Predisposing factors in degenerative spondylolisthesis

A radiographic and CT study

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Summary. *We report a prospective study analysing whether possible factors predisposing to degenerative spondylolisthesis (DS) must be present concomitantly in order to cause vertebral slipping. Standard and flexion-extension radiographs were obtained from 27 patients with DS and 27 without spondylolisthesis. The level of the intercrestal line, the lumbosacral angle, the presence of sacralization of L5 and vertebral motion at the L4–L5 level were assessed. Facet joint orientations were measured on CT scans. Only facet joint orientation and vertebral motion at the spondylolisthetic level were significantly different in patients with DS compared with controls. Facet joints were oriented more sagittally both at the spondylolisthetic level and at the levels above and below. An inverse linear correlation was found between the sagittal orientation of facet joints and the mobility of the slipped vertebra. Abnormal sagittal orientation of facet joints and hypermobility of the spondylolisthetic vertebra appear to play major roles among possible factors predisposing to DS. Both factors should be considered in the planning of surgical treatment.*

Résumé. *Nous rapportons une étude prospective analysant si des possibles facteurs prédisposant à un spondylolisthesis dégénératif (DS) doivent être présents en même temps, afin de provoquer un glissement vertébral. Les clichés standards et la flexion-extension ont été obtenus sur 27 patients avec DS et 27 sans olisthésis. Le niveau de la ligne intercrestal, l'angle lombo-sacré, la présence de sacralization de L5 et la mobilité vertébral au niveau L4–L5 ont été déterminés. L'orientation des*

facettes articulaires ont été mesurées sur des tomodensitométries. Seules l'orientation des facettes articulaires et la mobilité vertébrale au niveau olisthétic étaient différentes de façon significative chez les patients avec DS en comparaison avec le groupe de contrôle. Les facettes articulaires sont orientées plus sagittalement aux deux niveaux olisthétic et aux niveaux au-dessus et en-dessous. Une corrélation linéaire inverse fût trouvée entre l'orientation sagittale des facettes articulaires et de la mobilité de la vertèbre déplacée. L'orientation anormale des facettes articulaires et l'hypermobilité de la vertèbre olisthétic semble jouer un rôle important, prédisposant au DS. Les deux facteurs doivent être pris en consideration pour la planification d'un traitement chirurgical.

Introduction

Although degenerative spondylolisthesis (DS) was first described several decades ago [18], the aetiology and pathomechanisms of vertebral slipping are still unclear. This is true for DS at any lumbar level, but particularly for spondylolisthesis of L4 which is by far the most common site and that most frequently studied. It has been thought that excessive mechanical stresses at the L4–L5 level may cause degenerative changes in the disc and facet joints, leading to segmental instability [28]. Degenerative changes causing wear and anterior deformation of the articular processes, eventually allow the 4th lumbar vertebra to slip forward [5, 28]. However, this hypothesis does not explain

Fig. 1. The facet joint orientation in the horizontal plane was measured as the angle between a line drawn tangential to the posterior aspect of the vertebral body and a line drawn through the inter-articular gap at the medial and lateral extremities of the facet joints

the mechanism of anterior vertebral slip in patients with a coronal orientation of the facet joints. Furthermore, since degenerative changes of the disc and facet joints occur with ageing, additional predisposing factors must be involved in the process of vertebral slipping.

Conditions of abnormal stiffness at the lumbosacral junction including widening of the lumbosacral angle, sacralization of the 5th lumbar vertebra and a rectangular shape of this vertebra, have been thought to predispose to DS of L4 [28]. Other possible predisposing factors to spondylolisthesis could be abnormal sagittal orientation of the facet joints [12], widening of the angle between the pedicle and the inferior articular process in the sagittal plane [5, 18, 24], a high position of the L4–L5 disc space in relation to the intercrestal line [9], and hyperlaxity of the capsular ligamentous structures of the lumbar spine [22, 26].

The purpose of this prospective study was to analyse the prevalence of possible predisposing factors to DS, and to determine whether any combination of these factors can explain the pathomechanism of vertebral slipping.

Materials and methods

We analysed plain and standing flexion-extension radiographs and computed tomographic (CT) scans of 45 patients who had symptomatic degenerative spondylolisthesis of L4 with an

Fig. 2. The axial CT scans were made through the superior endplate and through the superior border of the pedicle

anterior vertebral slip equal to or greater than 8% of the sagittal diameter of the body of the slipped vertebra, and a decrease of the disc space below the slipped vertebra of less than 30% compared to the nearest adjacent normal disc.

On plain radiographs, we assessed the level of the intercrestal line compared to the L4–L5 disc space, the width of the lumbosacral angle, and the presence of partial or complete sacralization of the 5th lumbar vertebra. On flexion-extension radiographs, the sagittal translation and angular motion were measured at the L4–L5 level. The spondylolisthetic vertebra was considered as hypermobile when angular motion was greater than 8° [10] or sagittal translation exceeded 8% [1]. When angular motion was 3° or less the spondylolisthetic vertebra was considered hypomobile.

