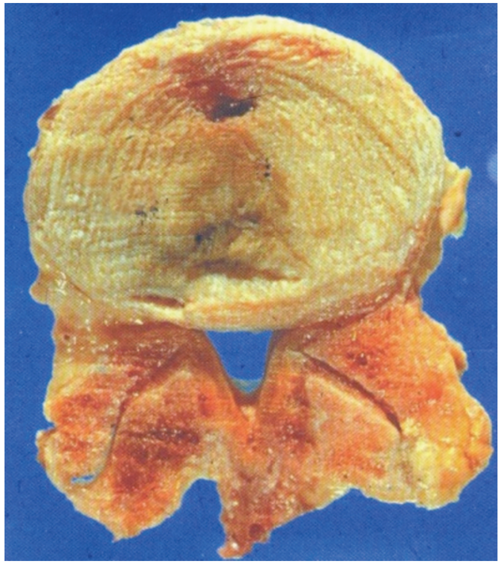
# 3. DISC DEGENERATION AND FACET JOINT ARTHRITIS

## Overview

Degenerative changes in the intervertebral disc are extremely important factors that determine spinal function in the elderly.

> Changes that are frequently observed include horizontal tears and fissures that occur between the center of the disc and the vertebral body endplates. These tears and fissures extend towards the posterior and lateral disk surfaces and produce fissures through the annulus fibrosus (Gunzburg, Szpalski and Andersson, 2004).



Anatomic axial section.

*Disc tear (Scott, Haldeman, Kirkaldy-Willis and Bernard, 2002, 28)*

Microscopic fragmentation has also been observed in the annulus fibrosus, which leads to degeneration of the individual fibers.

A common occurrence after the age of 50 are vertebral lesions at the margins and annular tears on the corners of the vertebral bodies that separate the annulus fibrosus from its connection to the bone.

Concentric cracks and cavities are commonly detected, as well as radial ruptures in the annulus fibrosus of the intervertebral disc. As the aging process develops, the following structures can take shape:

- fissures in the intervertebral plate that is in contact with the disc
- horizontal clefts
- chondrocyte death
- vascular penetration
- Schmorl nodule formation

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According to Gunzburg et al. (2004) and Postacchini (1999), disc thinning can be caused by the following:

- loss of water content within the disc (directly related to proteoglycan content that is lost with aging)
- transformation of soft nucleus pulposus tissue in highly organized collagen tissue
- gradual ossification of the intervertebral endplate and penetration of disc tissue towards the plate

As long as the cartilaginous endplate and annulus fibrosus are strong enough, they can contain the nucleus, even under heavy loads. As disc degeneration progresses, potentially weak points begin to appear in the subchondral bone and on the posterior and/or postero-lateral segments of the annulus fibrosus. These segments of the annulus fibrosus are thinner and have weaker connections to the vertebral bodies, whereby they become the points of the annulus fibrosus that are most vulnerable to disc herniation.

We need guidance here - a note on the Word doc says:

This picture needs to orient the reader, A/P, arrows pointing at the endplates and where the anchor points have become deficient

*Cartilaginous plate (Scott, Haldeman, Kirkaldy-Willis and Bernard, 2002, 29)*

In what is now considered a classical description, Kirkady-Willis (1992) described a tri-joint complex consisting of the intervertebral disc and the two facet joints as a single unit where, under normal conditions, the disc is the structure that receives the most load. The facets, the only synovial joints in the spine with hyaline cartilage over subchondral bone, provide load support on the posterior arch by stabilizing the segment during flexion and extension and protecting the disc from excessive torsion.

Taking these functions into consideration, it has been theorized that the degenerative changes of the facets are secondary to disc height loss leading to altered mechanical loads on the facet joints and subsequent degeneration.

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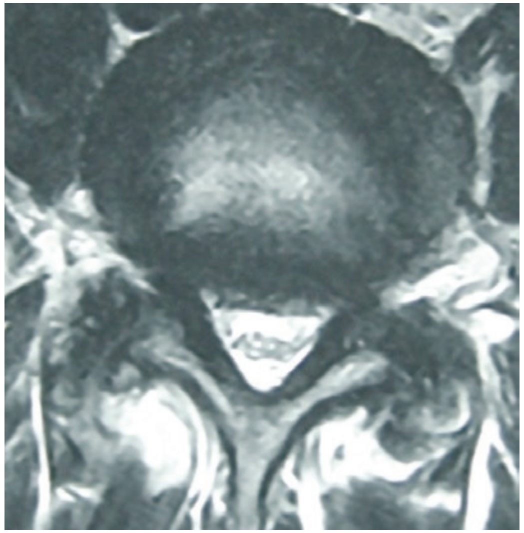
The mechanical consequences of disc degeneration, including loss of disc height and segment instability, increase the load on facets to the point of producing joint subluxation and cartilage deformation; thus, facet osteoarthritis is similar to that of any diarthrodial joint such as the hip or the knee. (Benoist, 2003).

