Spinal column and hip joint changes, and their correlation to back pain in young athletes

Radiological and clinical studies

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Dedicated to the memory of my
beloved parents for their endless
love, sacrifice, encouragement,
and support. Your inspiration
has always helped me rise to the
challenges throughout my entire
life. Your wisdom is admirable.

Content

Abbreviations

AEC
Automatic Exposure Control

BMI
Body Mass Index

CT
Computed Tomography

EQ-5D
Euro Qol-5 Dimensions

FAI
Femoroacetabular Impingement

FOV
Field of View

ICC
Intraclass Correlation Coefficient

LBP
Low Back Pain

MRI
Magnetic Resonance Imaging

PI
Pelvic Incidence

PT
Pelvic Tilt

SD
Standard Deviation

SS
Sacral Slope

TE
Time to Echo

TK
Thoracic Kyphosis

TR
Repetition Time

VAS
Visual Analogue Scale

κ
Cohen’s kappa coefficient

α-angle
Alpha angle

Abstract

Background
Young athletes are at increasing risk for spinal column injuries and back pain due to excessive sporting activities, with potential development of complications like spinal canal stenosis and chronic back pain later in life. Increased knowledge is necessary in order to make the correct diagnosis and to be able to adapt the appropriate preventive measures, rehabilitation programs, and treatments accordingly.

Purpose
The aim of this project was to identify MRI changes in the thoraco-lumbar spine and the lifetime prevalence of back pain at baseline and with continuing sporting activity, as well as the association between them, in young athletes compared with non-athletes. Another purpose was to investigate the relationship between the pelvic morphology and the hip cam change in young elite skiers compared with non-athletes.

Material and Methods
Seventy-five young elite alpine and mogul skiers (mean age 18), and 31 young elite football (soccer) players (mean age 17) were compared with 27 non-athletes (mean age 16). All subjects were invited to undergo MRI of the thoraco-lumbar spine. The MRI images were evaluated for vertebral changes and disc abnormalities such as Pfirrmann grade, disc desiccation, disc height loss, bulging, herniation, and Schmorl's nodes. All participants answered standardized questionnaires with questions related to back pain, training hours, spinal injuries, and health perception.

The skiers hip joints were examined for cam morphology (defined as α-angle >55°) with MRI, and sagittal spinal alignment measurements including Pelvic Incidence (PI) on standing lateral plain radiographs. All participants were invited to participate in a 2-year follow-up, but 35 skiers and 10 non-athletes dropped out due to personal reasons.

Results

The spinal column abnormalities were significantly higher in athletes than non-athletes. Fifty-six percent of skiers had at least one disc of Pfirrmann grade ≥ 3 compared with 30% of non-athletes ($p = 0.03$). Schmorl's nodes (46%) and disc height reduction (37%) were significantly more prevalent in skiers compared with non-athletes (0%) ($p < 0.001$). The football players had significantly higher rate of MRI changes than non-athletes, 89% compared with 54% when all disc degenerative changes were combined ($p = 0.006$). There was no significant difference in lifetime prevalence of back pain between athletes (50%) and non-athletes (44%). No significant correlation between MRI abnormalities and back pain was identified. Athletes had better health perception than non-athletes ($p = 0.03$). Skiers had significantly greater prevalence of cam morphology (49%) compared with non-athletes (19%, $p=0.009$). No correlation was shown between a low Pelvic Incidence (PI) and hip cam morphology. No significant interval difference in spinal column abnormalities, neither for skiers nor non-athletes, and no significant difference in terms of back pain was found between baseline and 2-year follow-up.

Conclusion

Young elite athletes demonstrated significantly more spinal column abnormalities than non-athletes, while lifetime prevalence of back pain was not different between the groups.
Skiers had greater prevalence of hip cam morphology compared with non-athletes. A low Pelvic Incidence (PI) was not correlated with abnormal cam morphology.

Between baseline and 2-year follow-up, there was no significant interval difference in spinal column findings on MRI, nor back pain prevalence, neither for skiers nor non-athletes.

Sammanfattning på svenska

Bakgrund
Unga elitidrottare löper ökad risk för höft- och ryggskador och smärta på grund av överbelastning med potentiell ökad risk för utveckling av komplikationer senare i livet. Ökad kunskap om dessa idrottsrelaterade överbelastningsskador och dess effekter är nödvändiga för att kunna ställa korrekt diagnos och anpassa rehabiliteringsprogram och behandling därefter, men även för utveckling av förebyggande åtgärder.

Syfte
Syftet med detta projekt var att identifiera ryggsförändringar med magnetkamera (MR) och registrera ryggsmärta, liksom sambandet mellan dem, hos unga elitskidåkare och elitfotbollsspelare jämfört med kontroller vid baslinjen, samt efter 2 års fortsatt idrottsaktivitet. Ett annat syfte var att undersöka förhållandet mellan sagitella rygg- och höftparametarar och cam morfologi hos unga elitskidåkare jämfört med kontroller.

Metod
Sjuttiofem unga elitskidåkare (medelålder 18) och 31 unga elitfotbollsspelare (medelålder 17) jämfördes med 27 kontroller (medelålder 16). MR av bröst- och ländrygg utfördes på samtliga studieindivider. MR-bilderna utvärderades avseende förändringar i kotor och diskar såsom disksignal, diskhöjd, diskbuktning, diskbråck, Schmorl's noduli, och kotkropparnas patologi. Alla deltagare besvarade frågeformulär avseende träningstimmar, ryggsmärta, och hälsouppfattning.

Skidåkarnas höfter undersöktes med MR avseende cam morfologi (α-vinkel > 55°) och sagittella rygg- och höftparametrar utvärderades med stående sagitella röntgenbilder av hela ryggraden och bäckenet. Alla deltagare blev inbjudna att delta i en 2-års uppföljning, men 35 skidåkare och 10 kontroller avstod på grund av personliga skäl.

Resultat
Idrottare hade fler ryggförändringar jämfört med kontroller. 56% av skidåkarna hade minst en disk med Pfirrmann-grad ≥3 jämfört med 30% av kontroller ($p = 0.03$). Förekomst av Schmorlska noduli (46%) och reducerad diskhöjd (37%) var mer frekvent hos skidåkare jämfört med kontroller (0%) ($p < 0.001$). Även fotbollsspelare hade högre grad av MR förändringar jämfört med kontroller, 89% jämfört med 54% när alla diskdegenerativa förändringar kombinerades ($p = 0.006$). Det fanns ingen signifikant skillnad i livstidsprevalens av ryggsmärta mellan idrottare (50%) och kontroller (44%). Det fanns heller ingen korrelation mellan ryggsförändringar och ryggsmärta. Idrottare hade bättre subjektiv hälsouppfattning än kontroller ($p = 0.03$). Skidåkare hade högre förekomst av cam morfologi (49%) jämfört med kontroller (19%, $p = 0.009$). Det fanns ingen korrelation mellan bäckenets incidensvinkel (pelvic incidence angle) och cam morfologi.

Varken för skidåkare eller kontroller fanns någon signifikant progress av ryggförändringar eller ryggsmärta mellan initiala undersökningen och efter 2 års uppföljning.

Slutsatser
Elitidrottare hade fler ryggsförändringar på MR jämfört med kontroller. Livstidsprevalensen av ryggsmärta skilde sig dock inte signifikant mellan grupperna. Skidåkare hade högre förekomst av cam morfologi jämfört med kontroller. Ryggförändringar och ryggsmärta förändrades inte under 2-års kontinuerlig idrottande.

List of papers

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. Wisam A. Witwit MD, Peter Kovac MD, Anna Swärd MD, Cecilia Agnvall PT, Carl Todd DO, PhD, Olof Thoreson MD, PhD, Hanna Hebelka MD, PhD, Adad Baranto MD, PhD.

Disc degeneration on MRI is more prevalent in young elite skiers compared to controls.

Journal of Knee Surgery, Sports Traumatology, Arthroscopy (KSSTA). 2018; 26 (1): 325-332.

II. Carl Todd DO, PhD, Wisam A. Witwit MD, Josefin Abrahamson PT, Anna Swärd MD, Pall Jonasson MD, PhD, Jon Karlsson MD, PhD, Adad Baranto MD, PhD.

A low Pelvic Incidence angle may not place young athletes at risk of developing cam morphological changes in the hip joint.

Jacobs Journal of Sports Medicine. 2018, 5 (1) 032.

III. Wisam A. Witwit MD, Olof Thoreson MD, PhD, Anna Swärd Aminoff MD, Carl Todd DO, PhD, Pall Jonasson MD, PhD, Gauti Laxdal MD, PhD, Hanna Hebelka MD, PhD, Adad Baranto MD, PhD.

Young soccer players have significantly higher disc degeneration on MRI compared to non-athletes.

Journal of Translational Sports Medicine. 2020; 3: 288–295.

IV. Wisam A. Witwit MD, Hanna Hebelka MD, PhD, Anna Swärd Aminoff MD, Josefin Abrahamson PT, Carl Todd DO, PhD, Adad Baranto MD, PhD.

A 2-year follow-up of MRI findings and back pain in the thoraco-lumbar spine of young elite skiers.

