Lumbar spondylolysis: a life long dynamic condition? A cross sectional survey of 4.151 adults

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Abstract Lumbar spondylolysis (LS) has been the subject of several studies focusing on adolescent athletes. Few, if any, studies have examined LS in the general population. Lysis of the pars interarticularis of the vertebra may be associated with slipping (olisthesis), or it may be stable. In the present survey of lumbar radiographs and general epidemiological data recorded from the Copenhagen Osteoarthritis Study cohort of 4.151 subjects (age range, 22–93 years), we identified the distribution and individual risk factors for LS-development. Men were significantly more at risk of L5 spondylolysis ($P = 0.002$). There were no sex-specific significant differences regarding LS-incidence at the L4 level. We found no significant differences of risk of LS between nulliparous or multiparous women (L4 $P = 0.54$ /L5 $P = 0.35$). Furthermore, we found no significant relationship between age at menopause and LS-development. Increased lumbar lordosis was associated to L4/L5 spondylolysis in men (L4 $P < 0.001$ /L5 $P = 0.008$). In women increased lumbar lordosis had a significant association with L5 spondylolysis ($P < 0.001$). Increased pelvic inclination was associated with L5 spondylolysis in both men and women

($P < 0.001$). There were no sex-specific differences regarding the occurrence of simultaneous slips/non-slips. In men, no individual risk factors for L4 slips with concomitant LS were found. In women slipped LS of L4 were significantly associated to aging ($P < 0.001$) and with *decreased pelvic inclination* ($P = 0.001$). In men slipped LS of L5 was significantly associated to increased BMI ($P = 0.002$), but not to aging ($P = 0.10$). In women, slips of L5 LS were significantly correlated to aging ($P = 0.005$), to BMI recorded at the time of radiographic examination ($P = 0.006$), and BMI measured 17 years before radiographic index examination ($P = 0.004$). The present study contrasts with commonly held views regarding lumbar spondylolysis. The prevalence of LS increases throughout life and is apparently not a condition restricted to adolescence. Although the cross-sectional nature of the present study prevents an exact estimate of the age at onset; future, sequential studies of the cohort may provide us with some important answers on this topic. Apart from aging–obesity, lordotic angle and pelvic inclination were found to be individual risk factors for LS.

Keywords Lumbar spine · Spondylolysis · Associated spondylolisthesis

Level of Evidence: Cross-sectional and retrospective Level II

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Introduction

Spondylolytic defects of the pars interarticularis of the vertebral arch of lumbar vertebrae (LS) have been the subject of several studies [2, 3, 8]. Symptomatic adolescents or patients recruited at spine centres have been the natural focus of investigation, while the distribution of spondylolytic lesions in the general population has

received far less attention [27]. The incidence of LS in the newborn is zero [12], while prevalences of LS have been found to be 4.5% in six-year-old school children, increasing to 6% in early adulthood. The male to female ratio is about 2:1 at the L5 level. LS is most often encountered at the fifth lumbar vertebra. Although 25% of LS progress to spondylolisthetic slips on the subjacent vertebra, these rarely exceed 40%, [19]. Slipping associated to LS is believed to coincide with the accelerated skeletal growth of adolescence and exhibits a marked tendency of slowing down with age. Spondylolysis does not usually give rise to specific symptoms, and general health and functional ability parameters of subjects with LS do not differ significantly from other individuals. Pathogenetically, most authors agree with Wiltse's classification of spondylolytic lesions into dysplastic, degenerative, traumatic or pathologic [7, 17, 28]. In the absence of singular high-energy trauma to the lumbar spine, dysplastic elongation or disturbed ossification, most spondylolytic lesions are considered to be fatigue fractures due to repetitive stress or microtrauma of the neural arch. The fact that LS is most often encountered in younger athletes participating in power sports supports this hypothesis [13, 16]. Furthermore, spondylolisthesis or LS have not been found in nonambulatory patients [21]. It is generally accepted that inherited predispositions for spondylolysis exist [23, 29].