When the degenerative process advances, cartilage degrades progressively, leading to the formation of erosions. These erosion sites are initially specific but ultimately spread to form subchondral bone sclerosis.



T2-weighted axial section showing facet degeneration.

*Facet degeneration*

Finally, the loss of stability in the tri-joint complex can lead to degenerative spondylolisthesis or degenerative scoliosis.

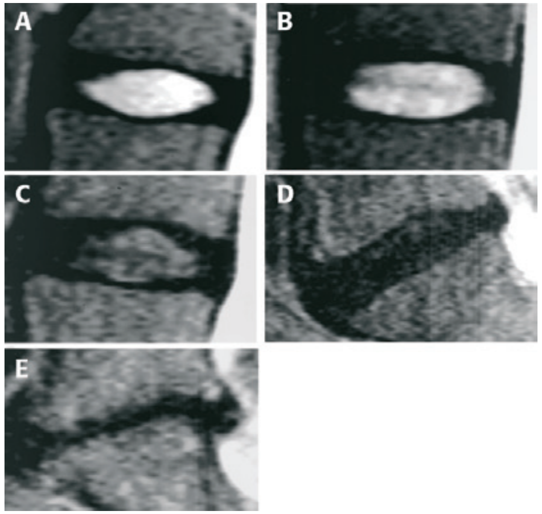
*Degenerative lumbar scoliosis*

Nociceptive nerve roots in the facet joints have been identified as possible sources of intervention in treating lumbar pain. However, the existence of the so-called “facet syndrome” is still controversial, as is its treatment and incidence. (Benoist, 2003).

At a later stage, facet hypertrophy, facet misalignment due to subluxation and the formation of osteophytes can narrow the spinal canal and generate stenosis, either central, lateral recess, foraminal or a combination of all three is common.

## Classification of Disc Degeneration

According to Pfirrmann et al. (2001), disc degeneration can be graded.




*Magnetic resonance and disc degeneration*

| | |
|---|---|
| **A. Grade I** | The young adult presents homogeneous images in the central area of the disc, whereas the periphery begins to show signal reduction in T2-weighted sequences. The loss of signal intensity in the nucleus pulposus in T2-weighted sequences is intimately associated with disc dehydration, due to proteoglycan alterations. |
| **B. Grade II** | In the second decade of life, hypointense linear bands appear inside the nucleus pulposus due to the presence of collagen fibers. |
| **C. Grade III** | Dif fuse signal loss appears in T2 images, associated with a decrease in inter ver tebral height. At this stage, radial tears can be seen on the posterior sur face of the discs, which are more visible if gadolinium is added to the MRI study. |
| **D. Grade IV** | Black discs appear with a significant decrease in height. |
| **E. Grade V** | Disc collapse that reflects severe disc degeneration. In this last stage, T1 and T2 show hypointense presence of gas is seen in the discs. This vacuum phenomenon is more visible in simple X-rays and CAT scan. However, MRI T1 images can show hyperintense presence of calcifications. |

Summary:

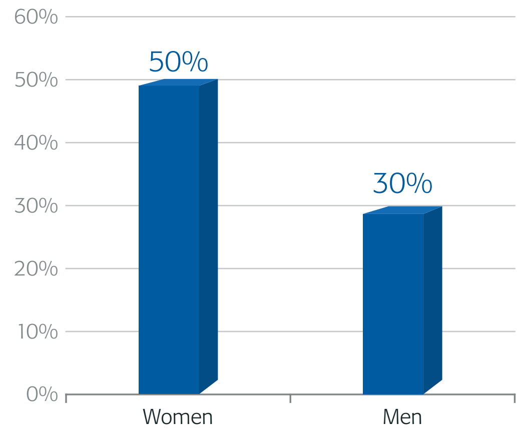
### DISC DEGENERATION AND FACET JOINT ARTHRITIS

Increased disc age and degeneration cause changes in the mechanical properties of the disc, which passes from a dynamic elastic stage to a more static and sometimes solid stage. It should be remembered that the spine aging process begins in the disc after the second decade of life. Disorders of normal cell activity are due to several factors: genetic, nutritional and mechanical. The initial event is not known, but once the degenerative process has begun, a series of biochemical and biomechanical factors begin to interact, generating a vicious cycle that gradually increases the degenerative process.

# 4. THE ADULT AND ELDERLY SPINE

## Anatomical Structures

From the fourth decade of life, both men and women, although in different proportions, can lose a certain percentage of bone density.




*Limit of percentage of bone density loss in men and women*

The concavity of the intervertebral endplate increases with age, as well as the observed loss in bone mass. Typical loss of height, frequently attributed to disc thinning, has a more probable cause in the migration of a normal disc towards this concavity (Benoist, 2003).