Manuscript pending publishing.

Additional papers

I. Olof Thoreson MD, PhD, Lars Ekström MD, Hans-Arne Hansson MD, PhD, Carl Todd DO, PhD, Wisam A. Witwit MD, Anna Swärd Aminoff MD, Pall Jonasson MD, PhD, Adad Baranto MD, PhD.

The effect of repetitive flexion and extension fatigue loading on the young porcine lumbar spine, a feasibility study of MRI and histological analyses.

Journal of Experimental Orthopaedics 2017. 4 (1): p.16.

II. Carl Todd DO, PhD, Wisam A. Witwit MD, Peter Kovac MD, Anna Swärd MD, Cecilia Agnvall PT, Pall Jonasson MD, PhD, Olof Thoreson MD, PhD, Leif Swärd MD, PhD, Jon Karlsson MD, PhD, and Adad Baranto MD, PhD.

Pelvic Retroversion is Associated with Flat Back and Cam Type Femoro-Acetabular Impingement in Young Elite Skiers.

Journal of Spine, 2016. 5(4): p. 326.

Chapter 1

Introduction

Back pain

Back pain is very common and considered a major health and economic burden for the society [1, 2]. There is a wide range of spinal and extra-spinal causative factors, such as disc herniation, spinal stenosis, spondylolisthesis, ligament injury, and muscle sprain [3, 4].

Spinal column changes

The increased interest in physical exercise and participation in sports among adolescents has resulted in a trend to start training, competing, and specializing in one specific sport at a very young age. Nowadays, it is a common opinion that high doses of training, with high intensity, for long periods of time, are required at young age in order to become an elite athlete [5, 6]. A high rate of radiological changes (26% - 90%) has been reported in the thoraco-lumbar spine of athletes who have great demands imposed upon the spine, such as wrestlers, gymnasts, weightlifters, divers, ice-hockey, skiers, long distance runners, soccer- and tennis players [7-11]. Examples of such changes are disc degeneration, disc herniation, apophyseal ring injury and fractures in the interarticularis processes. The incidence of these findings has also been reported to be higher during growth spurt and more common in athletes than in non-athletes [7, 8, 12-20].

Long-term effects

Evolution of the spinal column changes and back pain with time is not completely established. Certain studies have stated that most spinal column changes develop during the growth spurt of young athletes [7, 13, 16, 18]. Therefore, follow-up longitudinal studies of young athletes are considered important to identify the morphological change in the spinal column and register back pain with continuing sporting activity and aging. Studies are also needed to elucidate if athletes develop complications later in life.

Intervertebral disc anatomy

The intervertebral discs lie between the vertebral bodies, and consist of nucleus pulposus and annulus fibrosus (Figure 1) [21]. The nucleus pulposus is a proteoglycan mass with a high water binding capacity [22], and its gel-like characteristics are responsible for the resilience and flexibility of the spine [23-26]. The annulus fibrosus is a shell of fibrocartilage surrounding the nucleus pulposus and inserts on the vertebral ring apophysis [27-30]. The endplates are cartilaginous layers located between the disc components and the adjacent vertebral body.

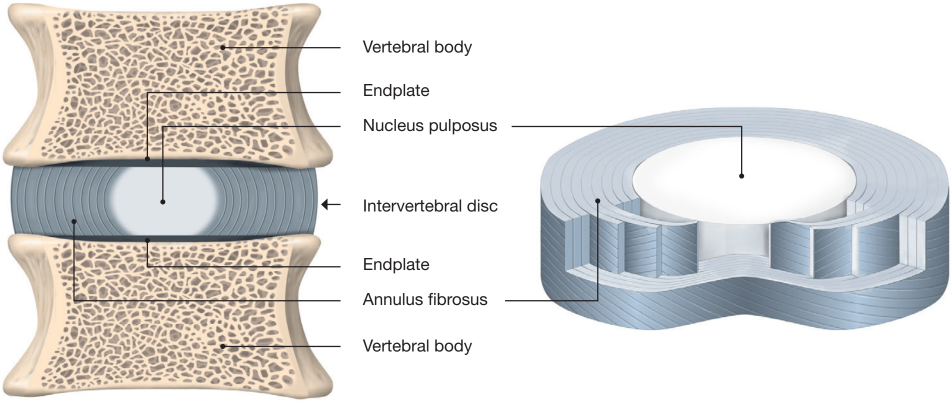


Figure 1. Disc anatomy with a central nucleus pulposus and peripheral annular fibrosus.

Facet joints anatomy

The facet joints are diarthrodial articulations with opposing articular cartilage surfaces between the vertebrae providing flexibility and stability to the spinal column [31].

Hip joint anatomy

The hip joint is a synovial joint between the axial skeleton (acetabulum) and the lower limb (femoral head) [32]. The acetabulum covers most of the femoral head. The cartilaginous acetabular labrum extends beyond the acetabular rim and thereby adds stability to the hip joint [32].

Intervertebral disc degeneration

Intervertebral discs are normally well hydrated in the younger population. Loss of disc fluid is a normal physiological process that increases with age [33, 34]. However, mechanical damage and overload injuries accelerate disc dehydration which represents an early sign of disc degeneration [19, 23, 35]. Other examples of disc degeneration are disc height reduction and disc bulge. The degenerated stiff discs reduce spinal column flexibility and increase stress to the skeletal spine [36] and thereby increasing the risk of back pain.

Disc degeneration can be evaluated on MRI T2 images according to Pfirrmann classification described below (Figure 2) [37].

Disc height reduction

Disc height loss can be due to acute trauma or part of chronic disc degenerative changes secondary to repetitive overload. It can be classified into mild, moderate, or severe (Figure 3) [38-41].

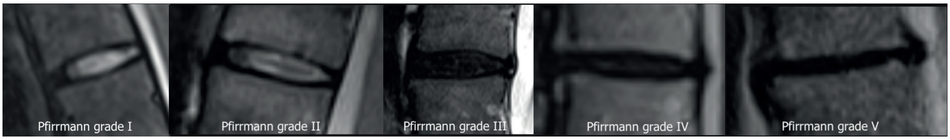


Figure 2. MRI T2-weighted images showing Pfirrmann grading.
Grade 1: Bright disc signal and normal height.
Grade 2: Inhomogeneous but keeping the bright signal and normal disc height.
Grade 3: Inhomogeneous intermittent gray signal. Normal or mildly reduced disc height.
Grade 4: Hypointense dark signal. Mild or moderate disc height reduction.
Grade 5: Hypointense black signal with collapsed disc space.

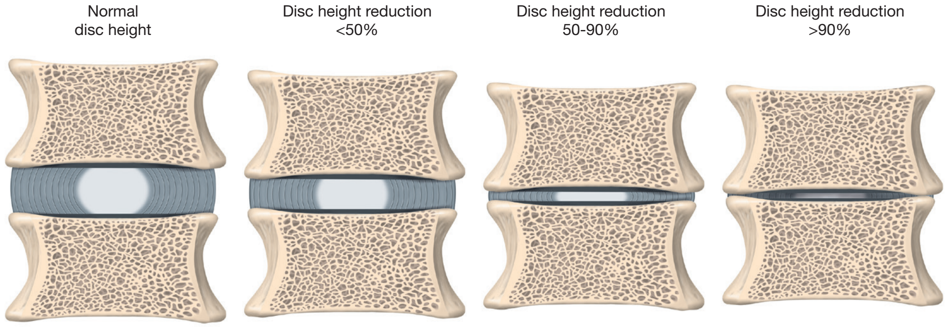


Figure 3. Disc height loss from mild (less than 50% height loss) to sever (more than 90% height loss).

Disc bulging and herniation

Loss of the annulus fibrosus elasticity can result in disc bulge beyond the vertebral body margin. The nucleus pulposus may herniate through a defect in the annulus fibrosus, if the latter has lost its integrity, resulting in a focal disc herniation. Disc herniation is classified into protrusion and extrusion. Disc protrusion is defined when the herniation neck is wider than the herniated component and disc extrusion is defined when the herniation neck is smaller than the herniated component [42].

Schmorl's nodes

Schmorl's node is the herniation of nucleus pulposus through the endplate into the vertebral body. Schmorl's nodes are usually considered asymptomatic, but they have also been implicated in the etiology of back pain [43].

High Intensity Zone (HIZ)

High intensity zone (HIZ) is a phenomenon seen on T2-weighted MRI images that reflects a deep radial tear of the annulus fibrosus. It is considered a possible cause of back pain [44-46].

Spondylolisthesis

Spondylolisthesis is the slippage of one vertebral body in relation to another. It can be of congenital, degenerative, or traumatic etiology [47, 48]. Spondylolisthesis can begraded according to Meyerding classification, which is considered one of the commonly adopted methods to grade the severity of spondylolisthesis (Figure 4) [49].