However, there are few, if any, reports examining the distribution of LS and associated risk factors in the adult, asymptomatic population. In this survey of general data, and standardized, weight-bearing lateral lumbar radiographs of the Copenhagen Osteoarthritis Study cohort of 4.151 individuals, we sought to address the following topics:

1. The age- and sex related distribution of LS in a predominantly Caucasian population.
2. The identification of risk factors for spondylolisthetic slip associated with LS.
3. The identification of risk factors for LS according to sex, age, smoking, occupational exposure to repetitive daily lifting, age at menopause, child births, pelvic inclination and angle of lordosis, and to longitudinal assessments of BMI.
4. The relationship between LS and self-reported low back pain.

Materials and methods

The Copenhagen Osteoarthritis Study

The Copenhagen Osteoarthritis Study (COS) is a sub-study of the Copenhagen City Heart Study (CCHS)

(Fig. 1). The CCHS is a longitudinal survey of an adult, Caucasian cohort of 4.151 subjects selected from the county of Österbro in Copenhagen using a random social security number algorithm. The survey has registered general life style and health parameters at four intervals since its beginning of 1976 [14, 15, 24].

Radiography

In 1993, standardised, lateral radiographs of the lumbar spine were recorded. There were 1.533 men with an average age of 62 years (range 23–93 years), and 2.618 women with an average age of 65 years (range 22–92 years). Radiographs were obtained standing. Feet pointed straightforward, lower extremities were positioned in neutral abduction-adduction. The X-ray beam was centered at the apical midpoint of the iliac crest. Tube to film distance was 120 cm.

Lumbar radiographs were assessed by a professor and a senior consultant in radiology (HR/HM). Cases of bilateral lysis of the pars interarticularis were identified. Associated spondylolisthetic slips were graded according to Meyerding (I–IV) [18]. Pelvic inclination/reclination was defined as the sacro-horizontal angle between a line parallel to the cephalad S1 endplate and the horizontal according to Wiltse. Lumbar lordosis

Fig. 1 Distribution of the study cohort in age-groups

was evaluated as the angle between the cephalad endplate of L1 and the cephalad S1 endplate.

Reliability

A subset of 50 radiographs was re-read after one month. Intra- and inter-rater reproducibility of pelvic inclination/reclination and angle of lordosis were evaluated using intra-class coefficients.

Physical characteristics and low back pain

At the 1976 and the 1993 survey the height and weight was measured, and BMI (kg/m^2) was calculated. At the 1993 survey, subjects answered a comprehensive musculo-skeletal questionnaire. Different qualities of recurrent low back pain and radicular pain inside one year prior to investigation were described: (1) Have you experienced recurrent episodes of low back pain? (2) If so, has low back been radiating to your buttocks? (3) Have you experienced low back pain radiating to thighs, lower leg and/or feet? (4) Have you experienced low back pain, radiating pain and sensory deficits?

Occupational exposure to heavy, repeated lifting

The CCHS 1993 questionnaire recorded the nature and duration of occupation since school formulated along the guidelines of The Danish National Board of Industrial Injuries, using the following categories: (1) primarily seated occupation, (2) standing, walking occupation, no repeated lifting, (3) daily repeated lifting equivalent to 50×20 kg, or 20×50 kg, (4) repeated daily lifting equivalent to $50\text{--}100 \times 20$ kg, or $20\text{--}50 \times 50$ kg, and (5) repeated daily lifting equivalent to $100\text{--}250 \times 20$ kg, or $50\text{--}100 \times 50$ kg.

Smoking and miscellaneous

The CCHS 1993 questionnaire recorded the smoking habits of the participants. We chose the following questions: “How many years of smoking?” and “How many cigarettes a day?” For women the number of childbirths and age at menopause was recorded (2,026 women had entered menopause, while 569 still had regular menstruations).

Exclusion criteria

Subjects with a history of previous spine surgery for any reason were omitted from the study (61 M/89 F).

