UNIVERSITEIT GENT

FACULTEIT GENEESKUNDE EN
GEZONDHEIDSWETENSCHAPPEN

Academic Year 2015 - 2016

Cross-sectional and longitudinal study of the radiological characteristics of the intervertebral disc. Evolution in function of age. Influence of repetitive micro trauma. Influence of (macro) trauma.

Charlotte VAN LANGENHOVE

Promoter: Prof. Dr. K. Verstraete

Research report presented in the 4th Master year for "CLERKSHIP:

Research for the Hospital Doctor" In the program of

Master of Medicine in Medicine

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Datum

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FOREWORD

In front of you lies the research report I worked on for the last 5 months. What started as only an idea last summer turned out to be an interesting and fascinating project. I have experienced this period of research as very instructive and useful. Yet the road leading to this result was not easy. At the beginning I had little knowledge of the subject. Every day I learned new skills and gained more and more information about the topic. In the end I have been able to achieve a result I am very satisfied with.

I would like to thank my promoter, Professor K. Verstraete for his valuable insight and guidance to complete this research. Without his pedagogic skills writing of the project would not been possible. I would also like to thank the other interns I shared an office with during the long hours of data collection. They helped my through the day with an occasional coffee break and told me it was time to go home at night. Especially I would like to thank Thiebault Saveyn, he helped me with the selection of the control population. Of course I'm grateful to my family, they made it possible for me to come this far and they encouraged me when this was needed.

Charlotte Van Langenhove
23 May 2016

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ABBREVIATIONS

AF	Annular fissure
ALIF	Anterior lumbar interbody fusion
CSF	Cerebrospinal fluid
HIZ	High-signal-intensity zone
MRI	Magnetic resonance imaging
NP	Nucleus pulposus
PLIF	Posterior lumbar interbody fusion
ROI	Reason of interest

ABSTRACT

Purpose: To investigate the MR imaging characteristics of normal and pathologic intervertebral discs and adjacent vertebral bodies in a control population and victims of cervical and lumbar vertebral trauma.

Study Design: Retrospective clinical survey.

Materials and Methods: Magnetic resonance images (MRIs) from 4 patient groups were compared: 1. 506 MRI images of patients with neck pain; 2. 114 patient with a normal MRI of the cervical spine; 3. 505 MRI images of patients with low back pain; 4. 173 patients with a normal MRI of the lumbar spine. The parameters investigated were: position of the centre of the nucleus pulposus, bulging, annular fissures, herniation, Pfirrmann classification, osteophytes, uncovertebral joint arthrosis, facet joint osteoarthrosis, listhesis, spondylolysis, Modic changes, Schmorl nodes, abnormal forces. The measurements were height of the disc, signal intensity of the nucleus pulposus, the annulus fibrosus, the herniated part and the area in the in the disc with the highest signal intensity.

Results: The most important findings in the cervical spine are:

- Most patients have their first MRI scan within the first 5 months after trauma.
- There is a remarkable difference between the position of the nucleus in normal and pathological patients. The position of the centre of the nucleus pulposus was never described.
- Disc C3-C4 is higher than every disc close to it.
- The height of the disc will decrease in older patients.
- Pfirrmann’s classification is an excellent grading tool for the cervical spine. Yet it is more difficult at level C2-C3 and C3-C4.
- Discs at high levels of the cervical spine are relatively dark in young patients because of the physics of the scan protocol.
- The signal intensity of the nucleus pulposus will decrease when people get older. Even in a young and healthy population.
- Discs can tear first and degenerate afterwards, but degeneration can also set in first without the presence of a fissure.
- All HIZs at the cervical spine are located at the caudal part of the disc.
- The presence of a HIZ does not influence the height of the disc.
- Annular fissures, bulging and protrusion, herniated discs are most prevalent at level C5-C6.
- In our study, patients with an expulsed disc are between 30 and 42 years old.
- Spontaneous regression occurs in 6,62% of all herniated discs.
- Retrolisthesis, Modic changes, uncovertebral arthrosis and osteophytes are most prevalent at level C5-C6.

- Modic changes are present in discs reduced in height.
- A combination of different Modic grades in one vertebral body is possible.
- Osteophytes occur mostly in dehydrated discs with a reduced height but can be present in discs without annular fissure, bulging, protrusion and herniation. This is a new finding.
- Uncovertebral arthrosis is more prevalent in older people and the disc height is often decreased.
- Facet joint osteoarthrosis is most prevalent at level C3-C4.
- Patients with a degenerative listhesis are older than patients without listhesis
- Operations are carried out most frequently at level C5-C6.

The most important findings in the lumbar spine are:

- Most of the patients are referred for an MRI in the second month after trauma.
- There is a remarkable difference between the position of the centre of the nucleus pulposus in normal people and the sample group. The centre of the nucleus pulposus will lie more posteriorly in normal people. The position of the nucleus was never reported in a large sample.
- The disc height is always higher than the disc level above except at level L5-S1.
- Disc height will reduce in older patients.
- The signal intensity in the nucleus pulposus will be higher if the disc space is higher, this findings was never described before.
- Pfirrmann's classification is an excellent grading tool for the lumbar spine.
- The signal intensity will reduce with age even in young and healthy control patients.
- Annular fissures and herniations are most prevalent at level L5-S1.
- The presence of a HIZ does not influence the height of the disc.
- Herniated disc are lower in height than disc without herniation.
- The posterior longitudinal ligament will protect the median part of the disc.
- Expulsion occurred in patients who had a minor trauma, which is a new finding.
- Bulging discs are most prevalent at level L4-L5.
- The height of discs with Modic grade I is lower than discs without Modic changes.
- Osteophytes are most prevalent at level L4-L5.
- Discs with osteophytes have a lower height than discs without osteophytes but they can occur in discs without annular fissure, bulging, protrusion and herniation.
- Patients with a degenerative listhesis are older than patients without listhesis.
- In case of degenerative listhesis there will be a degenerative disc prior to listhesis. In case of listhesis due to spondylolysis there will be motion of the disc first prior to degeneration.
- Anterolisthesis and retrolisthesis, Modic changes and facet joint osteoarthrosis are most prevalent at level L5-S1.

- Schmorl nodes are most prevalent at level L1-L2.
- Disc levels with a Schmorl node will degenerate faster.
- Most patients were operated at level L5-S1. A discectomy was carried out most of all surgeries.
- After a discectomy is performed, the height of the disc will reduce.

Conclusion: The study could confirm a lot of assumed statements about degeneration of the cervical and lumbar spine, such as: for the cervical spine degenerative discs are most prevalent at level C5-C6, the height of the discs will reduce over time, etc. For the lumbar spine degenerative discs are most prevalent at level L4-L5 and L5-S1, the height of the discs will reduce over time, etc.

But some previously unreported new findings could be described as well.

In the cervical spine we are to our knowledge the first to report: 1. the height of discs in patients with osteophytes; 2.the age of patients with osteophytes; 3. the position of the centre of the nucleus pulposus.

In the lumbar spine we are to our knowledge the first to report: 1. the signal intensity in relation to the height of the disc; 2. the nature of the trauma in expulsed disc fragments; 3. the position of the centre of the nucleus.

INTRODUCTION

1 NORMAL INTERVERTEBRAL DISC

1.1 ANATOMICAL CONSTITUTION

An intervertebral disc consists of **3 structures**, the nucleus pulposus and the annulus fibrosus and the cartilaginous end plates. There is a difference in proportional distribution between the cervical, dorsal and lumbar spine but its basic components are proteoglycan, collagen, and water. The nucleus pulposus is the gelatinous centre, rich in water. It can tolerate high pressure when healthy. The annulus fibrosus has a more fibrous structure and contains a much higher amount of collagen (1-3).

The intervertebral disc is a soft cushion in-between two consecutive vertebrae. The disc has **3 main functions**: it is a shock absorber that carries the weight of the body or the head in case of the cervical spine; it is a pivot which lets the spine bend, rotate and twist; it is a structure to hold the spine together as a ligament (1).

1.2 HISTOLOGICAL CONSTITUTION

The fibrocartilage of the vertebral disc is arranged in 15-25 **concentric sheets** forming the annulus fibrosus. The annulus is composed of an outer region of dense **fibrocollagenous tissue** containing occasional chondrocytes. Within the disc, there is a central cavity, which contains a **viscous fluid** (1, 3).

Circumferential ligaments reinforce the annulus. A ligament extending down the anterior aspect of the spine and a thinner but similar ligament on the posterior side. The outer fibers, called **Sharpey's fibers**, are anchored into the periosteum of the vertebral endplate, and into the anterior and posterior longitudinal ligament (1, 3, 4).

The disc is **avascular**. To obtain nutrients the disc cells depend on molecular diffusion from blood vessels at the disc's margins. A fall in nutrient supply can lead to degeneration (1).

2 PATHOLOGICAL DISC

It's important to understand the process of intervertebral disc degeneration. Disc pathology plays an important role in the changes of the other structures of the spine. It can cause osteoarthritis of the facet joints, vertebral endplate changes, spinal canal stenosis, or even vertebral instability.

Degeneration begins quite early in life and can be caused by a variety of genetic, physiologic and environmental changes, but due to normal aging as well. There is no clear difference between the "age-related changes" and the pathologic changes. (1, 2).

Disc degeneration doesn't need to be painful as can be proven by the high prevalence in asymptomatic patients.

2.1 *ANNULAR FISSURE*

Annular fissures can be separations between the annular fibers or between the annular fibers and their attachment to the bone. They can be classified by their orientation. A concentric fissure is a separation of the fibers parallel to the contour of the disc. A radial fissure extends from the nucleus peripherally to the annulus. A transverse fissure is a horizontally oriented radial fissure (5).

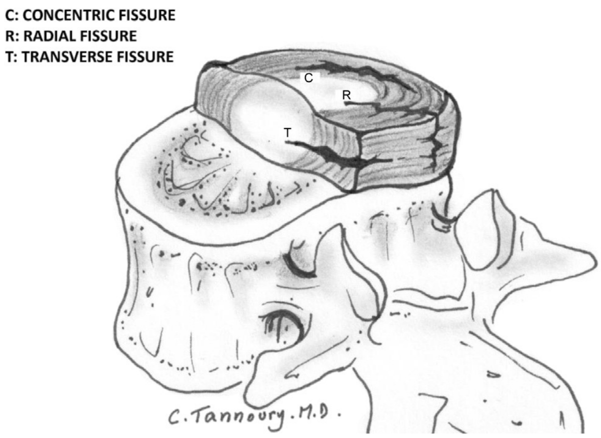


Figure 1: Fissures of the annulus fibrosus. C: Concentric fissure. R: Radial fissure. T: Transverse fissure (5).

On MRI imaging an annular fissure can show as a high-signal-intensity zone (HIZ). A HIZ is a small zone of high signal intensity on T2-weighted images or contrast enhanced T1-weighted images near the vertebral end plate. HIZ contain fluid or mucoid material from the nucleus that fill annular fissures (6).

2.2 *BULGING*

Bulging can be defined as the presence of disc tissue extending beyond the edges of the ring apophyses. This extension can be symmetrical or asymmetrical (5).

2.3 *HERNIATION*

Herniation is defined as the displacement of disc material beyond the limits of the intervertebral disc space. Disc material can be nucleus, cartilage, annular tissue or a combination. The disc material extends less than 25% of the periphery of the disc viewed in the axial plane (5).

2.3.1 Protrusion

A protrusion is defined when the greatest distance between the edges of the disc material presenting outside the disc space is less than the distance between the edges of the base of that disc material extending outside the disc space. Some fibers of the annulus are torn but the outermost fibers are still intact (4, 5).

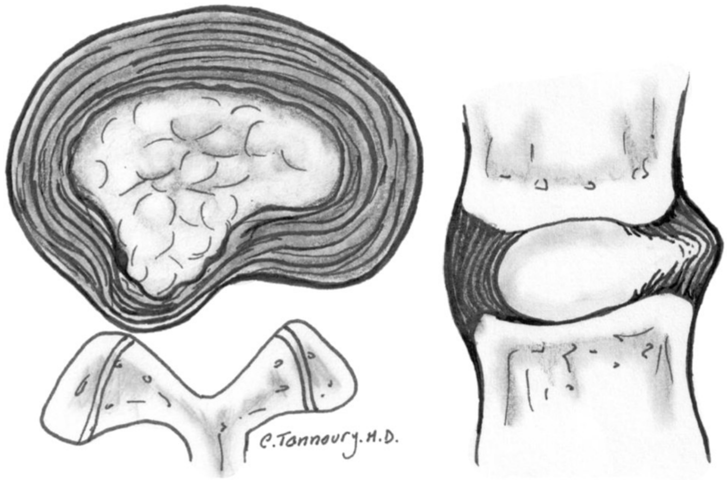


Figure 2: Axial and sagittal images show a protrusion of the disc. Images show displaced disc material (5).

2.3.2 Expulsion

An expulsion or extrusion is defined when the distance between the edges of the disc material beyond the disc space is greater than the distance between the edges of the base of the disc material or when no continuity exists between the disc material beyond the disc space and that within the disc space (5).

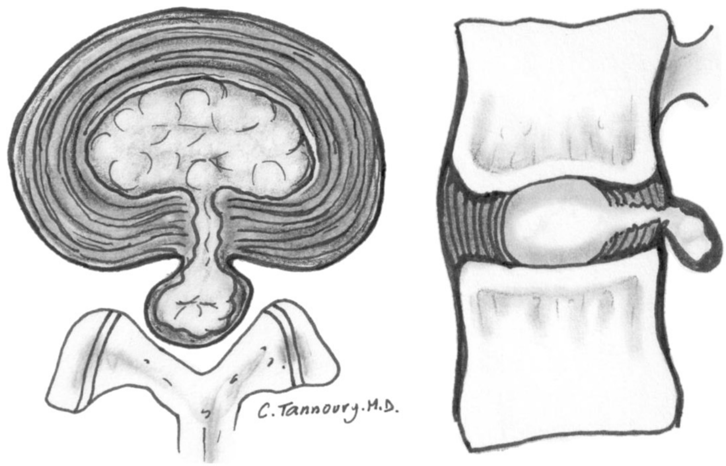


Figure 3: Axial and sagittal images show an extruded disc (5).

2.3.3 Intracorporal herniation

A herniated disc in the craniocaudad direction through the vertebral end plate is called an intracorporal herniation or Schmorl node. Schmorl nodes can form at adult age but when they are present in children or teenagers at multiple levels this is called Scheuermann's disease (4, 5).

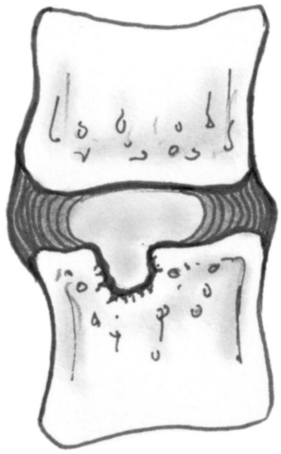


Figure 4: Sagittal image shows an intracorporal hernia or Schmorl node.

2.4 Modic changes

Changes in the vertebral body marrow are described by Modic in 1988. There are 3 main forms. Type I shows decreased signal intensity on T1-weighted images and an increased signal on T2-weighted images. This indicates the presence of bone marrow edema and inflammatory changes. Type II refers to an increased signal on T1-weighted images and an isointense or increased signal on T2-weighted images. Healthy bone marrow is replaced by fat. Type III is characterized by a decreased signal intensity on T1 and T2-weighted images. Reactive osteosclerosis is present. Modic changes can modify over time. For example type I can evolve in type II or convert back to a normal state (1).

3 MR imaging

Magnetic resonance imaging (MRI) can provide us the most relevant information for clinical assessment and diagnosis of intervertebral disc pathology. Degenerative changes of the disc result in changes of the water and proteoglycan content, these are probably responsible for the change in signal intensity on MRI (4).

3.1 T2 weighted images

Transverse relaxation time (T2) mapping correlates with changes in composition of intervertebral discs. For this reason most classification systems for degenerative disc changes use sagittal T2-weighted images. It has also a myelographic effect due to the high signal of the cerebrospinal fluid (CSF) and the intermediate signal of the spinal cord (7).

4 Pfirrmann classification

Disc degeneration can be classified using sagittal T2 weighted images as described by Pfirrmann et al. (8). Discs are divided into 5 grades. The height and structure of the disc and the signal intensity are taken into account (8).

Grade	Structure	Distinction of Nucleus and Anulus	Signal Intensity	Height of Intervertebral Disc
I	Homogeneous, bright white	Clear	Hyperintense, isointense to cerebrospinal fluid	Normal
II	Inhomogeneous with or without horizontal bands	Clear	Hyperintense, isointense to cerebrospinal fluid	Normal
III	Inhomogeneous, gray	Unclear	Intermediate	Normal to slightly decreased
IV	Inhomogeneous, gray to black	Lost	Intermediate to hypointense	Normal to moderately decreased
V	Inhomogeneous, black	Lost	Hypointense	Collapsed disc space

* Modified from Pearce (cited by Eyre et al[9]).

Table 1: Pfirrmann classification (8)

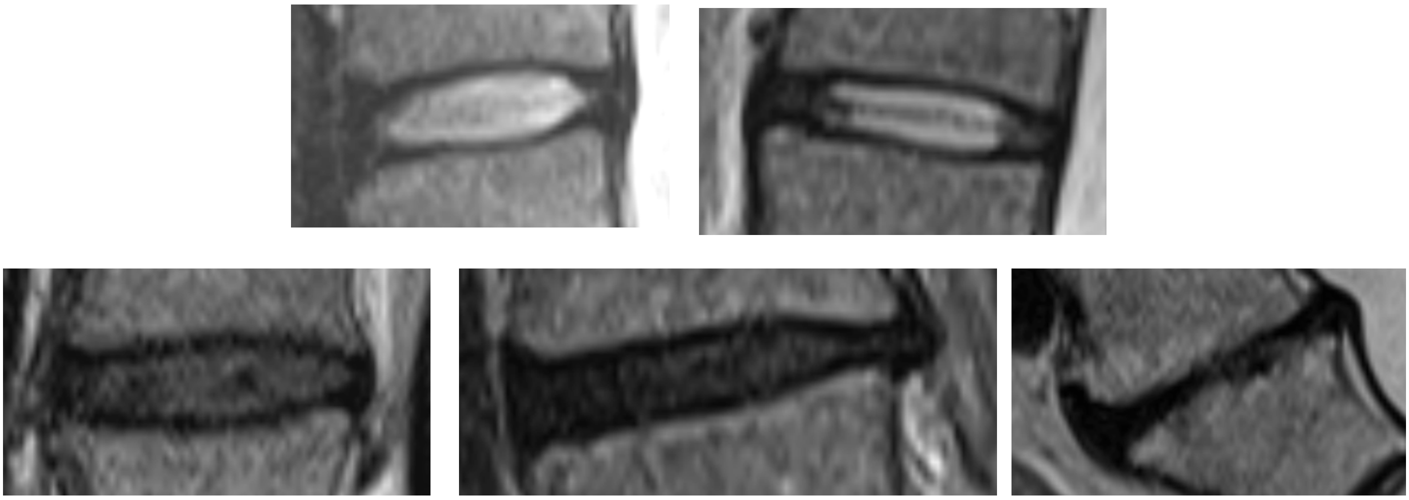


Figure 5: Illustration of the Pfirrmann classification. Top left: grade I, top right: grade II, bottom left: grade III, bottom middle: grade IV and bottom right: grade V.

GOALS OF THE RESEARCH

The purpose of this study was to investigate the validity of a number of hypotheses on the characteristics of the discs and the adjacent vertebra in the cervical and lumbar spine. Can the following hypotheses be confirmed or rejected by the results of this study?

- The height of the disc will be higher or as high as the disc space above.
- The ‘normal’ height of an intervertebral disc can be described in the cervical and lumbar spine.
- The disc space will become more and more narrow as people get older.
- Dehydrated nuclei (in the lumbar spine) are more common with increasing age.
- It is an irrelevant finding if a dark disc is seen in the cervical spine.
- The nucleus will not be in the middle of the intervertebral space at all times on sagittal images.
- The ‘typical levels’ where degeneration is more prevalent are L4-L5 and L5-S1 in the lumbar spine and C5-C6 and C6-C7 in the cervical spine.
- In case of anterolisthesis or retrolisthesis due to spondylolysis there will be a lysis first and the disc will degenerate afterwards.
- In case of degenerative anterolisthesis or retrolisthesis, there will be a degenerative disc prior to anterolisthesis or retrolisthesis.
- The signal will be bright in case of a recent herniation of the nucleus and will dehydrate and become darker over time.

MATERIALS AND METHODS

The institutional ethics committee approved this retrospective and longitudinal study. Belgian registration number: B670201526450.

1 STUDY GROUP

Four groups were investigated. One study group (n= 505) underwent imaging of the lumbar spine because of low back pain. The second study group (n= 506) underwent imaging of the cervical spine because of neck pain. Both of these groups consisted of patients that were reassessed by an independent radiologist because of insurance issues. These patients had car-accidents or occupational accidents in most cases. The date of their accident or trauma and the causal relation between the clinical manifestations and the radiological findings were reported.

The third and fourth group are control populations, one group for the lumbar spine (n=176) and one group for the cervical spine (n=114). They underwent imaging of the spine because of complaints of the neck or back but all of them were reviewed normal by independent radiologists. There were no pathological findings on these scans. These patients were selected randomly in the imaging database of our tertiary care centre.

The longitudinal part of the study was carried out by reviewing follow up MRIs from the same patients done over the course of several years. This was not carried out for the control group.

2 MAGNETIC RESONANCE IMAGING

Some patients of the study group had new imaging in our tertiary care centre but most of them were reviewed by their scans that were made in different hospitals all over the country. The imaging protocol in most cases was: for the cervical spine, T2-weighted sagittal images and T1-weighted sagittal images in combination with T2*-weighted axial images. For the lumbar spine, T2-weighted sagittal images and T1-weighted sagittal images in combination with T2-weighted and T1-weighted axial images.

The images of the control populations were made in our hospital. The images were obtained with a 1,5T-unit using the following sequences. The cervical spine: 3 to 4 mm sagittal T1-weighted and T2-weighted images. Some cases had STIR T2-weighted axial images. Three to 4 mm axial T2*-weighted images and also T1-weighted images in some cases. The lumbar spine: 3 to 4 mm sagittal T1-weighted and T2-weighted images. Some cases had STIR T2-weighted images. Three to 4 mm axial T2-weighted images and T1-weighted images.

3 IMAGE REVIEW/ASSESSMENT

A radiologist with over 25 years of experience reviewed all images. Every disc was reviewed as normal or abnormal. In an abnormal disc the pathology was described. The pathologies of the various discs were described in a standard way. The presence of bone marrow edema and Modic type I to III was registered. The type of herniation or protrusion and at which side of the disc it occurred was described. The presence of osteophytes at the posterior edge of the vertebral body was recorded. Bulging of the disc was described. If Schmorl nodes were present, they were described. The same was done when osteoarthrosis of the facet joints was present. Annular tears were described as well. A difference was made between radial, transverse, concentric tears and HIZ's. The presence of anterolisthesis, retrolisthesis and spondylolysis was noted. The presence of uncovertebral joint arthrosis was described in the cervical spine as well as the appearance at the left or right side or bilaterally. Intervertebral disc degeneration was diagnosed based on signal changes and reduced height of the disc. The degeneration was graded using the Pfirrmann classification (8). A detailed description of the kind of surgery was made which was seen on the images. The abnormal forces, like scoliosis, transitional anomaly, fused vertebrae and others were noted. The position of the nucleus pulposus was described reviewing the sagittal images. Is it more anteriorly or posteriorly or in the middle of the vertebrae? This was done at sight; the disc was divided into 4 equal parts and the middle.

	Finding	**Details**
Vertebral body	Modic changes	Type I to III or combination
	Osteophytes	Only if they are present at the posterior side
	Schmorl node	Cranially/caudally/both
	Uncovertebral joint arthrosis*	Left/right/bilateral
Disc space	Normal/abnormal	Abnormal: herniation, bulging, protrusion or AF
	Herniation	Location is described
	Bulging/protrusion	Presence or absence of bulging or protrusion
	Annular fissures	Radial/transverse/concentric tears/HIZ's
	Pfirrmann classification	Grade I to V
	Position of the NP	Anteriorly/middle/posteriorly
Other	Facet joint osteoarthrosis	Left/right/bilateral
	Listhesis	Anterolisthesis/retrolisthesis
	Spondylolysis	Left/right/bilateral
	Abnormal forces	Scoliosis/transitional anomaly/fused vertebrae/others

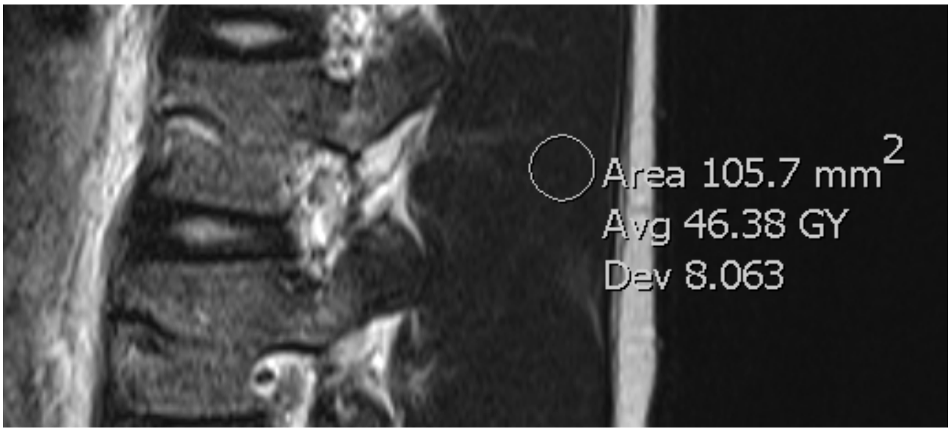
Table 2: Overview of the different recorded parameters. AF: annular fissure, NP: nucleus pulposus. *Only in the cervical spine.

4 MRI MEASUREMENTS

Several measurements were taken. To obtain a representative result all measurements were performed on a midsagittal T2-weighted image where most of the spinous processes were visible. The height of the discs was measured by a straight line through the highest part of the disc and in a 90° angle to the end plate of the vertebral body underneath.

