

Back Pain and MRI Abnormalities in the Thoraco-Lumbar Spine of Elite Long Distance Runners. A Cross-Sectional Study.

Olof Thoreson MD¹, Karin Svensson¹, Pall Jonasson MD², Peter Kovac MD³, Leif Swärd MD PhD¹, Adad Baranto MD, PhD¹

1. Department of Orthopaedics, Institute of Clinical Sciences at Sahlgrenska Academy, University of Gothenburg and Sahlgrenska University Hospital, Gothenburg, Sweden.
2. SportsMed Sweden AB, Carlanderska Hospital, Gothenburg, Sweden.
3. Department of Radiology, Institute of Clinical Sciences at Sahlgrenska Academy University of Gothenburg and Sahlgrenska University Hospital, Gothenburg, Sweden.

The study was approved by the Regional Ethical Review Board in Gothenburg at The Sahlgrenska Academy at Gothenburg University, Gothenburg, Sweden. Registration number: 348-08.

Correspondence and reprint requests to:

Olof Thoreson, MD Department of Orthopaedics Sahlgrenska Universit Hospital/Sahlgrenska

SE-413 45 Göteborg, Sweden

Telephone: +46 31 3421000

E-mail: olof.thoreson@vgregion.se

ABSTRACT

Study design

Observational cross-sectional study. The level of evidence 3.

Objective

The goal was to investigate the amount of MRI abnormalities in the thoracolumbar spine and the prevalence of back pain in male elite long distance runners compared to a control group of non-athletes in the similar age.

Summary of Background

Studies have shown that athletes have a higher prevalence of back pain and a greater number of spinal abnormalities on MRI, such as disc degeneration, compared to non-athletes. The associations between running and both back pain and spinal MRI abnormalities have not been clarified.

Data

Study participants were 22 male elite long distance runners (runner group) and 25 male non-athletes (control group) of 18-28 years of age.

Methods

Back pain was assessed by a three-part self-reported questionnaire. Sagittal T1 and T2 weighted MRI examinations from Th5 to sacrum was conducted to evaluate MRI abnormalities according to the study protocol.

Results

The runners reported a significantly higher prevalence of back pain (45%), compared to the control group (12%) ($P=0.011$). No statistically significant difference was found of MRI verified spinal abnormalities ($P=0.614$) or type of abnormalities between the groups. No statistically significant correlation between back pain and MRI abnormalities was established.

Conclusions

Elite level male long distance runners have a significantly higher prevalence of back pain but demonstrate no significant difference in the amount or type of spinal abnormalities compared to non-athletes. Further prospective studies are needed to validate the results.

Keywords

Running, Low back Pain, young adult, Magnetic resonance imaging, intervertebral disc displacement, athletes, sports, physical loading, cross-sectional studies.

1 BACKGROUND

Low back pain (LBP) is a common problem among the population as a whole. But also, among young athletes (Ferguson et al., 1974; Hangai et al., 2010; Haus et al., 2012; Hubbard, 1974; Mautner et al., 2012; Micheli et al., 1995; Schmidt et al., 2014). Several studies have shown a much higher prevalence of back pain among athletes compared to age-matched non-athletes (Baranto et al., 2006; Kujala et al., 1996; Sward et al., 1991). Underlying causes of LBP are not fully described, but participation in high-level athletics during adolescence increases the risks of both LBP and the development of MRI abnormalities such as disc degeneration (Baranto et al., 2006; Kujala et al., 1996; Lundin et al., 2001; Sward et al., 1991). Up to 30 % of all athletic activity absence, due to pain among athletes, is reported to be caused by LBP (Hainline, 1995; McCarroll et al., 1986).

There is limited knowledge of how and if axial spinal compression due to sporting activities, such as long-distance running, relates to back pain and the development of spinal abnormalities.

Hangai et al. (Hangai et al., 2009) made a cross-sectional study of different athletic groups (running, soccer, baseball, basketball, swimming and kendo) and non-athletes, which displayed that runners had a higher prevalence of lifetime back pain compared to the other studied athletic groups and significantly greater than the non-athletes. A cross-sectional study by Skoffer and Foldspang (Skoffer et al., 2008) concluded that LBP was positively associated with jogging compared to other sports, and also increased the number of hours jogging. Orienteers compete by navigating and running through the terrain in different distances where the Sprint is set to 12-15 minutes of running. Orienteers, like runners, have an axial compression (stride) but the results are mixed regarding its correlation to LBP (Bahr et al., 2004; Baranto et al., 2009; Foss et al., 2012). Foss et al. (Foss et al., 2012) conducted a 10-year cohort study and suggested that orienteering can be protective towards future LBP.