The height of the disc space and the sagittal translation were assessed using the methods of Farfan [7] and Dupuis et al. [3]. Measurements were made independently by a radiologist and an orthopaedic surgeon. To avoid the effects of different radiographic magnification, vertebral slipping and sagittal translation were calculated as percentages of the sagittal diameter of the slipped vertebral body. Patients with lateral views showing vertebral rotation and those who had radiographs of poor quality were excluded from the study.

On CT scans, facet joint orientation in the horizontal plane and facet tropism were measured at L3–L4, L4–L5 and L5–S1 (Fig. 1). Facet orientation in the horizontal plane tends to be sagittal in the cranial part and coronal in the distal part of the posterior joints [12]. Therefore, we used the method of Grobler et al. [12] measuring on axial CT scans at 2 positions through the middle part of the facet joints, at the superior endplate and at the superior border of the pedicle of the vertebra below (Fig. 2). The facet joints were considered markedly sagittal when the facet orientation exceeded 60° [29], and coronal when the facet orientation was less than the average value in the controls. In the presence of severe arthritic changes in the facet joints, measurements were accepted when the difference between the assessments of the two investigators was less than 5° . Facet tropism was diagnosed when the difference between the orientation of the right and left joint exceeded 5° [27].

Arthritic changes in the facet joints were classified on the basis of the severity of the alteration of the articular surfaces. Smooth articular surfaces were Grade 0, mild irregularities of the articular surfaces and/or small osteophytes were Grade I,

moderate changes to the articular surfaces and/or remodelling of the facets or large osteophytes, Grade II; and facet joints with marked irregularities of the articular surfaces with or without osteophytes and remodelling of the facets were Grade III. Remodelling was diagnosed when the articular surfaces showed a change in their original shape, including a tendency toward a more sagittal orientation as a result of wear of the frontal area, or a more coronal orientation when arthritic changes increased the frontal surfaces of the facets.

The control group was selected among patients who attended our hospital for low back pain and/or leg pain during a period of 8 months. To be included in the control group, patients had to have normal alignment of the lumbar spine on lateral radiographs with no evidence of spondylolisthesis and no decrease of the L4–L5 disc height greater than 30% compared to the first adjacent normal disc. All patients in the control group underwent flexion-extension radiographs and CT of the lumbar spine.

Statistical analyses were performed using analysis of variance, t-test and linear regression analysis.

Results

Twenty-seven patients with DS and 27 controls were entered into the study. There were 9 males and 18 females with an average age of 62 years (range: 49–76 years) in the DS group, and 15 males and 12 females with an average age of 65 years (range: 54–75 years) in the control group.

In the DS group, the mean percentage of vertebral slipping was 15% (range: 8%–33%). Anterior slipping was less than 15% in 13 patients and equal to or greater than this value in 14.

Motion at the spondylolisthetic level

On flexion-extension radiographs, the mean sagittal translation at the L4–L5 level was 7% (range: 0–13%) in the DS group, and 0 (range: 0–5%) in the control group ($P < 0.001$). The mean angular motion was 8° in both the DS group (range: 0–22°) and in the control group (range: 3°–17°). Thirteen patients (48%) with DS showed sagittal translation exceeding 8%, and 13 had angular motion greater than 8°. In 10 patients (37%) abnormal angular motion and sagittal translation co-existed. In the control group no patients had sagittal translation exceeding 8%, and 8 patients (30%) had angular motion greater than 8°.

Facet joint orientation and tropism

The orientation of the facet joints at the L4–L5 level was, on average, 62° in the DS group and 47° in the control group ($P < 0.001$). The facet joints were markedly sagittal, with the facet orientation exceeding 60°, in 14 patients in the DS group and in 2 controls. A coronal orientation of

Fig. 3. In the DS group, the sagittal orientation of the facet joints increased significantly from L5–S1 to L4–L5 ($P < 0.001$), but slightly decreased from L4–L5 to L3–L4. In the control group the sagittal orientation of the facets increased from L5–S1 to L4–L5 ($P = 0.01$), and from L4–L5 to L3–L4 ($P = 0.003$)

the facet joints, with less than 47°, was found in 4 patients with DS and in 8 controls. At the L3–L4 level the mean orientation of the facet joints was 61° in the DS group and 55° in the control group ($P = 0.04$). At the L5–S1 level, the average orientation of the facets was 44° in the DS group and 39° in the control group ($P = 0.06$). Thus, in the DS group, the sagittal orientation of facets increased significantly from L5–S1 to L4–L5 and then slightly decreased at L3–L4. In the control group, there was a progressive and significant increase in the sagittal orientation of the facet joints from L5–S1 to L3–L4 (Fig. 3).

A facet joint tropism was found in 13 (45%) patients with DS and in 12 (44%) in the control group ($P > 0.05$).

Level of the intercrestal line, lumbosacral angle and sacralization of L5

Five patients (19%) with DS and 3 (11%) in the control group had sacralization of the 5th lumbar vertebra. The intercrestal line was above the L4–L5 disc space in 11 patients with DS and in 13 controls; it crossed the L4–L5 disc in 10 patients of both groups and was below the L4–L5 disc in 6 patients with DS and in 4 controls. The mean lumbosacral angle measured 147° in patients with DS and 144° in the control group ($P > 0.05$).