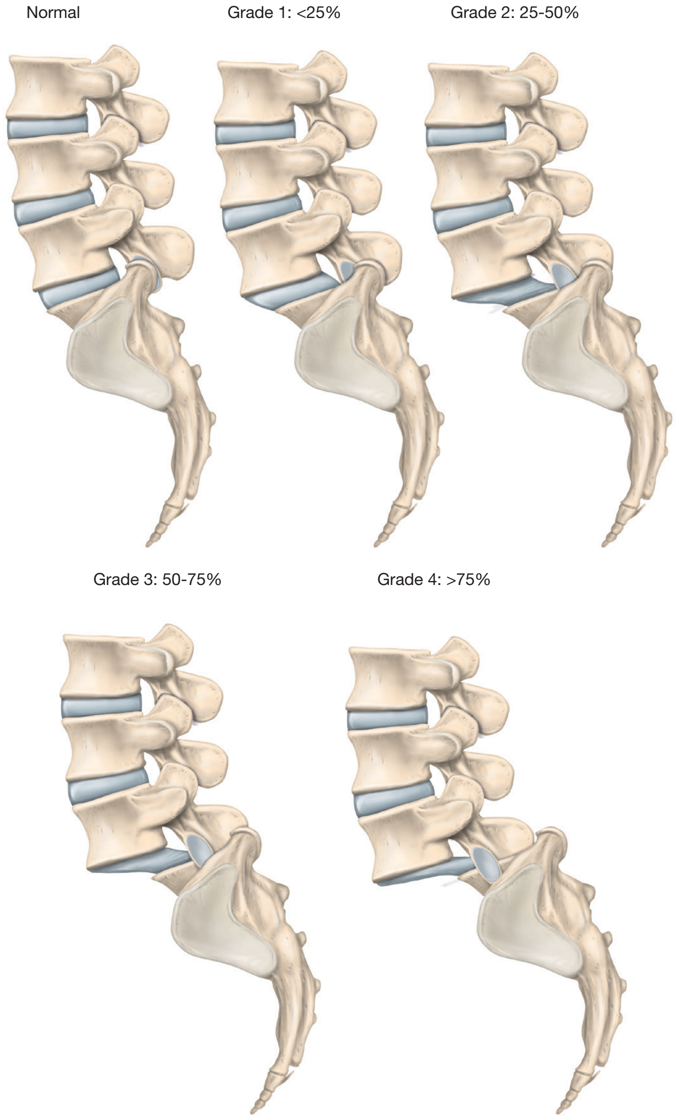


Figure 4. Spondylolisthesis grading 1 to 4 based on the severity of slippage of one vertebra on the other.

Apophyseal ring injury

Apophyseal ring fracture is an avulsion injury of the apophyseal ring that occurs during the ossification stage of the ring during growth period [50]. Apophyseal ring fracture is an important cause of back pain in adolescents [50].

Stress fracture

Stress fracture of the spinal column refers to a stress fracture of the pars interarticularis which is a part of the vertebrae located between the superior and inferior articular processes of the facet joints. Stress fracture may cause back pain and it can lead to the development of spondylolisthesis [51].

Vertebral body configuration

The most common etiologies of vertebral body shape changes are compression fractures and Scheuermann's disease [52]. Other rare etiologies include osseous dysplasia and metabolic diseases [53].

Skiing

Skiing, both alpine and mogul, is a high-risk sport when it comes to both traumatic and overload injuries [54-56], with the immature spine being even more vulnerable [57-59]. The spine and hips act as important dampers for overloading forces and are placed in vulnerable positions in both flexion and extension. There is a constant shift in the hip motion, from extended to an almost maximally flexed position. In mogul skiing, acrobatic jumps also lead to high forces that affect the spine and hips when landing. Force transfer is dependent on adequate range of motion, where joints of adjacent segments interact, and their positions affect each other.

Previous studies show a high rate of spinal changes in young skiers. However, these studies are mainly based on the analysis of plain radiographs [60, 61]. Magnetic Resonance Imaging (MRI) has a higher sensitivity and specificity than plain radiographs in terms of spinal abnormalities. It is assumed that MRI can detect spinal changes earlier than plain radiographs [62] and can characterize spinal changes in more detail.

Football

Football (Soccer) is a very popular sport around the world with a high incidence of trauma [63-65]. Injuries of the brain, cervical spine, knee joints, ankles, tendons and muscles [66-69] associated with football are well defined, but those of the thoracolumbar spine are not thoroughly studied, especially not with MRI. In this thesis, the spinal changes are evaluated and scrutinized with MRI examinations. The dynamics of this sport place rotational stress upon the axial spine and hip joints which may make individuals more susceptible to back injuries and back pain [70].

Back pain in young athletes

Variable results have been published in terms of incidence and prevalence of back pain and its association with excessive physical activity in young athletes [20, 60, 71]. In a review for the years 1951 to 2013, back pain was found to be a common complaint in athletes (1% - 79%) [72]. Both spinal and extra-spinal causative factors were identified such as disc herniation, spinal stenosis, spondylolisthesis, apophyseal ring injury, sacral stress fracture, avulsion fracture of the ischial tuberosity, ligament injury, and muscle sprain [7, 72-79]. In a recent systemic review on 43 studies [76], lifetime prevalence of lower back pain (LBP) in athletes was between 1% and 94% (highest in rowing and cross-country skiing) and point prevalence of LBP was 18% - 65% (lowest in basketball and highest in rowing).

A high prevalence of back pain (67%) has been reported in high school alpine skiers, especially after training progression [74]. Given these variable results and the wide range of back pain occurrence, more studies exploring back pain in athletes are needed. The potential association between back pain and spinal changes on MRI is another consideration in this thesis.

Correlation between spinal column pathologies and back pain

There is a wide range of spinal column abnormalities that can be related to back pain. Certain pathologies like vertebral fractures have established relationship with back pain [80]. The association between back pain and other morphological changes like disc degeneration, disc herniation, and annular tear is however less established [44-46, 81-83].

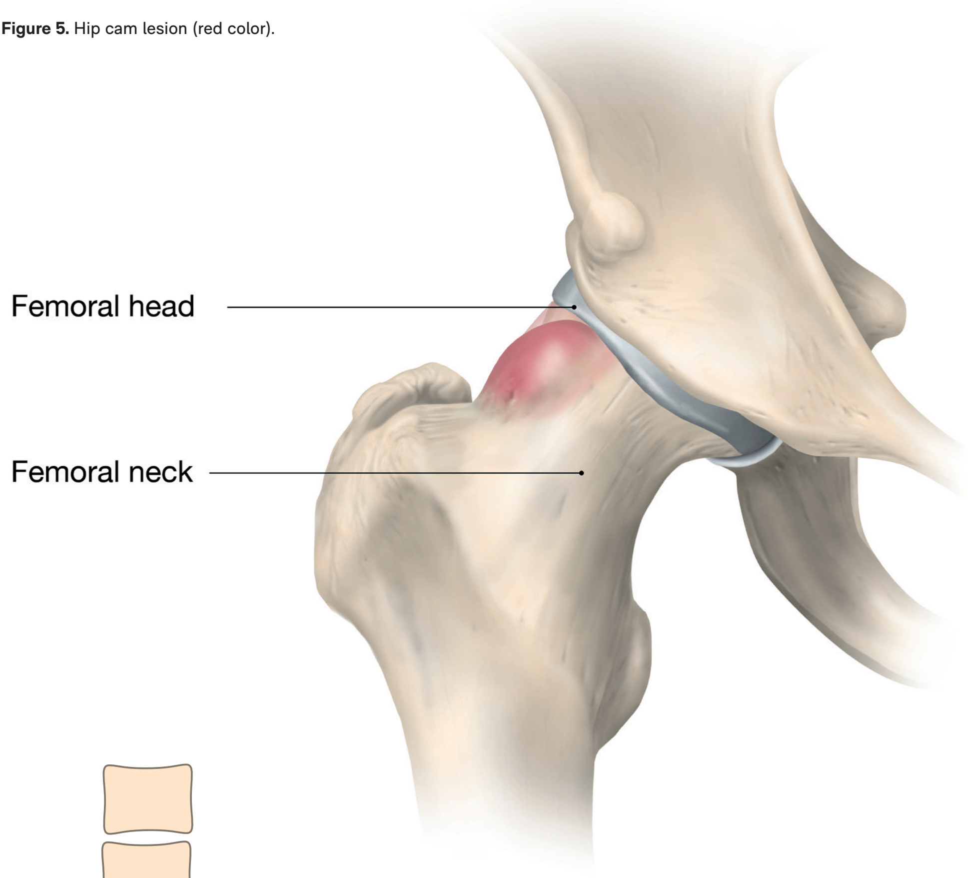
Cam morphology and femoroacetabular impingement syndrome (FAIS) in young athletes

The exact mechanism behind the growth disturbance of hip cam morphology (abnormal morphology at the femoral neck) (Figure 5) and pincer (abnormal morphology at the acetabular rim) is still not completely identified and understood. Prior studies suggested that the cam morphology is a consequence of an alteration of the open growth plate and that this is more common in young athletes [84-86]. This growth disturbance is thought to be due to overload injuries as a response to vigorous athletic activities creating circulation disturbance to the epiphysis [87-89]. Hip cam morphology has been shown to develop gradually during the growth period in football (soccer) players; however, without any significant increase in the prevalence of cam morphology after growth plate closure [90]. Researchers have suggested that the formation of cam morphology might be prevented by modification of athletic activity and rehabilitation during skeletal growth [86, 91].