Both spinal and non-spinal diagnoses have been reported as the cause of LBP in athletes. Among the spinal diagnoses are MRI abnormalities such as disc degeneration, spondylolisthesis, sacral stress

fracture, disc herniation, apophyseal ring injury, and back muscle and ligament tears while non-spinal diagnoses are conditions as sacroiliac joint dysfunction and intrapelvic problems. (Bono, 2004).

Studies have reported high prevalence (up to 90%) of MRI abnormalities in the spine among athletes (Baranto et al., 2006; Granhed et al., 1988; Hellstrom et al., 1990; Jackson et al., 1976; Sward, Hellstrom, Jacobsson, Nyman, et al., 1990; Sward, Hellstrom, Jacobsson, & Peterson, 1990). The prevalence of abnormalities has been reported to increase after the growth spurt during adolescence (Goldstein et al., 1991; Jackson et al., 1976; Tertti et al., 1990). Other studies have shown that the spine is especially vulnerable during the growth spurt (Abraham et al., 1997; Arkin et al., 1956).

Baranto et al. (Baranto et al., 2009) conducted a 15-year follow-up study with 71 athletes (weight lifters, ice-hockey players, orienteer, and wrestlers) and concluded that athletes have a higher risk of back pain and more MRI abnormalities than a control group of non-athletes. Notable was that the orienteers had a high prevalence of Schmorl's nodes. Hangai et al. (Hangai et al., 2009) showed though that runners had less disc degeneration compared to other athletes and non-athletes in a cross-sectional study.

The purpose of the present study was to investigate the amount of MRI abnormalities in the thoracolumbar spine and the prevalence of back pain in elite long

distance runners compared to a control group of non-athletes in the similar age.

The 0-hypothesis was that there was no difference, when comparing the amount of MRI abnormalities and prevalence of back pain, between male elite long distance runners, and an age-matched control group.

2 MATERIALS AND METHODS

2.1 Runners and controls

Twenty-two elite male long distance runners were recruited during 2013-2014 to the present study. The recruitment was done through contact with the coach of the Swedish National team and coaches of long-distance Clubs in Gothenburg, Linköping, Malmö and Stockholm. In some cases direct contact was taken with the athlete after reviewing national ranking lists. Inclusion criteria for the runners were male gender between 18-28 years of age. Elite long-distance runner, defined as to practice more than five times a week for at least the last five years, and not to be active in any other sports.

The control group consisted of 25 subjects between 20-25 years of age that were not active in any organized or elite sports activities at present or previously. Through flyers at the Gothenburg University, the control group was recruited. The control group participants were offered two cinema tickets as participation compensation. Inclusion criteria for the control group were male gender, maximum two exercises/week and 20-25 years of age.

Exclusion criteria for both groups were previous surgery in the thoracolumbar spine and obesity.

The recruitment of both groups occurred simultaneously but due to the difficulty to recruit runners the age span of the runner group was increased and therefore, the age is not completely matched.

2.2 Sample size and power

Power and the sample size was calculated by using statistics from a study by Baranto et al. (Baranto et al., 2009). The sample size for back pain gave sample size 23 by using power 0.8. The sample size for MRI abnormalities was 9 with power 0.8.

2.3 MRI examinations

The study participants were investigated with an MRI examination of the thoracolumbar spine, from Th5 to sacrum. The majority of the MRI examinations were performed using a 3.0 Tesla MRI in Gothenburg, and a smaller amount with 1.5 Tesla MRIs in Malmo, Linkoping, and Stockholm. Sagittal T1 images and T2 images of the thoraco and lumbar spine were taken. sag2 [B]. All examinations were led by a certified radiology nurse. Study protocol: SURV_MT_SAG; SURV_MT_COR; Ref_SNV_16 ref cervical; 25 T2W B-Rygg sag1 [A]; 25 T1W B-Rygg sag1 [B]; Ref_spine_15 ref; 25 T2W L-Rygg sag2 [A]; 25 T1W L-Rygg.