Signal intensities were measured using a circular ROI in different areas: centre of the nucleus pulposus, posterior part of the annulus fibrosus, in the herniated part of the disc and in the area of the disc with the highest signal intensity.

To be able to standardise the signal intensity over the different MRI systems, the signal intensity and the standard deviation of the air surrounding the patient was measured using a circular ROI. The signal intensity of the cerebrospinal fluid (CSF) and the signal intensity of the paravertebral muscles were measured using a circular ROI as well. At the cervical spine the same technique was used but the signal intensity of the musculus capitis inferior was measured instead of the paravertebral muscles.



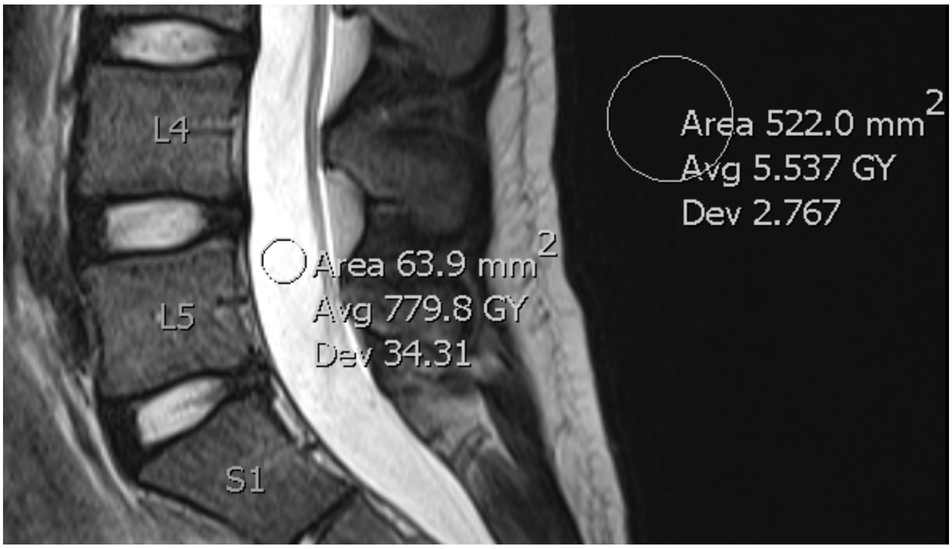
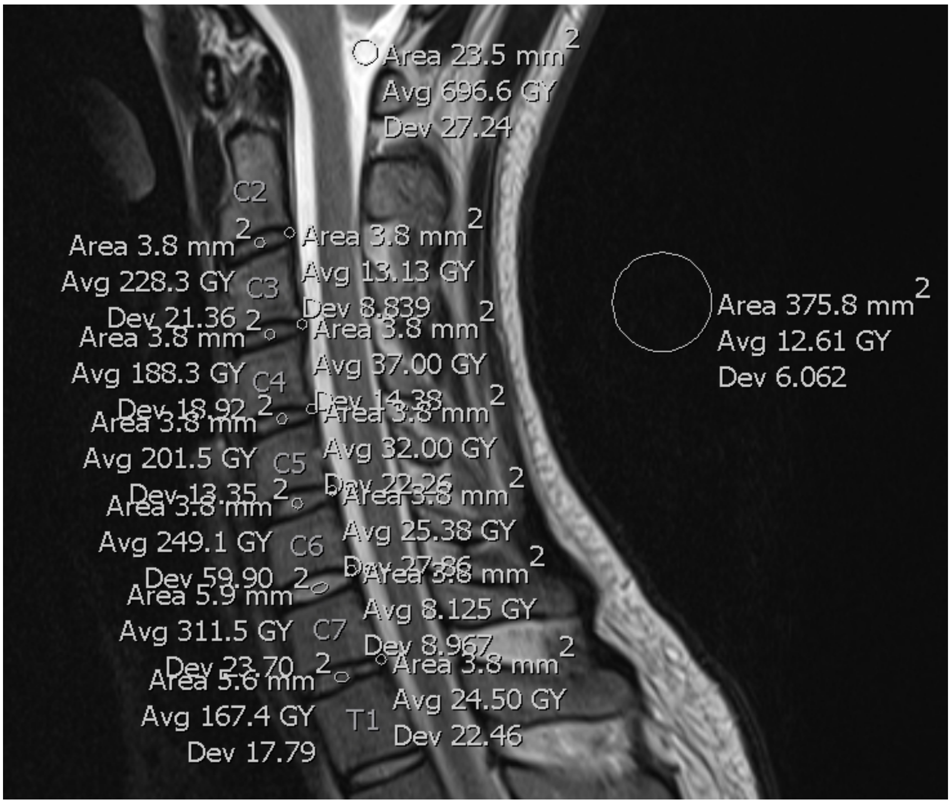


Figure 6: Illustration of the ROI measurements in the lumbar spine. The first shows the measurement of the nucleus pulposus and annulus fibrosus. On the second image the ROI is placed in the area of the paravertebral muscles. The third image shows the measurements of the CSF and the air surrounding the patient.



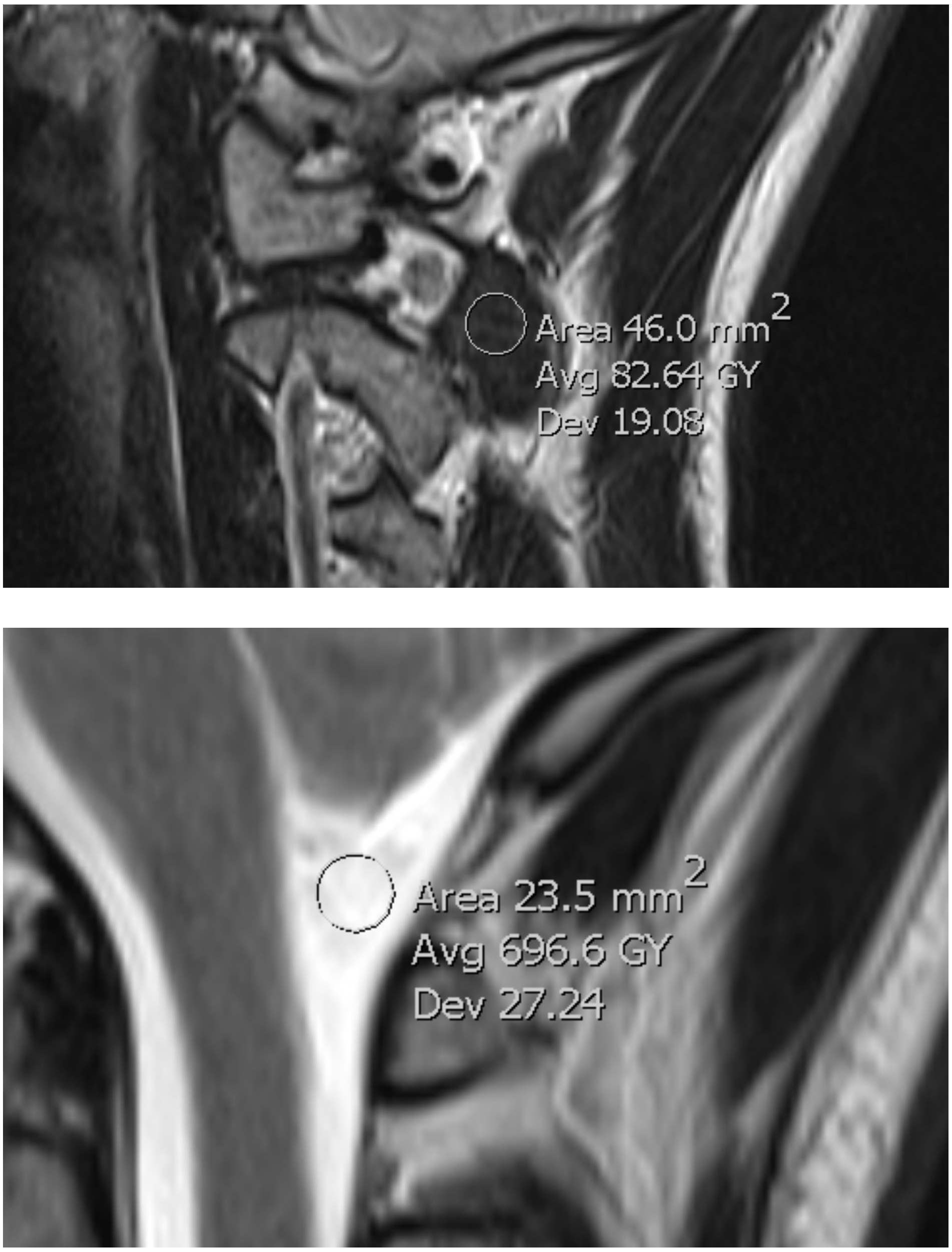


Figure 7: Illustration of the ROI measurements in the cervical spine. The first image shows the measurements of the nucleus and annulus at every level, the measurement of the CSF and the air surrounding the patient. The second image shows the measurement of the signal intensity of the muscle. The third image is a detailed image of the way the signal intensity of the CSF was measured.

5 DATA ANALYSIS

More than 144 data points were noted per scan. To standardize the signal intensity measured on different scans with different scan protocols the signal intensity of the nucleus, annulus and the herniated part was divided by the signal of the air surrounding the patient.

Statistical analysis was performed using software package SPSS 23.0 for Windows (SPSS, Chicago, IL, USA). Basic descriptive statistics were performed where appropriate. Correlation was investigated using Pearson's correlation coefficient and Spearman's correlation coefficient for non-parametric variables. Student's t-test was used to determine if two sets of data were significantly different from each other.

Unless stated otherwise, the level of statistical significance was set at p=0,05.

RESULTS

1 CERVICAL SPINE

The database consisted of **506 MRI images** of the cervical spine, including **283 individual patients**. The patients age ranges from 13-80 years old (mean: 41,5). Out of 283 patients, 168 (59,4%) are female and 115 (40,6%) are male. The patient with the longest follow up in our database had 5 scans.

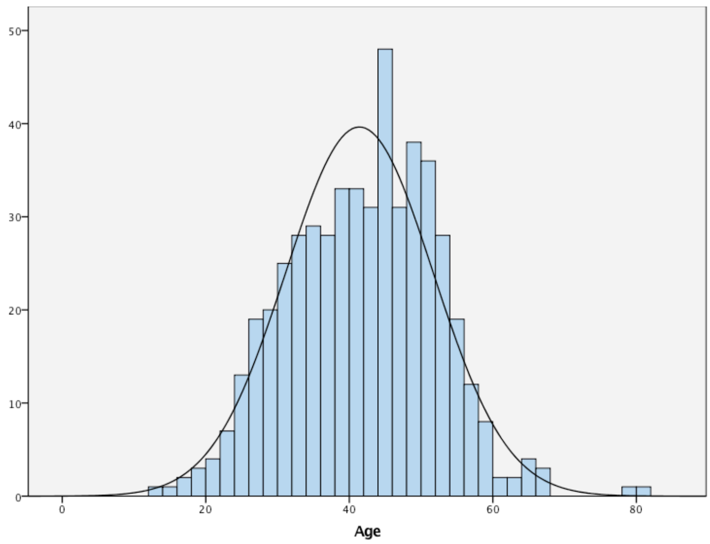


Figure 8: Age distribution of patients who underwent cervical imaging.

1.1.1 Control population

The control population consists of **114 patients**. Fifty-seven (50%) males and 57 (50%) females. Age ranges from 18 to 36 years old (mean: 27). Six patients are 18 years old (3 males, 3 females), 6 patients are 19 years old (3 males and 3 females), 6 patients are 20 years (3 males and 3 females) old and so on.

1.2 TRAUMA MECHANISM

The events were divided into four categories. Forty-seven (16,6%) patients had an occupational accident and in 48 (17,0%) patients the occupational accident happened on the road, 155 (54,8%) patients had traffic accidents and 33 (11,7%) patients had other accidents that didn't fit into the first categories.

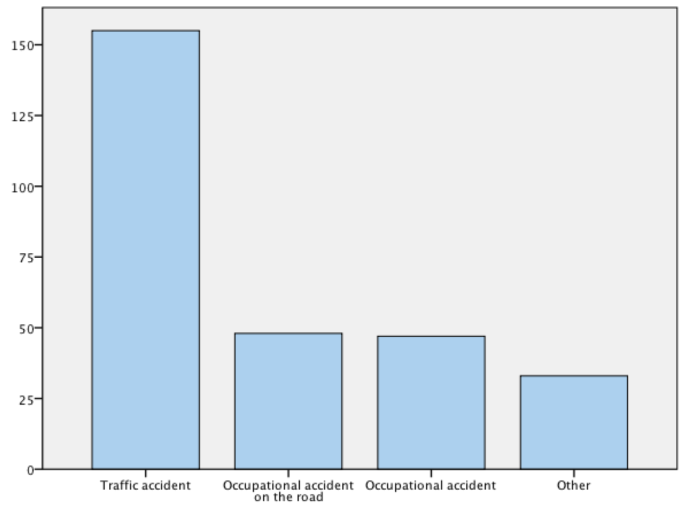


Figure 9: Bar chart of different kinds of accidents. First traffic accidents, second occupational accidents on the road, third occupational accidents and last 'other'. Y-axis shows the number of patients.

Mechanisms of trauma. Most of the patients had a whiplash trauma (n= 136, 48,1%), Forty-one (14,5%) patients had combined accidents. An accident was a combined accident if the accident was more severe than a rear-end collision. Thirty-nine (13,8%) patients fell in an occupational setting. In 15 (5,3%) patients a heavy object fell down onto them and they had a contusion of the cervical spine. Four (1,4%) patients were victims of aggression. Three (1,1%) patients had rotational accidents. Three patients (1,1%) had lifted a heavy weight. Two (0,7%) had neck pain after surgery. In 40 (14,1%) patients the exact description of their trauma was missing.

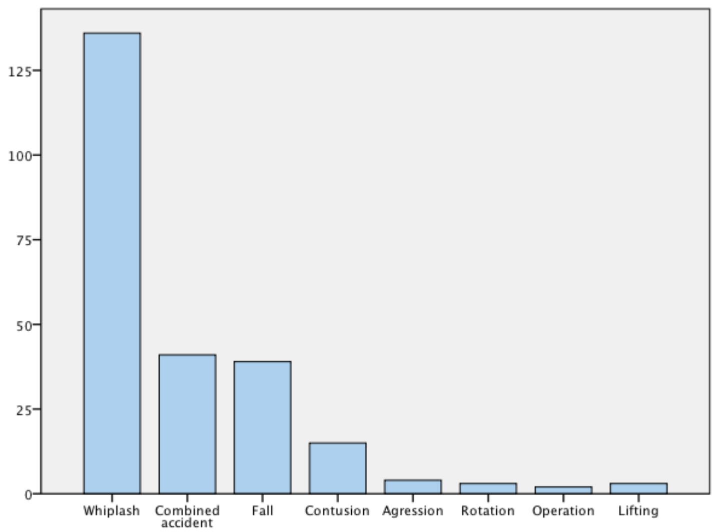


Figure 10: bar chart giving an overview of the different kinds of trauma.

1.2.1 Gender in relation to the kind of trauma

Female population. Most of the patients had whiplash trauma (N= 90, 53,6%), twenty-one (12,5%) patients had combined accidents. Twenty-one (12,5%) patients fell in an occupational setting. In 5 (3%) patients a heavy object fell down onto them and they had a contusion of the cervical spine. One (0,6%) patient was a victim of aggression. Two (1,2%) patients had rotational accidents. One patient

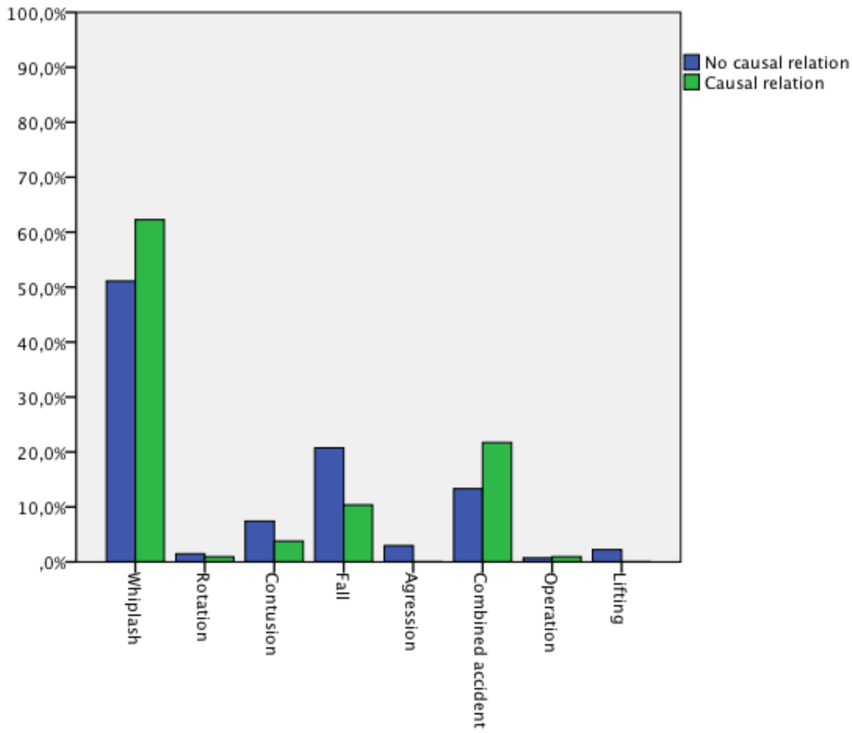
(0,6%) had lifted a heavy weight. Two (1,2%) had neck pain after surgery. In 25 (14,9%) patients the exact description of their trauma was missing.

The **male** population had similar distribution of the kinds of accidents. Most of the patients had whiplash trauma (N= 46, 40%), Twenty (17,4%) patients had combined accidents. Eighteen (15,7%) patients fell in an occupational setting. In 10 (8,7%) patients a heavy object fell down onto them and they had a contusion of the cervical spine. Three (2,6%) patients were victims of aggression. One (0,9%) patient had a rotational accident. Two patients (1,7%) had lifted a heavy weight. In 15 (13%) patients the exact description of their trauma was missing.

In conclusion: male patients have less whiplash trauma and more severe accidents. They also fall more and have more contusions of the spine. And they are more frequently victims of aggression.

1.2.2 Causal relationship between trauma and radiological findings

In most cases (143, **55,4%**) the expert radiologist found **no causal relation** between the accident and the radiological findings. In 111 (**43%**) cases there is a **causal relation** between the accident and the radiological findings. Only in case of a combined accident there is more frequently a causal relationship between the trauma and the radiological findings.



Mechanism	No causal relation	Causal relation	TOTAL
Whiplash	69 **(51,1%)**	66 (48,9%)	135
Rotation	2 **(66,7%)**	1 (33,3%)	3
Contusion	10 **(71,4%)**	4 (28,6%)	14
Fall	28 **(71,8%)**	11 (28,2%)	39
Aggression	4 **(100%)**	0	4
Combined accident	18 (43,9%)	23 **(56,1%)**	41
Operation	1 (50%)	1 (50%)	2
Lifting	3 **(100%)**	0	3
TOTAL	**135 (56%)**	**106 (44%)**	**241**

Table 3/figure 11: The relation between the different mechanisms of trauma and the causal relation between the trauma and the radiological findings.

1.3 Interval between accident and first MRI

The time between the accident and the date of the scan was expressed in months. The time has a range between 63 months before the accident and 540 months after the accident. In 26 patients there are scans before the accident. The patients had complaints of the neck even before the accident.

If only the first scan which was made after the accident is considered the amount of months ranges from 0 to 540. **The graph underneath shows most patients get an MRI scan within the first 5 months after the accident.**

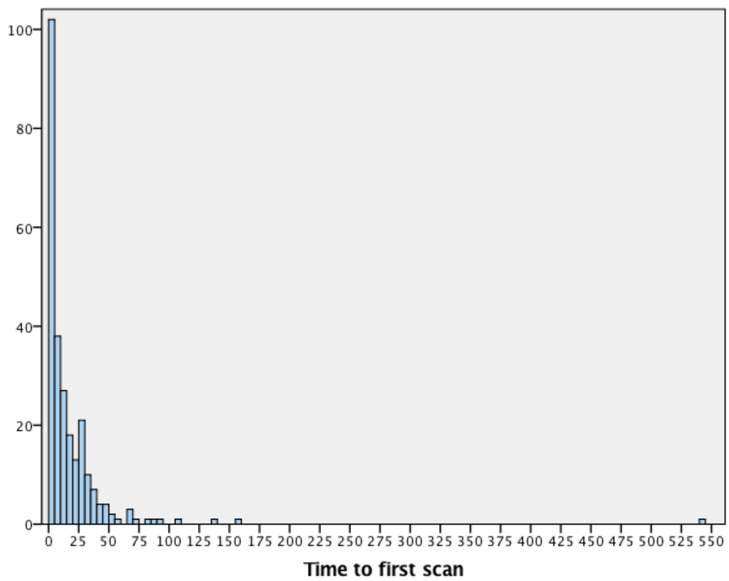


Figure 12: Time (in months) between the accident and the first MRI. One bar represents five months.

Key point: Most patients are referred for an MRI scan within the first 5 months after trauma.

1.4 HEIGHT OF THE DISC

The mean height of the intervertebral disc space between C5 and C6 is the lowest. The disc space between C3 and C4 is **higher** than every disc space close to it. Detailed information can be found in the appendix.

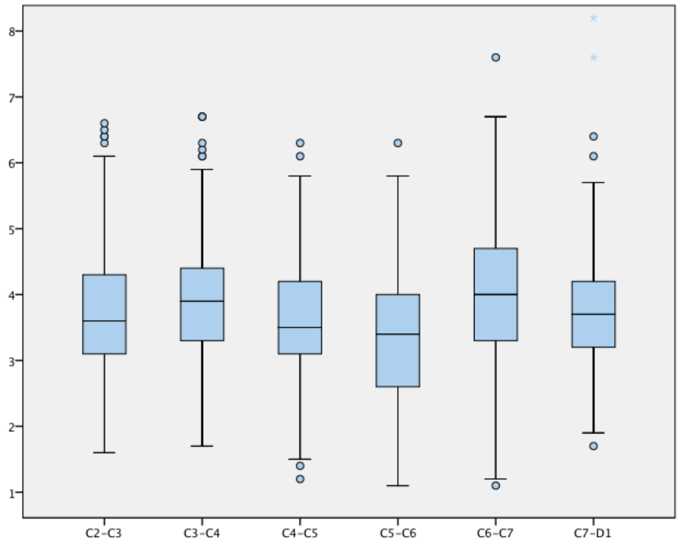


Figure 13: Boxplot showing the height of the different intervertebral disc spaces. Height is expressed in mm.

Key point: Disc C3-C4 is higher than every disc close to it.

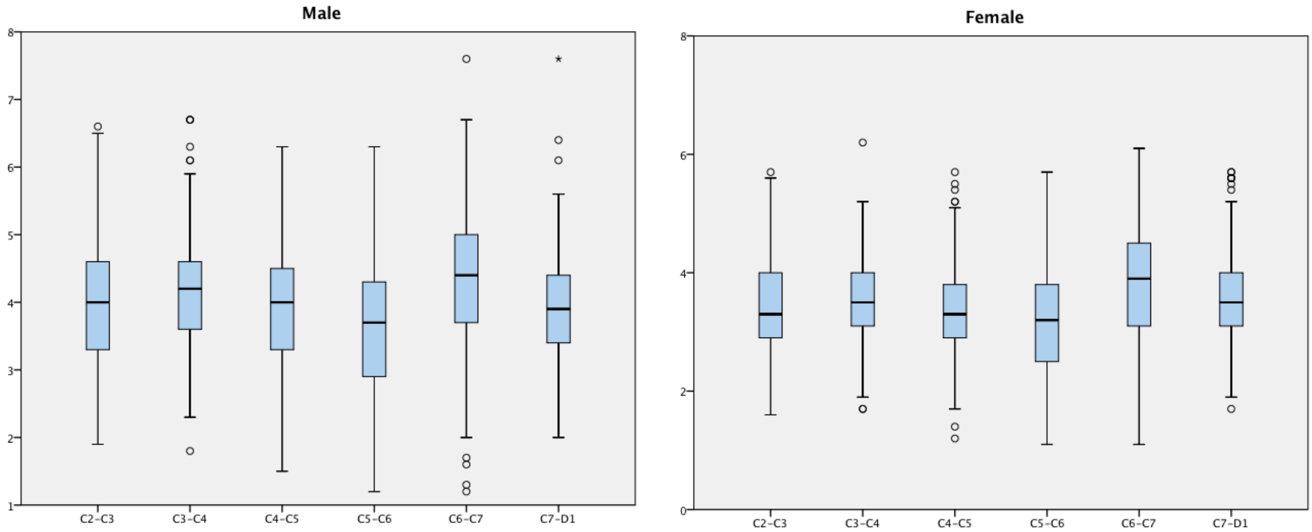


Figure 14: Boxplots of the height of the disc in males and females side by side. Height in mm.

1.4.1 Height of the disc in control population

The disc space between C3 and C4 is higher than the ones surrounding it, like in our sample group. The height of C5-C6 and C6-C7 is higher than in the sample group. These levels degenerate faster. Details can be found in the appendix.

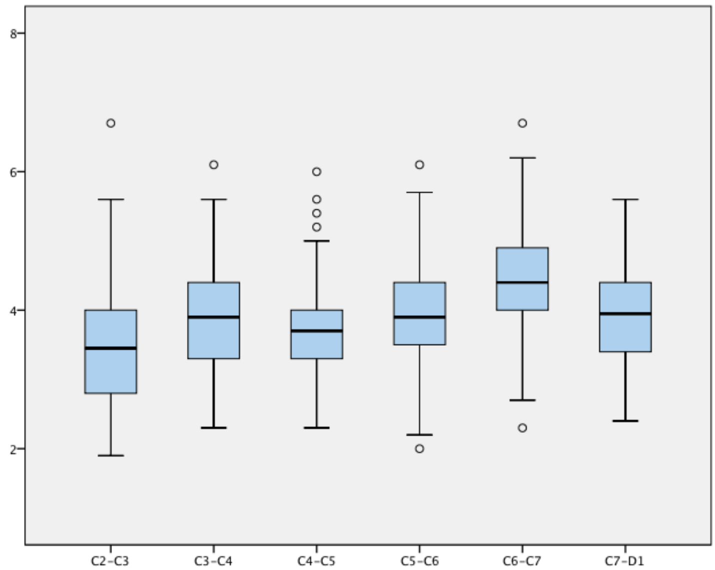


Figure 15:Boxplot of the height of the disc spaces of the cervical spine in the control population. Height in mm.