Femoroacetabular impingement syndrome (FAIS) has been described as a motion- or positional-related pain syndrome in the groin or hips, which can be related to cam and pincer or a combination of both [92-94]. It has been suggested that morphological changes such as increased femoral anteversion and acetabular retroversion are associated with predisposition for FAIS [95, 96]. Moreover, it has recently been hypothesized that the spino-pelvic complex (Figure 6) may lead to the development of cam FAI and that an increased acetabular over-coverage due to a low Pelvic Incidence (PI) may influence hip joint range of motion [97].

FAIS diagnosis is based upon clinical history, physical examination and investigations using plain radiographs, CT [98], and MRI [99, 100]. Measurement of the α-angle is used to determine the prominence of the anterior femoral head-neck junction [100].

Figure 5. Hip cam lesion (red color).



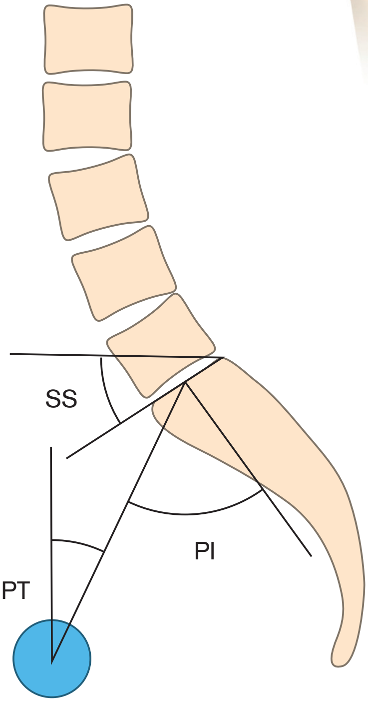


Figure 6. Pelvic balance measurements including the angles of Pelvic Incidence, Pelvic Tilt and Sacral Slope.

Prevalence of cam morphology in athletes

Several studies have shown a high prevalence of hip cam morphology in young athletes, in different sports such as football, ice-hockey, and basketball [90, 91, 101, 102]. Therefore, it is hypothesized that the abnormal morphology of hip cam is acquired secondary to vigorous athletic activity during growth period [84, 85, 90, 101-106]. A significant dose-response relationship between football practice during skeletal growth and the development of hip cam morphology has previously been described [105]. Additionally, it was found that the prevalence of MRI-verified cam morphology (α-angle ≥55°) was higher among young skiers (42%) than non-athletes, but lower compared with age-matched ice hockey players (75%) [107].

The relationship between the hip and spine

A well-balanced spino-pelvic-hip complex assists humans to maintain an upright posture, forward gaze, and minimize energy expenditure [108, 109]. Such a relationship allows for sagittal balance of the trunk that is positioned upon the femoral heads in relation to the pelvic girdle. The pelvic girdle acts as a mobile platform that is governed by both morphological and functional pelvic parameters [110].

Areas with limited research related to the topic

1. How different types of overloading impact may affect the thoracolumbar spine in young athletes.

2. Thoraco-lumbar spine specific changes on MRI in young athletes (alpine skiers, mogul skiers, and football/soccer players).

3. How spinal column abnormalities and back pain develop and change with continuing sporting activity and age.

4. The association between MRI changes and back pain in young athletes.

5. How spino-pelvic alignment potentially affects the hip joints, and if related to femoroacetabular impingement syndrome (FAIS).

6. Do spine abnormalities occur during growth spurt? Do these abnormalities change with age? Do they lead to more abnormalities in the spine and hips and/or back and hip pain in a longitudinal perspective?

Clinical relevance

Evidence-based knowledge regarding spinal column abnormalities in young athletes is of high relevance to be able to adapt the appropriate preventive measures, rehabilitation programs, diagnosis, and treatment accordingly. Increasing awareness among coaches and health professionals is necessary in order to reduce the risk of spine injuries and back pain.

Chapter 2

Aims

Study 1: To study the prevalence of back pain and thoraco-lumbar MRI changes in young alpine and mogul skiers compared with non-athletes.

Study 2: To investigate the relationship between Pelvic Incidence and hip cam morphology in young alpine and mogul skiers.

Study 3: To investigate the occurrence of MRI abnormalities and back pain in young football (soccer) players compared with non-athletes.

Study 4: To investigate the potential change in spinal column abnormalities and back pain in young skiers with continuing sporting activity and age.

Chapter 3

Patients and Methods

Study populations

Studies 1 and 2

The participants (n=75) were elite skiers (age range 16-20 years) recruited from Åre Ski Academy in Östersund, Jämtland County, Sweden. The skiers included both alpine (n = 59) and mogul skiers (n = 16). For comparison, non-athletic first-year high school students (n = 27) were recruited from Järpen, Jämtland County, Sweden (age range 15-18 years).

Study 3

The study participants (n=31) were football (soccer) players from the Icelandic U16 national team (age range 15-19 years). The non-athletic control group (n=27) was the same as in Studies 1 and 2.

Study 4

Two-year follow-up of the same participants as in Study 1 including young elite alpine and mogul skiers (age range 19-21 years) and non-athletes (age range 18-20 years).

Inclusion criteria

The included athletes were actively practicing skiers and football (soccer) players at elite level.

The inclusion criteria defining the non-athletes were no previous nor present participation in any organized athletic activities, neither any physical activity more than 2 hours per week.

Exclusion criteria

Athletes and non-athletes were excluded if they had had an episode of traumatic injury of the thoraco-lumbar spine or a history of previous surgery to the spine, pelvis, or hip joints. In addition, the exclusion criteria included pregnancy and any history of systemic disease including inflammatory arthritis or pelvic inflammatory disorders.

MRI of the thoraco-lumbar spine

The MRI protocol included sagittal T2 (TR4463/TE110) and T1 (TR560/TE21) weighted sequences, with field of view (FOV) 480 x 480 mm to 512 x 512 mm and slice thickness 4 mm. The FOV was large in order to cover the spine from mid thoracic to upper sacrum. The MRI examinations of the skiers and non-athletes were conducted at the Department of Radiology at Östersund Hospital, Sweden. The MRI examinations of the football players were conducted at the National University Hospital of Iceland, Reykjavik, Iceland. All MRI examinations were performed using 1.5 Tesla scanners.

Each MRI was evaluated according to a standardized protocol including disc and vertebral characteristics as previously published and summarized below (Table 1) [7, 13]. Each parameter was recorded separately. Additionally, it was enough with one disc graded ≥1 for disc signal, disc height, disc bulge, or disc herniation according to the standardized protocol to consider that individual being positive for degenerative disc changes.

Each disc (between the levels T6 to S1) was also graded according to Pfirrmann classification [37]. The total numbers of discs graded as Pfirrmann ≥3 per individual were recorded. Additionally, individuals with at least one disc graded Pfirrmann ≥3 were registered. Analysis of MRI findings was also repeated after the exclusion of participants with scoliosis in study 3.

Table 1. MRI standardized protocol. The spinal column changes are illustrated in Figures 9 - 14.

Disc signal reduction	0 = Normal	1 = Moderately reduced	2 = Severely reduced	
Disc height reduction	0 = Normal	1 = Reduction ≤50%	2 = Reduction 50–90%	3 = Reduction >90%
Disc bulging	0 = Normal	1 = Bulging disc		
Disc herniation	0 = Normal	1 = Disc extrusion		
Schmorl's nodes	0 = Normal	1 = Slight	2 = Moderate to severe	
Apophyseal injuries	0 = Normal	1 = Slight,	2 = Moderate to severe	
Vertebral body configuration	0 = Normal	1 = Wedging	2 = Flattening	3 = Increased AP diameter
Spondylolisthesis	0 = Absent	1 = Present		
High Intensity Zone (HIZ)	0 = Absent	1 = Present		
Stress fractures	0 = Absent	1 = Present		

Accordingly, spinal column changes were graded in two different ways in which the former included a wider spectrum of parameters while the latter (Pfirrmann classification) evaluated disc signal and height only.

The intra-observer reliability was assessed by repeating the evaluation of the MRIs after one year, blinded to the first evaluation. To assess inter-observer agreement, another experienced radiologist evaluated the MRI examinations in approximately one third of the participants.

MRI of the hip joints

MRI examinations of the bilateral hips were performed using a GE Optima 450 Wide 1.5 Tesla (Milwaukee, USA) using a coil surface HD 8ch Cardiac array by GE. No intra-articular contrast was utilized. The cam morphology is most often seen at the anterior superior femoral head-neck junction [111-113]. Therefore, seven clockwise radial images in 30° intervals, from 9 o´clock (posterior) to 3 o´clock (anterior, 180°) around the proximal femur were assessed [101].