The MRI images were evaluated in a blinded manner by an experienced radiologist (co-author 4) and a senior spine surgeon (co-author 6), for comparison. All subjects had been unidentified and given a number, and the MRI examinations were mixed and evaluated randomly. The images were evaluated according to a standardized protocol, including assessment of disc signal, disc bulging, disc height, apophyseal injury, disc herniation, Schmorls nodes (Intra spongius disc herniation), the shape of vertebrae, fractures, and spondylolisthesis. Fractures and spondylolisthesis were graded as existing or non-existing whereas all other changes were graded from 0-3 with 3 representing the greatest change. Disc degeneration was classified according to Pfirrmann et al. (2001) (Pfirrmann et al., 2001) and defined as signs of disc bulging, disc height reduction, decreased disc signal intensity or a disc hernia. Detail descriptions regarding diagnostic criteria and definitions are according to the previous study by Baranto et al. (Baranto et al., 2009).

2.4 Back pain questionnaires

All runners and controls answered a three-part questionnaire according to Swärd et al. (Swärd, Hellstrom, Jacobsson, & Peterson, 1990) and Baranto et al. (Baranto et al., 2009). The questionnaire includes a part regarding present or past back pain, the Oswestry Questionnaire (ODI) and the EuroQoL (EQ5D ©EuroQoL Group 1990) questionnaire.

2.5 Statistical analysis

Data was statistically described in terms of mean and standard deviation (SD), median and range, or frequencies and percentage when appropriate. Comparison of numerical variables between runners and control was done using an independent t-test. A nonparametric Mann-Whitney U test was used for ordinal data. For comparing categorical data in two by two tables, a Chi-square test was performed. Fisher's exact test was used when expected cell count was less than 5. All tests were two-sided, and significance was set at $p < 0.05$ for each test. The analysis were carried out using SPSS (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.). The VAS scale in the questionnaire was not evaluated in this study whereas it is mainly for individual follow up and not to be compared between different participants.

3 RESULTS

3.1 Baseline characteristics

The median age for the study group was 23 years (range 18-28 years). The median age for the runners was 23 years (range 18-28), one runner was 18 years old, one was 26 and one runner was 28 years old, the

remaining were between 20-25 years of age. The median age for the control group was 23 years (range 21-25).

Three of the controls and two of the runners had a part-time occupation involving physical activity. The three controls worked in stock work, one runner worked in home care assistance, and the other runner worked part-time as a personal assistant. The remaining study participants were students.

3.2 Health assessment

Assessment of general health was rated and 21 (95%) of the runners rated their health as excellent or very good as compared to 17 (68%) in the control group. Nobody in either group rated their health as poor.

3.3 Physical exercise

The runners were exercising at a much higher frequency compared to the controls as seen in Table 1.

Table 1. Number of current training hours per week stratified by controls and runners. Number and (%).

Number of weekly exercise hours?	Controls, n=25	Runners, n=22
>11 hours	0 (0.0)	14 (63.6)
9-11 hours	0 (0.0)	6 (27.3)
6-8 hours	0 (0.0)	2 (9.1)
3-5 hours	6 (24.0)	0 (0.0)
0-2 hours 0 (0.0)	16 (64.0)	0 (0.0)
0 hours 0 (0.0)	3 (12.0)	0 (0.0)

3.4 MRI abnormalities

Due to software malfunction the MRI examinations was lost for one of the runners. Therefore, the total number of runners was reduced to 21. No clinical difference could be seen between the 1.5 Tesla coil exams and the 3.0 Tesla coil exams.

A total of 353 abnormalities were found in the study group as a whole, with 124 (35%) in the runner group and 229 (65%) in the control group. MRI abnormalities could be seen among

20 (95%) runners and the median number of changes in each was 4 (range 3-8). In the control group, MRI abnormalities could be seen in 22 (88%) individuals and the median number of changes was 7 (range 3-16). The result could not display a

significant difference in total amount of abnormalities or specific abnormality. Disc degeneration was seen in 15 (71%) runners and 19 (76%) of the controls (figure 1 and 2).



Figure 1: A) MRI of a 20 years old runner's spine showing disc degeneration on L5-S1 level. B) MRI of the spine of a 22 years old control male with disc degeneration on L4-L5 and L5-S1 levels.



Figure 2: A) MRI of a 24 years old runner's spine showing disc degeneration on L5-S1 level. B) MRI of the spine of a 23 years old control male with disc degeneration on L4-L5 and L5-S1 levels.

There was no statistical significance between the two groups when comparing number of unique individuals for each radiological abnormality, as presented in Table 2.

Table 2. Presented below is every unique individual with one or more abnormality for each pathology and (%).