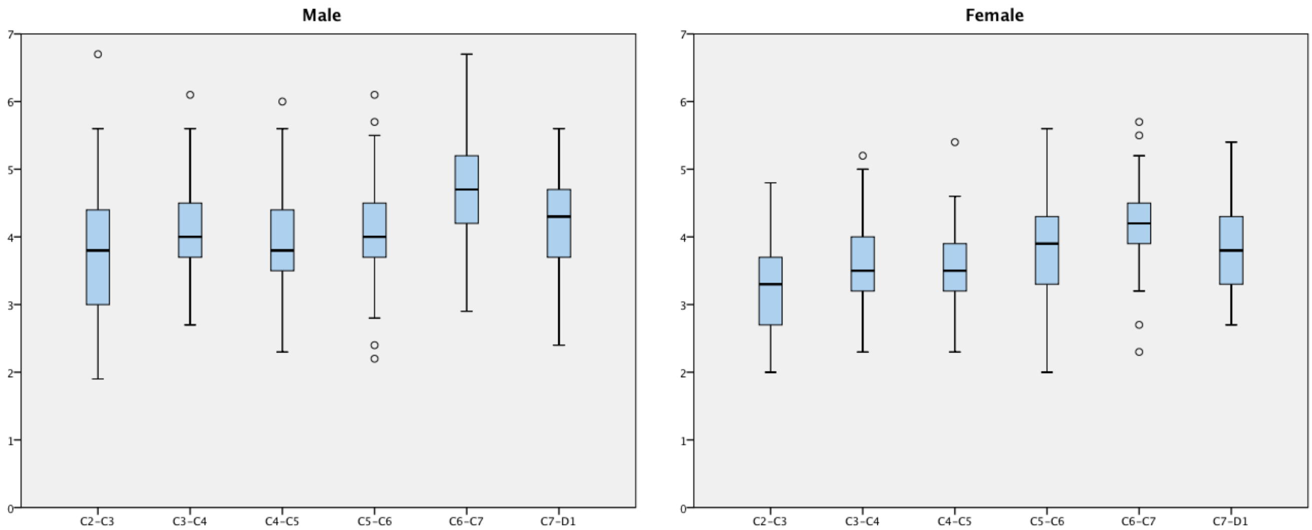


Figure 16: Height of the disc spaces displayed in male and female patients in the control population. Height in mm.

1.4.2 Height in relation to age

The height of the discs was correlated with the age of the patients. The aim of this test was to identify whether the height of intervertebral discs will decrease, increase or remain unchanged when people get older.

The height will **decrease significantly** with an increase in age at levels **C5-C6** ($p < 0{,}001$) and **C6-C7** ($p<0{,}001$). The other levels show a decrease in height (except C2-C3, which goes up), but are not statistically significant.

At level C5-C6 and level C6-C7 in male patients the height of the disc will decrease 0,02 mm each year, in female patients it will decrease 0,03 mm each year.

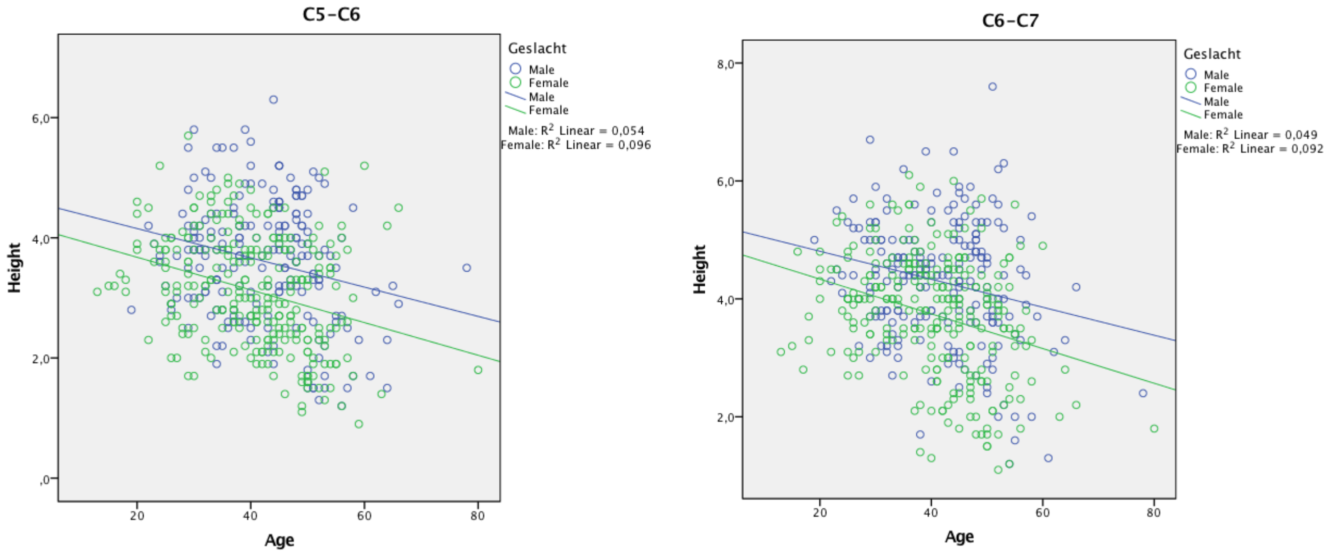


Figure 17: Scatterplot shows the best fitting line through the dots. Left level C5-C6 and right level C6-C7. The height is expressed in mm. Age in years. Blue dots for males, green dots for females. Remark the decrease in height with increasing age.

Levels C5-C6 and C6-C7 will decrease more than the other levels because these levels will degenerate first.

In **female patients** alone there is a decrease in height at every level. Only levels C5-C6 ($p<0,001$), C6-C7 ($p<0,001$) and C7-D1 ($p=0,002$) have a statistically significant decrease in height.

In **male patients** the height of the discs will decrease at every level except C2-C3. It will decrease statistically significant at levels C5-C6 ($p=0,001$) and C6-C7 ($p=0,001$). At level C2-C3 ($p=0,001$) the height appears to increase with increasing age.

Key point: The height of the disc will decrease in older patients.

1.4.3 Height in relation to age in control population

In contrary to the sample group, the height of the disc will **increase** at every level in relation to the age in the control population (aged 18-36 years old). This finding is statistically significant at level C2-C3 ($p=0,02$), C4-C5 ($p=0,03$) and C5-C6 ($p=0,01$).

1.4.4 Height post- and premenopausal

At all age groups the mean height of the discs in male patients is higher than the height of the discs in female patients. The difference between the height of discs in young females in contrary to postmenopausal females is especially remarkable at level C6-C7. This is known to be a level affected by degeneration. In the male population the discs of the older population are lower at levels C5-C6 and C6-C7 but higher at the other levels. This could be due to the fact the group of males older than 55 is too small (n=16) to generate a useful result.

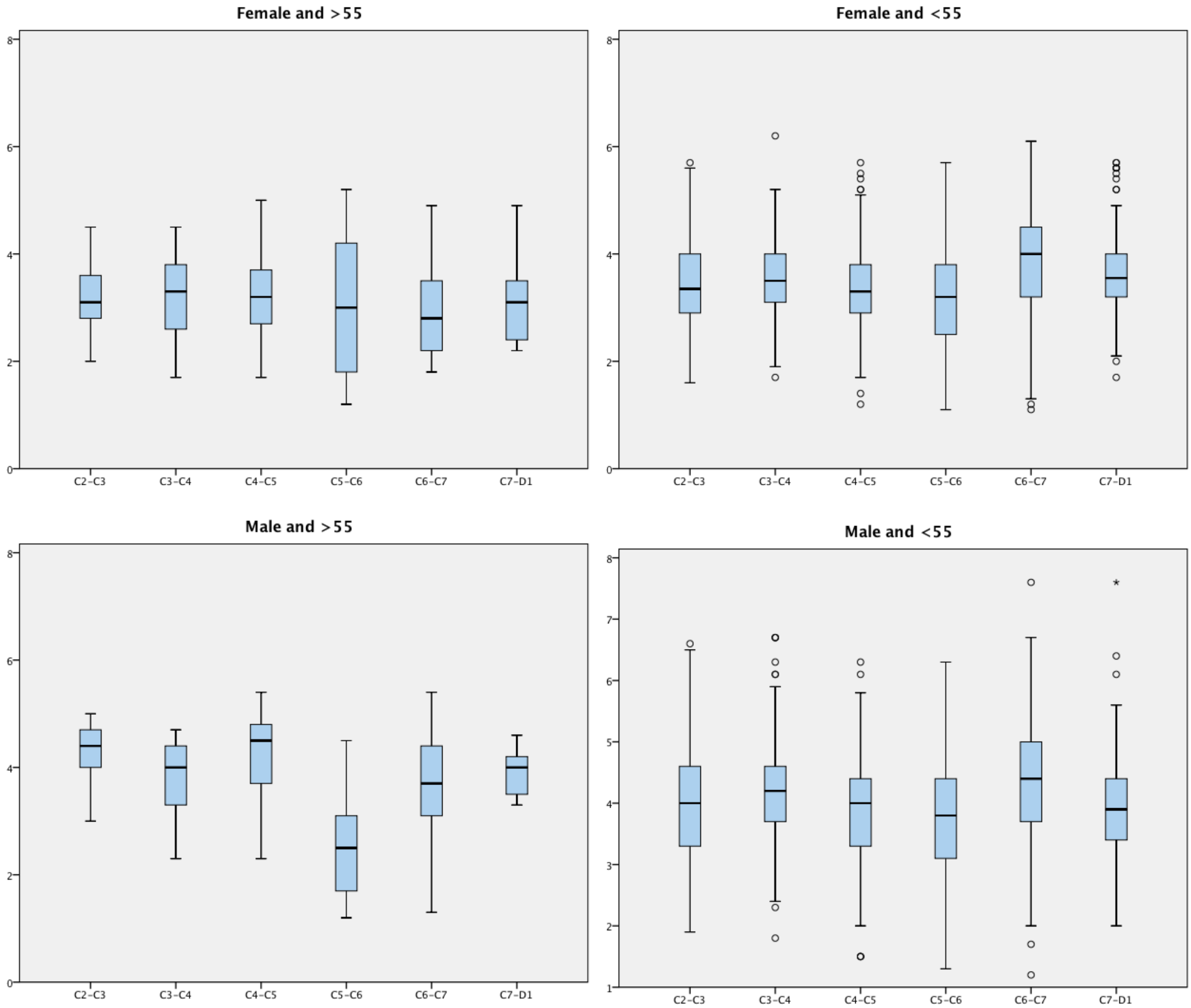


Figure 18: Boxplots displaying the height (mm) of the disc in females and males in two age groups, one over 55 years old and one younger.

1.5 SIGNAL INTENSITY

1.5.1 Signal intensity in relation to age

Correlation between the signal intensity of the nucleus pulposus and the age was calculated. **The signal intensity lowers at all levels with increasing age.** This finding is also statistically significant at all levels. P< 0,001 at level C2-C3, C3-C4, C6-C7 and C7-D1; p= 0,001 at level C4-C5 and p= 0,01 at level C5-C6.

It is possible the correlation is less significant at levels C4-C5 and C5-C6 because these levels degenerate first and will have a reduced height earlier in life.

1.5.2 Signal intensity in relation to age in the control population (18-36y)

The signal intensity will decrease significantly at every level (except level C3-C4) with increasing age. P<0,001 at levels C2-C3 and C7-D1, p=0,01 at level C4-C5, p=0,006 at level C5-C6 and p=0,002 at level C6-C7. So even between 18 and 36 years old there is already a change in signal intensity and water content.

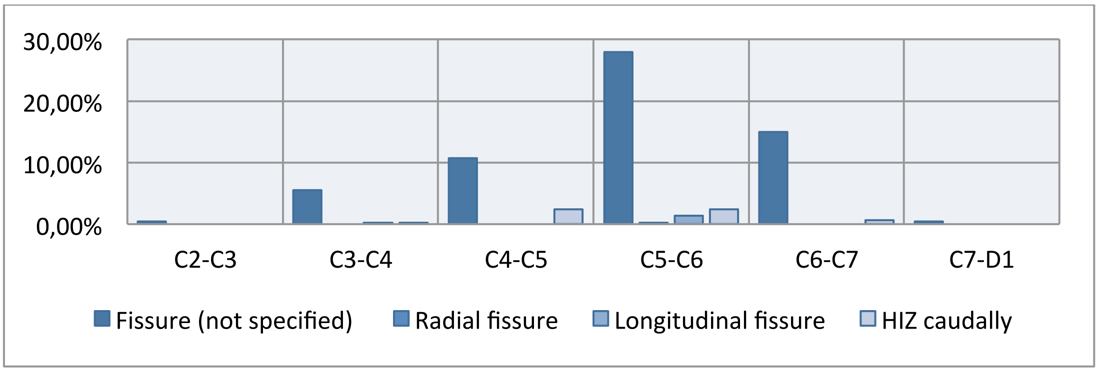
Key point: The signal intensity of the nucleus pulposus will decrease if people get older. Even in a young and healthy population.

1.5.3 Signal intensity in relation to height

At levels C2-C3 (p<0,001), C3-C4 (p<0,001), C4-C5 (p<0,001) and C5-C6 (p=0,015) the **signal of the nucleus pulposus will decrease when the height increases**. At levels C6-C7 and C7-D1, there is no statistical significance.

1.6 *ANNULAR FISSURES*

The table underneath shows **annular fissures** are most present at level **C5-C6**. Of 3036 reviewed discs 340 (11,20%) have an annular fissure or HIZ.



	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
No fissure	**502 (99,2%)**	**471 (93,1%)**	**426 (84,2%)**	**309 (61,1%)**	**400 (79,1%)**	**499 (98,6%)**
Fissure (not specified)	2 (0,4%)	28 (5,5%)	54 **(10,7%)**	141 **(27,9%)**	76 **(15%)**	2 (0,4%)
Radial fissure				1 (0,2%)		
Longitudinal fissure		1 (0,2%)		7 (1,4%)		
HIZ caudally		1 (0,2%)	12 (2,4%)	12 (2,4%)	3 (0,6%)	
Missing	*2 (0,4%)*	*5 (1%)*	*14 (2,8%)*	*36 (7,1%)*	*27 (5,3%)*	*5 (1%)*

Table 4/ figure 19: Prevalence of annular fissures in the cervical spine.

Key point: Annular fissures are most prevalent at level C5-C6.

1.6.1 HIZ

High-signal-intensity zones are most prevalent in the cervical spine at levels **C4-C5 and C5-C6**. **All HIZ were found at the caudal part of the annulus in our sample group probably due to hyperflexion forces**. See table above.

All of these HIZ were seen on discs with herniation and bulging. In theory HIZ can occur on normal discs but in our sample group this cannot be demonstrated.

Key point: All HIZ at the cervical spine are located at the caudal part of the disc.

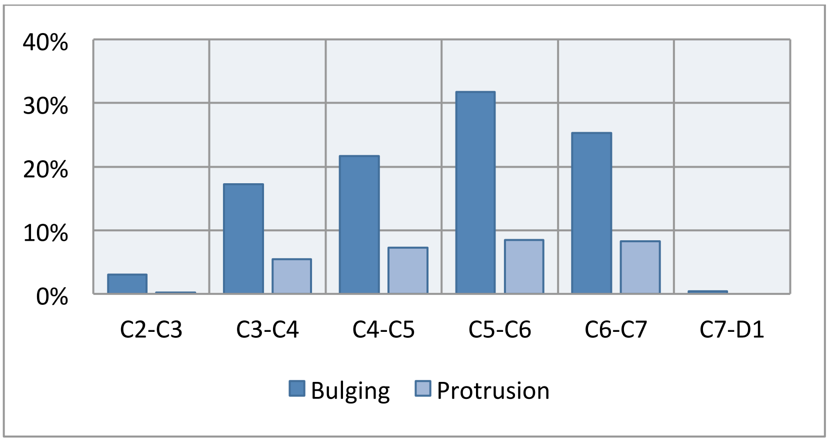
1.6.2 HIZ and height

There is no statistical significant difference in height between the height of discs with a **HIZ** and discs without a HIZ**.** The mean height of the discs with a HIZ is higher than the mean height of our sample. At level C4-C5 the mean height is even higher than that of the control population. For details see appendix.

Key point: The presence of a HIZ does not influence the height of the disc.

1.7 BULGING

The table underneath shows **bulging and protrusion** are most frequent at levels **C4-C5, C5-C6 and C6-C7**. It can also state a bulging disc is more frequent than a protruding disc.



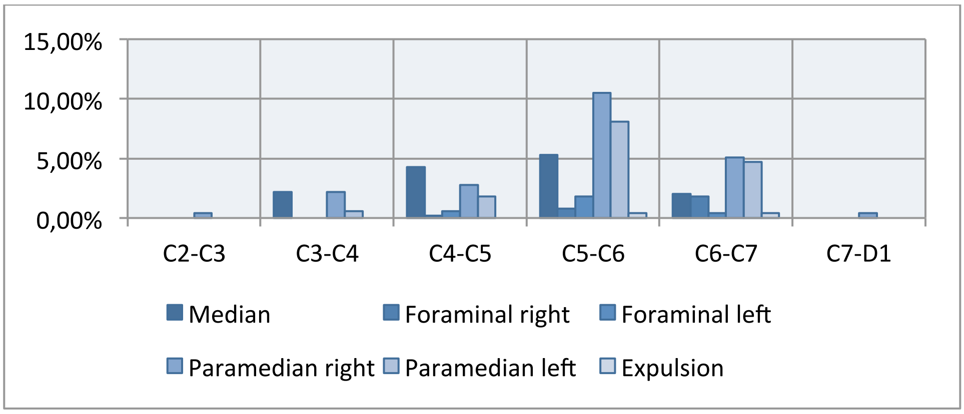
	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1	*TOT*
Normal	**488 (96,4%)**	**386 (76,3%)**	**345 (68,2%)**	**266 (52,6%)**	**309 (61,1%)**	**499 (98,6%)**	
Bulging	15 (3%)	87 **(17,2%)**	110 **(21,7%)**	161 **(31,8%)**	128 **(25,3%)**	2 (0,4%)	*503*
Protrusion	1 (0,2%)	28 **(5,5%)**	37 **(7,3%)**	43 **(8,5%)**	42 **(8,3%)**		*151*
Missing	*2 (0,4%)*	*5 (1%)*	*14 (2,8%)*	*36 (7,1%)*	*27 (5,3%)*	*5 (1%)*	*89*

Table 5/ figure 20: Prevalence of bulging and protrusion in the cervical spine.

Key point: Bulging and protrusion is most prevalent at level C5-C6.

1.8 HERNIATION

The table underneath shows **herniated discs** are most frequent at level **C5-C6 and C6-C7**. Paramedian herniations are reported most followed by median herniations. Foraminal herniations are less frequent.



	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1	*TOT*
Normal	**502 (99,2%)**	**476 (94,1%)**	**443 (87,5%)**	**334 (66,0%)**	**406 (80,2%)**	**499 (98,6%)**	
Herniation	**2 (0,4%)**	**25 (5%)**	**49 (9,7%)**	**136 (26,8%)**	**73 (14,4%)**	**2 (0,4%)**	
Median		11 (2,2%)	22 (4,3%)	27 (5,3%)	10 (2%)		*70*
Foraminal right			1 (0,2%)	4 (0,8%)	9 (1,8%)		*14*
Foraminal left			3 (0,6%)	9 (1,8%)	2 (0,4%)		*14*
Paramedian right	2 (0,4%)	11 (2,2%)	14 (2,8%)	53 **(10,5%)**	26 **(5,1%)**	2 (0,4%)	*108*
Paramedian left		3 (0,6%)	9 (1,8%)	41 **(8,1%)**	24 **(4,7%)**		*77*
Expulsion				2 (0,4%)	2 (0,4%)		*4*
Missing	*2 (0,4%)*	*5 (1%)*	*14 (2,7%)*	*36 (7,1%)*	*27 (5,3%)*	*5 (1%)*	*89*

Table 6/ figure 21: Amount of herniated discs in the cervical spine.

Key point: Herniated discs are most prevalent at level C5-C6.

1.8.1 Age and herniated disc

The mean age of the **patients with herniated discs is significantly (p<0,05) older** compared to patients in our sample without herniated discs. The patients with herniated discs have a mean age of 42,3 and these without have a mean age of 41,5 years old.

1.8.2 Time between trauma and herniation

The database contains six cases in which there is an image without herniation and on follow-up imaging a herniation has developed.

Imaging before the accident:

1. 2 months after the trauma the herniation was first seen, it was not present on imaging 14 months before the accident.
2. 27 months after the trauma the herniation was first seen, it was not present on imaging before the accident.

Imaging after the accident:

3. 27 months after the trauma the herniation was first seen, it was not present on imaging 2 months after the accident.
4. 21 months after the trauma the herniation was first seen, it was not present on imaging in the days following the accident.
5. 25 months after the trauma the herniation was first seen, it was not present on multiple imaging 3, 10 and 16 months after the accident.
6. 107 months after the trauma the herniation was first seen, it was not present on imaging 87 months after the accident.

Case 5 and 6 probably had a second (non reported) trauma.

1.8.3 Height of herniated disc

Investigation of the height of herniated disc showed **no statistically significant difference** between it and the height of discs without herniation. Details can be found in the appendix.

1.8.4 Herniation on two consecutive levels

In our database, **twenty-five** patients have a herniation on two consecutive levels. In only three patients only one herniation is present and the second one is seen on follow up imaging.

1. First MR: protrusion at C4-C5 and herniation at C5-C6. Second MR: herniation at both levels
2. First MR: herniation at C5-C6. Second MR: herniation at level C5-C6 and C6-C7. Third MR: expulsion of the herniation at level C6-C7
3. First MR (one month after trauma): herniation at C6-C7 and bulging at C5-C6. Second MR (9 months later): herniation at levels C5-C6 and C6-C7

Only in the third case there was an annular fissure visible on the first MR, before the herniation.

1.8.5 Herniation and scoliosis

In 13 patients a herniation and scoliosis of the cervical spine is reported. Six out of 13 patients have a herniation on the right side of the spine and a dextroconvex scoliosis or they have a herniation on the left side of the spine and a sinistroconvex scoliosis. Four out of 13 patients have a herniation on the left side of the spine and a dextroconvex scoliosis or they have a herniation on the right side of the spine and a sinistroconvex scoliosis. Four out of 13 have a median herniation.

1.8.6 Herniation and signal intensity

There is **no statistically significant difference** between the signal intensity of the nucleus in **old** herniations and the signal intensity of the nucleus in **recent** herniations.

The same test was done on the signal intensity of the **herniated part** in old herniations and recent herniated discs. There was **no statistical difference** between these signals.

1.8.7 Expulsion

Expulsion is present in **four patients**. Two patients have an expulsion of the nucleus at level C5-C6 and 2 patients have an expulsion at level C6-C7. Two of these 4 patients are male; two are female. All of them are quite **young**. They age 30, 32, 32 and 42 years old. In two cases follow up images after the expulsion are available. One patient was operated, the other case showed spontaneous regression of the expulsed fragment, after 20 months only a small herniation remains. A remarkable finding was that the height of this disc stays the same over the time of the follow up after expulsion and regression.

Key point: In our study, patients with an expulsed disc are between 30 and 42 years old.

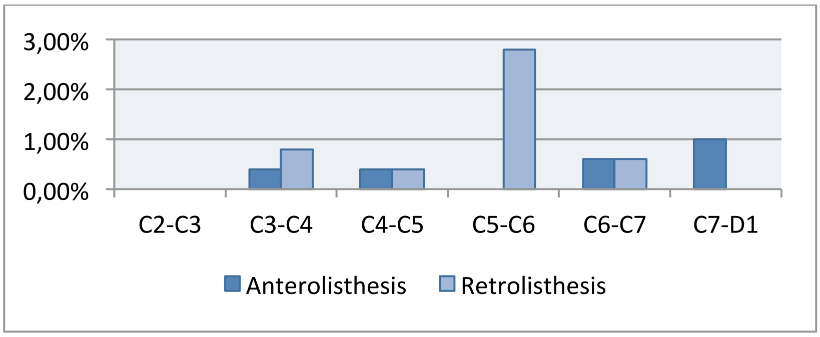
1.8.8 Regression

In **16 patients** (19 images) there is **spontaneous** regression of herniated discs. Spontaneous regression occurs in 6,62% of all herniated discs. The age of these patients range from 26 to 55 years old. The time since the last scan ranges from 7 to 38 months. In **4 patients** the herniated part **fully resorbs**. The age range of these patients is 40 to 49 years old.

Key point: Spontaneous regression occurs in 6,62% of all herniated discs.

1.9 Listhesis

The table bellow shows the prevalence of anterolisthesis and retrolisthesis. Only one patient has a unilateral spondylolysis. The other cases of listhesis are degenerative.



	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Normal	**504 (99,6%)**	**495 (97,8%)**	**488 (96,4%)**	**456 (90,1%)**	**473 (93,5%)**	**496 (98,0%)**
Anterolisthesis		2 (0,4%)	2 (0,4%)		3 (0,6%)	5 (1%)
Retrolisthesis		4 (0,8%)	2 (0,4%)	14 **(2,8%)**	3 (0,6%)	
Missing	*2 (0,4%)*	*5 (1%)*	*14 (2,8%)*	*36 (7,1%)*	*27 (5,3%)*	*5 (1%)*

Table 7/ figure 22: Prevalence of listhesis in the cervical spine.

Key point: Retrolisthesis is most prevalent at level C5-C6.

1.9.1 Listhesis and age

The age of patients with a degenerative listhesis is **significantly (p<0,001) older** compared to the age of patients without listhesis.