Alpha angle (α-angle)

The cam morphology was defined by measuring the a-angle according to Nötzli et al. [114]. The α-angle is an angle between a line drawn along the femoral neck axis and a line drawn from the center of the femoral head to the point at which the bone breaks through a best-fit circle around the femoral head (Figure 7). The accuracy and diagnostic value of the a-angle have recently been questioned [115, 116]. The intra- and interrater reliability have varied from low to moderate (up to 30% variation; ICC 0.6) [99, 115, 117] and good to excellent (ICC 0.7-0.9), respectively [116, 118]. Moreover, the cut-off value has been debated. Initial studies have used an a-angle value of 50-55° [114, 119], while later studies on healthy populations consider this value being too low and have instead suggested 60-63° [116, 119, 120]. In the present study, cam morphology was defined as an a-angle of 55° or above.

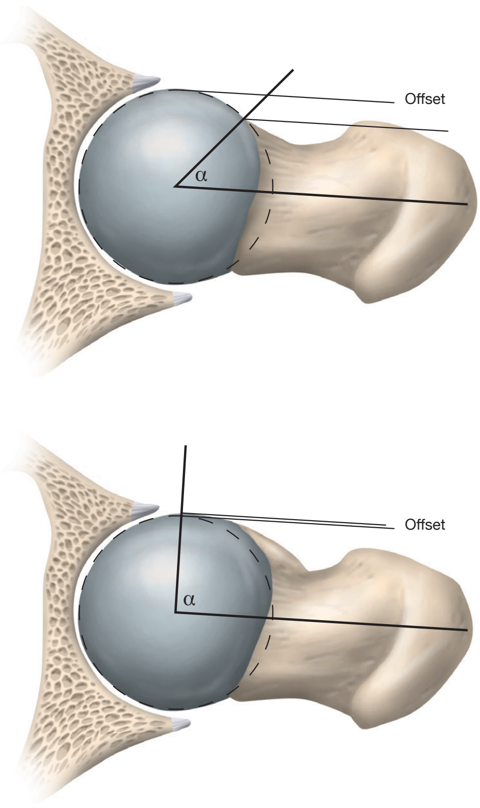


Figure 7. α-angle measurement with one line along the long axis of femoral neck and the other line through an offset at the junction of the femoral head and neck.

Whole spine radiographs

Skiers and non-athletes were examined using standing plain radiographs of the whole spine with both anterior-posterior and lateral views. Participants were instructed to stand with the feet together in a natural upright posture, without spinal rotation, with arms hanging by their side for frontal views and arms horizontal resting on supports for sagittal views [121]. The total measurement time was approximately 10 minutes. Automatic Exposure Control (AEC) was utilized to achieve low radiation dose. The edges were accentuated to clearly identify the endplates and vertebral bodies.

Spino-pelvic parameters

Geometrical measurements relating to the spino-pelvic complex (Figure 8) were measured and recorded in degrees according to the following; Pelvic Incidence angle (PI), a morphological parameter, is the angle measured from a perpendicular through the long axis of sacrum and extended to the center of the femoral head. Pelvic Tilt (PT), a positional parameter, is the angle measured from a perpendicular line starting at the center of the femoral head and extended to the mid sacral plate. Sacral Slope (SS) [6], a positional parameter, is the angle measured from the superior endplate of S1 and a horizontal axis [122, 123].

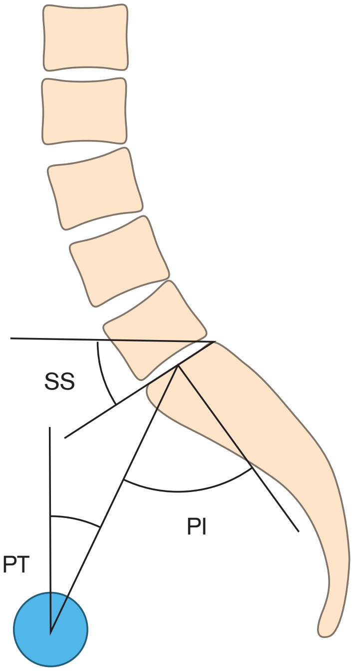


Figure 8. Pelvic balance measurements including the angles of Pelvic Incidence, Pelvic Tilt and Sacral Slope.

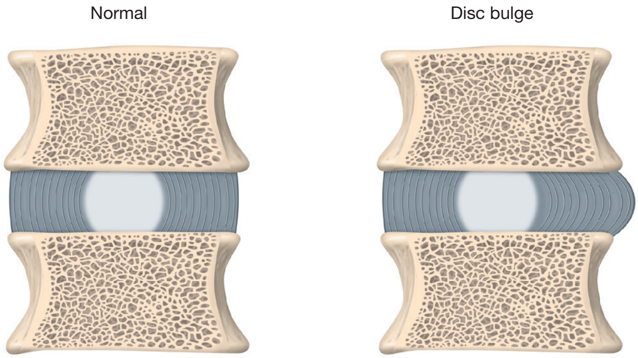


Figure 9. Disc bulge is defind as more than 50% of the disc circumference extends beyond the vertebral body margin.

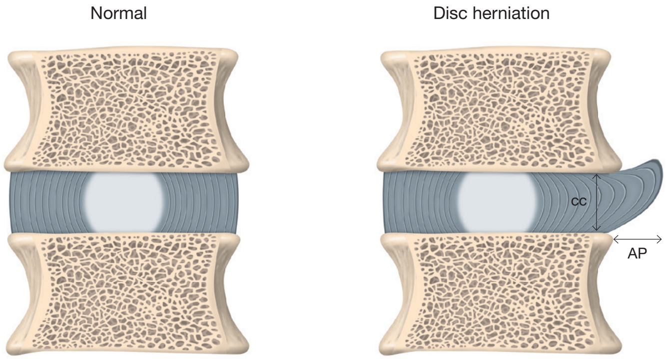


Figure 10. Disc herniation is a focal protrusion or extrusion of the disc beyond the vertebral body margin. CC: Craniocaudal. AP: Anteroposterior.

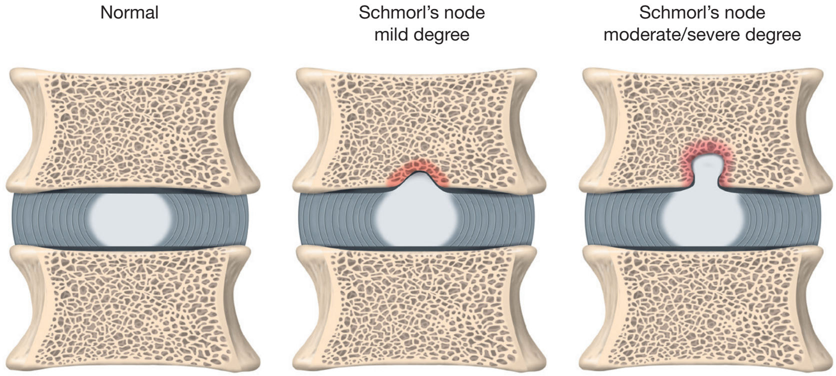


Figure 11. Schmorl's nodes are the disc herniation through the vertebral endplate.

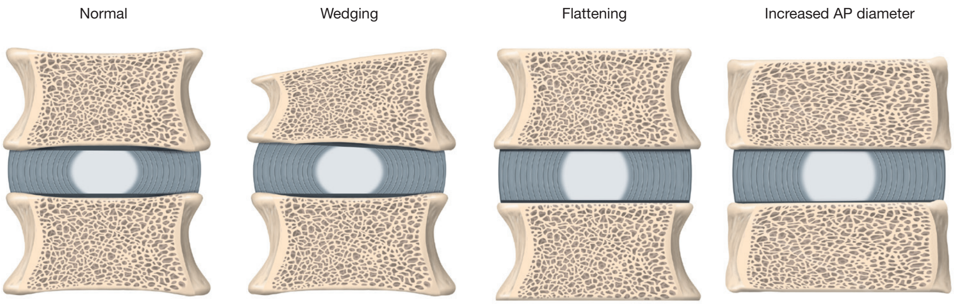


Figure 12. Vertebral body configuration demonstrating normal shape, wedging deformity, flattning of the endplate, and degenerative vertebral body height loss with apparent increased anteroposterior (AP) diameter.

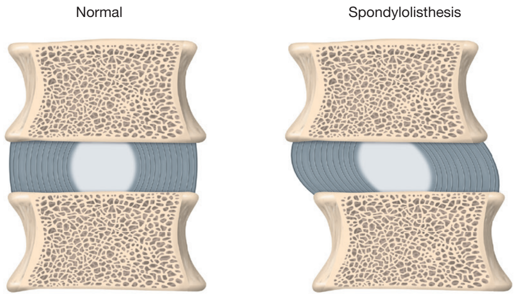


Figure 13. Spondylolisthesis is the gliding of one vertebra on the other.

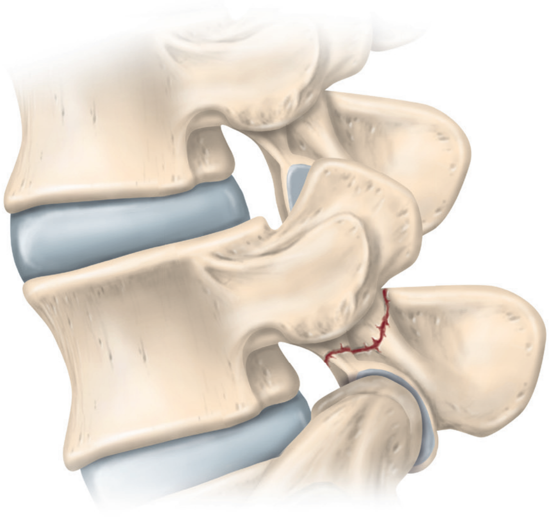


Figure 14. Stress fracture of pars interarticularis.