MRI Abnormality	Controls, n=25	Runners, n=21	P-value
Disc-signal	16(64)	11(52)	>0.05
Disc-bulging	11(44)	8(38)	>0.05
Disc-height	18(72)	14(67)	>0.05
Apophyseal injury	0(0)	0(0)	>0.05
Shape vertebrae	4(16)	6(29)	>0.05
Schmoris nodes	17(68)	8(38)	>0.05
Dischemia	2(8)	0(0)	>0.05
Spondylolisthesis	0(0)	0(0)	>0.05
Retrolisthesis	2(8)	2(10)	>0.05
Scoliosis	7(28)	4(19)	>0.05
HIZ	4(16)	0(0)	>0.05

3.5 Back pain questionnaires

3.6 Thoraco-lumbar back pain

The result displayed a statistic significant difference ($p= 0.011$) between the groups where the runners have had or had back pain to a higher extent (Table 3). In the control group two participants' experienced back pain on a daily basis, the third one had back pain up to once a year. Amongst the ten **Table 3.** Prevalence of back pain stratified by controls and runners. Chi-square test, $p =$

runners with reported back pain, three were unable to give an estimate of how often they had back pain per year. One had back pain on a daily basis, and the remaining six had 1-10 episodes of back pain per year.

0.011. Number and (%).

Back pain.	Controls, n=25	Runners, n=22
No back pain	22 (88.0)	12 (55.0)
Back pain	3 (12.0)	10 (45.0)

Regarding the duration of back pain, five (38%) runners reported 6-12 months, four (31%) more than a year and four (31%) more than five years. Two controls reported back pain for more than five years, and one control had experienced back pain for more than a year.

Six of the runners did not know the cause of their back pain; one had been in an accident and four related their troubles to running. Two of the controls related their back pain to their work environment, and the third related it to a difference in leg length.

Two runners and two controls reported that training improved their back pain.

The ten runners had quit their training session due to back pain zero times (10%), once (50%), 2-10 times (30%) and more than ten times (10%). None of the controls had been forced to quit training sessions due to back pain.

The reported back pain prevalence (57%) was highest among the runners that had a weekly training amount of 6-11 hours. This is to be compared with a rate of 40% reporting back pain amongst the runners training more than 11 hours weekly. This difference was not statistically significant ($p=0.651$).

3.7 ODI and EQ-5D

All participants scored lower than 19% on the ODI equaling to minimal disability. All participants had a score of 1 or below

in the EQ-D5 questionnaire, indicating good health.

3.8 Correlation between back pain and MRI abnormalities

There was no statistical significance in the correlation between back pain and MRI abnormalities in either group or the group as a whole ($p>0.457$).

4 DISCUSSION

The 0-hypothesis regarding back pain was in this study disproved. The 0-hypothesis regarding the total amount of MRI abnormalities could not be disproved.

There was no significant difference in total amount or type of MRI abnormalities between the runners and the control group. The control group had, however, more abnormalities in median with 7 (3-16) compared to 4 (3-8) in the runners. Regarding disc degeneration and Schmorl's nodes, no difference could be seen between the groups, which is in contrast to earlier findings between athletes in other sports including orienteers and non-athletes (Baranto et al., 2009; Hellstrom et al., 1990). The findings were in accordance with earlier results by Hangai et al. (Hangai et al., 2009), where 33 male and ten female runners had less disc degeneration compared to both non-athletes and other athletes. The indication that repetitive axial loading is not causing vertebrae and disc injuries is also supported by the authors' earlier research regarding cyclic axial loading (Thoreson et al., 2010). Young porcine cadaver spines displayed

no loss of disc strength after 20 000 compressions, but the result could also be related to the mild axial loading. In speculation, running could be harmless or even protective for the spine regarding the development of MRI abnormalities possibly due to increased nutrition and fluid into the disc and vertebrae.

Back pain was significantly more frequent in the runner group compared to the control group of non-athletes. This is also in concurrence with Hangai et al. (Hangai et al., 2009) where runners had significantly higher level of lifetime back pain than non-athletes. It is well known that athletes have higher prevalence of back pain than non-athletes (Baranto et al., 2006; Kujala et al., 1996; Sward et al., 1991). The origin of athletic back pain could be due to many reasons such as higher physical demands on skeletal and muscle tissue. The present study did not concur with earlier studies that back pain and amount of hours training were positively linked (Foss et al., 2012; Schmidt et al., 2014; Skoffer et al., 2008).