Key point: Patients with a degenerative listhesis are older than patients without listhesis.

1.9.2 Listhesis and height of the disc

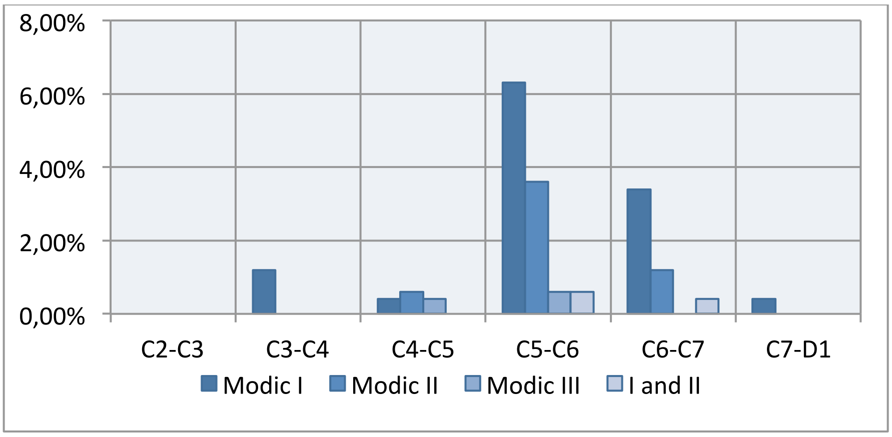
The height of discs with a listhesis is only **significantly (p=0,02) decreased at level C4-C5** compared to discs without listhesis. Details can be found in the appendix.

1.9.3 Listhesis and signal intensity

The signal intensity of discs with a listhesis is **not statistically different** at any level compared to discs without listhesis.

1.10 Modic changes

The table below shows **Modic** changes are most prevalent at level **C5-C6**.



	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Normal	**504 (99,6%)**	**495 (97,8%)**	**485 (95,8%)**	**417 (82,4%)**	**455 (89,9%)**	**499 (98,6%)**
Modic I		6 (1,2%)	2 (0,4%)	32 **(6,3%)**	17 **(3,4%)**	2 (0,4%)
Modic II			3 (0,6%)	18 **(3,6%)**	6 **(1,2%)**	
Modic III			2 (0,4%)	3 (0,6%)		
I and II				3 (0,6%)	2 (0,4%)	
Missing	*2 (0,4%)*	*5 (1%)*	*14 (2,8%)*	*33 (6,5%)*	*26 (5,1%)*	*5 (1%)*

Table 8/ figure 23: Prevalence of Modic changes in the cervical spine.

Key point: Modic changes are most prevalent at level C5-C6.

1.10.1 Modic I and height

The mean height of discs where Modic I changes are present **is lower** than the mean height of the control population at every level except at level C7-D1. More details are found in the appendix.

The height of the discs where Modic I is present is **significantly lower** at levels **C3-C4** (p=0,007) and **C6-C7** (p=0,005) compared to the discs without Modic I changes.

1.10.2 Modic II and height

The height of the discs where Modic II changes are present **will reduce even more**. More details are found in the appendix.

The height of the disc where Modic II is present is **significantly lower** at levels **C4-C5** (p=0,009) and **C5-C6** (p=0,007) compared to the discs without Modic II changes.

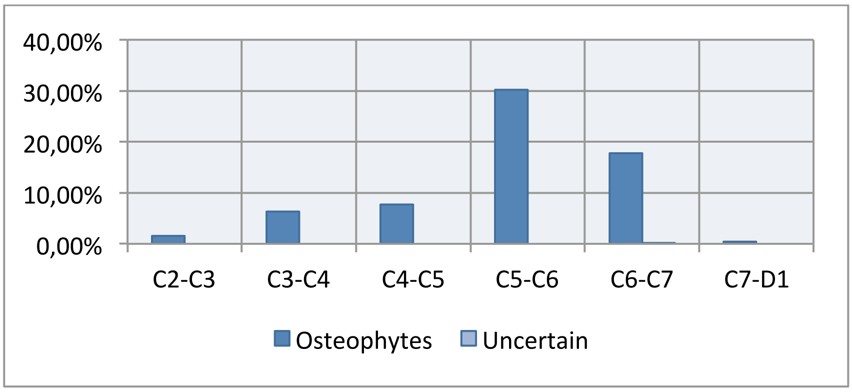
Key point: Modic changes are present in discs reduced in height.

1.10.3 Age and Modic changes

The age of the patients with Modic changes (mean= 43,9) is **higher** than the age of the patients without Modic changes (mean= 41,5). This finding is statistically **significant** (p<0,001).

1.11 Osteophytes

Osteophytes are most prevalent at levels **C5-C6 and C6-C7** in our sample group.



	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
No osteophytes	**496 (98%)**	**470 (92,9%)**	**453 (89,5%)**	**320 (63,5%)**	**391 (77,3%)**	**499 (98,6%)**
Osteophytes	8 (1,6%)	32 (6,3%)	39 (7,7%)	153 **(30,2%)**	90 **(17,8%)**	2 (0,4%)
Uncertain					1 (0,2%)	
Missing	*2 (0,4%)*	*4 (0,8%)*	*14 (2,8%)*	*33 (6,5%)*	*24 (4,7%)*	*5 (1%)*

Table 9/ figure 24: Prevalence of osteophytes in the cervical spine.

Key point: Osteophytes are most prevalent at level C5-C6.

1.11.1 Height and osteophytes

The height of discs with osteophytes is **significantly lower** than discs without osteophytes at levels C3-C4 (p=0,001), C4-C5 (p=0,015), C5-C6 (p<0,001) and C6-C7 (p<0,001). At levels C2-C3 and C7-D1 the discs with osteophytes are higher. The result at levels C2-C3 and C7-D1 is probably not significant because there are only respectively 8 and 2 discs with osteophytes in our sample.

1.11.2 Osteophytes in normal discs

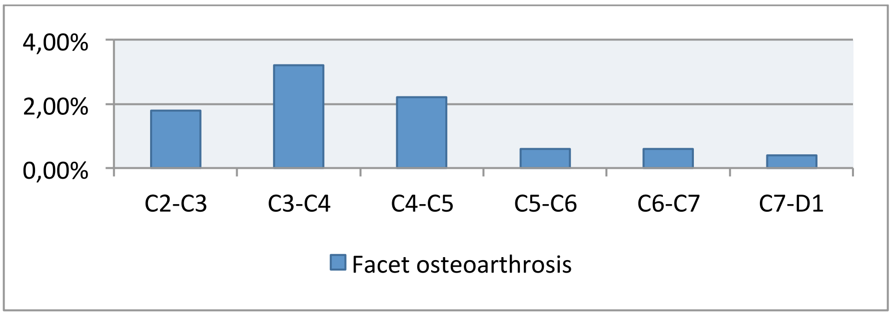
Can osteophytes also occur in normal discs? Normal disc are discs without annular fissure, bulging, protrusion or herniation. A disc at the level where anterolisthesis of facet osteoarthrosis is present can be defined as normal.

At level C2-C3 osteophytes are present in two normal discs, at level C3-C4 in 5 normal discs, at level C4-C5 in one, at level C5-C6 in 10 and at level C6-C7 in 14.

Key point: Osteophytes occur mostly in discs with a reduced height but can be present in discs without annular fissure, bulging, protrusion or herniation.

1.12 Facet joints

The table below shows facet osteoarthrosis is most prevalent at levels **C3-C4** and **C4-C5**.



	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Normal	**3 (0,6%)**	**9 (1,8%)**	**26 (5,1%)**	**29 (5,7%)**	**14 (2,8%)**	**5 (1%)**
Facet osteoarthrosis	9 (1,8%)	16 **(3,2%)**	11 **(2,2%)**	3 (0,6%)	3 (0,6%)	2 (0,4%)
Missing	*494 (97,6%)*	*481 (95,1%)*	*469 (92,7%)*	*474 (93,7%)*	*489 (96,6%)*	*499 (98,6%)*

Table 10/ figure 25: Prevalence of facet osteoarthrosis in the cervical spine.

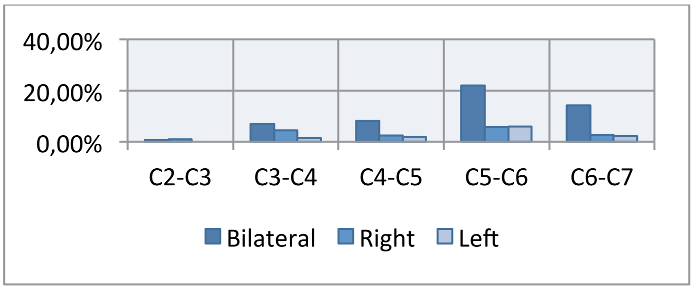
Key point: Facet joint osteoarthrosis is most prevalent at level C3-C4.

1.12.1 Age and facet osteoarthrosis

The age in patients with facet osteoarthrosis is **significantly** (p=0,001) **higher** than in patients without osteoarthrosis of the facet joints.

1.13 UNCOVERTEBRAL ARTHROSIS

The prevalence of uncovertebral arthrosis is highest at levels **C5-C6 and C6-C7.**



	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7
Normal	**496 (98%)**	**439 (86,8%)**	**431 (85,2%)**	**308 (60,9%)**	**392 (77,5%)**
Bilateral	3 (0,6%)	35 (6,9%)	41 (8,1%)	112 **(22,1%)**	72 **(14,2%)**
Right	5 (1%)	22 (4,3%)	12 (2,4%)	29 (5,7%)	13 (2,6%)
Left		7 (1,4%)	10 (2%)	30 (5,9%)	11 (2,2%)
Missing	*2 (0,4%)*	*3 (0,6%)*	*12 (2,4%)*	*27 (5,3%)*	*18 (3,6%)*

Table 11/ figure 26: Prevalence of uncovertebral arthrosis in the cervical spine.

Key point: Uncovertebral arthrosis is most prevalent at level C5-C6.

1.13.1 Age and uncovertebral arthrosis

The **age** of patients with uncovertebral arthrosis (mean= 44,6) is **significantly** (p<0,001) **higher** than those in our sample without uncovertebral arthrosis (mean= 39,7).

1.13.2 Height and uncovertebral arthrosis

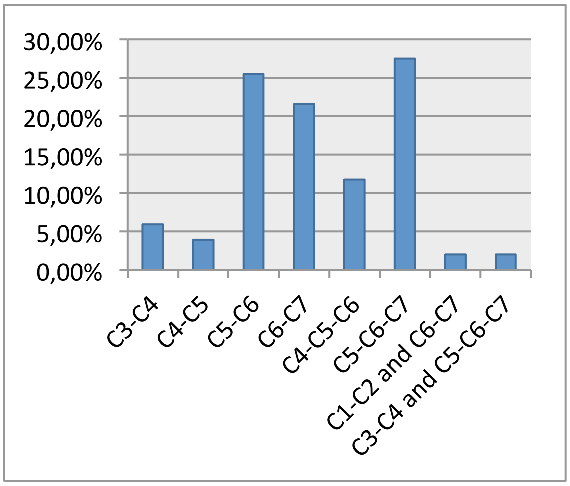
The height of disc where uncovertebral arthrosis is present is lower than in disc without uncovertebral arthrosis at all levels. It is a **significant decrease in height** at levels C3-C4 (p=0,039), C4-C5 (p<0,001), C5-C6 (p<0,001) and C6-C7 (p<0,001).

Key point: Uncovertebral arthrosis is present in older people and the disc height is often decreased.

1.14 Post-operative changes

Fifty-one (**10,1%**) scans show **postoperative** changes in 36 patients. All of these patients underwent **cage implantation**. In 455 (89,9%) scans, no operation is carried out. Ten (3,9%) patients underwent surgery already at the time of their first scan.

Cage implantation in carried out mostly at **levels C5-C6 and C6-C7**.



	N	%
C3-C4	3	5,9
C4-C5	2	3,9
C5-C6	13	25,5
C6-C7	11	21,6
C4-C5-C6	6	11,8
C5-C6-C7	14	27,5
C1-C2 and C6-C7	1	2,0
C3-C4 and C5-C6-C7	1	2,0
Total	**51**	**100,0**

Table 12/ figure 27: Levels where a cage was implanted. N= number of scans.

Key point: Operations are carried out most frequently at level C5-C6.

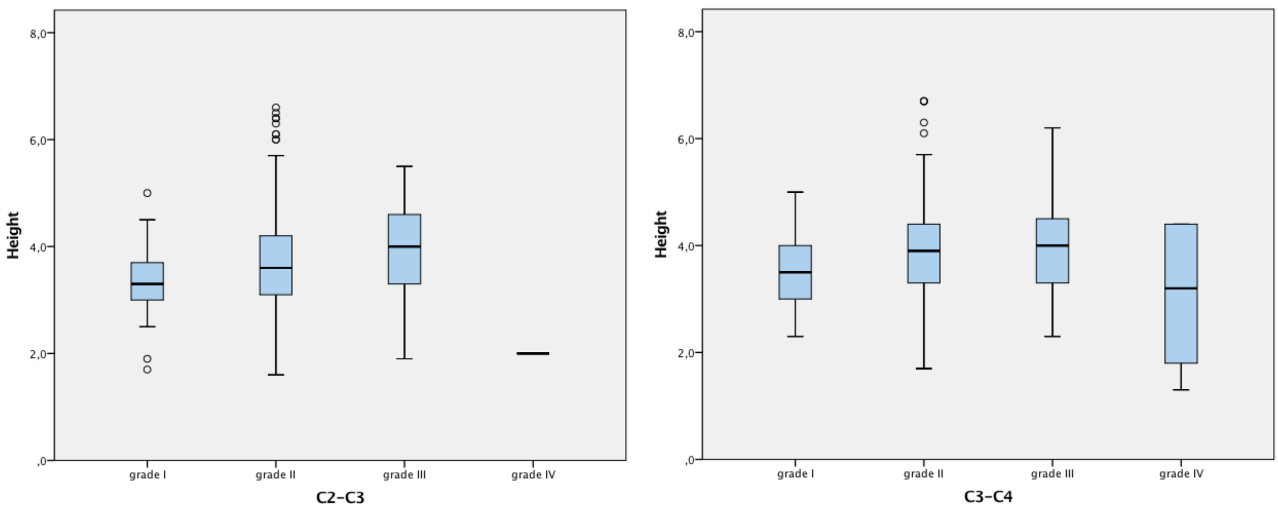
1.14.1 Herniation after operation

In 13 cases patients have a herniated disc at the adjacent level of a cage herniation. In only **one case**, that of a 54 year old female it is sure the **herniation** of disc C4-C5 developed **after the surgical fusion** of C5-C6-C7.

1.15 PFIRRMANN CLASSIFICATION

1.15.1 Correlation between Pfirrmann's classification and height

Boxplots were made of the relation between the height of the discs and their Pfirrmann classification. The disc should have the same height when classified as grade I and grade II and becomes more and more narrow from grade III to V.



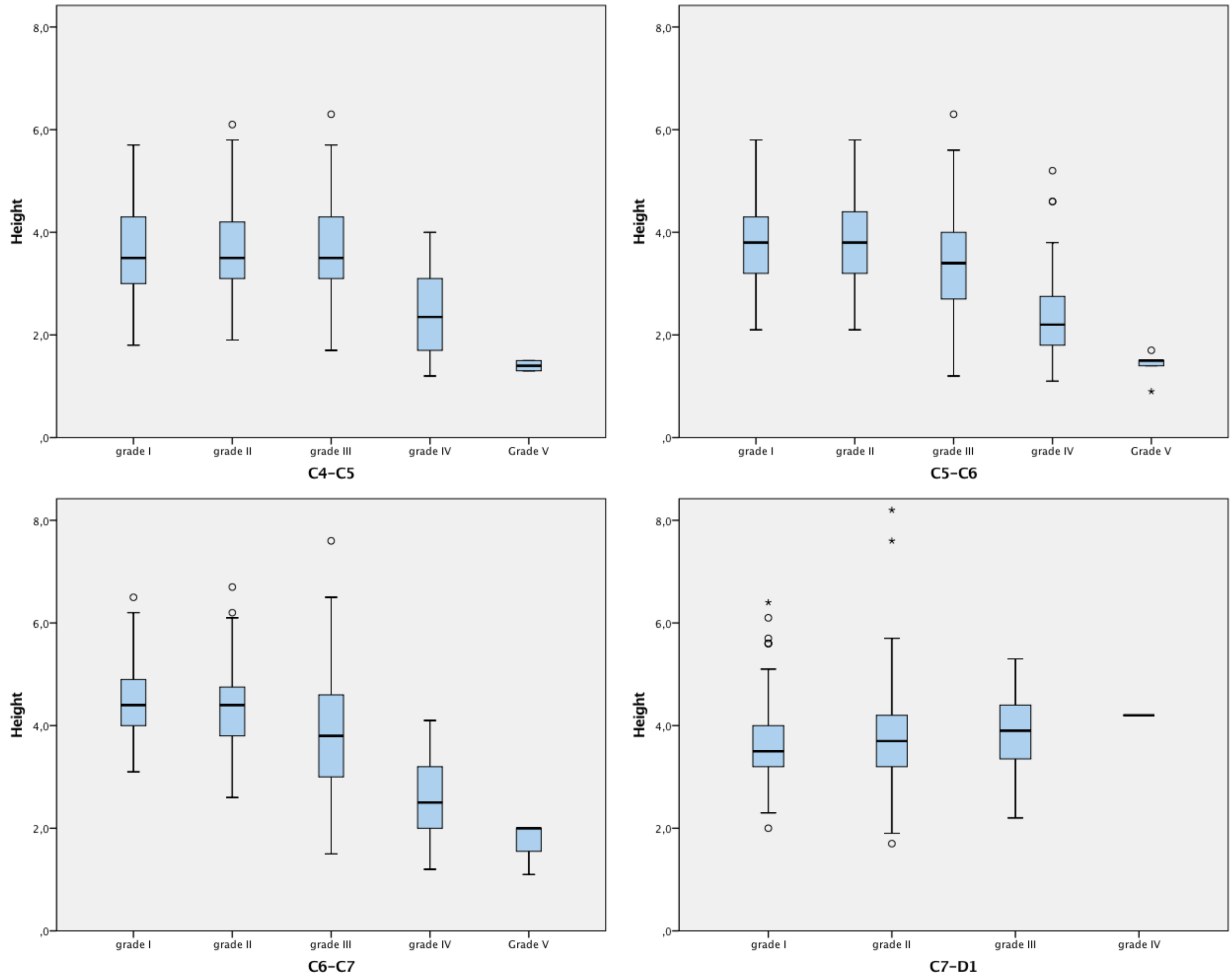


Figure 28: Correlation between the height of the disc and its Pfirrmann classification. Height is defined in mm.

1.15.2 Correlation between Pfirrmann's classification and height in control population

In our control population only Pfirrmann grade I and grade II are present because only images reviewed as normal were selected. The height should be equal in grade I and grade II.

There was **no significant difference** between the height of discs with grade I and grade II on most of the levels. At level C2-C3 (p=0,003) and level C3-C4 (p=0,002) the height of discs with Pfirrmann grade II are significantly higher.

1.15.3 Correlation between Pfirrmann's classification and the signal of their nucleus

Boxplots were made of the relation between the signal intensity of the nucleus and the Pfirrmann classification. The disc should become darker when the Pfirrmann classification becomes higher.

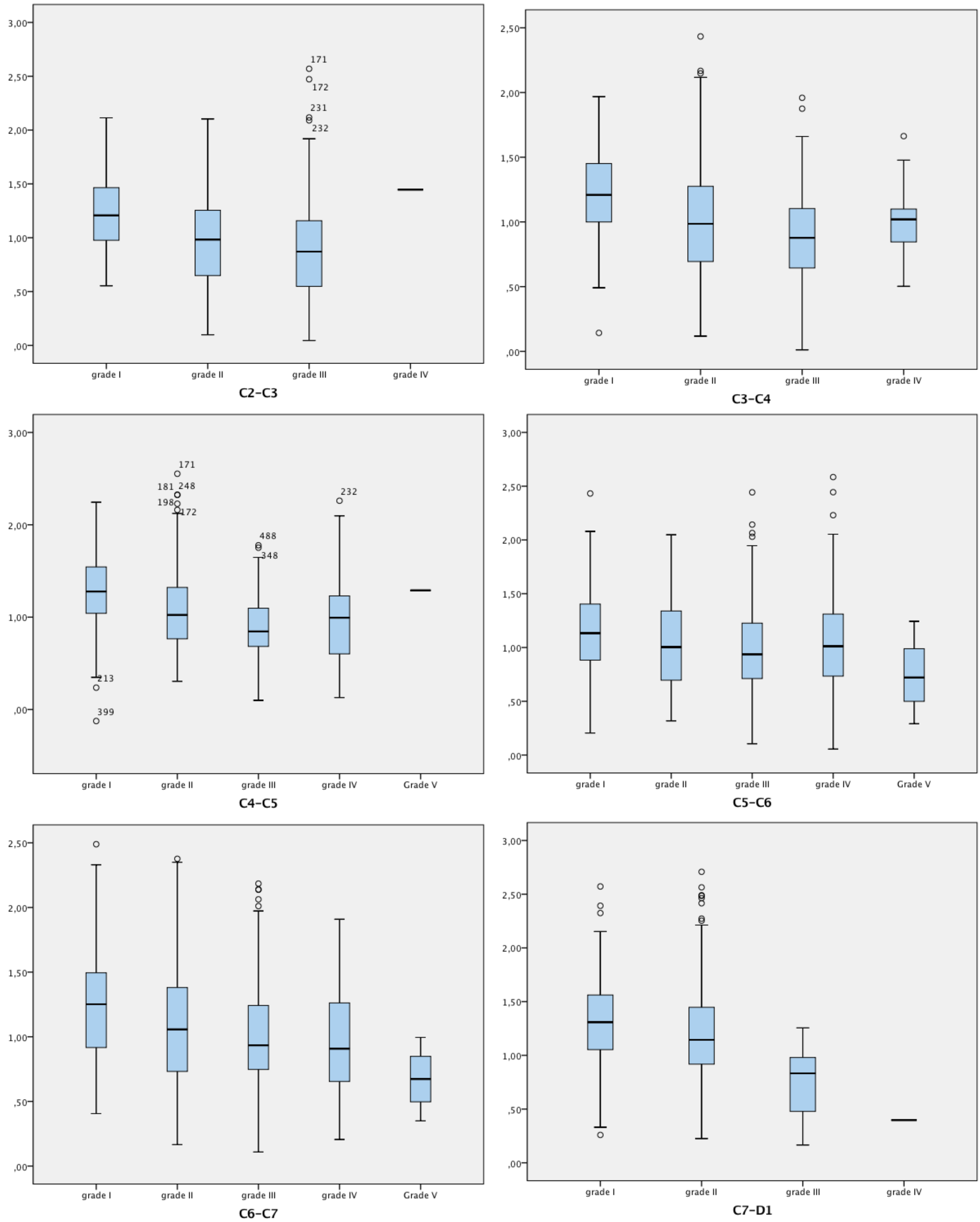


Figure 29: Boxplot with Pfirrmann classification on the X-axis and signal intensity on the Y-axis.

1.15.4 Correlation between Pfirrmann's classification and the signal of the nucleus in control population

In our control population only Pfirrmann grade I and grade II are present because only images reviewed as normal were selected. The height should be equal in grade I and grade II. The signal of discs with **grade II** is **significantly darker at every level** than the signal of discs with grade I. P<0,001 at level C2-C3 to level C5-C6, p= 0,006 at level C6-C7 and p=0,04 at level C7-D1.

Key point: Pfirrmann's classification is an excellent grading tool for the cervical spine. Yet it is more difficult at level C2-C3 and C3-C4.

1.16 Position of the nucleus

At every level the position where the centre of the nucleus pulposus was seen on sagittal imaging was reported. At every level the most prevalent position of the centre of the nucleus pulposus was in the **middle**. At the **top levels** of the cervical spine the second most prevalent position of the centre of the nucleus pulposus was **more posteriorly** (levels C2-C3 and C3-C4). At the **lower levels** the second most prevalent position was **more anteriorly** (levels C5-C6, C6-C7 and C7-D1).

Figure 30: Image shows the position of the nucleus on each level: middle, anteriorly of posteriorly. The diameter of the circle is an indication for the number of patients.

1.16.1 Position of the nucleus in the control population

The position of the centre of the nucleus pulposus was noted using the same method in the control population. The **results** are more or less the **same** in the sample group and the control population. At every level of the spine most of the nuclei lie in the middle. At the top part of the spine some of them lay more posteriorly. At the bottom part of the spine some of them lie more anteriorly. The level at which the position of the centre of the nucleus pulposus changes from posterior to anterior (later called: the shifting point) is different in the control and sample group. In the sample population the **shifting point** is at level **C4-C5**. In the control population the shifting point is level **C3-C4**. This means in the control population more nuclei lie anterior to the middle.

1.16.2 Position of the nucleus and degeneration

The signal intensity of the nucleus is looked at in relationship to the position of the centre of the nucleus pulposus. The signal intensity is similar at every level if the disc is in the middle, anterior or posterior. This means **nuclei that are not in middle will not degenerate faster**.

Key point: There is a remarkable difference between the position of the centre of the nucleus pulposus in normal and pathological patients.

2 LUMBAR SPINE

The study consisted of **505 MRI images** of the lumbar spine. These images belong to **272 individual patients**. The youngest patient is 14 years old, the oldest 85 years old (mean: 40,8). Out of 272 patients 174 (64%) are male, 98 (36%) are female. The patient with the longest follow-up had 7 scans in our database.

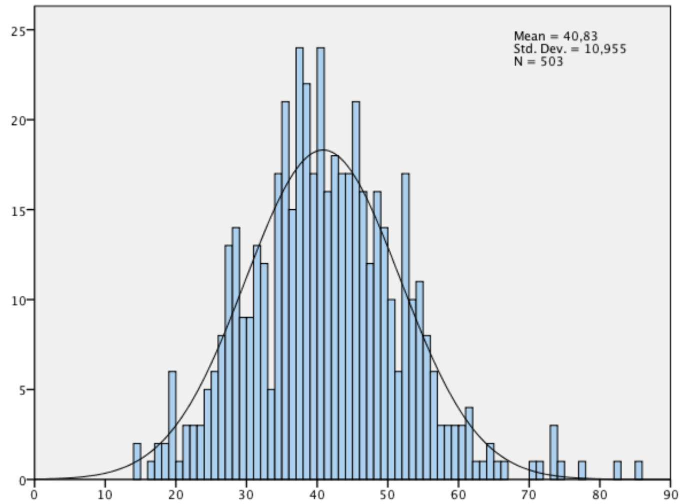


Figure 31: Age distribution of patients who underwent lumbar imaging. X-axis age in years and Y-axis frequency.