Back pain questionnaires

All athletes and non-athletes answered a questionnaire that was developed by Swärd et al. [10] and Baranto et al. [13] . The questionnaire was adapted from the Visual Analogue Scale [124], Oswestry Disability Index (ODI), and EuroQoL (EQ-5D) questionnaires [125]. Back pain was defined as present or previous pain of any kind in the thoraco-lumbar spine. The Oswestry Disability Index (ODI) evaluates back pain in relation to daily life activities where pain severity and disability are rated subjectively [127]. The EuroQol questionnaire (EQ-5D) is used to assess the health of subgroups of the population including assessment of health status as excellent, very good, good, or poor. Physical and athletic activities were investigated with questions regarding present and previous activity levels. The current activity level was further categorized according to the weekly training and exercise hours.

Ethical considerations

The project was approved by the Regional Ethical Review Board in Gothenburg, Sweden (ID number: 692-13).

All study participants received both written and oral presentation about the project. The parents of those underage received the same information. All participants provided written and verbal informed consent.

MRI impose no significant risk or potential complications to the enrolled individuals. Whole spine radiographs have potential radiation risks but considered very low. Automatic Exposure Control (AEC) was also utilized to further decrease radiation exposure [128]. Nonetheless, all radiographs were performed for other projects, and they were only re-examined in the present project.

Statistical analysis

The data was analysed using IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp. The description of data was expressed in terms of mean, standard deviation (SD) [129], and range including frequencies and percentages. For comparison of continuous variables, the Student Independent T-Test was used. Pearson's Chi-square test was performed to compare the distribution of back pain between the groups, and Fisher's exact test to compare the distribution between the groups when the expected cell count was less than 5. McNemar test was utilized to compare the associations between baseline and follow-up categorical variables.

Intra-class correlation coefficient (ICC) was performed to compare variables such α-angle clock positions, PI, PT, and SS. The Kappa statistics were used to summarize the inter- and intra-observer reliability of the ratings. The schema of Landis and Koch was used to interpret the strength of agreement [130]. All tests were two-tailed, and the alpha level was set at 0.05 ($p<0.05$).

Sample size calculations were based on previous studies of young athletes using the same method, demonstrating both clinical and radiological significant results [7, 13, 131].

Chapter 4

Results

Study I

Results

MRI examinations of 65 elite skiers and 26 non-athletes were available for the final data analysis. Ten skiers and one non-athlete were not examined due to failure to attend appointments, difficulties with timings, and claustrophobia.

In terms of back pain questionnaires, one skier and two non-athletes did not answer the questionnaires with a total of 74 elite skiers and 25 non-athletes were available for final data analysis.

Group characteristics

Tables 2 and 3 summarize the demographic characteristics and the training hours per week of skiers and non-athletes.

Forty-eight skiers (78%) subjectively perceived their general health as very good to excellent compared to twelve (48%) of the non-athletes (p=0.03).

Table 2. Demographic characteristics.

	Skiers (n=75)	Non-athletes (n=27)	p-value
Age, n (SD)	18.2 (1.1)	16.4 (0.6)	<0.001b
Gender, F/M	47% / 53%	67% / 33%	0.07[a]
Height, cm (SD)	174 (8)	172 (9)	0.20[b]
Weight, kg (SD)	70 (9)	67 (18)	0.40[b]
BMI (SD)	22.9 (2)	22.7 (5)	0.80[b]

BMI, Body Mass Index, [a] Chi-square Test, [b] Independent sample t-test, F= Female. M=Male.

Table 3. Training hours per week stratified by skiers and non-athletes.

Training hours per week	Skiers (n=74)	Non-athletes (n=23)
>11 hours	27 (37%)	0
9-11 hours	28 (38%)	0
6-8 hours	18 (24%)	4 (17%)
3-5 hours	1 (1%)	11 (48%)
0-2 hours	0	7 (30%)
0 hours	0	1 (4%)

Chi-Squared Test. Number and (%)

Radiological findings

More skiers, 56%, had at least one disc Pfirrmann grade ≥3 compared to 30% of non-athletes (p=0.03). Schmorl's nodes and discs with reduced height were significantly more common in skiers than non-athletes. Schmorl's nodes were seen in 46% of skiers and reduced disc height found in 37% of skiers compared to 0% of non-athletes (p<0.001). When all parameters in the standardized protocol were combined, the skiers had a significantly higher rate of radiological changes than non-athletes, 82% compared with 54% (p=0.007) (Figure 15, table 4).

The mean number of discs with Pfirrmann grade ≥3 was 1.1 per individual in skiers (median 1 and range 0-6) versus 0.6 in non-athletes (median 0 and range 0-3).

Minimal or no findings were evident in both skiers and non-athletes related to spondylolisthesis, stress fractures, apophyseal injuries, HIZ, and abnormal configuration of the vertebrae. Statistical analysis was not amenable.

There were no statistically significant differences in the prevalence of disc degenerative changes when alpine skiers (77%) were compared with mogul skiers (93%). Schmorl's nodes were present in 42% of alpine skiers and 56% of mogul skiers without any statistically significant difference.

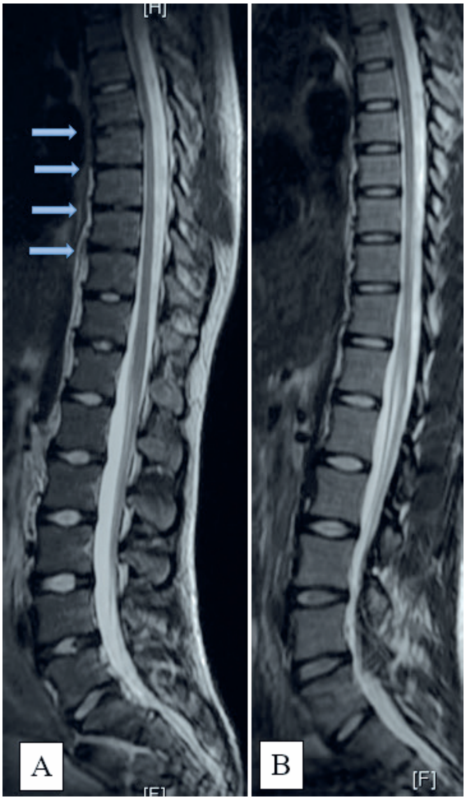


Figure 15. MRI T2-weighted sagittal images of the thoraco-lumbar spine. A: Athlete with disc signal and height reduction at T6-T7 through T9-T10 (arrows), when compared to discs above and below. B: Non-athlete without abnormalities in the thoraco-lumbar spine.

Back pain

There were no significant differences in the lifetime prevalence of back pain between skiers (50%) and non-athletes (44%) nor between mogul (53%) and alpine skiers (50%). There was no statistical correlation between spinal column abnormalities and lifetime prevalence of back pain in skiers. Back pain was neither correlated with age nor gender.

There was no significant difference in duration and onset of back pain between the groups. However, a significant difference was shown for the greatest level of pain recorded on visual analogue scale (VAS 1-10 cm) during the past 6 months in skiers (VAS 5.3, SD 3.1) compared with non-athletes (VAS 2.4, SD 2.0) (p=0.02). Only skiers (10%) reported pain radiating to the thighs.

Validity

In terms of Pfirrmann protocol, there was an almost perfect agreement between the radiologists with Cohen's kappa coefficient $\kappa = 0.83$. The observed agreement between the radiologists was 89% in the standardized protocol, with almost perfect disc signal agreement $\kappa = 0.83$, moderate disc bulge agreement $\kappa = 0.53$, and fair disc height agreement $\kappa = 0.35$.
The intra-observer agreement of the standardized protocol was substantial to almost perfect with $\kappa = 0.79$ to $\kappa = 1.00$.

Table 4. MRI changes and lifetime prevalence of back pain stratified into skiers and non-athletes.

	Skiers	Non-athletes	p-value [a]
Pfirrmann grade ≥3	36 (56%)	8 (30%)	**0.03**
Schmorl's nodes ≥1	30 (46%)	0 (0%)	**<0.001[b]**
Disc-signal reduction ≥1	45 (69%)	11 (42%)	**0.02**
Disc-bulging ≥1	44 (68%)	12 (46%)	**0.04**
Disc-height reduction ≥1	24 (37%)	0 (0%)	**<0.001[b]**
Disc hernia ≥1	1 (2%)	0 (0%)	N/A
High Intensity Zone (HIZ)	5 (8%)	0 (0%)	0.32
Degenerative disc changes	53 (82%)	14 (54%)	**0.007**
Lifetime prevalence of back pain	37 (50%)	11 (44%)	p = 0.60
Discs with Pfirrmann grade ≥3 per individual Mean (range)	1.1 (0-6)	0.6 (0-3)	N/A

[a] Chi-squared Test. [b] Fisher´s Exact Test. N/A, not analyzable, violating statistical assumptions.
Bold style indicating statistical significance.

