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ORIGINAL ARTICLE

Association between vertebral cross-sectional area and lumbar disc displacement – a population-based study

Laura Ollila[1,2] · Petteri Oura[1,2] · Jaro Karppinen[1,2,3,4] · Jaakko Niinimäki[1,2] · Juho-Antti Junno[1,5,6]

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Abstract

Purpose Vertebral dimensions may constitute a potential risk factor for degenerative changes in the spine. Previous studies have found a positive association between vertebral height and both type 2 Modic changes and intervertebral disc height loss. Also, vertebral endplate size has been associated with disc degeneration. However, only a few studies have investigated the association between vertebral dimensions and lumbar disc displacement (LDD). This study aimed to investigate the association between vertebral cross-sectional area (CSA) and LDD among the general middle-aged Finnish population. We hypothesized that larger vertebral CSA is associated with LDD.

Materials and methods The study was conducted by using data from the Northern Finland Birth Cohort 1966 (NFBC1966). At the age of 46, a subpopulation of NFBC1966 underwent clinical examinations including magnetic resonance imaging (MRI) ($n = 1249$). MRI scans were used to measure L4 CSA and evaluate the presence of LDD (bulge, protrusion, and extrusion/sequestration) in the adjacent discs. The association between L4 CSA and LDD was analysed using logistic regression, with adjustment for sex, education, body mass index, leisure-time physical activity, smoking, diet, and L4 height.

Results Larger L4 CSA was associated with LDD; an increase of 1 cm^2 in vertebral CSA elevated the odds of LDD relative to no LDD by 10% (adjusted odds ratio 1.10, 95% CI 1.01–1.19). The association was similar among either sex.

Conclusions Larger L4 vertebral CSA was associated with LDD in our study sample. Even though smaller vertebral size exposes our vertebrae to osteoporotic fractures, it simultaneously seems to protect us from LDD.

Keywords Lumbar disc displacement · Vertebral cross-sectional area · Cohort study · Magnetic resonance imaging · Middle-age

Introduction

Lumbar disc displacement (LDD) occurs when intervertebral disc material extends beyond the disc space [1]. When disc tissue extends over the edges of ring apophyses throughout the disc, it is called bulging. Lumbar disc herniation (LDH) is divided into protrusion, extrusion and sequestration. In protrusion displacement of disc material extends less than 25% outside of the disc space. A herniated disc is classified as extrusion when the distance between the edges of the disc material outside of the disc space is greater than the base of the disc material. If displaced disc material has lost all connection with the disc, a herniated disc is specified as sequestration [1].

LDD is a common spinal disorder among adults [2, 3]. Symptomatic LDD occurs in 1–3% of patients [2]; the symptomatic disc changes were typically extrusions, rarely protrusions or bulges [4]. The incidence of disc herniations

✉ Laura Ollila
laura.ollila@student.oulu.fi

1 Medical Research Center Oulu, Oulu University Hospital and University of Oulu, P.O. Box 5000, 90014 Oulu, Finland

2 Research Unit of Health Sciences and Technology, Faculty of Medicine, University of Oulu, P.O. Box 5000, 90014 Oulu, Finland

3 Rehabilitation Services of South Karelia Social and Health Care District, Valto Käkelän Katu 3, 53130 Lappeenranta, Finland

4 Finnish Institute of Occupational Health, Aapistie 1, 90220 Oulu, Finland

5 Department of Archaeology, Faculty of Humanities, University of Oulu, Oulu, Finland

6 Faculty of Medicine, Cancer and Translational Medicine Research Unit, University of Oulu, Oulu, Finland

ranges from 2 to 5 cases per 1000 adults annually [2, 3, 5]. Typically, LDH occurs at L4-L5 and L5-S1 levels [6–8].

There are various identified risk factors for LDD. Generally, these risk factors are age, male sex, smoking, occupation, exposure to vibration of motor vehicles, and family history of LDD [3, 8, 9]. As for biomechanical factors, it has been hypothesized that vertebral dimensions could be a risk factor for degenerative changes in the lumbar spine. There was a positive association between vertebral height and type 2 Modic changes in the lumbar spine [10]. Harrington et al. (2001) [11] found that endplate shape in both sexes and larger size of the endplates in men was associated with LDH. The risk of LDH increases if the disc material has torn off the vertebral endplate [12]. Also, differences in adjacent endplates increased the risk of LDH, especially at L4-L5 and L5-S1 levels [13, 14]. Many studies have shown that the size of vertebral endplates is associated with disc degeneration ([11, 13, 15]. Videman et al. (2014) [16] found an association with higher vertebra and disc height loss, speculating that there might be an association between degenerative changes in the lumbar spine and larger vertebrae.