Statistical analysis

Gender specific differences of prevalences of spondylolytic lesions at each lumbar level, and relationships between self-reported low back pain and spondylolysis were investigated by Chi-Square analyses, and odds ratios and 95% confidence intervals were calculated. Statistical relationships of continuous variables and the presence of L4 and L5 spondylolysis were investigated by independent samples Student's *t*-tests. Possible risk factors for slips/non-slips were evaluated using Student's *t*-tests. Continuous variables were furthermore entered into multivariate regression analyses. The level of significance was adjusted to $P < 0.003$ (*Bonferroni's adjustment*). All statistical analyses were performed using the SPSS 13.0 software package (Chicago, Ill).

Results

Radiography

Intra-reader agreements of lumbar and pelvic measurements were very high: assessment of pelvic inclination had intraclass coefficients of 0.91 (HR), and 0.88 (HM), and assessment of lordotic angle was 0.96 (HR) and 0.90 (HM). Inter-reader agreement was also good: 0.88 for pelvic inclination, and 0.95 for lordotic angle. We found 1 case of L1 spondylolysis (1 F), 2 cases of L2 spondylolysis (1 M/1 F), 7 cases at the L3 level (2 M/5 F), 52 cases at the L4 level (17 M/35 F), and 123 cases of L5 spondylolysis (62 M/61 F). There were no cases of dysplastic neural arches.

Distribution according to gender

We included 4,001 subjects in the study (1,495 M/2,506 F).

Prevalences and level of LS are summarized in Table 1. Men were significantly more at risk of L5 spondylolysis compared to women ($P = 0.002$; OR 1.2 (95% CI 1–1.5)), while there was no sex-specific significant difference regarding L4 LS. In females we found no significant relationships between nulliparous or multiparous women regarding LS-development (L4 $P = 0.54$ /L5 $P = 0.35$). We found no significant relationship between age at menopause and LS, and number of childbirths had no significant association with LS (Table 4).

Spondylolysis and vertebral slip

At the L4 level 42 of 52 cases of LS (80%) had progressed to Meyerding Grade 1 or 2 slips, and at the L5

Table 1 Prevalences of spondylolysis and sex related differences in distribution ($n = 4.001$)

	Men ($n = 1.495$) n	Women ($n = 2.505$) n	χ^2 P	OR	(95% CI)
L1 spondylolysis	0 (0.0%)	1 (0.1%)	–	–	–
L2 spondylolysis	1 (0.1%)	1 (0.1%)	–	–	–
L3 spondylolysis	2 (0.1%)	5 (0.2%)	0.47	1.4	(0.2–7.7)
L4 spondylolysis	17 (1.1%)	35 (1.4%)	0.29	1.2	(0.6–2.2)
L5 spondylolysis	62 (4.1%)	61 (2.4%)	0.002	1.2	(1.0–1.5)

OR odds ratio, CI confidence interval

level 85 of 123 of spondylolysis (69%) had progressed to Meyerding Grade 1–3 slips (Table 2). There were no sex-specific differences regarding slips/non-slips. In men, no singular risk factor for L4 slips was found ($P_{\text{age}} = 0.64$). In women L4 slips were significantly associated to aging ($P < 0.001$ mean difference 16.2 years; standard error 4.3 years (95% CI 7.3–25.1)), and with *decreased pelvic inclination* ($P = 0.001$ mean difference 8.6°; standard error 2.9° (95% CI –14.7 to –2.5)). In men L5 slips were significantly associated to increased BMI measured at the time of radiography (1993) ($P = 0.002$ mean difference 3.76 kg/m², standard error 1.5 kg/m² (95% CI 1.4–6.0)), but not to aging ($P = 0.10$). In women, L5 slips were significantly correlated to aging ($P = 0.005$ mean difference 11.3 years, standard error 3.8 years (95% CI 3.5–19.0)), to BMI measured at the time of radiography (1993) ($P = 0.006$ mean difference 3.0 kg/m², standard error 1.0 kg/m² (95% CI 1.2–6.3)), and BMI measured in 1976 ($P = 0.004$ mean difference 3.8 kg/m², standard error 1.2 kg/m² (95% CI 1.2–6.3)).