There was no significant correlation between back pain and MRI abnormalities in either the runners or the control group. Earlier studies have shown both a higher prevalence of back pain and MRI abnormalities in athletes than non-athletes (Lundin et al., 2001; Sward et al., 1991; Sward, Hellstrom, Jacobsson, & Peterson, 1990). The cause of back pain in runners could be of a non-spinal origin, and therefore not visualized on MRI, meanwhile athletes in other sports who demonstrate spinal

MRI abnormalities may correlate their cause of back pain to the spinal origin.

4.1 Limitations

The age limitations were a possibility too high to avoid age-related spinal abnormalities such as disc degeneration. The age range in the groups was possibly too wide to achieve adequate comparison. The group size could have needed to be higher to be able to detect statistical significance. The study only included male participants. It is difficult to retrospectively quantify the occurrence, the total amount of axial loading and its correlation to back pain. A possible bias is that earlier elite long distance runners with back pain and/or MRI abnormalities could have quit running due to back pain and, therefore, were not included in the study. The questionnaire regarded both present and past back pain, and the earlier back pain can be hard to remember correctly therefore making it subject to bias.

4.2 Conclusion

Elite level male long distance runners have a significantly higher prevalence of low back pain, but no difference in amount or type of spinal abnormalities compared to non-athletes. Further prospective studies are needed to validate the results.

4.3 Acknowledgments

The authors acknowledge the financial support of The Medical Society of Gothenburg, Sweden, The Research Council of the Swedish Sports Confederation, Anna and Edwin Bergs Foundation and Government Grants under the LUA/ALF agreement. The authors thank all staff at Aleris, Radiology Department, Gothenburg, Sweden, Christer Johansson, Origo Verus AB, Gothenburg, Sweden for statistical assistance and Arne Holm for help with recruiting runners.

5 References

- Abraham, T., Holder, L., & Silberstein, C. (1997). The retroisthmic cleft. Scintigraphic appearance and clinical relevance in patients with low back pain. *Clin Nucl Med*, 22(3), 161-165.
- Arkin, A. M., & Katz, J. F. (1956). The effects of pressure on epiphyseal growth; the mechanism of plasticity of growing bone. *J Bone Joint Surg Am*, 38-A(5), 1056-1076.
- Bahr, R., Andersen, S. O., Loken, S., Fossan, B., Hansen, T., & Holme, I. (2004). Low back pain among endurance athletes with and without specific back loading--a cross-sectional survey of cross-country skiers, rowers, orienteers, and nonathletic controls. *Spine (Phila Pa 1976)*, 29(4), 449-454.
- Baranto, A., Hellstrom, M., Cederlund, C. G., Nyman, R., & Sward, L. (2009). Back pain and MRI changes in the thoraco-lumbar spine of top athletes in four different sports: a 15-year follow-up study. *Knee Surg Sports Traumatol Arthrosc*, 17(9), 1125-1134. doi: 10.1007/s00167-009-0767-3
- Baranto, A., Hellstrom, M., Nyman, R., Lundin, O., & Sward, L. (2006). Back pain and degenerative abnormalities in the spine of young elite divers: a 5-year follow-up magnetic resonance imaging study. *Knee Surg Sports Traumatol Arthrosc*, 14(9), 907-914. doi: 10.1007/s00167-005-0032-3
- Bono, C. M. (2004). Low-back pain in athletes. *J Bone Joint Surg Am*, 86-A(2), 382-396.
- Ferguson, R. J., McMaster, J. H., & Stanitski, C. L. (1974). Low back pain in college football linemen. *J Sports Med*, 2(2), 63-69.
- Foss, I. S., Holme, I., & Bahr, R. (2012). The prevalence of low back pain among former elite cross-country skiers, rowers, orienteers, and nonathletes: a 10-year cohort study. *Am J Sports Med*, 40(11), 2610-2616. doi: 10.1177/0363546512458413
- Goldstein, J. D., Berger, P. E., Windler, G. E., & Jackson, D. W. (1991). Spine injuries in gymnasts and swimmers. An epidemiologic investigation. *Am J Sports Med*, 19(5), 463-468.
- Granhed, H., & Morelli, B. (1988). Low back pain among retired wrestlers and heavyweight lifters. *Am J Sports Med*, 16(5), 530-533.
- Hainline, B. (1995). Low back injury. *Clin Sports Med*, 14(1), 241-265.
- Hangai, M., Kaneoka, K., Hinotsu, S., Shimizu, K., Okubo, Y., Miyakawa, S., . . . Ochiai, N. (2009). Lumbar intervertebral disk degeneration in athletes. *Am J Sports Med*, 37(1), 149-155. doi: 10.1177/0363546508323252
- Hangai, M., Kaneoka, K., Okubo, Y., Miyakawa, S., Hinotsu, S., Mukai, N., . . . Ochiai, N. (2010). Relationship between low back pain and competitive sports activities during youth. *Am J Sports Med*, 38(4), 791-796. doi: 10.1177/0363546509350297
- Haus, B. M., & Micheli, L. J. (2012). Back pain in the pediatric and adolescent athlete. *Clin Sports Med*, 31(3), 423-440. doi: 10.1016/j.csm.2012.03.011
- Hellstrom, M., Jacobsson, B., Sward, L., & Peterson, L. (1990). Radiologic abnormalities of the