2.1.1 Control population

The control population consist of **173 patients**. Eighty-five (49,1%) male patients and 88 (50,9%) female patients. Age ranges from 18 to 35 years old with a mean age of 26,3 years old.

2.2 TRAUMA MECHANISM

Four categories were defined. One hundred and forty-seven (54,4%) patients had an occupational accident and in 16 (5,9%) patients the occupational accident happened on the road, 69 (25,4%) patients had traffic accidents and 31 (11,4%) patients had other accidents that didn't fit into the first categories.

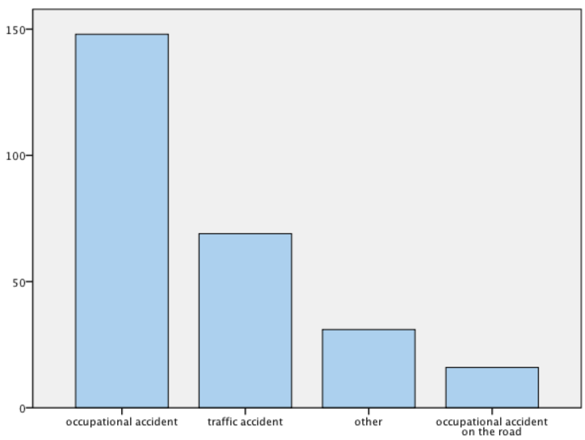


Figure 32: Bar chart of different kinds of accidents. First occupational accidents, second traffic accidents, third 'others' and last occupational accidents on the road. Y-axis shows the number of patients.

Mechanisms of trauma. Most of the patients fell down (n= 78, 28,7%), Sixty-three patients (23,2%) had a car accident. Fifty patients (18,4%) had lifted a heavy object. Fifteen (5,5%) patients had combined accidents. An accident was combined if a car accident was more severe than a rear-end collision. Seven (2,6%) patients made a rotational movement. Five (1,8%) patients were victims of aggression. Five (1,8%) had back pain after surgery. In 4 (1,5%) patients a heavy object fell down onto them and they had a contusion of the lumbar spine. In 45 (16,5%) patients the exact description of their trauma was missing.

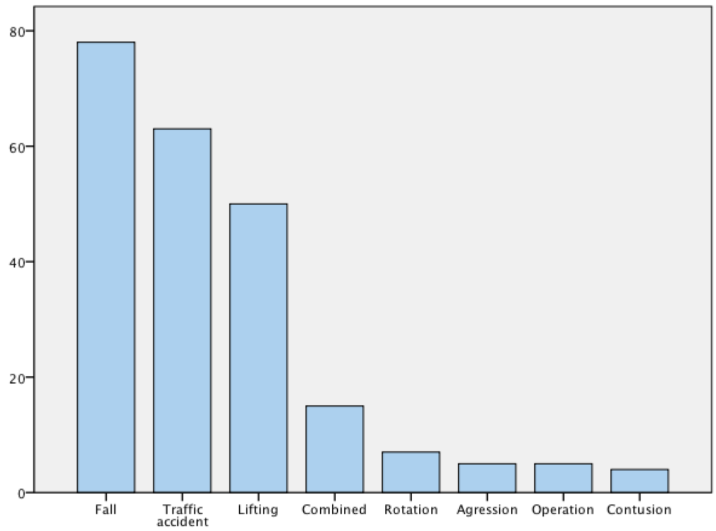


Figure 33: Bar chart with an overview of the different kinds of trauma.

2.2.1 Gender in relation to the kind of trauma

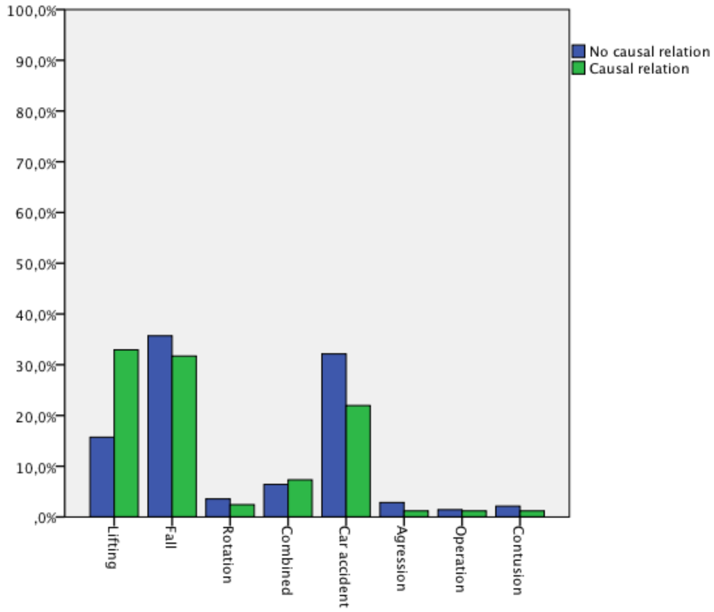
Female patients. Most of the female patients had car accidents (n=29, 29,6%). Twenty-six of them fell down (26,5%). Seventeen female patients (17,3%) had lifted a heavy object. Four (4,1%) patients had combined accidents. An accident was combined if a car accident was more severe than a rear-end collision. Three (3,1%) had back pain after surgery. Two (2%) patients made a rotational movement. Two (2%) patients were victims of aggression. In one (1%) case a heavy object fell down onto the victim and there was a contusion of the lumbar spine. In 14 (14,3%) patients the exact description of their trauma was missing.

Male population. Most of the patients fell down (n= 52; 29,9%), Thirty-four patients (19,5%) had a car accident. Thirty-three (19%) had lifted a heavy object. Eleven (6,3%) patients had combined accidents. An accident was combined if a car accident was more severe than a rear-end collision. Five (2,9%) patients made a rotational movement. Three (1,7%) patients were victims of aggression. In 3 (1,7%) patients a heavy object fell down onto them and they had a contusion of the lumbar spine. Two (1,1%) had back pain after surgery. In 31 (17,8%) patients the exact description of their trauma was missing.

In conclusion: female patients tend to have more rear-end collisions and fall more often than male patients in our sample.

2.2.2 Causal relationship between trauma and radiological findings

In most cases (143; **59,4%)** there is **no causal relationship** between the accident and the radiological findings. In 88 (**36,8%**) cases there is a **causal relationship** between the accident and the radiological findings. Only in case of lifting heavy objects there are more cases in which there is a causal relationship between trauma and the radiological findings.



Mechanism	**No causal relation**	**Causal relation**	**TOTAL**
Lifting	22 (44,9%)	27 **(55,1%)**	49
Fall	50 **(65,8%)**	26 (34,2%)	76
Rotation	5 **(71,4%)**	2 (28,6%)	7
Combined	9 **(60%)**	6 (40%)	15
Car accident	45 **(71,4%)**	18 (28,6%)	63
Aggression	4 **(80%)**	1 (20%)	5
Operation	2 **(66,7%)**	1 (33,3%)	3
Contusion	3 **(75%)**	1 (25%)	4
Total	**140 (63,1%)**	**82 (36,9%)**	**222**

Table 13/ figure 34: The relation between the different mechanism of trauma and their relation to the radiological findings.

2.3 *INTERVAL BETWEEN THE ACCIDENT AND FIRST MRI*

The time between the accident and the date the scan was made is expressed in months. The time has a range between 76 months before the accident and 121 months after the accident. In 32 cases scans before the accident were available. These patients had complaints of the back before they had an accident.

The time between the accident and the first scan which was made after the accident ranges from 0 to 121 months. **The graph below shows most patients are referred for an MRI scan in the second month after their trauma.**

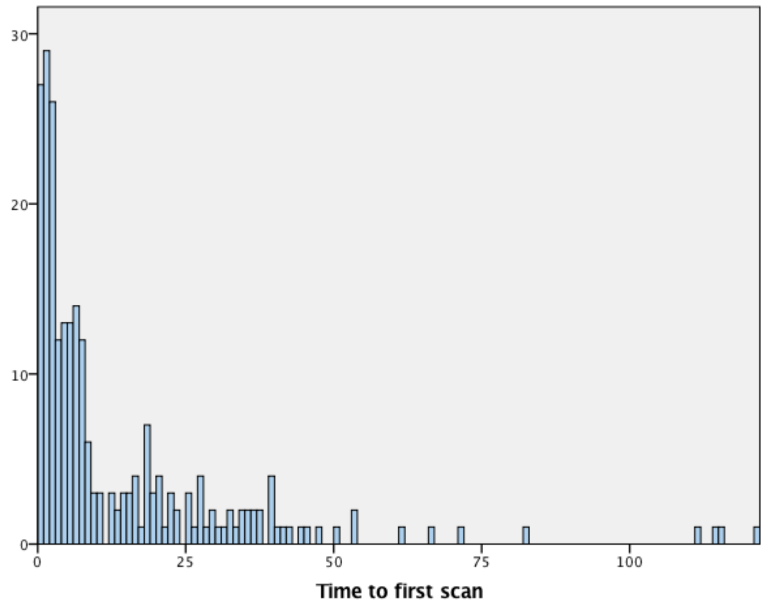


Figure 35: Time (in months) between the accident and the first MRI. One bar represents one month.

Key point: Most of the patients are referred for an MRI within the second month after trauma.

2.4 HEIGHT OF THE DISC

Every disc space is **higher than the disc space above** from level D12-L1 to L3-L4. Level **L4-L5** and **L5-S1** are **less high**, probably because these are degenerative levels. Detailed information can be found in the appendix.

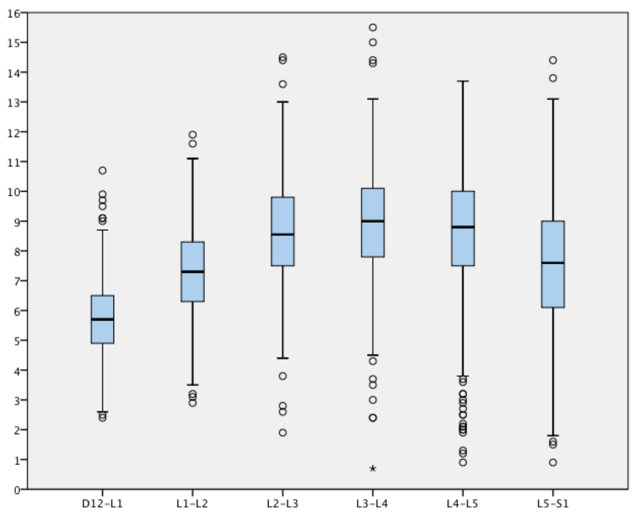


Figure 36: Boxplot showing the height of the discs in our sample population. Height is expressed in mm.

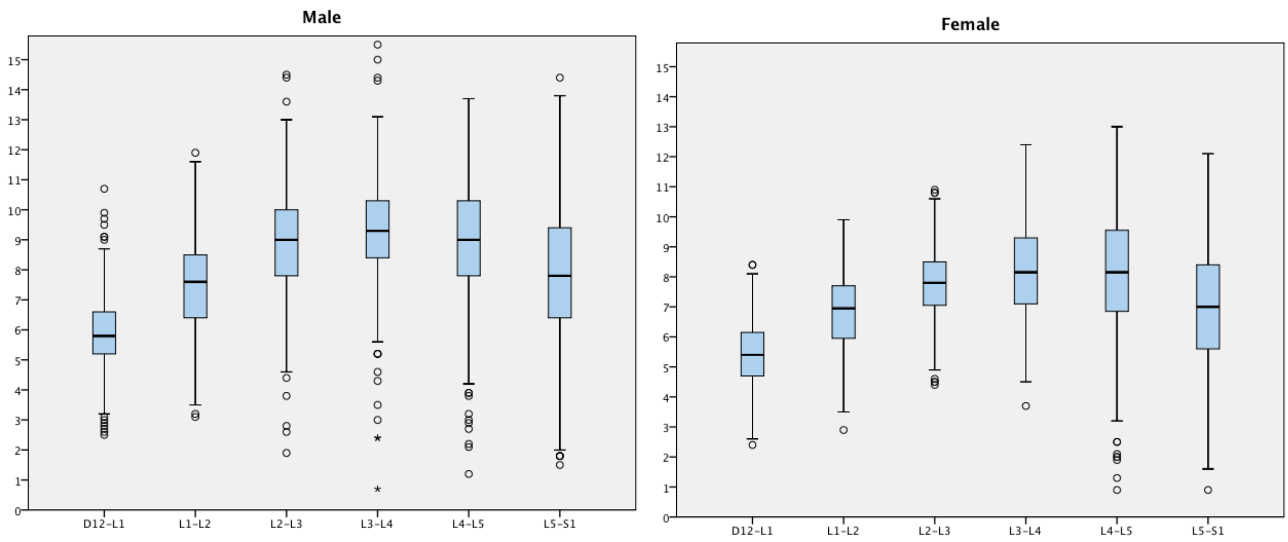


Figure 37: Boxplot of disc height (mm) in male and female patients.

2.4.1 Height of the disc in control population

The disc space is **higher** than the **disc space above** at every level except for level L5-S1. In our sample group the height of disc L4-L5 is probably decreased because of degeneration. Details can be found in the appendix.

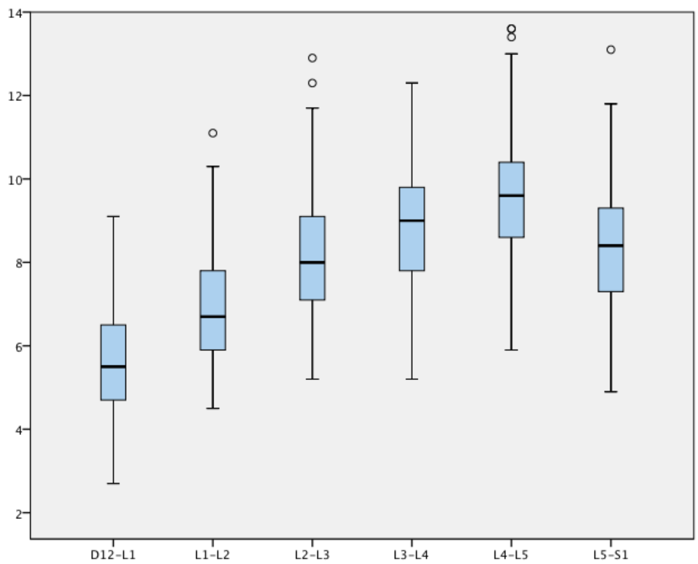


Figure 38:Boxplot displays height of the disc spaces of the lumbar spine in the control population. Height in mm.

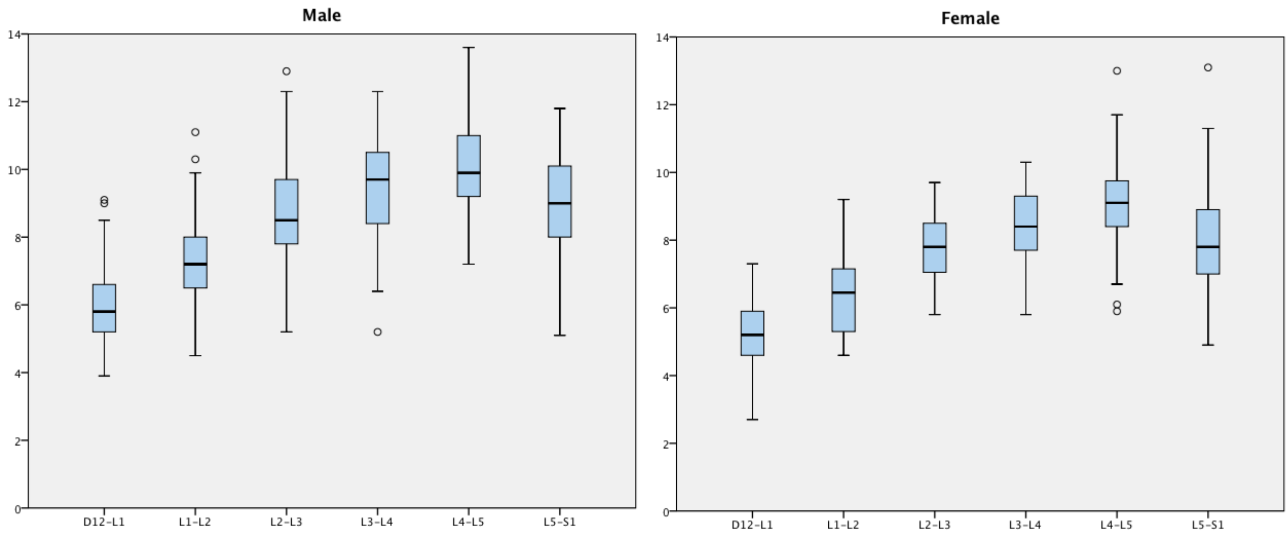


Figure 39: Height of the disc spaces displayed in male and female patients in the control population. Height in mm.

Key point: The disc height is always higher than the disc level above except at level L5-S1.

2.4.2 Height in relation to age

The height of the disc is expected to decrease over increasing age. The correlation between the height of the disc and the age of the patient is only significant at level D12-L1 (p=0,014) and L1-L2 (p=0,01) but this correlation is positive. This means the height of the disc will be **higher in older patients**.

The same test in **female patients** shows a significant decrease at level L3-L4 (p=0,02), L4-L5 (p<0,001) and level L5-S1 (p=0,03). The height will decrease every year with respectively 0,02 mm; 0,07 mm and 0,03 mm.

The same test in **male patients** shows an increase in height when the age increases. This finding is significant at level D12-L1 (p<0,001), L1-L2 (p<0,001) and L4-L5 (p=0,01). The height will increase with 0,03 mm every year at levels D12-L1, L1-L2 and L4-L5.

Key point: Disc height will reduce in older patients.

2.4.3 Height in relation to age in control population

A positive correlation is observed at every level between the height of the disc in relationship to the age. This means in our control population **discs will become higher in older patients**. Yet, these findings are not statistically significant except at level L5-S1 (p=0,003).

2.4.4 Height post- and premenopausal

At all age groups the mean height of the discs in male patients is higher than the height of the discs in female patients. The difference between the height of discs in young females in contrary to postmenopausal females is especially remarkable at level L4-L5. This is known to be a level affected by degeneration. In male patients the discs of the older part of the population are lower at levels L2-L3 and L3-L4 but higher at the other levels.

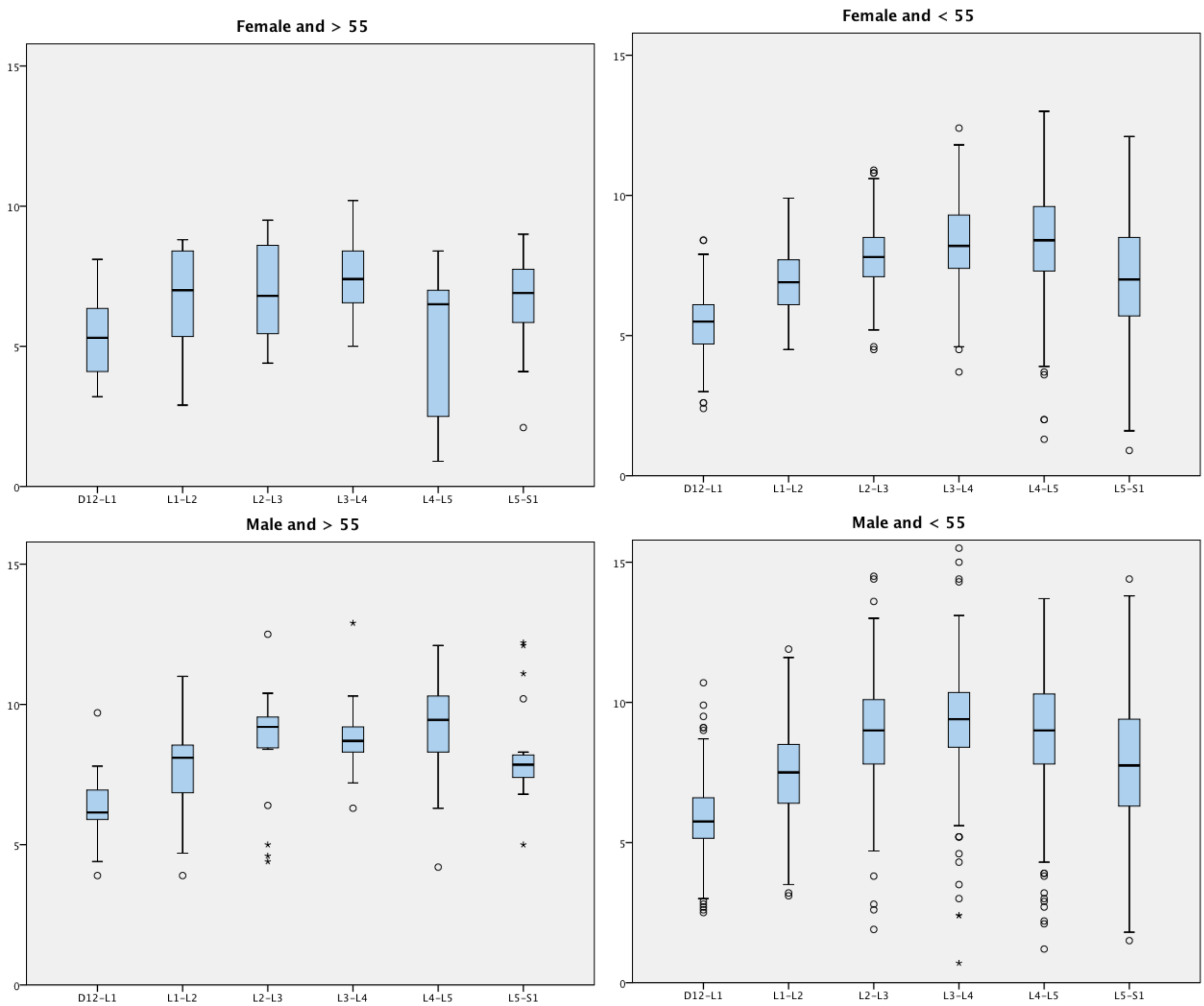


Figure 40: Boxplots displaying the height (mm) of the discs in females and males in two age groups, one over 55 years old and one younger.

2.5 *SIGNAL INTENSITY*

2.5.1 Signal intensity in relation to age

Correlation between the signal intensity of the nucleus pulposus and the age was performed. The signal intensity **lowers at every level with increasing age**. This finding is also statistically **significant** at every level. P=0,003 at level D12-L1, p=0,001 at level L1-L2, p<0,001 at level L2-L3 and L3-L4, p=0,01 at level L4-L5 and p=0,04 at level L5-S1.

2.5.2 Signal intensity in relation to age in the control population

Correlation between the signal intensity of the nucleus pulposus in relation to the age (18 to 36 years old) shows a **decreased signal with increasing age**. This finding is **significant** ($p<0,001$) at every level.

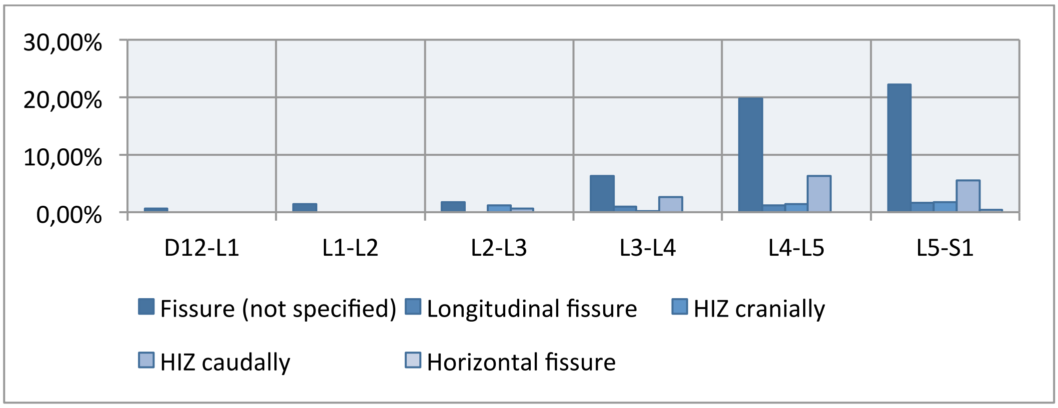
Key point: The signal intensity will reduce with age even in young and healthy control patients.

2.5.3 Signal intensity in relation to height

The signal intensity of the nucleus should normally become lower when the height of the disc is lower. At every level an **increasing signal of the nucleus is observed when the height of the disc is higher**. This finding is also statistically significant at every level except level L1-L2. P=0,04 at level D12-L1, p=0,001 at level L2-L3 and level L3-L4, p<0,001 at level L4-L5 and level L5-S1.

2.6 Annular fissures

The table below shows annular fissures are most prevalent at levels **L4-L5** and **L5-S1**.



	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
No fissure	**498 (98,6%)**	**498 (98,6%)**	**486 (96,2%)**	**447 (88,5%)**	**334 (66,1%)**	**317 (62,8%)**
Fissure (not specified)	3 (0,6%)	7 (1,4%)	9 (1,8%)	32 (6,3%)	100 **(19,8%)**	112 **(22,2%)**
Longitudinal fissure				5 (1%)	6 (1,2%)	8 (1,6%)
HIZ cranially			**6 (1,2%)**	1 (0,2%)	7 (1,4%)	9 (1,8%)
HIZ caudally			3 (0,6%)	13 **(2,6%)**	32 **(6,3%)**	28 **(5,5%)**
Horizontal fissure						2 (0,4%)
Missing	*4 (0,8%)*		*1 (0,2%)*	*7 (1,4%)*	*26 (5,1%)*	*29 (5,7%)*

Table 14/ figure 41: Prevalence of annular fissures in the lumbar spine.