Distribution according to age

The distribution of L4 and L5 spondylolysis according to age is graphically represented in Fig. 2a, b. The mean age of men with accumulated LS was 61 years (range 28–85), and in women the mean age was 60 years (range, 22–83). In both men and women the occurrence of L4 spondylolysis was significantly associated to age (M $P = 0.04$ /F $P = 0.01$). At the L5 level, however, no significant correlation between aging and L5 spondylolysis was found in men, and in women an

inverse significant relationship between aging and L5 spondylolysis was found ($P < 0.001$) (Table 3).

Distribution according to BMI

Mean male BMI was 25.7 kg/m² in 1976 increasing to 26.4 kg/m² seventeen years later in 1993. Mean female BMI was 24.4 kg/m² in 1976, increasing to 25.7 kg/m² in 1993. The distribution of BMI according to age-groups is presented in Fig. 3. We found significant relationships between increased BMI in 1976 and L4 LS in both men and women (Table 3).

Other continuous variables

Increased lumbar lordosis was significantly associated to the presence of L4/L5 spondylolysis in men (L4 $P < 0.001$ /L5 $P = 0.008$). In women we found that increased lumbar lordosis was highly significantly correlated to L5 spondylolysis ($P < 0.001$). Increased pelvic inclination was significantly associated with L5 spondylolysis in both men and women ($P < 0.001$). Occupational exposures to repeated daily lifting or package years of smoking were not associated to spondylolysis in either sex (Table 3).

Degenerative spondylolisthesis and pain

Prevalences of self-reported low back pain and sex-specific differences are summarized in Table 4. We found no statistically significant relationships between low back pain and LS. Women consistently reported more back pain than men.

Table 2 Degree of spondylolytic slipping according to Meyerding (0–4) and sex related differences between slips or non-slips at each level

Meyerding grade	0	1	2	3	4	Total no.	χ^2	(Male/female ratio)
Sex	M/F	M/F	M/F	M/F	M/F	non-slips/slips	P	OR (95% CI)
L3 spondylolysis	1/1	2/3	0/1	–	–	1/6	0.71	1.2 (0.8–1.9)
L4 spondylolysis	3/7	11/23	3/5	–	–	10/52	0.57	1.0 (0.7–1.3)
L5 spondylolysis	15/23	38/31	7/5	2/2	–	38/85	0.07	1.2 (0.9–1.5)

OR odds ratio, CI confidence interval

Fig. 2 **a** The distribution of L4 spondylolysis on age-groups. **b** The distribution of L5 spondylolysis on age-groups

Multivariate logistic regression analysis

After applying multivariate logistic regression analyses and adjusted level of significance ($P < 0.004$), only increased lumbar lordosis correlated significantly with L4 spondylolisthesis ($P < 0.001$), and increased pelvic inclination with L5 spondylolysis in men ($P < 0.001$). In women, only increased pelvic inclination correlated with L5 spondylolysis ($P = 0.002$).

Discussion

This review of a randomly selected cohort of 4,151 subjects seems to contrast with several commonly held views regarding lumbar spondylolysis. This may reflect the fact that most previous reports on LS and spondylolisthetic progression have focused on children and adolescents vigorously participating in sports—often highly selected at various spine centers—and, with one

Table 3 Background data and statistical relationships to lumbar spondylolysis ($n = 4,001$)