- thoraco-lumbar spine in athletes. *Acta Radiol*, 31(2), 127-132.
- Hubbard, D. D. (1974). Injuries of the spine in children and adolescents. *Clin Orthop Relat Res*(100), 56-65.
- Jackson, D. W., Wiltse, L. L., & Cirincoine, R. J. (1976). Spondylolysis in the female gymnast. *Clin Orthop Relat Res*(117), 68-73.
- Kujala, U. M., Taimela, S., Erkintalo, M., Salminen, J. J., & Kaprio, J. (1996). Low-back pain in adolescent athletes. *Med Sci Sports Exerc*, 28(2), 165-170.
- Lundin, O., Hellstrom, M., Nilsson, I., & Sward, L. (2001). Back pain and radiological changes in the thoraco-lumbar spine of athletes. A long-term follow-up. *Scand J Med Sci Sports*, 11(2), 103-109.
- Mautner, K. R., & Huggins, M. J. (2012). The young adult spine in sports. *Clin Sports Med*, 31(3), 453-472. doi: 10.1016/j.csm.2012.03.007
- McCarroll, J. R., Miller, J. M., & Ritter, M. A. (1986). Lumbar spondylolysis and spondylolisthesis in college football players. A prospective study. *Am J SportsMed*, 14(5), 404-406.
- Micheli, L. J., & Wood, R. (1995). Back pain in young athletes. Significant differences from adults in causes and patterns. *Arch Pediatr Adolesc Med*, 149(1), 15-18.
- Pfirmsmann, C. W., Metzendorf, A., Zanetti, M., Hodler, J., & Boos, N. (2001). Magnetic resonance classification of lumbar intervertebral disc degeneration. *Spine (Phila Pa 1976)*, 26(17), 1873-1878.
- Schmidt, C. P., Zwingenberger, S., Walther, A., Reuter, U., Kasten, P., Seifert, J., . . . Stiehler, M. (2014). Prevalence of low back pain in adolescent athletes - an epidemiological investigation. *Int J Sports Med*, 35(8), 684-689. doi: 10.1055/s-0033-1358731
- Skoffer, B., & Foldspang, A. (2008). Physical activity and low-back pain in schoolchildren. *Eur Spine J*, 17(3), 373-379. doi: 10.1007/s00586-007-0583-8
- Sward, L., Hellstrom, M., Jacobsson, B., Nyman, R., & Peterson, L. (1990). Acute injury of the vertebral ring apophysis and intervertebral disc in adolescent gymnasts. *Spine (Phila Pa 1976)*, 15(2), 144-148.
- Sward, L., Hellstrom, M., Jacobsson, B., Nyman, R., & Peterson, L. (1991). Disc degeneration and associated abnormalities of the spine in elite gymnasts. A magnetic resonance imaging study. *Spine (Phila Pa 1976)*, 16(4), 437-443.
- Sward, L., Hellstrom, M., Jacobsson, B., & Peterson, L. (1990). Back pain and radiologic changes in the thoraco-lumbar spine of athletes. *Spine (Phila Pa 1976)*, 15(2), 124-129.
- Terti, M., Paajanen, H., Kujala, U. M., Alanen, A., Salmi, T. T., & Kormanen, M. (1990). Disc degeneration in young gymnasts. A magnetic resonance imaging study. *Am J Sports Med*, 18(2), 206-208.
- Thoreson, O., Baranto, A., Ekstrom, L., Holm, S., Hellstrom, M., & Sward, L. (2010). The immediate effect of repeated loading on the compressive strength of young porcine lumbar spine. *Knee Surg Sports Traumatol Arthrosc*, 18(5), 694-701. doi: 10.1007/s00167-009-1001-z