Key point: Annular fissures are most prevalent at level L5-S1.

2.6.1 HIZ

High-signal-intensity zones are most prevalent in the lumbar spine at levels **L4-L5** and **L5-S1**. HIZ are more frequently reported at the caudal part of the annulus in our sample group. See table above.

At level L2-L3 one HIZ was observed in a normal disc. At level L4-L5 10 times a HIZ was observed in a normal disc. At level L5-S1 a HIZ was observed in 3 normal discs. In this case a normal disc is a disc without bulging, protrusion or herniation.

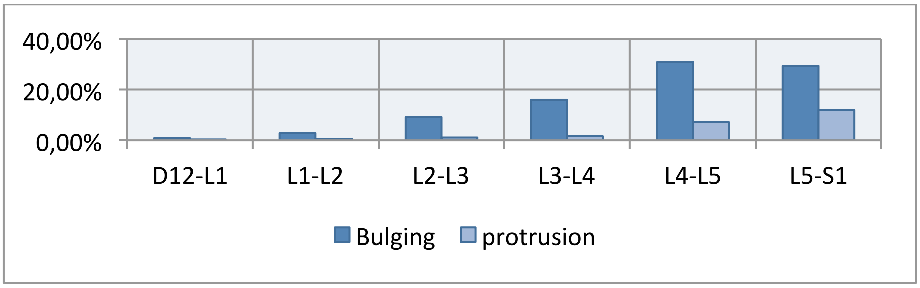
2.6.2 HIZ and height

There is **no statistical significant difference in height** between the height of discs with a HIZ and discs without a HIZ. The mean height of the discs with a HIZ is observed to be higher than the mean height of our sample at levels L4-L5 and L5-S1. For details see appendix.

Key point: The presence of a HIZ does not influence the height of the disc.

2.7 *BULGING*

The table below shows bulgings and protrusions are most prevalent at levels **L4-L5** and **L5-S1**. Bulging discs are more frequent than protruding discs.



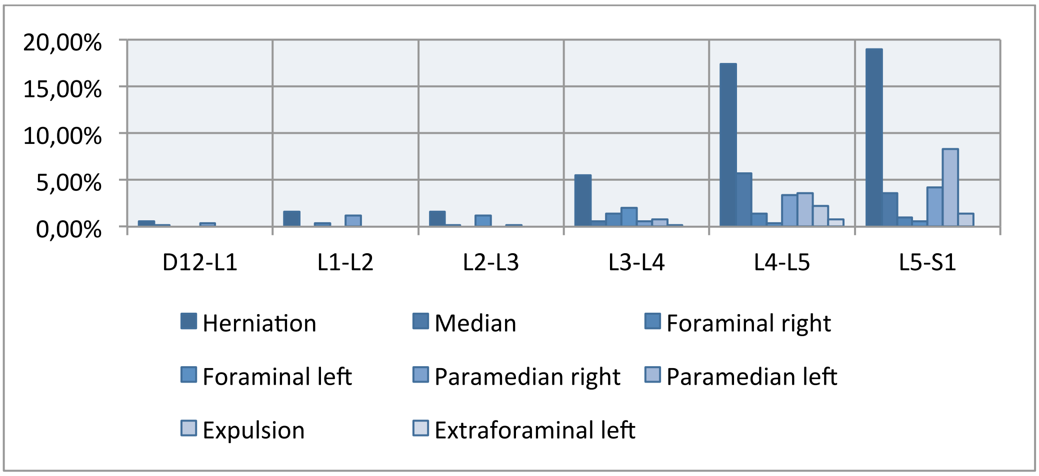
	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1	*TOT*
No bulging	**495 (98%)**	**488 (96,6%)**	**453 (89,7%)**	**409 (81%)**	**287 (56,8%)**	**270 (53,5%)**	
Bulging	4 (0,8%)	14 (2,8%)	46 (9,1%)	81 (16%)	156 **(30,9%)**	148 **(29,3%)**	*449*
Protrusion	2 (0,4%)	3 (0,6%)	5 (1%)	8 (1,6%)	36 **(7,1%)**	61 **(12,1%)**	*115*
Missing	*4 (0,8%)*		*1 (0,2%)*	*7 (1,4%)*	*26 (5,1%)*	*26 (5,1%)*	*64*

Table 15/ figure 42: Prevalence of bulging and protrusion in the lumbar spine.

Key point: Bulging discs are most prevalent at level L4-L5.

2.8 *HERNIATION*

The table below shows herniated discs are most prevalent at levels **L4-L5** and **L5-S1**. **Paramedian** herniations are reported most, followed by **median** herniations of the nucleus.



	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1	*TOT*
Normal	**498 (98,6%)**	**497 (98,4%)**	**496 (98,2%)**	**470 (93,1%)**	**391 (77,4%)**	**380 (75,2%)**	
Herniation	**3 (0,6%)**	**8 (1,6%)**	**8 (1,6%)**	**28 (5,5%)**	**88 (17,4%)**	**96 (19%)**	
Median	1 (0,2%)		1 (0,2%)	3 (0,6%)	29 **(5,7%)**	18 **(3,6%)**	*52*
Foraminal right		2 (0,4%)		7 (1,4%)	7 (1,4%)	5 (1%)	*21*
Foraminal left			6 (1,2%)	10 (2%)	2 (0,4%)	3 (0,6%)	*21*
Paramedian right	2 (0,4%)	6 (1,2%)		3 (0,6%)	17 **(3,4%)**	21 **(4,2%)**	*49*
Paramedian left			1 (0,2%)	4 (0,8%)	18 **(3,6%)**	42 **(8,3%)**	*65*
Expulsion				1 (0,2%)	11 (2,2%)	7 (1,4%)	*19*
Extraforaminal left					4 (0,8%)		*4*
Missing	*4 (0,8%)*		*1 (0,2%)*	*7 (1,4%)*	*26 (5,1%)*	*29 (5,7%)*	

Table 16/ figure 43: Amount of herniated discs in the cervical spine.

Key point: Herniations are most prevalent at level L5-S1.

2.8.1 Age and herniated disc

The age of patients with a herniated disc is **slightly younger** compared to the age of patients in our sample without herniated discs. Yet this finding is **not statistically significant**.

2.8.2 Time between trauma and herniation

The database contains seven cases in which there is an image without herniation and on a follow-up image a herniation has developed.

Scans before the trauma:

1. Male, 19y. 2 months before the trauma there was only a bulging disc, 1 month after the accident a herniation developed.

Scans after the trauma:

2. Male, 54y. 7 months after the trauma there was only a bulging disc, 26 months later a herniation developed.
3. Male, 36y. 12 months after the trauma there was only a bulging disc, 19 months after the trauma a herniation developed.
4. Male, 47y. 1 month after the trauma there was only a protruding disc, 6 months after the trauma a herniation developed.
5. Male, 52y. 1 month before the trauma and 2 months after there was a normal, 8 months after the trauma a herniation developed .
6. Male, 34y. 1week after the trauma there was only a protruding disc, 54 months after the accident a herniation developed.
7. Female, 39y. 33 months after the trauma there was only a protruding disc, 62 months after the trauma a herniation developed.

Case 6 and 7 could have had a second, non reported, trauma.

2.8.3 Height of herniated disc

The mean height of herniated discs **is lower at every level** compared to the height of discs without herniation. Yet this finding is only **significant** at level **L1-L2** (p=0,005) and **L2-L3** (p=0,009). Details can be found in the appendix.

The mean height of **old herniations is lower at every level** compared to the height of discs without herniation. The finding is **significant** at level **L1-L2** (p=0,03), **L4-L5** (p=0,008) and **L5-S1** (p=0,01).

Key point: Herniated disc are lower in height than disc without herniation.

2.8.4 Herniation on two consecutive levels

In our database, **seventeen** patients have a herniation at two consecutive levels. Only three patients have imaging where only one herniation is present and the second one is seen on follow-up images.

- First case: 35-year-old male. Herniation at level L2-L3, 26 months later also herniation at level L3-L4.
- Second case: 37-year-old male. New herniation at level L5-S1 and an old one at level L4-L5.
- Third case: 52-year-old male. Herniation at level L5-S1, one month later expulsion at level L4-L5.

2.8.5 Herniation and scoliosis

Fifteen patients have a herniation and scoliosis of the lumbar spine. Five out of 15 patients have sinistroconvex scoliosis and a herniation at the left side or a dextroconvex scoliosis and a herniation at the right side. Four out of 15 patients have a herniation on the right side and a sinistroconvex herniation. The other patients have a median herniation.

2.8.6 Herniation and signal intensity

The signal intensity of the **nucleus** in **old** herniations is **not significantly different** compared to the signal intensity of the nucleus in **recent** herniations.

The signal intensity of the **herniated part** in **old** herniations is not **significantly different** compared to the signal intensity of the herniated part in **recent** herniations.

2.8.7 Expulsion

Expulsion is present in **18** scans of the lumbar spine. The mean age of these patients is **older** than the mean age of our sample but **not statistically significant** older. Fourteen **(77,8%)** of these patients are **males** and 4 **(22,2%)** of these patients are **females**. In 3 cases the patients lifted a heavy object, in 5 cases they fell and in 6 six cases they had a car accident. Detailed investigation of the description of the accidents revealed these patients did not have severe trauma but most of them had **minor trauma**.

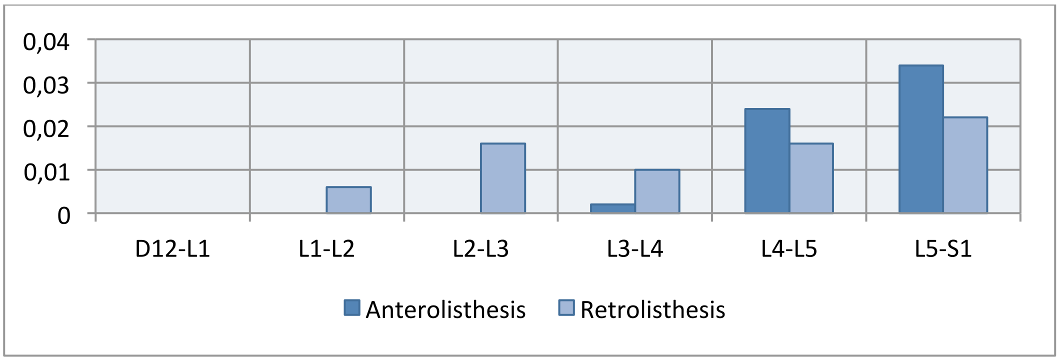
Key point: Expulsion occurred in patients who had a minor trauma.

2.8.8 Regression

In **15 patients** (19 images) there is a spontaneous regression of herniated discs. The age of these patients range from 21 to 56 years old. The time since the last scan ranges from 3 to 29 months. In **4** patients the herniated part is **fully resorbed.** The age range of these patients is 21 to 38 years old.

2.9 LISTHESIS

The table below shows the prevalence of anterolisthesis and retrolisthesis. Listhesis is more frequent at levels **L4-L5 and L5-S1.**



	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Normal	**501 (99,2%)**	**502 (99,4%)**	**496 (98,2%)**	**492 (97,4%)**	**461 (91,3%)**	**452 (89,5%)**
Anterolisthesis				1 (0,2%)	12 **(2,4%)**	17 **(3,4%)**
Retrolisthesis		3 (0,6%)	8 (1,6%)	5 (1%)	8 (1,6%)	11 (2,2%)
Missing	*4 (0,8%)*		*1 (0,2%)*	*7 (1,4%)*	*24 (4,8%)*	*25 (5%)*

Table 17 /figure 44: Prevalence of listhesis in the lumbar spine.

	L2-L3	**L3-L4**	**L4-L5**	**L5-S1**
Lysis left	1			
Lysis right				1
Bilateral		1	4	15

Table 18: Prevalence of spondylolysis in the lumbar spine.

In contrary to the findings in the cervical spine, most listhesis in the lumbar spine are due to a bilateral spondylolysis.

Key point: Anterolisthesis and retrolisthesis is most prevalent at level L5-S1.

2.9.1 Listhesis and age

The age of patients with a **degenerative listhesis** is **significantly (p<0,001) older** than the age of patients without degenerative listhesis.

The mean age of patients with a **listhesis** due to **spondylolysis** is **younger** than the age of patients without listhesis. Yet this finding is not statistically significant.

Key point: Patients with a degenerative listhesis are older than patients without listhesis.

2.9.2 Listhesis and height of the disc

The height of discs with a **degenerative listhesis** is **significantly lower** at level L1-L2 (p=0,002), L2-L3 (p<0,001) and L4-L5 (p=0,001) compared to the height of discs without listhesis.

The height of discs with a **listhesis** due to **spondylolysis** is **only significantly lower** at level L3-L4 (p<0,001) compared to the height of discs without listhesis.

Details can be found in the appendix.

Key point: The height of discs with a degenerative listhesis is reduced. In a listhesis due to spondylolysis the height is only lower at level L3-L4.

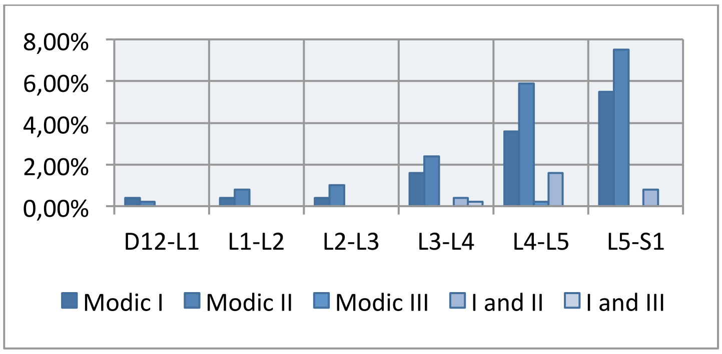
2.9.3 Listhesis and signal intensity

The signal intensity of discs with a **degenerative listhesis** is **not significantly** different compared to the signal intensity of discs without listhesis.

The signal intensity of discs with a **listhesis** due to **spondylolysis** is **not significantly** different compared to the signal intensity of discs without.

2.10 MODIC CHANGES

The table below show the prevalence of Modic changes. Modic changes are most prevalent at level **L4-L5 and L5-S1**.



	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Normal	**498 (98,6%)**	**499 (98,8%)**	**497 (98,4%)**	**475 (94%)**	**423 (83,8%)**	**412 (81,6%)**
Modic I	2 (0,4%)	2 (0,4%)	2 (0,4%)	8 (1,6%)	18 **(3,6%)**	28 **(5,5%)**
Modic II	1 (0,2%)	4 (0,8%)	5 (1%)	12 (2,4%)	30 **(5,9%)**	38 **(7,5%)**
Modic III					1 (0,2%)	
I and II				2 (0,4%)	8 (1,6%)	4 (0,8%)
I and III				1 (0,2%)		
Missing	*4 (0,8%)*		*1 (0,2%)*	*7 (1,4%)*	*25 (4,9%)*	*23 (4,6%)*

Table 19 /figure 45: Prevalence of Modic changes in the lumbar spine.

Key point: Modic changes are most prevalent at level L5-S1.

2.10.1 Modic I and height

The mean height of discs where Modic I changes are present is lower than the mean height of the control population at every level. More details are found in the appendix.

The height of discs where **Modic I** is present **is significantly lower** than the height of discs without Modic change at levels **L2-L3** (p<0,001), **L3-L4** (p<0,001), **L4-L5** (p<0,001), **L5-S1** (p<0,001).

Key point: The height of discs with Modic grade I is lower than discs without Modic changes.

2.10.2 Modic II and height

Comparison of the height of discs where Modic I is present and the height of discs where Modic II is present shows no remarkable results. Details can ben found in the appendix.

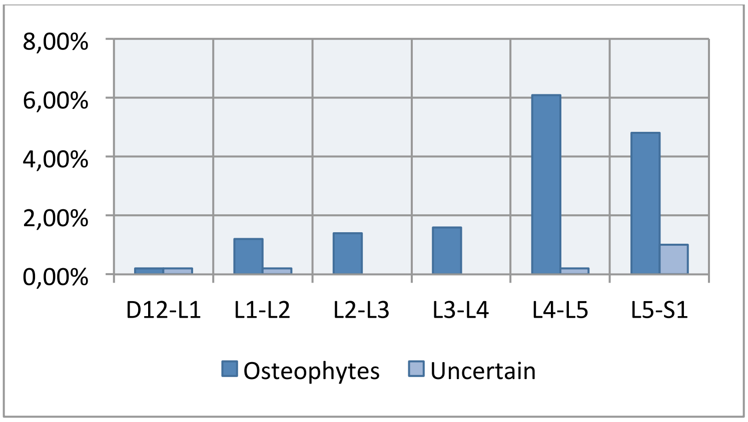
The height of discs where Modic II is present is significantly lower at level L2-L3 (p=0,01), L3-L4 (p<0,001), L4-L5 (p=0,03) and L5-S1 (p<0,001) compared to discs without Modic II.

2.10.3 Post-op Modic

Forty-two (**32,3%)** patients with Modic changes underwent surgery. Twenty-eight (65,2%) of these patients had a **discectomy, whereas the others had others types of surgery**. Eighty-eight (67,7%) of the patients with Modic changes didn't have surgery.

2.11 OSTEOPHYTES

Osteophytes are most prevalent at levels **L4-L5** and L5-S1.



	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
No osteophytes	**499 (98,8%)**	**498 (98,6%)**	**497 (98,4%)**	**490 (98,4%)**	**449 (88,9%)**	**447 (88,5%)**
Osteophytes	1 (0,2%)	6 (1,2%)	7 (1,4%)	8 (1,6%)	31 **(6,1%)**	24 **(4,8%)**
Uncertain	1 (0,2%)	1 (0,2%)			1 (0,2%)	5 (1%)
Missing	*4 (0,8%)*		*1 (0,2%)*	*7 (1,4%)*	*24 (4,8%)*	*29 (5,7%)*

Table 20/ figure 46: Prevalence of osteophytes in the cervical spine.

Key point: Osteophytes are most prevalent at level L4-L5.

2.11.1 Height and osteophyte

The height of discs with osteophytes is **lower** than the height of discs without osteophytes at every level. This finding is **significant** at levels L1-L2 (p=0,005), L2-L3 (p=0,009), L3-L4 (p=0,04), L4-L5 (p=0,02).

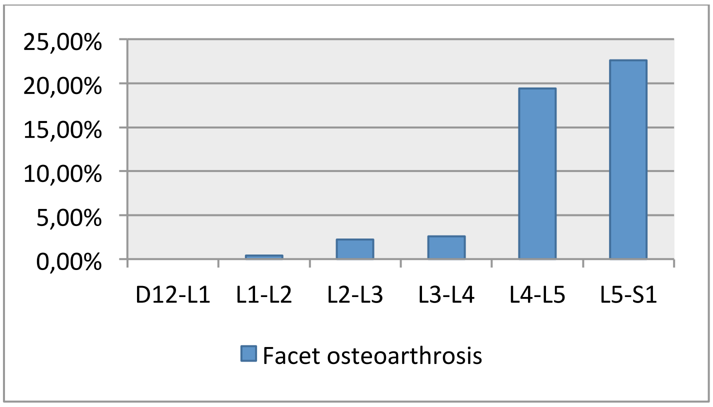
2.11.2 Osteophytes in normal discs

Can osteophytes occur in normal discs? Normal discs are defined as discs without annular fissure, bulging, protrusion or herniation. One normal disc with osteophytes was observed at level D12-L1, one at level L1-L2, 5 at level L2-L3 and 1 at level L5-S1.

Key point: Discs with osteophytes are lower in height than discs without osteophytes but they can occur in discs without annular fissure, bulging, protrusion or herniation.

2.12 *FACET JOINTS*

The table below shows facet osteoarthrosis is most prevalent at levels **L4-L5** and **L5-S1**.



	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Normal			**8 (1,6%)**	**22 (4,4%)**	**52 (10,3%)**	**57 (11,3%)**
Facet osteoarthrosis		2 (0,4%)	11 (2,2%)	13 (2,6%)	98 **(19,4%)**	114 **(22,6%)**
Missing	*505*	*503*	*486*	*470*	*355*	*334*

Table 21/ figure 47: Prevalence of facet osteoarthrosis in the lumbar spine.

Key point: Facet joint osteoarthrosis is most prevalent at level L5-S1.

2.12.1 Age and facet osteoarthrosis

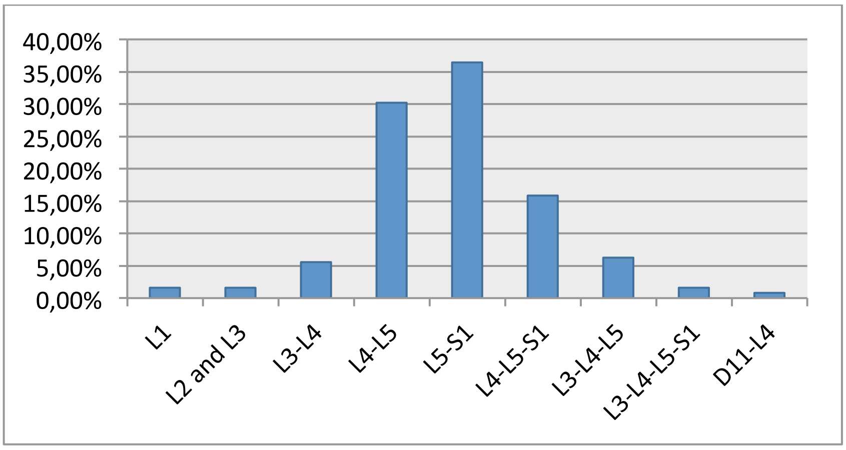
The age in patients with facet osteoarthrosis is **significantly** (p=0,009) **higher** than in patients without osteoarthrosis of the facet joints.

2.13 *POST-OPERATIVE CHANGES*

Postoperative changes are seen in 125 **(24,8%)** scans. In 380 (75,2%) scans no operation is carried out. In 69 scans **(54,8%)** a **discectomy** was performed. In 32 scans (**25,3%)** a **PLIF and cage** implantation was carried out. In 3 scans (2,4%) a PLIF was performed without cage implantation. In 3 (2,4%) cases an ALIF and cage implantation was performed. Four (3,2%) scans showed a disc prosthesis. In 6 (4,8%) scans a laminectomy was performed. Three scans (2,4%) were taken post kyphoplasty. In 2 (1,6%) scans a semi rigid fixation was present. Two (1,6%) scans were taken after a sequester was removed. There was one (0,8%) scan that showed an interspinous spacer and one (0,8%) scan was taken after stabilisation material was removed.

Twenty-nine (12,1%) patients underwent surgery already at the time of their first scan.

Operations are carried out most at levels **L4-L5** and **L5-S1**. The table below shows operations are carried out a lot at **multiple** levels as well.



	N	%
L1	2	1,6
L2 and L3	2	1,6
L3-L4	7	5,6
L4-L5	38	30,2
L5-S1	46	36,5
L4-L5-S1	20	15,9
L3-L4-L5	8	6,3
L3-L4-L5-S1	2	1,6
D11-L4	1	0,8
Total	**126**	**100,0**

Table 22/ figure 48: Levels where operation was performed. N=number of scans.

Key point: Most patients were operated at level L5-S1. A discectomy was carried out most of all surgeries.

2.13.1 Herniation after operation

In **3 cases** patients have a herniated disc at the **adjacent level** of a cage herniation. In none of these cases it is sure the herniation developed after the surgery.

2.13.2 Height after discectomy

At level L3-L4 (p=0,02), L4-L5 (p=0,002) and level L5-S1 (p<0,001) the height of discs post discectomy is **significantly lower** than the height in the sample.

Key point: After a discectomy is performed, the height of the disc will reduce.

2.13.3 Signal intensity after discectomy

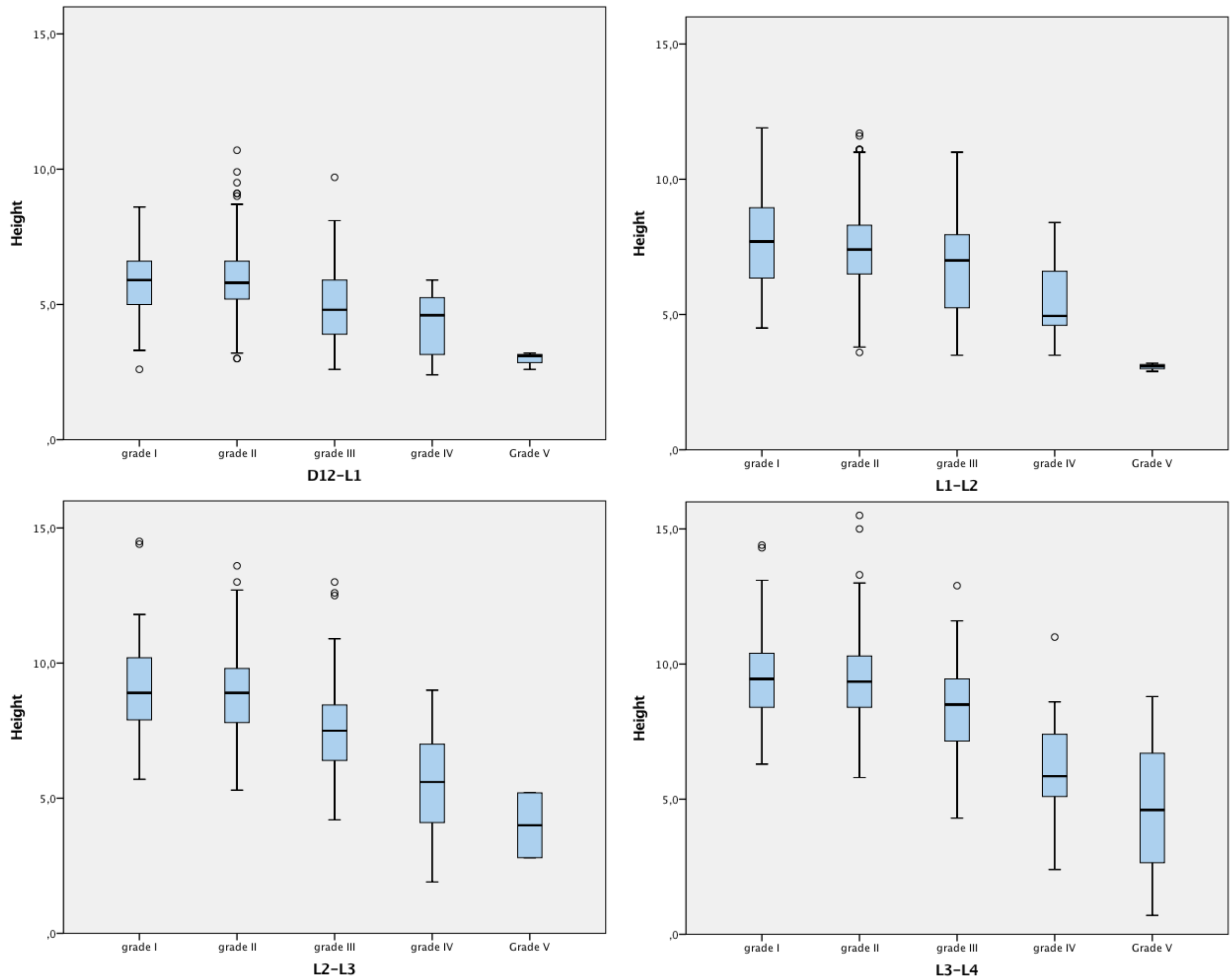
There is **no significant difference** between the signal intensity after discectomy compared to the signal intensity of the sample.