	Men ($n = 1,495$)			Women ($n = 2,506$)		
	Mean (range)	L4 spondyl ($n = 17$) P	L5 spondyl ($n = 62$) P	Mean (range)	L4 spondyl ($n = 35$) P	L5 spondyl ($n = 61$) P
Age (years)	62 (23–93)	0.04	0.32	65 (22–92)	0.01	<0.001
BMI 1976 (kg/m^2)	25.7 (16–38)	0.03	0.42	24.4 (16–45)	0.01	0.84
BMI 1993 (kg/m^2)	26.4 (15–44)	0.23	0.06	25.7 (15–51)	0.14	0.09
ΔBMI 1976–1993 (kg/m^2)	0.9 (–11–10)	0.27	0.03	1.6 (–14)	0.73	0.99
Weight (kg)	80 (42–147)	0.68	0.29	67 (37–135)	0.45	0.11
Height (cm)	174 (147–199)	0.21	0.21	161 (134–192)	0.07	0.86
L1/S1 angle ($^\circ$)	52 (0–95)	<0.001	0.008	52 (0–91)	0.057	<0.001
Pelvic inclination ($^\circ$)	38.1 (0–82)	0.14	<0.001	37.4 (0–89)	0.16	<0.001
Age at menopause	—	—	—	48 (33–69)	0.42	0.42
Child births	—	—	—	1.6 (0–9)	0.07	0.14
Package years ^a	15 (0–188)	0.87	0.12	15 (0–144)	0.25	0.36
Primarily seated occupation ^b	1.2 (0–51)	0.11	0.86	3.7 (0–60)	0.70	0.94
Standing, walking, no repeated lifting	15.0 (0–50)	0.42	0.26	14.2 (0–60)	0.51	0.69
Years, lifting < 50 × 20 kg, or < 20 × 50 kg daily	7.6 (0–55)	0.36	0.94	5.6 (0–56)	0.78	0.07
Years, lifting 50–250 × 20 kg, or 20–100 × 50 kg daily	6.5 (0–54)	0.89	0.50	0.3 (0–40)	0.23	0.52
Years, lifting 20–250 × 20 kg, or 10–100 × 50 kg daily	1.9 (0–52)	0.84	0.48	0.03 (0–25)	0.81	0.76

^a Package-years years of smoking 1 package or more of cigarettes a day (20 cigarettes)

^b Occupations according to the guidelines of The Danish National Board of Industrial Injuries

Independent samples t -tests

Fig. 3 BMI kg/m² according to age-groups

notable exception, with limited follow up periods and numbers [5, 7, 10, 16, 25, 26]. The present study also has some limitations. Only one x-ray projection, lateral standing, of the lumbar spine was available. Although recorded in a strictly standardized manner, only bilateral pars defects were discernible. However, Amato has demonstrated that most bilateral defects are actually visible in the lateral projection [1]. Other limitations pertain to *recall bias*, the ability of the study subjects to accurately recall for instance duration and nature of physical labour, years of smoking and number of daily cigarettes and so forth. However, the CCHS/COS cohort is a highly educated group answering almost identical main questionnaires in four independent surveys from 1976 to 2002-and a whole array of sub-questionnaires which different sub-studies have bombarded the participants with over the years.

First of all, we did not find a vast difference in prevalences of spondylolysis at the L4 and L5 level: in

a total of 185 cases of lumbar spondylolysis, 52 were located at the L4 level (28%), and 123 located at the L5 level (66%), resulting in a L4/L5 ratio of 1:2.3. The L4/L5 ratio has been thought to be much higher in earlier reports. In a longitudinal study of 500 first graders Beutler et al. identified 30 cases of LS: 27 at the L5 level and only 1 unilateral pars defect at L4. Other reports also suggest that L5 LS has been thought to be far the most common location [1, 4, 20]. Again, several of these studies evaluated subjects recruited at spine centers.

Secondly, women were as much affected of spondylolysis at the L4 level as men, and while men were significantly more affected by L5 spondylolysis compared to women, odds ratio was only 1.2 (95% CI 1.0–1.5). Most other studies have claimed much higher male to female ratios.