Also, nutrient supply to the intervertebral discs appears to have a role in disc degeneration [17]. Nutrient supply takes place mainly by diffusion through the endplates and sometimes this route can be impeded. Decreased blood and nutrient supply may be factors that predispose the disc to degenerative changes.

In this study, we aimed to investigate the association between vertebral CSA and LDD in a large general population sample of middle-aged Finns. We hypothesized that larger CSA of the L4 vertebra is associated with LDD.

Methods

Study population

The NFBC1966 is a prospective longitudinal population-based cohort study with an unselected population ($N = 12{,}058$ live births) comprising inhabitants of the two northernmost provinces of Finland (Oulu and Lapland). The study population consisted of individuals whose expected date of birth were between January 1st 1966 and December 31st 1966. Cohort participants and their mothers have been followed since 1966. In 2012, when the cohort participants were aged 46 years, postal questionnaires were sent to all participants whose addresses were known to gathered information of participants health status, socioeconomic status and lifestyle habits. The response rate was 66% ($n = 6825$). At the age of 46 years, cohort members who were living at known addresses in Finland ($n = 10{,}282$) were invited to clinical examinations. A total of 5861 (57%) subjects attended the clinical examinations. Those who attended to the clinical examinations and were living within 100 km of the city of Oulu ($n = 1988$), were invited to lumbar magnetic resonance imaging (MRI). In all 448 participants of the clinical examination did not participate MRI due to (1) not showing up, (2) claustrophobia, (3) severe obesity preventing the imaging or (4) a pacemaker. 1540 participants underwent MRI examination. Before statistical analysis, there were excluded cases that had missing data or vertebral pathologies such as segmentation error, endplate erosion, severe disc degeneration, spondylolisthesis or Schmorl's nodes. The final study population consisted of 1249 participants.

Lumbar magnetic resonance imaging

Magnetic resonance imaging scans were performed with a 1.5-T imaging system (Signa HDxt, General Electric, Milwaukee, WI) between years 2012 and 2015. Routine lumbar spine protocol was followed in the imaging sequences including T2-weighted fast-recovery fast spin-echo (frFSE) images in sagittal (TR/effTE 3500/112 ms, 4 averages, FOV 280 × 280 mm, acquisition matrix 448 × 224, slice thickness 3 mm with 1 mm interslice gap) and transverse planes (TR/effTE 3600/118 ms, 4 averages, FOV 180 × 180 mm, acquisition matrix 256 × 224, slice thickness 4 mm with 1 mm interslice gap).

NeaView Radiology software (Neagen Oy, Oulu, Finland) version 2.31, which is collectively in use on clinical workstations in Oulu University Hospital, was used to evaluate the MRI scans. As for LDD, an experienced reader of spine MRI (JK) evaluated the L3-L4 and L4-L5 discs, classifying discs into the following categories: no herniation, bulge, and protrusion/extrusion. The exact protocol is described by [18] Saukkonen and colleagues (2020). In order to ensure sufficient sample sizes in our study groups, the "bulge" and "protrusion/extrusion" groups were combined to represent lumbar disc displacement (LDD). The LDD variable served as the outcome in the study.

One of the researchers (PO) measured 8 vertebral dimensions from the corpus of the L4 vertebra. Width dimension consists of the mean of maximum and minimum mediolateral dimensions and depth dimension was mean of the superior, inferior and middle anteroposterior dimensions. L4 height was measured using the sagittal view and the most medial slice that was available. The CSA was calculated by using the acknowledged formula CSA = π x vertebral width/2 × vertebral depth/2 [19]. Vertebral height dimension was calculated using anterior height, posterior height and minimum height. The protocol has been described in a previous publication [20]. Vertebral CSA was used as the predictor variable in the study.

Confounders

Body mass index (BMI), smoking, leisure time physical activity, socioeconomic status, diet, and vertebral height were considered as confounders. We expected these to confound the association between LDD and vertebral CSA. During the clinical examinations cohort participants were taken measurements such as height and weight. BMI was calculated using these measurements (kg/m^2). Smoking history and current smoking status were inquired by two questions: 1) "Have you ever smoked cigarettes (yes/no)?" and 2) "Are you currently smoking (yes/no)?". Three categories were formed from the answers: 1) current smoker, 2) former smoker, and 3) never smoker. Leisure time physical activity was inquired by one question "How often do you participate in brisk physical activity/exercise during your leisure-time?". The term "brisk" was defined as physical activity that causes at least some sweating and gets out of breath, corresponding to moderate-to-vigorous intensity. The response alternatives were (1) daily, (2) 4–6 times a week, (3) 2–3 times a week, (4) once a week,(5) 2–3 times a month, and 6) once a month or less often. Four categories were formed from the answers: (1) ≥ 4 times a week, (2) 2–3 times a week, (3) one a week, 4) < once a week. Socioeconomic status was evaluated based on the number of years the subject had attended school for (< 9 years, 9–12 years, > 12 years). This was determined by asking: "What is your basic education?" (1) Less than 9 years of ground school, (2) ground school, or (3) matriculation examination. Diet was clarified by asking and there were 6 different answer categories: (1) No specific diet, (2) lactose-free diet, (3) gluten-free diet, 4) weight loss diet, (5) vegetarian diet and (6) other diet. The initial categories were not altered for analysis.