2.14 *PFIRRMANN CLASSIFICATION*

2.14.1 Correlation between Pfirrmann's classification and height

Boxplots were made of the relation between the height of the discs and the Pfirrmann classification of the discs. The discs should have the same height when classified as grade I and grade II and become more and more narrow from grade III to V.

In contrast to the cervical spine here **the results are as expected** at all levels.



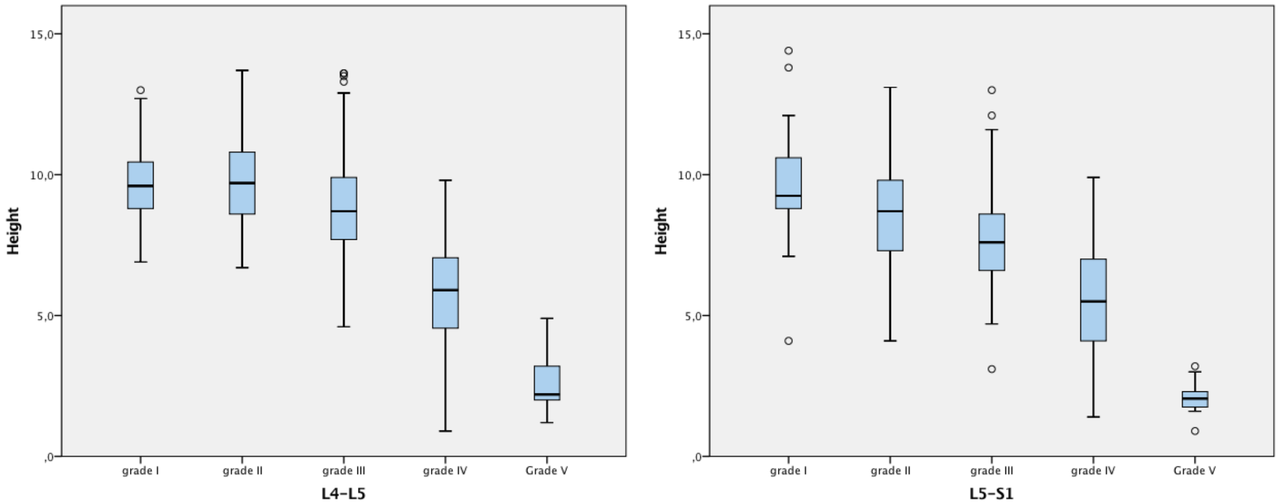


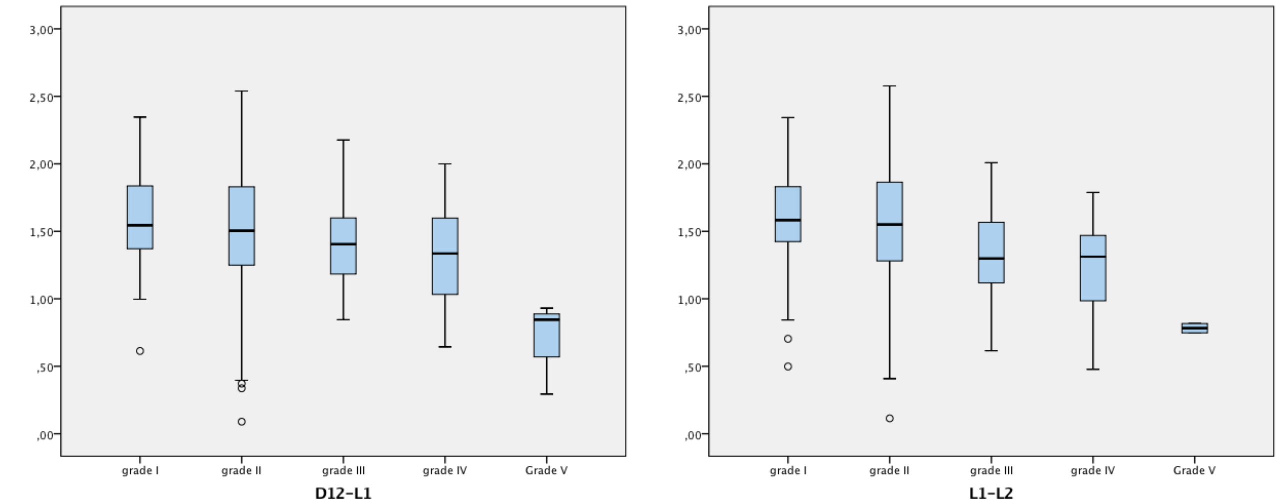
Figure 49: Correlation between the height of the disc and its Pfirrmann classification. Height is defined in mm.

2.14.2 Correlation between Pfirrmann's classification and height in control population

In our control population only Pfirrmann grade I and grade II is present, the height in these 2 categories should be more or less the same. At level **L2-L3** (p<0,001), **L3-L4** (p=0,04) and level **L5-S1** (p=0,004) the height in disc with grade II is **significantly lower** than in discs with grade I.

2.14.3 Correlation between Pfirrmann's classification and the signal of the nucleus

Boxplots of the relation between the signal intensity of the nucleus and the Pfirrmann classification were made. The discs are expected to become darker when the Pfirrmann classification becomes higher.



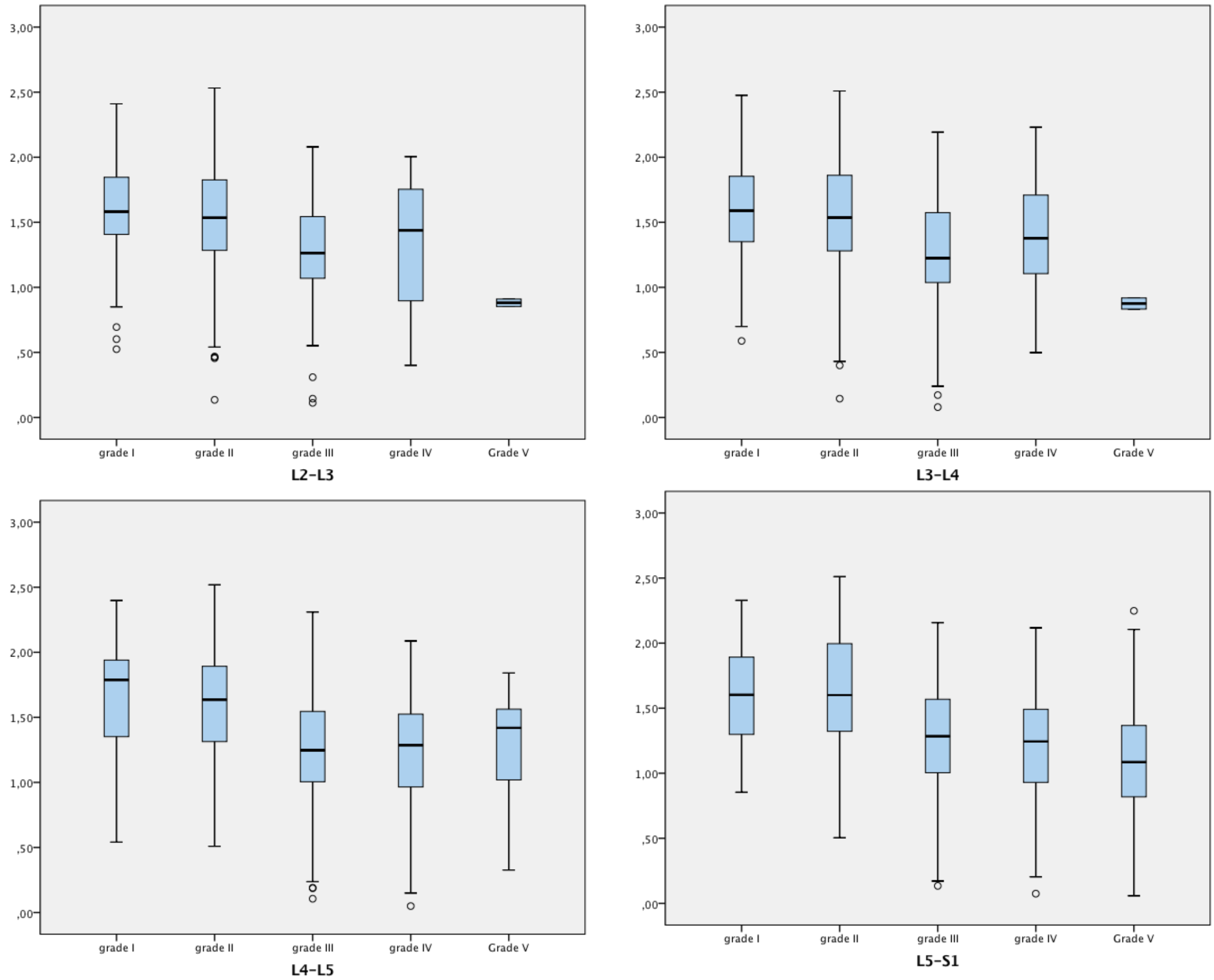


Figure 50: Boxplot with Pfirrmann classification on the X-axis and signal intensity on the Y-axis.

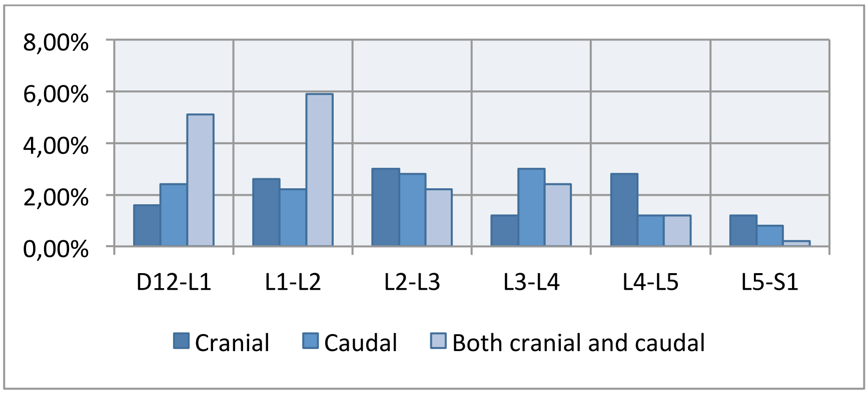
2.14.4 Correlation between Pfirrmann's classification and the signal of the nucleus in control population

Comparison of the signal intensity of the nucleus in discs with Pfirrmann grade I and discs with Pfirrmann grade II shows **no significant difference** between the signal intensities.

Key point: Pfirrmann's classification is an excellent grading tool for the lumbar spine.

2.15 Schmorl Node

The table below shows Schmorl nodes are most prevalent at level D12-L1 and L1-L2.



	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
No Schmorl nodes	**455 (90,1%)**	**451 (89,3%)**	**464 (91,9%)**	**465 (92,1%)**	**453 (89,7%)**	**465 (92,1%)**
Cranial	8 (1,6%)	13 (2,6%)	15 (3%)	6 (1,2%)	14 (2,8%)	6 (1,2%)
Caudal	12 (2,4%)	11 (2,2%)	14 (2,8%)	15 (3%)	6 (1,2%)	4 (0,8%)
Both cranial and caudal	26 **(5,1%)**	30 **(5,9%)**	11 (2,2%)	12 (2,4%)	6 (1,2%)	1 (0,2%)
Missing	*4 (0,8%)*		*1 (0,2%)*	*7 (1,4%)*	*26 (5,1%)*	*29 (5,7%)*

Table 23/ figure 51: Prevalence of Schmorl nodes in the lumbar spine.

In 18 (64,3%) cases the nodes are due to Scheuermann's disease. In 6 (21,4%) cases intracorporal herniations are present and in 4 (14,3%) cases intracorporal herniations and Scheuermann's disease are both present.

Key point: Schmorl nodes are most prevalent at level L1-L2.

2.15.1 Schmorl node and disc pathology

The table underneath shows there are **less healthy nuclei** when Schmorl nodes are present at almost every level (except level D12-L1).

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Schmorl	95,7%	**75,9%**	**47,5%**	**39,4%**	**11,5%**	**0%**
No Schmorl	97,8%	96,2%	89,9%	77,6%	41,3%	35,7%

Table 24: Table show the percentage of normal discs when a Schmorl node is present or without Schmorl nodes.

Key point: Disc levels with a Schmorl node will degenerate faster.

2.16 *Position of the nucleus*

At every level the position of the centre of the nucleus pulposus was reported on sagittal images. At level D12-L1 and L1-L2 the most prevalent position of the centre of the nucleus pulposus was the

posterior part of the vertebrae. At level L2-L3, L3-L4, L4-L5 and L5-S1 the most prevalent position of the centre of the nucleus pulposus was in the **middle**.

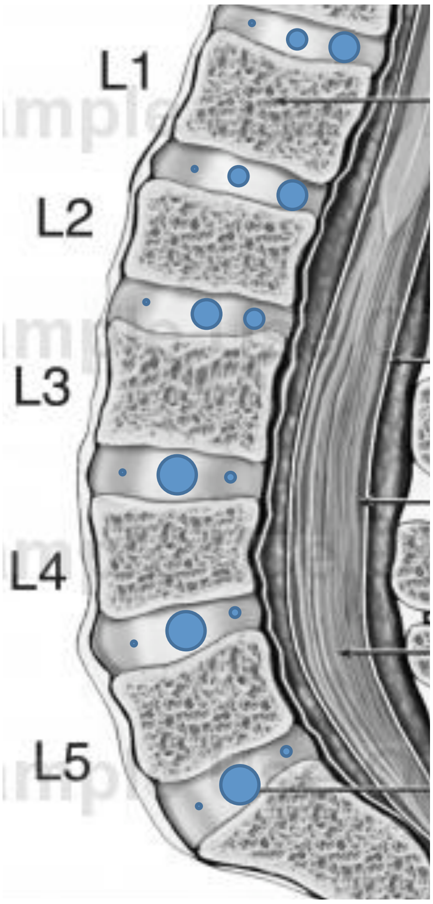


Figure 52: Image shows the position of the centre of the nucleus pulposus on each level: middle, anteriorly or posteriorly. The diameter of the circle represents the number of patients.

2.16.1 Position of the nucleus in the control population

At levels D12-L1, L1-L2 and L2-L3 most of the nuclei are posterior to the middle. Second most common position for the nucleus is in the middle of the vertebrae. At level L3-L4 and L4-L5 most of the nuclei lay in the middle and the second most common spot is posterior. At level L5-S1 the position of the nucleus is equally as common in the middle as in the posterior part of the vertebrae.

Key point: There is a remarkable difference between the position of the centre of the nucleus pulposus in normal people and the sample group. The centre of the nucleus pulposus lies more posteriorly in normal people.

DISCUSSION

Our study has some weak spots. First, **the multiplicity of MRI systems** made it difficult to compare the signal intensity. The signal intensity of the nucleus and expulsed fragments is corrected by dividing it through the signal intensity of air. A second fact to keep in mind is that it is a retrospective study with a **selection bias**. An independent radiologist reassessed the patients to detect the causal relationship with trauma.

1 CERVICAL SPINE

1.1 HEIGHT OF DISC

In our sample and control group the height of C3-C4 is higher than the disc spaces surrounding it. In our control population from C4-C5 to C6-C7 the discs space is always higher than the one above. **C7-D1 is a different disc space because it is attached to the rib cage.** In our sample group **C5-C6 has the lowest height because degeneration sets in first at this level** (9). Frobin et al. (10) carried out measurements on plain radiographs of the cervical spine in 135 normal patients. They reported the height of level C3-C4 is the highest as well. The height at level C4-C5 and C5-C6 was more or less the same and the height of level C6-C7 was lower but it was only measured on a quarter of the patients. Yukawa et al. (11) performed measurements of the disc space in 1230 asymptomatic volunteers. The lowest height was measured at level C5-C6 and the highest at level C6-C7. If only the young age groups are considered the height of level C5-C6 is not the lowest. In some age groups C3-C4 is the highest disc.

At almost every level a decrease of the disc height is observed if patients get older. This finding is confirmed by Yuwaka et al. who report the same (11).

In contrary to the expected result the height of the discs will become higher if patients become older in our control population. This may be **due to measurement errors in darker discs at, older age**. In darker discs it is difficult to distinguish the disc from the vertebral end plate.

At some levels (C2-C3, C3-C4, C4-C5 and C7-D1) the height of the discs will increase in older males (>55 years old). This could be due to a small sample size (n=16) or due to measurement errors as discussed above.

1.2 SIGNAL INTENSITY

The signal intensity is significantly lower in older patients at every level in the sample group and the control population. **This means, even in normal patients the nucleus will dehydrate over time.** Ulbrich et al. (12) and Adulkarim et al. (9) described a decrease in signal intensity in older patients as well. They described more degenerative discs at high levels (C2-C3 etc.) in young patients and as age progresses the lower levels become involved. **To our opinion the discs at high levels (C2-C3, C3-C4**

etc.) are relatively darker in young patients because of the scan protocol used. De Bruin et al. (13) concluded low signal intensity of intervertebral discs on fluid sensitive images in young patients without other degenerative signs might be a part of the natural course. Schleich et al. (14) suggest a higher T2 signal in lower cervical discs reflects an increasing water and proteoglycan content to resist a higher mechanical load in these lower levels.

The signal intensity of the nucleus pulposus will decrease when the height increases. This finding is different than expected, because this would suggest that discs can dehydrate without losing height. However, it is the opinion of the promoter of this thesis, with more than 26 years of experience, that this might be an effect of the physics of the scan protocol. This paradoxical sign of signal decrease with increasing height is only observed in fast-spin-echo T2 sequences, and not in STIR-T2 sequences, which are more sensitive to changes in water content. Because T2-StIR sequences were not always available and not investigated this study, this paradoxical phenomenon remains a topic for further research.

Key point: Discs at high levels of the cervical spine are relatively dark in young patients because of the physics of the scan protocol.

1.3 Annular fissures

Ernst et al. (15) investigated the prevalence of annular tears in asymptomatic patients. They reported annular tears in 36,7% of 30 asymptomatic volunteers. Lee et al. (16) reported 43,5% of all discs or 85,9% of all patients to have an annular fissure in asymptomatic patients. In our study annular fissures are reported only in 11,20% of all discs.

All HIZ were found at the caudal part of the annulus fibrosus in the cervical spine. This could be due to **hyperflexion forces** where there will be more traction to the caudal part of the annulus.

To our knowledge, the height of the disc in case of a HIZ was never described. Discs with a HIZ have a higher mean height than discs without HIZ in our sample group (not significant). At most levels the height of discs with a HIZ is lower than the control group, except at level C4-C5. **This could proof discs can tear first and degenerate afterwards**. Of course there will be cases where discs will dehydrate without fissure or tear of the annulus. More or less the same was concluded by Lama et al. (17) **intervertebral discs can herniate before or after they degenerate.**

Key point: Disc can tear first and degenerate afterward but degeneration can also set in first.

1.4 BULGING

To our knowledge, our study is the **first to describe the level of bulging discs on a large sample group.** Bulging is most frequent at level **C5-C6**. Nakashima et al. (18) investigated 1211 asymptomatic subjects of which 87,6% had disc bulging. Spinal canal compression was most prevalent at level C5-C6 (but was also due other causes than bulging of the dis). In the study by Stadnik et al. (15) 73% of the asymptomatic patients have a bulging disc.

1.5 HERNIATION

In contrary to bulging and annular fissures, herniation is far less common in asymptomatic patients. Only 3% of the asymptomatic patients in the study of Ernst et al. had a herniation (15). This makes it easier to conclude a herniation seen on imaging will be the cause of the patient's pain.

Most of the herniations are present at the paramedian part of the disc. Anatomical drawings of the posterior longitudinal ligament show the ligament is a firm band that covers the posterior part of the vertebral bodies in a craniocaudad direction. A tick layer protects the median part of the disc as the peripheral areas of the disc are only protected by some of the fibers of the ligament. This could explain why there are less herniations in the median part of the disc than the more peripheral parts.

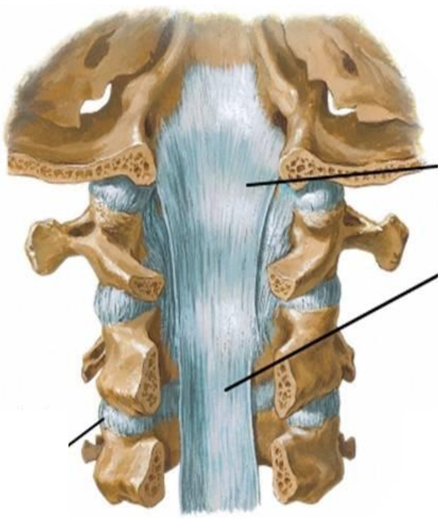


Figure 53: The longitudinal posterior ligament in the cervical spine.

The time between the accident and the herniation development ranges between 2 and 107 months. A prospective study by Pettersson et al. (19) followed patients for 2 years after whiplash trauma and showed **herniation can develop even one year after trauma.** The patient in case 6, where there was no herniation on imaging 87 months after trauma and a herniation was reported on imaging 107 months after trauma probably had a second non-reported trauma. The theory of Pettersson can be applied to the other cases.

The height of the disc with a herniation is not different to the height of disc without herniation. **Early after trauma there is probably no effect of a herniation on the height of the disc.** Most of our scans are made in the first months after trauma. It is also possible the volume of expulsed content is too low in a herniated disc to provoke a decrease in height.

We would like to investigate the influence of a herniation on the formation of new herniations at the adjacent levels. Only 3 cases are presented in our study and to our knowledge literature only discusses the formation of herniations at the adjacent level after surgery (adjacent segment disease).

The presence of scoliosis will not affect the side where a herniation will form.

Our hypothesis is the signal will be bright in case of a recent herniation of the nucleus and will dehydrate and become darker over time. There was no statistically significant difference between the signal of a recent and old herniation in our study. It is possible the **multiplicity of MRI systems and scan protocols** is a cause for this.

In our study 4 patients with an expulsed fragment of the disc where all **young**, their age lies between 30 and 42 years old. Other authors described cases where patients were 29, 39, 40, 43, 76 years old (15, 20-23).

Sixteen patients have spontaneous regression of a herniated disc. In 4 patients even a full resorption. The time between the herniation and regression varies from 4 to 9 months, 5 months and 2 years according to different articles (20, 22, 23). Also there is a higher chance an expulsed fragment will regress spontaneously because of a higher water content and inflammatory mediated resorption (22). The literature describes regression of expulsed fragments but in our sample group spontaneous regression of herniated discs without expulsion is observed as well. **Yet, in all cases with a spontaneous regression there was an annular fissure.** In some cases there can be a regression of a herniation that is not included in the study because there was no follow-up after the first observation of the hernia.

1.6 LISTHESIS

First of all it is important to keep in mind only 35 cases of listhesis are reported in fewer individual patients. To our knowledge, Suzuki et al. (24) presented the largest group of cervical degenerative listhesis. In their study they reported C4-C5 as the most prevalent level, followed by C5-C6. The same finding was supported by a couple smaller studies (25-27). Most of the cases have a **retrolisthesis at level C5-C6**. The same finding was seen in the study of Suzuki et al (24). The correlation between listhesis and disc degeneration is not entirely clear (24). A **decrease in height** and signal intensity was reported at most levels, yet not statistically significant due to a small sample group and the **multiplicity of MRI systems.**

1.7 Modic

Modic grade I is most prevalent in our study. Modic changes are most prevalent at level C5-C6. The disc height is lower in Modic I than in patients without Modic changes and the height even decreased when Modic II is present. In the large study group of Sheng-yun et al. (28) who compared the lumbar and the cervical spine Modic II was most prevalent and Modic III was least prevalent. The study of Matsumoto et al. (29) showed Modic changes are most prevalent at level C5-C6. They showed grade I can change to grade II and III. Grade I goes back to normal as well but they didn't show grade II or III go back to a normal bone marrow. **To our knowledge no article described the combination of different Modic grades in one vertebra on cervical level.**

Key point: A combination of different Modic grades in one vertebral body is possible.

1.8 Osteophytes

To our knowledge there is no study that describes the prevalence of osteophytes in the cervical spine, a correlation to the height of the disc or osteophytes in normal discs. Our study showed osteophytes are most prevalent at levels C5-C6. Yet, MRI is not the first choice imaging technique to investigate the presence of osteophytes. The height of discs where osteophytes are present is significantly lower than the height of discs without osteophytes. **Osteophytes at levels with a normal disc are more frequent in the cervical spine than the lumbar spine. It is possible in the cervical spine the Sharpey fibers are torn in a front-to-back movement but without visible changes on MRI.**

Key point: New finding: The height of discs with osteophytes is reduced.

1.9 Facet joints

The prevalence of facet joint arthrosis is low in our study. Facet osteoarthrosis is difficult to assess on MRI. CT and plain radiograph are better diagnostic tools.

1.10 Uncovertebral arthrosis

As literature supports, uncovertebral arthrosis is most prevalent at levels C5-C6 and C6-C7 (30). Patients with uncovertebral arthrosis are **older** and the **height of these discs is lower.**

Key point: Patients with uncovertebral arthrosis are older and the height of the disc is lower.