It is generally acknowledged that most spondylolytic lesions occur during the accelerated growth of adolescence, especially in subjects participating in power sports, and that concomitant spondylolisthetic slip, when it occurs, demonstrates a pronounced tendency to arrest its progression in the earliest decades [12]. We found that the presence of L4 spondylolysis in both sexes was in fact significantly associated with aging throughout life (M $P = 0.04$ /F $P = 0.01$), while L5 spondylolysis in women had the expected inverse relationship with aging ($P < 0.001$). We have no clear-cut explanation for the difference between the L4 and L5 levels in regard to aging. It is well known that degenerative L4 spondylolisthesis is five to six times more common than lumbar L5 spondylolisthesis in the absence of pars defects, and that the iliolumbar ligaments act as powerful stabilisers of the L5 vertebra restraining forward slipping of L5 on S1 [9, 22]. Therefore, the pathogenesis of L4 spondylolysis may contain elements of both degeneration and biomechanical stress acting on the neural arch.

Spondylolisthetic progression of spondylolysis was significantly influenced by aging at both the L4 and L5 level in women, while no such relationship could be ascertained in men. Furthermore, slipping at the L5

Table 4 Prevalences and distribution of recurrent low back pain within one year prior to investigation ($n = 4.001$)

	Men ($n = 1.495$)		Women ($n = 2.506$)		χ^2	OR	95% CI
	<i>n</i>	(%)	<i>n</i>	(%)			
Low back pain	720	(48.2)	1.435	(57.3)	<0.001	1.4	(1.2–1.6)
Low back pain radiating to gluteal regions	264	(17.7)	693	(27.7)	<0.001	1.7	(1.5–2.0)
Low back pain and long radicular pain	356	(23.8)	777	(31.0)	<0.001	1.4	(1.2–1.6)
Long radicular pain and sensory deficits	161	(10.8)	279	(11.1)	0.38	1.0	(0.8–1.2)

OR odds ratios, CI confidence intervals

level was significantly associated to an increase in BMI in both men and women at the time of radiography (1993), and for women a correlation between increased BMI recorded in 1976 and slip at the L5 level assessed in 1993, could be established. Contrary to slip progression slowing down in later decades, as reported in several earlier studies, our study suggests that spondylolisthetic slipping is a life-long process, and that overweight may enhance slipping.

In women L5 slips were significantly associated to decreased pelvic inclination. Wiltse observed a natural tendency for the sacrum to become more vertically oriented with increased slip to counteract the changing biomechanical resultant load vectors across the L5/S1 joint associated to spondylolisthesis [28]. Our study confirmed Wiltse's observations.

We found significant relationships between increased BMI measured in 1976 and prevalences of L4 spondylolysis in both men and women. It seems fair to conclude that overweight may act as biomechanical stress enhancers at the neural arch at the L4 level, while that the iliolumbar ligaments at the L5 level restrain this effect. Increased lumbar lordosis and increased sacral tilt (increased sacro-horizontal angle) was found to be highly significant risk factors for the presence of spondylolysis. Again, the increase in resultant downward orientation of the vectors of load and gravity associated to excessive lumbar lordosis and sacral tilt, may act in exacerbating the adverse biomechanical forces acting on the lumbosacral region, as demonstrated by Farfan and Hanson [6, 11].

Occupational exposure to repeated daily lifting or smoking did not seem to bear any significant influence on the development of spondylolysis.

Like most other studies we did not find any positive correlations between different qualities of low back pain and spondylolysis.

In conclusion, we find that the present study contributes valuable new information regarding the distribution and natural history of low lumbar spondylolysis. Spondylolysis does not exclusively seem to be a disease of childhood or adolescence. Women are more often affected by the condition than hitherto believed. Contrary to current views, spondylolysis does in fact progress to spondylolisthetic slips *in the majority of cases*, and the slip seems to be a, albeit discrete, continuing process throughout life. Individual parameters such as sacral tilt, lordotic angle and BMI may constitute risk factors for the development or progression of spondylolysis and associated slips.

Surely, caution should always be exercised when interpreting results from purely cross-sectional studies (although the present study also considers possible risk

factors across a time-span of 17 years), however, we find that the results presented here may be valuable in delineating future prospective studies of lumbar spondylolysis.

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