Statistical analysis

Descriptive statistics were calculated as means and standard deviations (SD), or frequencies and percentages. Logistic regression was used to analyse the association between vertebral CSA (primary predictor) with LDD category (outcome). Odds ratios (OR) and 95% confidence intervals (CI) were extracted as measures of effect size. Individuals with no LDD were used as the reference group. The statistical analysis was performed using SPSS version 26 (IBM, Armonk, NY, USA). P values < 0.05 were considered statistically significant.

Ethical approval

The study adheres to the principles of the Declaration of Helsinki and is approved by the Ethical Committee of the Northern Ostrobothnia Hospital District. All participants were voluntary and signed informed consents at each stage of study. The data were handled on a group level and personal details were replaced by using identification codes.

Results

Study sample

A total number of 567 males and 682 females were included in the analyses (Table 1). The mean age of MRI imaging was 46.8 years for both men and women (SD 0.4 years). The mean BMI among men were 26.8 (SD 3.7) kg/m^2 and women 26.2 (SD 5.0) kg/m^2. Most subjects had attended school for 9 to 12 years (73.2% of men and 71.0% of women). Also, 49.7% of men and 60.0% of women had never smoked. Most individuals were physically active 2–3 times a week (34.2% of men and 40.5% of women) and followed no specific diet (71.3% of men and 64.7% of women). The prevalence of LDD at L3-L4 and L4-L5 levels was 48.5% among men and 42.2% among women. The mean L4 CSA was 13.3 (SD 1.7) cm^2 among men and 10.5 (SD 1.3) cm^2 among women.

Association between vertebral cross-sectional area and disc displacement

When investigating the association between L4 CSA and LDD using logistic regression, we found that unadjusted and adjusted analyses provided highly similar results (Table 2). Larger vertebral CSA was associated with higher odds of LDD; according to the adjusted model, an increase of 1 cm^2 in vertebral CSA elevated the odds of LDD by 10% (adjusted OR = 1.10, 95% CI 1.01–1.19).

Discussion

Our main finding was that larger vertebral CSA was associated with higher odds of LDD (representing disc bulging, protrusion and extrusion) in a large population-based sample of middle-aged Finns. In our study, LDD was quite common, as almost 50% of the men (n = 275) and over 40% of women (n = 288) had bulging, protrusion or extrusion. Our finding implies that smaller vertebral size may protect from disc displacement such as herniation.

Our finding is in line with previous studies that have associated larger vertebral endplate size with LDD [11, 13, 14], and with those that have associated vertebral dimensions such as vertebral height with degenerative changes in the lumbar spine [10]. Also, increased vertebral height was associated with adjacent disc height loss [16] and it was speculated that this might be associated with disc degeneration processes in the spine.

Table 1 General characteristics of the sample ($n=1249$)

Variable	Men ($n=567$)	Women ($n=682$)	P value
Exact age at MRI, years[a]	46.8 (0.4)	46.8 (0.4)	0.490
Body mass index at age 46[a], kg/m^2	26.8 (3.7)	26.2 (5.0)	0.001
Education, years			
<9[b]	3.2 (18)	2.6 (18)	
9–12[b]	73.2 (415)	71.0 (484)	
>12[b]	23.6 (134)	26.4 (180)	0.482
Smoking history			
Non-smoker[b]	49.7 (282)	60.0 (409)	
Former[b]	33.5 (190)	24.9 (170)	
Current[b]	16.8 (95)	15.1 (103)	0.001
Leisure-time physical activity at age 46, times/week			
<1[b]	28.9 (164)	22.6 (154)	
1[b]	20.6 (117)	19.9 (136)	
2–3[b]	34.2 (194)	40.5 (276)	
≥ 4[b]	16.2 (92)	17.0 (116)	0.040
Diet at age 46			
No specific diet[b]	71.3 (404)	64.7 (441)	
Lactose-free[b]	14.5 (82)	14.8 (101)	
Gluten-free[b]	1.4 (8)	3.8 (26)	
Weight-loss[b]	2.8(16)	5.3 (36)	
Vegetarian[b]	1.6 (9)	3.1 (21)	
Other[b]	8.5 (48)	8.4 (57)	0.007
Presence of disc displacement at L3-L4 and L4-L5			
Normal discs[b]	51.5 (292)	57.8 (394)	
Bulges, protrusion or extrusion[b]	48.5 (275)	42.2 (288)	0.027
Dimensions of L4 at age 46			
Cross-sectional area[a], cm^2	13.3 (1.7)	10.5 (1.3)	0.001