1.11 Post-operative changes

Due to our study design in only one of the cases it is certain an adjacent segment disease develops. A large meta-analysis by Shriver et al. (31) showed an overall incidence of adjacent segment degeneration was 8,3% and 0,9% in adjacent segment disease.

1.12 PFIRRMANN CLASSIFICATION

Nor the height of the disc in correlation to the Pfirrmann classification, nor the signal of the nucleus in correlation to the Pfirrmann classification has the expected result at level C2-C3 and C3-C4. **At levels C2-C3 and C4-C5 the Pfirrmann classification is difficult to define**. This could have a number of possible explanations. At these levels discs will become darker because of the physical effects of the **scan protocol**, not only because of degeneration. Therefore it is **difficult to measure** the height of a dark nucleus.

1.13 POSITION OF THE NUCLEUS

To our knowledge, no study ever described the position of the centre of the nucleus pulposus in symptomatic and asymptomatic patients. The shifting point is different between the normal patients and the symptomatic patient. **The change of posture of the cervical spine in older people may change compared to younger people.** The article of Beattie et al. (32) described the migration of the nucleus pulposus in the lumbar spine due to posture changes. The nucleus pulposus will move forward when the patient lies straight on the back in comparison to patients lying with the legs bent.

Levels where the nucleus pulposus does not lie in the middle will not degenerate faster.

Key point: New finding: The position of the nucleus was never described. The change of posture may change the position of the nucleus.

2 LUMBAR SPINE

2.1 HEIGHT OF DISC

In our sample population the disc height will become higher from D12-L1 to L3-L4 and decrease at level L4-L5 and L5-S1. In the control population the disc height becomes higher from D12-L1 to L4-L5 and the height of L5-S1 is lower. **This can proof the 'typical levels' where degeneration is more prevalent are L4-L5 and L5-S1** (33). Nguyen et al. (34) described the same finding of our control population in 17 patients. They measured the anterior and posterior part of the nucleus but the disc becomes higher from L1-L2 through L4-L5 as well and is lower at level L5-S1. Teichtahl et al. (35) measured the disc height in 57 patients and found the same results as our sample population, higher from L1-L2 to L3-L4 and lower at l4-L5 and L5-S1. This can mean the disc will become higher from D12-L1 to L4-L5 in young patients without degenerative discs and L4-L5 will be lower in older patients because of degeneration.

In contrary to the cervical level there is no clear decrease in disc height at every level with increasing age. In the sample group as well as the control group the height of the disc will become higher in older people. **It is only possible measurement mistakes were made.** In darker discs it is difficult to distinguish the disc from the vertebral end plate. Only in astronauts the height of the disc can become higher over time, due to reduces loads (36). Battié et al. (37) showed a moderate correlation between the narrowing height of the disc when aging.

2.2 SIGNAL INTENSITY

Dehydrated nuclei are more common with increasing age at every level in the sample and control population. **Even in normal and young (18 to 36 years old) people the signal intensity will be lower in older people.** Battié et al. (37) describes a decrease in signal intensity within an aging population. Yet it is important to keep in mind there is a broad variety in results within age groups. **Dehydration is a part of normal degeneration with or without the presence of pathology.**

The signal intensity is higher in higher discs at every level. To our knowledge no study group ever described the height of the lumbar disc in correlation to its signal intensity.

Key point: New finding: The signal intensity will be higher if the disc space is higher.

2.3 ANNULAR FISSURES

L4-L5 and L5-S1 are the most prevalent levels for annular fissures and HIZs. **These levels are exposed to the highest forces.** Kanayama et al. (33) and Seon-Yu et al. (38) reported these levels to be the most prevalent places for HIZs and annular fissures as well.

In contrary to the cervical spine, in the lumbar spine HIZs at the **cranial part of the nucleus** are reported. In our opinion HIZs at the cranial part of the nucleus in the lumbar spine are provoked by lordosis of the spine. HIZs at the caudal part of the nucleus form due to damage when a flexion movement is carried out.

HIZs do not play a roll in height reduction of the disc. The most important structure to maintain the disc height is the nucleus pulposus. A HIZ does not affect the nucleus pulposus.

2.4 BULGING

The highest prevalence of bulging discs is at level L4-L5 and L5-S1. In the study of Pokhraj et al. (39) who described the intervertebral disc in 109 patients the most prevalent levels are L3-L4 and L4-L5. They also report a smaller amount of bulging discs at level L4-L5 25,8% to 30,9% in our study. They reported 25,8% bulging discs at level L3-L4 to 16% in our study. The study of Battié et al. (37) reported level L3-L4 and L4-L5 as highest prevalent levels for disc bulging.

2.5 HERNIATIONS

Like several other studies, in our study most of the herniated discs are present at level L5-S1 and L4-L5 (33, 37-39). Most of the herniations are present at the paramedian part of the disc. As explained in the section about the cervical spine, **the posterior longitudinal ligament** is a firm band that covers the posterior part of the vertebral bodies in a craniocaudad direction. **A tick layer protects the**

median part of the disc as the peripheral areas of the disc are only protected by some of the fibers of the ligament. This could explain why there are less herniations in the median part of the disc than the more peripheral parts.

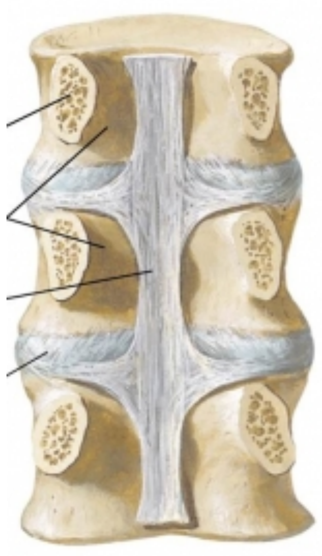


Figure 54: Longitudinal posterior ligament in the lumbar spine.

Key point: The posterior longitudinal ligament will protect the medial part of the disc.

The patients with a herniated disc are slightly younger in our population, yet this finding is not significant. It is possible there are more herniations in younger people because their nucleus is still hydrated and a soft disc will herniate faster.

The height of herniated discs is lower than the height of discs without herniation. This is a logical finding because the nucleus pulposus will lose water.

It would be interesting to investigate whether one herniation can trigger the formation of a new herniation on the adjacent levels. Only 3 cases can be presented, which has no value. **To our knowledge there is no study except after surgery to investigate the presence of a second herniation on an adjacent level.**

The presence of scoliosis will not affect the side where a herniation will form.

A significant difference between the signal intensity of an old and new herniation could not be demonstrated, probably due to the variety of MRI systems. Henmi et al. (40) showed a relationship between a hydrated herniated part and the duration of the illness. A hydrated herniated part will heal faster. The dehydrated ones already lost water and are unable to decrease their volume because of dehydration. Rasekhi et al (41) investigated the difference between a group of hydrated and dehydrated herniated parts. The group with dehydrated herniated parts was older and have had lumbar pain for a longer period of time.

Eighteen scans showed an expulsed disc fragment. Important to report is the nature of their trauma was minor in most cases. **It is not necessary to have a severe trauma for the formation of an expulsion.**

Key point: New finding: It is not necessary to have a severe trauma to have an expulsion.

In 15 patients a spontaneous regression of herniated and expulsed discs is observed with a full resorption in 4 patients. All of these patients had an annular fissure. Resorption was seen 3 to 29 months after the previous scan. The study carried out by Takada et al. (42) demonstrated the resorption rate of different kinds of herniations. **Protrusions have barely any resorptive capacity, extrusions can resorb in 6 to 12 months and sequestrations can resorb within 3 to 12 months.** Also some other study discussed the regression of disc herniation is less frequent than regression of sequestrated herniations. Cellular mechanisms are thought to contribute to resorption (43, 44).

2.6 LISTHESIS

Our study shows listhesis is most prevalent at levels L5-S1 and L4-L5. It is also remarkable bilateral spondylolysis is most frequent at the level L5-S1. The study of Vogt et al. (45) who did research on a group of elderly women described L4-L5 as the most prevalent level and L5-S1 as the second most prevalent level.

The height of discs with degenerative listhesis is significantly lower than the height of discs without degenerative listhesis. In listhesis due to bilateral spondylolysis the height will not be significantly lower. **In our opinion in case of a degenerative listhesis, there will be a degenerative disc prior to listhesis (this means a decreased height).** Facet osteoarthrosis will subsequently develop and the vertebral bodies adjacent to the disc will move forward or backward. **In case of listhesis due to spondylolysis there will be increased antero-posterior forces and motion of the disc first and subsequently the disc will degenerate.** The age of patients with a degenerative listhesis is significantly older. The study of Been et al. (46) also demonstrates the age in patients with degenerative listhesis is older than normal people. Vogt et al. (45) showed a decreased disc height at levels L3-L4 and L5-S1 when retrolisthesis was present. This was not seen in case of anterolisthesis.

Key point: In degenerative listhesis there will be degeneration prior to listhesis. In case of listhesis due to spondylolysis there will be motion of the disc first prior to degeneration.

There is no significant difference between the signal intensity of the nucleus pulposus in degenerative listhesis or listhesis due to spondylolysis. **This is probably due to the fact these images were made in different centres with different MRI systems which makes it hard to compare them.**

2.7 MODIC

Modic changes are most prevalent at level L4-L5 and L5-S1. According to data in the literature, these levels are preferentially affected (1, 33). Modic grade II is most prevalent, Modic grade III is least prevalent. **The height of discs with Modic changes is significantly lower than normal discs**. There is no clear difference between Modic grade I and grade II in terms of disc height. Probably the disc space is already narrow in Modic grade I and doesn't decrease any more after the acute phase (Modic I). Modic grade I changes will form due to micro-instability after degeneration. Luoma et al. (47) showed the same results. In most discs with Modic grade I, the discs height was decreased. In all discs where Modic grade III changes were present the height was decreased. In the 18 to 74 months of follow-up in their study some of the Modic I changes disappeared, others progressed to grade II or III. Teichtahl et al. (35) calculated the height of the disc is lower at levels with Modic changes at levels L3-L4, L4-L5 and L5-S1. They also show the chance of Modic increased 1,6 time with every mm reduced height.

2.8 OSTEOPHYTES

The prevalence of osteophytes is highest at level L4-L5, followed by L5-S1. Pokhraj et al. (39) present in their article levels L3-L4 and L5-S1 as the most prevalent location for osteophytes.

Osteophytes are less frequent in the lumbar spine than the cervical spine. **It is possible in the cervical spine the Sharpey fibers are torn in a front-to-back movement.** There are less Sharpey fibers in the cervical spine and the forces are bigger. The lumbar spine has stronger Sharpey fibers and there is also more muscular protection and less front-to-back manoeuvres are carried out. Al-Rawahi et al. (48) suggest osteophytes (both anterior and posterior) can be an **adaptive rather than degenerative adjustment to withstand most of all bending and secondly compressive forces.** Bending of the spine is much more present in the cervical than the lumbar spine.

The height of discs with osteophytes is significantly lower than discs without osteophytes. **This makes us believe degeneration will set in first before osteophytes will form.** Yet osteophytes can be present in normal discs at well.

2.9 FACET JOINTS

The prevalence of facet joint arthrosis is low in our study. Assessment of facet osteoarthrosis is rather difficult on MRI. CT and plain radiography are better diagnostic tools.

2.10 *POST-OPERATIVE CHANGES*

In 24,8% of the scans postoperative changes are present. Most frequently discectomy and PLIF with cage implantation were performed. Height after discectomy decreased significantly at every level compared to the sample group**.** The study of Son et al. (49) showed a decreased height in height ration (compared to the disc above) in long term follow-up after discectomy. In our study only in 3 cases after cage implantation the development of a herniation at the adjacent level was reported. However in none of the cases the time of development of the herniation could be calculated. Pan et al. (50) performed a meta-analysis about the prevalence of adjacent segment degeneration (5,6 to 100%) and adjacent segment disease (2,7% to 21,4%) and concluded the prevalence is very high.

There is no significant difference in signal intensity after discectomy in our study. **The signal intensity is probably higher but due to different MRI systems used and scans made on different times after surgery our result is not significant.**

2.11 *PFIRRMANN CLASSIFICATION*

At the lumbar spine boxplots displaying the height and signal intensity of the discs turn out just like expected. The height of discs with grade I and grade II is the same and from grade III on decreases gradually. The signal intensity goes down gradually from grade I to V. This only proves the Pfirrmann classification is easy to apply in the lumbar spine.

In the control population, with people between 18 and 35 years old there is already a decrease in height visible. **Even at young age degeneration is present.**

2.12 *SCHMORL NODE*

The prevalence of Schmorl nodes lies between 10,7% (level L1-L2) and 2,2% (level L5-S1). The study of Kannayama et al. (33) showed a prevalence of 4,0 to 9,5%. The prevalence was not different among the levels. Dar et al. (51) reports the highest prevalence of Schmorl nodes in the lumbar spine at the top levels, the prevalence decreases at every lower level.

When Schmorl nodes (intracorporal herniations included) are present the percentage of pathological (a disc is pathological if a herniation, bulging or annular tear present) discs is higher. **Discs with Schmorl nodes will degenerate faster.** To our knowledge Teraguchi et al. (52) are the only authors who studied the association between Schmorl nodes and degeneration of the disc. They report an association between disc degeneration and Schmorl nodes in 12,3% of their sample.

2.13 *POSITION OF THE NUCLEUS*

In our sample population the most prevalent place for the centre of the nucleus pulposus at level D12-L1 and L1-L2 is posterior to the middle. At the other levels the centre of the nucleus pulposus is positioned in the middle of the vertebrae most of the time. In our control population there is a slightly different position. The most prevalent place of the centre of the nucleus pulposus at level D12-L1, L1-

L2 and L2-L3 is at the posterior part. At the other levels, the centre of the nucleus pulposus is positioned mostly in the middle. **This means in the control population the disc lies posterior on more levels. To our knowledge no other study ever reported the location of the nucleus in such a large population.** The study by Beattie et al. (32) described the increase of the distance from the posterior margin of the nucleus to the posterior margins of the vertebrae when a patient lies fully extended instead of flexed. **Extension will make the nucleus to move forward.** There may be a change of posture of the lumbar spine in older people compared to younger people**.**

Key point: New finding: The position of the nucleus was never reported in a large sample. The posture of the patients may change the position of the nucleus.

CONCLUSION

1 CERVICAL SPINE

The most important findings are:

- Most patients have their first MRI scan within the first 5 months after trauma.
- There is a remarkable difference between the position of the nucleus in normal and pathological patients. The position of the centre of the nucleus pulposus was never described.
- Disc C3-C4 is higher than every disc close to it.
- The height of the disc will decrease in older patients.
- Pfirrmann's classification is an excellent grading tool for the cervical spine. Yet it is more difficult at level C2-C3 and C3-C4.
- Discs at high levels of the cervical spine are relatively dark in young patients because of the physics of the scan protocol.
- The signal intensity of the nucleus pulposus will decrease when people get older. Even in a young and healthy population.
- Discs can tear first and degenerate afterwards, but degeneration can also set in first without the presence of a fissure.
- All HIZs at the cervical spine are located at the caudal part of the disc.
- The presence of a HIZ does not influence the height of the disc.
- Annular fissures, bulging and protrusion, herniated discs are most prevalent at level C5-C6.
- In our study, patients with an expulsed disc are between 30 and 42 years old.
- Spontaneous regression occurs in 6,62% of all herniated discs.
- Retrolisthesis, Modic changes, uncovertebral arthrosis and osteophytes are most prevalent at level C5-C6.
- Modic changes are present in discs reduced in height.
- A combination of different Modic grades in one vertebral body is possible.
- Osteophytes occur mostly in dehydrated discs with a reduced height but can be present in discs without annular fissure, bulging, protrusion and herniation. This is a new finding.
- Uncovertebral arthrosis is more prevalent in older people and the disc height is often decreased.
- Facet joint osteoarthrosis is most prevalent at level C3-C4.
- Patients with a degenerative listhesis are older than patients without listhesis
- Operations are carried out most frequently at level C5-C6.

2 LUMBAR SPINE

The most important findings are:

- Most of the patients are referred for an MRI in the second month after trauma.
- There is a remarkable difference between the position of the centre of the nucleus pulposus in normal people and the sample group. The centre of the nucleus pulposus will lie more posteriorly in normal people. The position of the nucleus was never reported in a large sample.
- The disc height is always higher than the disc level above except at level L5-S1.
- Disc height will reduce in older patients.
- The signal intensity in the nucleus pulposus will be higher if the disc space is higher, this findings was never described before.
- Pfirrmann's classification is an excellent grading tool for the lumbar spine.
- The signal intensity will reduce with age even in young and healthy control patients.
- Annular fissures and herniations are most prevalent at level L5-S1.
- The presence of a HIZ does not influence the height of the disc.
- Herniated disc are lower in height than disc without herniation.
- The posterior longitudinal ligament will protect the median part of the disc.
- Expulsion occurred in patients who had a minor trauma, which is a new finding.
- Bulging discs are most prevalent at level L4-L5.
- The height of discs with Modic grade I is lower than discs without Modic changes.
- Osteophytes are most prevalent at level L4-L5.
- Discs with osteophytes have a lower height than discs without osteophytes but they can occur in discs without annular fissure, bulging, protrusion and herniation.
- Patients with a degenerative listhesis are older than patients without listhesis.
- In case of degenerative listhesis there will be a degenerative disc prior to listhesis. In case of listhesis due to spondylolysis there will be motion of the disc first prior to degeneration.
- Anterolisthesis and retrolisthesis, Modic changes and facet joint osteoarthrosis are most prevalent at level L5-S1.
- Schmorl nodes are most prevalent at level L1-L2.
- Disc levels with a Schmorl node will degenerate faster.
- Most patients were operated at level L5-S1. A discectomy was carried out most of all surgeries.
- After a discectomy is performed, the height of the disc will reduce.

PERSPECTIVES FOR FURTHER RESEARCH

Imaging of the spine is a very interesting topic where a lot more research can be done. In our research population more measurements can be carried out. The focus of our study went to MRI images but many patients had CT and plain radiography as well. The following questions could be answered:

- How many imaging studies were made in every case?
- In how many cases is an MR performed (shortly) after a CT scan?
- What is the time interval between CT and MRI?
- What is the radiation dose of these imaging studies?
- Why are the patients operated?
- Did they have a paresis or neurologic deficits?
- Will a lager expulsed fragment resorb faster or slower?
- Do patients with a higher BMI index have more degenerated discs? The thickness of the subcutis can be measured.
- Has disc pathology an influence on muscle atrophy or vice versa? The signal intensity of the muscles can be measured.

To investigate the signal intensity in recent en old herniation a prospective study should be carried out with a 10-year follow up or longer.

It would also be interesting to study the difference between degenerative fissures of the annulus and traumatic fissures.

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APPENDIX

CERVICAL

	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Valid	504	501	493	471	473	503
Missing	2	5	13	35	33	3
Mean	3,67	3,81	3,59	3,34	3,98	3,71
Median	3,60	3,90	3,50	3,30	4,00	3,70
Std. Deviation	0,890	0,874	0,865	0,999	1,064	0,787
Minimum	1,6	1,3	1,2	0,9	1,1	1,3
Maximum	6,6	6,7	6,3	6,3	7,6	8,2

Table 1: Height of the cervical discs. Height is expressed in mm.

	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Valid	114	114	114	114	114	114
Missing	0	0	0	0	0	0
Mean	3,496	3,872	3,717	3,971	4,449	3,985
Median	3,450	3,900	3,700	3,900	4,400	3,950
Std. Deviation	0,8072	0,7364	0,6609	0,7389	0,7188	0,7149
Minimum	1,9	2,3	2,3	2,0	2,3	2,4
Maximum	6,7	6,1	6,0	6,1	6,7	5,6

Table 2: Height of discs in the control population.

	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Valid	2	25	49	136	73	2
Missing	0	0	0	0	0	0
Mean	4,300	3,496	3,839	3,213	3,715	4,050
Median	4,300	3,400	3,700	3,100	3,700	4,050
Std. Deviation	0,4243	0,6717	0,8321	0,9353	0,9935	0,4950
Minimum	4,0	1,9	2,5	0,9	1,7	3,7
Maximum	4,6	4,5	5,7	5,5	5,9	4,4

Table 3: Height of discs where a herniation is present.

	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Valid		6	4	14	1	
Missing		0	0	0	5	
Mean		4,383	2,575	2,864	3,100	
Median		4,500	2,550	2,500	3,100	
Std. Deviation		1,6376	0,6551	1,4908	0	
Minimum		2,4	1,8	1,5	3,1	
Maximum		6,1	3,4	6,3		

Table 4: Height of discs with listhesis.

	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Valid		6	2	29	16	2
Missing		0	0	3	1	0
Mean		3,083	3,000	2,859	3,169	4,200
Median		2,650	3,000	3,000	3,150	4,200
Std. Deviation		0,9152	1,6971	1,0655	1,1836	0,2828
Minimum		2,3	1,8	1,5	1,3	4,0
Maximum		4,3	4,2	5,5	5,3	4,4

Table 5: Height of discs with Modic I.

	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Valid			3	18	5	
Missing			0	0	1	
Mean			2,067	2,406	2,060	
Median			2,100	2,350	2,000	
Std. Deviation			0,1528	0,8025	0,2608	
Minimum			1,9	0,9	1,8	
Maximum			2,2	4,5	2,5	

Table 6: Height of discs with Modic II.

	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Valid	8	62	61	162	82	
Missing	0	2	2	9	14	
Mean	3,500	3,752	2,982	2,759	3,106	
Median	3,400	3,700	3,200	2,600	3,050	
Std. Deviation	0,7368	0,9922	0,8831	1,0332	1,1508	
Minimum	2,6	1,7	1,2	0,9	1,1	
Maximum	4,4	5,9	5,3	6,3	5,9	

Table 7: Height of discs with uncovertebral arthrosis.

	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-D1
Valid		1	12	12	3	
Missing		0	0	0	0	
Mean		4,200	4,017	3,658	4,300	
Median		4,200	3,750	3,550	5,000	
Std. Deviation			0,8737	0,9472	1,4799	
Minimum		4,2	3,2	2,2	2,6	
Maximum		4,2	5,7	4,8	5,3	

Table 8: Height of discs with HIZ.

LUMBAR

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Valid	501	505	503	498	478	477
Missing	4	0	2	7	27	28
Mean	5,716	7,277	8,555	8,987	8,619	7,401
Median	5,700	7,300	8,600	9,000	8,800	7,600
Std. Deviation	1,3342	1,5887	1,8351	1,8522	2,2707	2,3218
Minimum	2,4	2,9	1,9	0,7	0,9	0,9
Maximum	10,7	11,9	14,5	15,5	13,7	14,4

Table 1: Height of the discs

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Valid	173	173	173	173	173	173
Missing	0	0	0	0	0	0
Mean	5,651	6,873	8,212	8,956	9,566	8,438
Median	5,500	6,700	8,000	9,000	9,600	8,400
Std. Deviation	1,1042	1,2793	1,4347	1,4063	1,4009	1,5723
Range	6,4	6,6	7,7	7,1	7,7	8,2
Minimum	2,7	4,5	5,2	5,2	5,9	4,9
Maximum	9,1	11,1	12,9	12,3	13,6	13,1

Table 2: Height of the discs in the control population

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Valid	3	8	8	28	88	96
Missing	0	0	0	0	0	0
Mean	4,900	5,288	7,088	7,554	7,572	6,580
Median	5,500	4,600	6,100	8,200	7,850	6,900
Std. Deviation	1,3077	1,5282	2,9019	2,1086	1,9226	1,9691
Minimum	3,4	3,8	3,8	3,0	2,2	1,4
Maximum	5,8	7,2	11,3	10,4	13,6	11,0

Table 3: Height of herniated discs

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Valid		3	8	5	16	16
Missing		0	0	0	0	0
Mean		4,033	5,463	8,120	5,969	6,381
Median		4,600	4,750	8,000	6,550	5,950
Std. Deviation		0,9815	2,2803	1,7050	2,3041	2,7039
Minimum		2,9	3,3	6,5	0,9	1,8
Maximum		4,6	9,6	10,9	10,2	12,1

Table 4: Height of discs with a degenerative listhesis.

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Valid				1	4	9
Missing				0	0	0
Mean				0,700	6,775	6,500
Median				0,700	6,750	7,100
Std. Deviation					1,4796	3,0315
Minimum				0,7	5,2	0,9
Maximum				0,7	8,4	9,5

Table 5: Height of discs with listhesis due to spondylolysis

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Valid	2	2	2	8	18	27
Missing	0	0	0	0	0	1
Mean	5,250	4,300	2,250	6,450	6,183	5,322
Median	5,250	4,300	2,250	6,150	6,200	5,200
Std. Deviation	0,7778	0,5657	0,4950	1,5973	3,4158	2,5363
Minimum	4,7	3,9	1,9	4,7	1,3	1,8
Maximum	5,8	4,7	2,6	9,7	13,5	13,0

Table 6: Height of discs Modic I

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Valid	1	4	5	12	29	33
Missing	0	0	0	0	1	5
Mean	4,900	5,225	5,100	5,058	6,486	4,918
Median	4,900	5,150	3,700	4,600	6,600	4,900
Std. Deviation		2,4019	2,9249	2,3372	2,6284	2,4791
Minimum	4,9	3,1	2,8	2,4	1,2	0,9
Maximum	4,9	7,5	10,1	9,1	10,5	9,3

Table 7: Height of discs Modic II

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Valid			9	14	39	37
Missing			0	0	0	0
Mean			7,078	8,564	9,010	7,995
Median			7,800	8,850	8,900	7,600
Std. Deviation			1,7448	0,9229	1,8374	1,4738
Minimum			4,7	6,3	6,1	5,5
Maximum			9,5	10,3	13,5	10,3

Table 8: Height of discs with HIZ.

	D12-L1	L1-L2	L2-L3	L3-L4	L4-L5	L5-S1
Valid				4	33	36
Missing				0	0	2
Mean				7,625	7,073	6,108
Median				7,500	7,500	5,950
Std. Deviation				2,0934	2,7378	1,8808
Minimum				5,2	2,0	1,8
Maximum				10,3	10,4	10,4

Table 9: Height after discectomy.