Fracture of the intervertebral plate is significant when the vertebral body begins to collapse, but difficult to diagnose in a traditional assessment of vertebra shape in osteoporosis.

Up to 80% of intervertebral plate fractures are not recognized in conventional X-rays.

However, Schmorl nodes, which arise from a series of microtraumatic events, are easy to recognize on MRI images and may be associated with a disc extrusion or edema located in the vertebral body adjacent to the fracture.

On the other hand, in contrast with intervertebral endplate thinning and the risk of fracture frequently observed in humans, sclerosis formation may also be detected on the endplate; as the degenerative process progresses these sclerotic changes (dense areas of cortical bone) can lead to a incorrect interpretation of normal bone density measurements of the intervertebral body, hence careful interpretations of these scans in the setting of advanced degeneration is warranted.

Ossification of the cartilaginous layer has also been seen with increased age. Specifically located calcification directly affects endplate permeability and can cause loss of daily volume of the fluid exchanged by the disc, which can interrupt the flow of nutrients to the disc and lead to disc dehydration (Benoist, 2003).

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## Complementary Studies

The structural changes that appear with age and in imaging studies are not synonymous with symptoms, therefore a careful history and physical examination is paramount to determine if the changes noted on imaging are the culprits in the presenting patient's symptoms.

In fact, pain may exist with few visible alterations and, likewise, individuals showing evident changes due to age may not experience or have experienced any pain.

### X-Rays

Changes seen by X-rays that appear during spine aging are classified in various stages (Hardacker, 1997).

| | |
|---|---|
| **Phase I** | These usually begin to appear after the age of 20. The following characteristics can be seen:<br>• subluxations;<br>• normal curve rectification;<br>• minimum damage to soft tissue and discrete reduction in intervertebral disc height. |
| **Phase II** | These appear more frequently between 20 and 40 years of age. The following characteristics can be seen:<br>• increase in subluxation severity;<br>• irregularities in smooth vertebra margins;<br>• alterations in physiologic curves;<br>• outgrowth (osteophytes) on vertebra margins;<br>• reduction in the height of intervertebral discs;<br>• signs of degeneration resulting from dehydration, which can produce instability.<br> Anteroposterior view.  Lateral view.<br>X-ray of lumbar spine with spondylosis |
| **Phase III** | These appear, on average, between 40 and 65 years of age. The following characteristics can be seen:<br>• initiation of a vertebral body fusion process;<br>• formation of osteophyte bridges;<br>• morphological deformation of vertebral bodies;<br>• loss of disc function and significant degeneration;<br>• atrophy of soft tissues, mainly muscles. |
| **Phase IV** | These appear regularly after the age of 65. The following characteristics can be seen:<br>• loss of shape and function in most vertebrae;<br>• loss of curve shape, due to increase or inversion;<br>• complete fusion of many vertebral bodies;<br>• disc calcification. |

## Spinography

The following characteristics can be seen in the panoramic view:

- loss of vertebral body morphology
- intervertebral disc height loss
- loss of facet joint congruence
- subluxations corresponding to the degree of degeneration are visible, including instability with loss of physiologic curves detected in the lateral view
- bone bridges form in the final stage that result in blocks of bone and loss of stiffness in the physiological curves of the spine

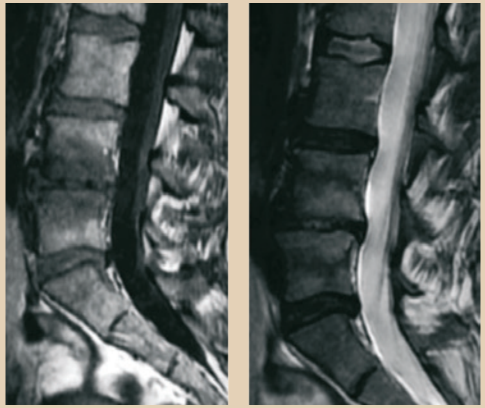
## Magnetic Resonance Imaging (MRI)

The changes in the vertebral end plates caused by degenerative processes, as described by Modic, Masaryk, Ross and Carter (1988), is an interesting phenomenon and are referred to and classified as Modic changes of which there are three types:

**Type I**

The changes to the bone marrow are seen as hypointense signals in T1 and hyperintense in T2, which increase if gadolinium is used. The hypointense areas are associated with replacement of the normal bone marrow by fibrovascular tissue, while the T2 hyperintense areas are due to the increase in free water and increased detection of hypervascularity by gadolinium.