[a]Mean (standard deviation), [b]Percentage (number of individuals). MRI = Magnetic resonance imaging

Table 2 Association between L4 vertebral CSA and LDD according to logistic regression models ($n=1249$)

	Crude model			Adjusted model[1]		
	OR	95% CI	P	OR	95% CI	P
Normal discs ($n=686$)	1	–	–	1	–	–
Bulge, protrusion or extrusion ($n=563$)	**1.10**	**1.04–1.16**	**0.001**	**1.10**	**1.01–1.19**	**0.021**

[1]Adjusted for sex, education years, body mass index, leisure-time physical activity, smoking, diet, and L4 height. OR = Odds ratio (given per one cm^2 in L4 CSA), CI = Confidence interval, $P = P$ value. Bold denotes statistical significance

There is an evidence that endplate shape has also a major role with presence of LDD [11]. They considered that circular shape of the endplate may have increased annular tension levels and thereby endplate shape might predispose to LDD. However, [12] Rajasekaran et al. (2013) indicated later that LDD is more commonly the result of endplate defects than annulus ruptures. The endplate defects are indicated to be an independent risk factor for disc degeneration [12, 21]. Moreover, [22] Lama et al. (2013) indicated that disc herniation might initiate degenerative changes in lumbar discs and disc herniation might precede disc degeneration changes.

Overall, endplate defects are significantly associated with LDD [12, 21] and endplate defects might be associated with vertebral dimensions. [23] Wang et al. (2012) described that endplate lesions or trauma could expose bone to disc substances and initiate inflammation process and bone formation of the endplate. Also, vertebral height was associated with disc degeneration [10, 16] and we can

consider that larger vertebral dimensions might widely be the risk factor for degenerative changes in spine.

Our cross-sectional study is unable to reveal the mechanisms behind the association. Speculatively, one explanation could be that the larger diffusion area might be prone to decreased nutrient supply to the disc and thereby predispose the disc to LDD. Also, [17] Huang et al. (2014) confirmed that nutrient supply to the intervertebral disc might play a role in disc degeneration when there is a loss of contact with the endplates and capillaries.

Some studies have indicated that differences between adjacent vertebral body dimensions play a role in the development of LDH [13, 14]. Disc herniations were more common if there were differences between size of the endplates in adjacent vertebral bodies at L4-L5 and L5-S1 levels [13, 14]. These reports, combined with the present population-based findings, strongly suggest that vertebral dimensions have a potential role in LDD, such that the discs adjacent to large vertebrae may be particularly prone to LDD. Further studies are needed in order to reveal specific mechanisms and to confirm whether the larger vertebral size is an independent risk factor for LDDs.

The strengths of this study were its large study population, including over 1200 participants consisting of both sexes. Furthermore, vertebral CSA data were systematically collected from lumbar MRI scans and the lumbar scans were taken at the age of 46 years which was considered a good time point for the assessment of association between vertebral dimension and LDD because the prevalence of LDH is generally greatest at the age between 30 and 50 years [2, 3]. This study also had some limitations. Vertebral dimensions were measured at one time point and the lumbar MRI scans were also obtained at only one time point at the age of 46 years. Because this cross-sectional data we could only assess association and not causality. Also, we investigated only association between L4 CSA and LDD and these MRI findings cannot be used to deduce association between other observations such as larger vertebral CSA and low back pain.

We conclude that larger L4 vertebral CSA predispose to LDD. In our study sample an increase of 1 cm^2 in vertebral CSA elevated the odds of LDD by 10% in both sexes. This finding implicates that smaller vertebral size may protect from disc herniations. This is an interesting finding especially considering the fact that several studies have indicated clear temporal trends in vertebral size [24, 25]. Currently, vertebral CSA is significantly smaller than, for example, during Mediaeval period. Reduced CSA makes our vertebrae more prone to osteoporotic fractures [19, 26], but on the other hand, it seems to protect us from some lumbar disc disorders.

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