Study II

Results

A total of 87 participants (61 skiers and 26 non-athletes, 174 hips) were included in the final analysis. Drop-outs were due to difficulties with timings for radiographs and MRI appointments, traveling abroad, and failure to attend appointments. The mean age of the enrolled population was 18 (±1.5) years. Gender differences highlighted fewer females in the skiers’ group (48%) than non-athletes (65%). BMI was 23 for both groups.

Skiers had a higher prevalence of hip cam morphology (a-angle >55°, Figure 7) in the right (38%), left (39%), and bilateral hips (28%) compared with non-athletes (right: 12%; left: 12%; bilateral: 4%, p=0.02). It was also significant at an individual level with 49% of the skiers having cam morphology compared to 19% of the non-athletes (p=0.009). The average Pelvic Incidence angle (PI, figure 8) was 52° (±9°) for participants with bilateral cam morphology (n=18) and 50° (±11°) for those without cam morphology (n=50). The latter was not statistically significant.

Table 5 shows the mean a-angle across all clock positions. There was a significant difference between skiers and non-athletes at every clock position. The 1 o´clock position showed the largest difference with a mean a-angle for the skiers 52° (±6°) and 48° (±5°, p=0.001) for non-athletes. The greatest frequency of a-angle >55° occurred at the 1 o’ clock position for the skiers’ right hip (30%) and left hip (34%) compared with non-athletes’ right hip (8%) and left hip (4%).

There was no difference in the mean value of the PI angle, which was 51° (±12°) for the skiers compared with non-athletes 50° (±10°).

No significant correlation was found between a low PI angle and increased a-angle measurements across all clock positions in either group. Similar results were shown for the Pelvic Tilt (PT) and Sacral Slope (SS) variables.

Table 5. Mean a-angle in bilateral hips across 9 to 3 o’clock positions stratified by groups.

Clock Position	Skiers (n=61)	non-athletes (n=26)	p-value*
9	39° (4.1)	37° (3.4)	0.001
10	43° (5.1)	41° (3.5)	0.05
11	45° (3.9)	42° (3.2)	<0.001
12	49° (4.9)	46° (4.3)	0.003
1	52° (6.1)	48° (4.6)	<0.001
2	47° (5.5)	45° (6.3)	0.03
3	43° (5.1)	40° (4.1)	<0.001

Values are presented in degrees as mean (SD). *Independent T-Test between skiers and non-athletes

Study III

Results

MRI examinations of 27 elite football (soccer) players and 26 non-athletes were available for the final MRI examinations analysis. Drop-out reasons included difficulties with appointments timing and claustrophobia.

Demographic characteristics of the participants are presented in Table 6.

The majority of football players (91%) had more than 9 hours exercise per week while 83% of non-athletes had an average 0–5 training hours weekly (Table 7).

The total number of discs with Pfirrmann grade ≥3 was shown to be higher in the football players than non-athletes (Tables 8 and 9).

Statistical analysis was not possible given the minimal findings in both football players and non-athletes in terms of spondylolisthesis, stress fractures, HIZ, apophyseal injuries, and vertebrae abnormal configuration.

Back pain

The lifetime prevalence of back pain was reported by 52% of football players and 44% of non-athletes, this was not statistically significant. The severity of pain was low with average of 1.6 (on VAS scale) in football players and 2.4 in non-athletes. There was no association between back pain and spinal column MRI changes.

Validity

Good inter-observer agreement was shown with Cohen's kappa coefficient ranging between $\kappa = 0.70$ and $\kappa = 0.81$. The intra-observer agreement was also good, with Cohen's kappa coefficient ranging between $\kappa = 0.67$ and $\kappa = 0.88$.

Table 6. Demographic characteristics of football (soccer) players and non-athletes.

	Football players (n = 27)	Non-athletes (n = 26)
Gender, Female/Male	0% / 100%	67% / 33%
Age, years (SD)	17 (1.0)	16.4 (0.6)
Weight, Kg (SD)	74 (7)	67 (18)
Height, cm (SD)	182 (6)	172 (9)

Table 7. Training hours per week stratified by football players and non-athletes.

Training hours per week	Football players (n = 31)	Non-athletes (n = 23)
0-2	0	8 (35%)
3-5	0	11 (48%)
6-8	3 (9%)	4 (17%)
9-11	6 (19%)	0
>11	23 (72%)	0

Table 8. MRI changes stratified by football players and non-athletes.

MRI changes	Football (n=27)	Non-athletes (n=26)	p-value[†]
Individuals with Pfirrmann grade ≥3 changes	10 (37%)	8 (30%)	p=0.60
Total discs with Pfirrmann grade ≥3 changes	26 (8%)	14 (4%)	p=0.90
Reduced disc-signal	13 (48%)	11 (42%)	p=0.80
Disc-bulging	21 (78%)	12 (46%)	**p=0.02**
Reduced disc-height	10 (37%)	0	**p<0.001**
Schmorl's nodes	6 (22%)	0	**p=0.02**
Disc hernia	8 (30%)	0	**p=0.004**

[†] Fisher´s Exact Test.

Bold style indicates statistically significant values.

Table 9. MRI changes stratified by football players and non-athletes with exclusion of participants with scoliosis.

MRI changes	Football (n=27)	Non-athletes (n=18)	p-value[†]
Individuals with Pfirrmann grade ≥3 changes	10 (37%)	4 (21%)	p=0.30
Total discs with Pfirrmann grade ≥3 changes	26 (8%)	7 (3%)	p=0.03
Reduced disc-signal	13 (48%)	7 (37%)	p=0.50
Disc-bulging	21 (78%)	7 (37%)	**p=0.006**
Reduced disc-height	10 (37%)	0	**p<0.001**
Schmorl's nodes	6 (22%)	0	**p=0.02**
Disc hernia	8 (30%)	0	**p=0.004**

[†] Fisher´s Exact Test.

Bold style indicates statistically significant values.

Study IV

A total of 30 young elite alpine and mogul skiers and 16 non-athletes were followed-up from the baseline study 2 years earlier.

Group characteristics

The participants' demographic characteristics are summarized in Table 10. The mean body mass index was identical between the groups.

Two-year follow-up of skiers and non-athletes

There was no significant interval difference in the spinal column abnormalities nor back pain between the baseline and follow-up groups in neither skiers nor non-athletes (Table 11).

Table 10. Demographic characteristics.

	Skiers (n=30)	Non-athletes (n=16)
Female	43%	75%
Mean (SD) age, years	20 (0.6)	19 (0.5)
Mean (SD) height, cm	174 (8)	171 (10)
Mean (SD) weight, kg	68 (10)	65 (16)
Mean (SD) BMI*	22 (2)	22 (5)

*Body Mass Index

Table 11. MRI findings at baseline and 2-year follow-up in skiers and non-athletes.

	Skiers					Non-athletes				
	Baseline		Follow-up			Baseline		Follow-up		
	(360 discs)		(360 discs)			(360 discs)		(360 discs)		
	% (n)	Mean (SD)	% (n)	Mean (SD)	p-value	% (n)	Mean (SD)	% (n)	Mean (SD)	p-value
Pfirrmann grade ≥3	8% (29)	1.0 (1.2)	9% (33)	1.1 (1.2)	0.6	5% (9)	0.6 (0.8)	2% (4)	0.3 (0.4)	0.1
Disc height reduction	4% (16)	0.5 (1.2)	5% (18)	0.6 (0.9)	0.5	4% (8)	0.5 (1.3)	2% (4)	0.3 (0.8)	0.3
Disc signal reduction	12% (42)	1.4 (1.2)	11% (38)	1.3 (1.4)	0.6	7% (13)	0.8 (1.2)	11% (38)	1.3 (1.4)	0.6
Disc bulge	9% (34)	1.1 (1.1)	7% (26)	0.9 (0.9)	0.3	9% (34)	1.1 (1.1)	7% (26)	0.9 (0.9)	0.3
Schmorl's nodes	8% (27)	0.9 (1.5)	5% (17)	0.6 (1.0)	0.1	8% (27)	0.9 (1.5)	5% (17)	0.6 (1.0)	0.1
Spondylolisthesis, apophyseal injuries, stress fractures, HIZ, and vertebrae configuration										N/A

There were minimal findings without significant interval change regarding spondylolisthesis, apophyseal injuries, stress fractures, high intensity zone (HIZ), and vertebrae configuration abnormalities.

Radiological findings - Skiers vs non-athletes

The MRI findings are summarized in Tables 12 and 13. When analyzed on an individual level, there were significantly more skiers (63%) with intervertebral discs graded Pfirrmann ≥3 compared with non-athletes (25%) (p=0.03). The average number of discs with Pfirrmann ≥3 changes was 1.1 for skiers (range 1-4) and 0.3 for non-athletes (range 0-1). There was higher rate of degenerated discs in skiers (73%) than non-athletes (44%, p=0.05), when the standardized protocol parameters of reduced discs signal, height, bulge, or herniation were combined.

Table 12. MRI findings in skiers and non-athletes per individual.