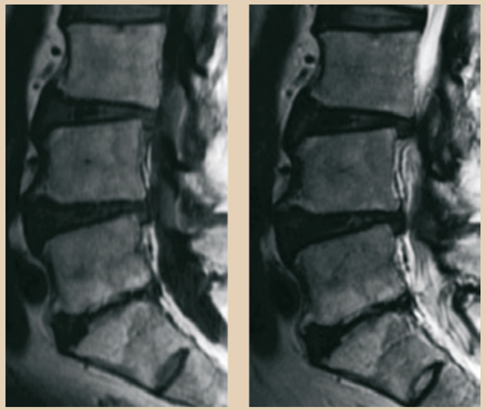
It is highly probable that Modic I changes are associated with lumbar pain. These can progress over the years to Type II changes.



*Modic I*

**Type II**

The changes in bone marrow are seen as hyperintense, both in T1 and T2 sequencing, without changes with gadolinium, reflecting fatty marrow.



*Modic II*

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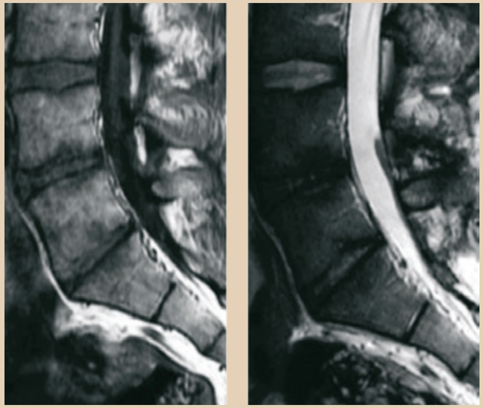
| | | |
|---|---|---|
| **Type III** | Hypointense areas are seen in T1 and T2, which increase with the use of gadolinium, representing hyperostosis due to the formation of cartilaginous Schmorl nodes. |  *Modic III* |


Summary:

## THE ADULT AND ELDERLY SPINE

The spine in the elderly patient presents multiple alterations, due to the lack of intervertebral disc hydration and the structural changes to vertebrae. These changes are visible in X-rays, computed tomography and MRI.

These structural changes are not always synonymous with pain symptomatology, therefore careful examination of the patient is paramount for successful treatment.

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# 5. AGING

## From the Normal to the Pathological

The large majority of individuals present visible changes to spinal structures over time, although many of these are asymptomatic.

- MRI shows degenerative disc processes in between 90% and 100% of asymptomatic individuals over the age of 50.
- Hyperintense areas are seen in T2 sequencing in between 20% and 50% of individuals over the age of 50.
- Bulging and even herniated discs are seen in approximately 20% of cases.
- Modic I and II intervertebral endplate changes are present in approximately 7% to 17% of asymptomatic subjects, respectively.

Disc degeneration is generally considered to be the primary source of pure lumbar pain, though many other structures surrounding the spine may lead to pain.

Pain and incapacity are sometimes the clinical expressions of an aged spine.

The nociceptive nerve fibers identified in the annulus and the nucleus can become sensitized by the cytokines and neuropeptides present in the degenerated disc. However, other nociceptive sources of pain can be present, including muscles, ligaments and facets. The painful disc is not easy to identify when there are multiple levels of degeneration.

It should also be remembered that the pain is not only nociceptive. Central nervous system awareness can also be responsible for chronic pain.

Radicular pain is another possible source of pain, in which disc herniation produces compressive, mechanical pain. In addition, disc height loss, the presence of disc-osteophyte complexes and disc pathology in the central, lateral recess and/or intervertebral foramen can compress nerve roots, causing radicular pain and/or neurogenic claudication.

On the other hand, midline compression may occur, causing central stenosis of the neural tube and a subsequent clinical picture of pain due to the following reactions:

- bulging disc
- ligamentum flavum hypertrophy
- bone hypertrophy
- osteophyte formation on facets

Disc degeneration, in combination with facet osteoarthritis and remodeling of bone tissue, can cause hypermobility such as spondylolisthesis, which can in turn exacerbate pathologies such as foraminal, lateral recess or central stenosis subsequently leading to neurologic symptoms (radiculopathy and/or neurogenic claudication).

This same mechanism can also explain the presence, along with disc and facet degeneration, of muscular atrophy that leads to degenerative scoliosis and the possibility of evolution towards progressive spine disorganization, instability and imbalance. (Grob, 2003; Benoist, 2009).


**Summary:**

### AGING

Over time, the body undergoes structural changes due to various factors (such as nutritional habits, body weight, physical activity, the type of work performed, environmental and genetic factors, etc.) that determine the appearance of anatomical and morphological changes in the spine. These alterations can translate clinically into pain or functional limitations.

The major challenge is to distinguish structural and anatomic changes due to age from the pathological changes that cause pain and neurologic compromise.

Many spine degradation-causing factors are still unknown. The role of genetic predisposition appears crucial, but the environmental factor is also a significant factor.

Up until now, adequate nutrition, maintaining physical activity, avoiding smoking and avoiding frequent loads appear to be the only ways at our disposal to prevent these degenerative processes from being symptomatic (Benoist, 2003).


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