	Skiers (n=30) % (n)	Non-athetes (n=16) % (n)	p-value
Pfirrmann grade ≥3	63% (19)	25% (4)	**0.03**
Disc height reduction	37% (11)	13% (2)	0.1
Disc signal reduction	68% (20)	25% (4)	**0.01**
Disc bulge	57% (17)	31% (5)	0.1
Schmorle's nodes	23% (7)	38% (6)	0.3
Disc endplate grade ≥4	50% (15)	38% (6)	0.4
Degenerative disc changes	73% (22)	44% (7)	**0.05**

Bold style indicating statistically significant values.

Table 13. MRI findings in skiers and non-athletes per total number of discs.

	Skiers (360 discs)		Non-athletes (192 discs)		p-value*
	% (n)	Mean (SD)	% (n)	Mean (SD)	
Pfirrmann grade ≥3	9% (33)	1.1 (1.2)	2% (4)	0.25 (0.4)	**0.001***
Disc signal reduction	11% (38)	1.3 (1.4)	1.5% (3)	0.2 (0.4)	**0.001***
Disc height reduction	5% (18)	0.6 (0.9)	2% (4)	0.25 (0.8)	0.08
Disc bulge	7% (26)	0.9 (0.9)	2% (4)	0.25 (0.5)	0.01*
Schmorle's nodes	5% (17)	0.6 (1)	7% (14)	0.9 (1.3)	0.2
Disc endplate grade ≥4	9% (32)		5.7% (11)		0.18
Degenerated discs	7%		3%		**0.001***

*A Chi-squared test for the comparison of two proportions.

Bold style indicating statistically significant values.

Back pain

The lifetime prevalence of back pain was reported by 46% of skiers and 40% of non-athletes, which was not statistically significant. Back pain was associated with discs' abnormalities in skiers (p=0.04), however, not in the non-athletes (p=0.68).

Validity

The intra-observer agreement was very high for all parameters with Cohen's Kappa Coefficient ranging between $\kappa = 0.85$ and $\kappa = 0.95$.

The interobserver agreement measurements were not performed. However, the baseline study, evaluated by the same radiologists, demonstrated high agreement [132].

Chapter 5

Discussion

The present project included three studies focusing on the spinal column findings on MRI and back pain in young athletes. A fourth study was focused on the spinopelvic complex parameters and hip cam change in young skiers.

Degenerative changes

The three studies focusing on the spinal column findings and back pain in young athletes showed that elite skiers and football (soccer) players had higher prevalence of disc degenerative changes in the thoraco-lumbar spine (up to 89%) than non-athletes (54%). They also displayed a higher prevalence of Schmorl's nodes as well as other spinal column abnormalities than non-athletes. There was no significant difference in the lifetime prevalence of back pain in athletes (46%) and non-athletes (40%).

The findings of the present project were in concordance with previous studies of athletes practicing other sports such as volleyball, ice-hockey, diving and American football [7, 20, 60, 71, 133, 134]. In a prior study of professional beach volleyball players (mean age 28), disc degeneration (79%) and spondylolysis (21%) were three times higher in volleyball players than the general population [20].

The higher prevalence of spinal column changes in young athletes is believed to be secondary to overloading the spine with excessive training associated with rotational stress acting upon the spine from the multidirectional dynamics of the sports [10, 135]. Increasing awareness among sport leaders and parents and implementing the appropriate rehabilitation programs are considered important preventive measures.

Schmorl's nodes were shown to be less prevalent in football players and skiers (22% - 46%) compared with athletes of other sports such as gymnasts (71%) and orienteers (100%) [7, 132]. Additionally, disc height reduction was present in 37% of the football players, similar to gymnasts (38%) but less than wrestlers (86%) and weight lifters (100%) [7]. These differences are likely to be related to the different load impact upon the spine from different sports. In football and skiing, there is both rotational stress and axial loading with repetitive minor trauma increasing the risk for disc degeneration and desiccation. Meanwhile, axial overload upon the spine is the major stress component in sports like weight lifting, increasing the risk of predominantly disc height reduction.

Follow-up of the study population

Upon 2-year follow-up, no significant new MRI abnormalities nor significant changes in back pain prevalence were found.

Both at baseline and at follow-up, the average age of the studied cohorts, 18 and 20 years respectively, were beyond the growth spurt age. This can potentially explain the rare occurrence of new findings similar to what previously been suggested that most abnormalities in the younger population occur during growth spurt when the spine is most susceptible to injuries [16].

The above appears to be consistent with what has previously been reported in young athletes participating other sports such as weight lifting, ice-hockey, and diving [7, 13, 16, 18, 20]. Nonetheless, the lack of significant difference upon follow-up can be in part due to the short-term follow-up interval and the limited sample size of the follow up group, which may have affected the results. Additionally, athletes who had had back pain might have stopped training and therefore they were dropped from the follow-up group.

Prior longitudinal studies of athletes showed variable degrees of deterioration of spinal column findings on long term follow-up (up to 15-year follow-up). The latter could be attributed to a longer duration of overload through continuous sporting activity and additionally it could be secondary to normal aging [136-138]. Further long term longitudinal prospective studies with larger population groups are therefore warranted for future research projects of young athletes. Incorporation of new imaging techniques like functional MRI and T2 mapping analysis is also advised to obtain a more objective quantitative estimates [139-141]. These modalities have higher sensitivity to detect subtle abnormalities that might have occurred during a short-term follow-up.

Back pain

The lifetime prevalence of back pain was not significantly different between athletes and non-athletes. While this could be a true representation of the populations, other alternative factors may include recall bias, selection bias, and additionally the small size of the groups. Previous studies defined a wide range of back pain prevalence in young athletes [7, 13, 20, 60, 71, 131, 142]. In a literature review of 43 papers, 1-year prevalence of back pain was 26-76% [76]. Therefore, prospective studies with real time assessment and characterization of back pain in young athletes are warranted.

Correlation between MRI changes and back pain

Back pain was associated with spinal column abnormalities in skiers on follow-up. A similar relationship had previously been reported in young athletes [13, 131]. However, other studies, including the baseline study in the present thesis, reported no such association [7, 132, 142-145]. These findings suggest that disc and vertebral abnormalities can be linked to complications including back pain later in life. Nonetheless, back pain could also be due to other extra-spinal factors such as muscle strain and ligament sprain [7, 72, 75, 76].

FAIS and spinal sagittal parameters

Hip cam morphology was more prevalent in the young elite skiers (49% vs non-athletes 19%, p=0.009). However, there was no correlation between a low PI angle and an increased a-angle in skiers compared with non-athletes. The skiers were actually shown to have a marginally higher mean PI angle than non-athletes (51° vs. 50°). This suggests that cam morphology may be, to some extent, a response to the high-level loading from skiing, but on the other hand, it questions the significance of a low PI angle as a risk factor in this particular age-group and sporting discipline.

The relationship between the hip and spine pathology

Spine-hip-pelvis movement is coordinated to provide balance, stability, and flexibility to the human body. Hip pathology or stiffness reduces pelvic mobility and may overload the spinal column and vice versa [146]. Previous studies have proposed that individuals with a low PI angle may compensate with an anterior PT and increase the risk of mechanical hip joint impingement, which may lead to the development of cam morphology (9, 16, 17, 28). The present study was unable to substantiate this association.

Strengths and Limitations

The utilization of MRI to evaluate all participants, and the inclusion of multiple parameters and grading systems added value to the present project. Furthermore, the participants were within a similar age range and considered a good representation for adolescent age population. The height, weight, and body mass indices were also similar for athletes and non-athletes.

The groups size was considered a potential limitation. The intention was to include as many volunteers as possible. The major obstacles were the limited resources given the need for young athletes within a similar age range and the need for MRI examination of each individual. Another limitation was the large number of dropouts on follow-up.

Being an observational study, other confounders such as personal hobbies, nutrition, and smoking might have biased the studies.

The questionnaires can be affected by recall bias. They are also subject-reported information and difficult to be assessed objectively.

Chapter 6

Conclusion

Young elite athletes (skiers and football players) demonstrated higher prevalence of spinal column abnormalities than non-athletes. Lifetime prevalence of back pain was not significantly different between the groups.

Skiers had greater prevalence of hip cam morphology compared with non-athletes. A low Pelvic Incidence (PI) was not correlated with abnormal cam morphology.

Between baseline and 2-year follow-up, there was no significant interval difference in spinal column findings on MRI, nor back pain prevalence, neither for skiers nor non-athletes.

Chapter 7

Future Perspective

Spreading awareness among sport leaders and parents is important to prevent spinal column injuries and modify rehabilitation programs. Future long-term follow-up studies are warranted to elucidate the risk of potential future complications. Future projects are recommended to be prospective and to include larger population groups if feasible. Prospective studies are especially important for back pain assessment to reduce recall bias and subjectivity. In terms of MRI assessment, the implementation of endplate defect score is advised. The latter was utilized in the final study of the present project and believed to be an adequate objective parameter. The use of more sophisticated tissue analysis methods and imaging techniques like quantitative and functional MRI methods, and also regional disc analysis may add value in future studies.

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