Relationship between predisposing factors

In the DS group there was an inverse linear correlation between motion of the spondylolisthetic vertebra and the sagittal orientation of the facet

Fig. 4. An inverse linear correlation exists between the sagittal orientation of the facet joints and the amount of sagittal translation on flexion-extension radiographs at the spondylolisthetic level ($P = 0.01$)

Fig. 5. There is an inverse linear correlation between the sagittal orientation of the facet joints and the degree of angular motion on flexion-extension radiographs at the spondylolisthetic level ($P < 0.001$)

joints. Both sagittal translation and angular motion increased progressively as the sagittal orientation of the facet joints decreased, and vice versa (Figs. 4 and 5). In the 14 patients with markedly sagittal facet joints, the spondylolisthetic vertebra was hypomobile in 8 and hypermobile in 4. The 4 patients with coronally oriented facets (less than 47°) and 2 of the 4 who had slightly sagittal facets (less than 55°) showed a hypermobility of the spondylolisthetic vertebra.

The level of the intercrestal line, the presence of sacralization of L5, and the widening of the lumbosacral angle did not correlate with the amount of vertebral slipping, the degree of motion of the spondylolisthetic vertebra, the facet joint orientation or the severity of the degenerative changes in the facets.

Fig. 6. There is a linear correlation between the sagittal orientation of facet joints and the amount of vertebral slipping ($P = 0.02$)

The amount of vertebral slipping was correlated to the sagittal orientation of the facet joints in the horizontal plane ($P = 0.02$) (Fig. 6), whereas there was no correlation between the slip and the degree of motion of the spondylolisthetic vertebra.

There was no correlation between the severity of arthritic changes in the facet joints at the spondylolisthetic level and the severity of vertebral slip, the amount of vertebral motion and the facet orientation of the spondylolisthetic vertebra. However, the orientation of the facet joints seemed to influence the pattern of remodelling in the posterior joints. Hypertrophic degenerative processes were only seen in the presence of facet joints which were coronally oriented.

Discussion

The measurement of facet joint orientation on axial CT scans has been shown to be accurate and can be reproduced [14]. Using this method, several investigators have assessed the orientation of lumbar facet joints in patients with DS [12, 17, 22, 29]. However, measurements were performed at imprecise levels in the facet joints [22], and in some the control groups were not matched for age [12, 17], which may not provide comparable data since facet joints undergo morphological changes with ageing [30]. Our study shows that in patients with DS, the facet joints at the level of the spondylolisthesis are, on average, significantly more sagittal than those of age-matched controls.

The causes of the abnormal orientation of the facet joints in patients with DS are not clear. If excessive stress on posterior joints caused re-

modelling to an abnormal sagittal orientation, one would expect to find this mainly at the level of the spondylolisthesis. However, our results showed that in patients with DS of L4, the facet joints were oriented more sagittally than normal at the L4–L5 level and at the levels above and below. The difference was statistically significant for the L3–L4 level, but L5–S1 also showed a definite trend toward more sagittal orientation of the facets. These findings suggest a constitutional predisposition to abnormal sagittal orientation of the facets in patients with DS.

In normal subjects, the sagittal orientation of the facet joints increases progressively from L5–S1 to the upper lumbar levels [27, 30]. A similar trend was observed in our control group whereas, in patients with DS, the orientation of the facet joints at the L4–L5 level was similar, or even more sagittal, than at L3–L4. This may be due to high mechanical stress occurring at the level of the spondylolisthetic vertebra, which causes remodelling of the facet joints. This hypothesis needs investigation by longitudinal studies. Nevertheless, our results indicate that in patients with DS, the markedly sagittal orientation of the facet joints is due to a constitutional predisposition, possibly accentuated by an abnormal mechanical stress on the facet joints.

Widening of the lumbosacral angle, sacralization of L5, or a low intercrestal line, could favour degenerative changes at the L4–L5 facet joints leading to vertebral spondylolisthesis [9, 28], as might facet tropism with associated excess rotational stress [5, 17]. Our patients with DS had, on average, greater lumbosacral angles than the controls, but the difference was not statistically significant; neither did we find a significant difference in the incidence of sacralization of L5, the position of the intercrestal line nor the incidence of facet tropism.

The frequency and the amount of vertebral hypermobility in patients with DS are not well known. Inoue et al. [17] reported abnormal angular motion and sagittal translation in 46% of patients with DS, but they did not state their criteria for abnormal motion. We analysed only patients without any, or with only a mild decrease of disc height, in order to limit the influence of disc degeneration on vertebral motion [25]. Radiographic analysis revealed that 37% of patients with DS had both abnormal angular motion and sagittal translation, indicating a marked hypermobility of the spondylolisthetic vertebra. However, we also identified a sub-group of subjects showing decreased vertebral motion at the spondylolisthetic

level, i. e. they had minimal sagittal translation associated with little or no angular motion.

We found an inverse relationship between the degree of sagittal orientation of the facet joints and the hypermobility of the spondylolisthetic vertebra. Vertebral motion at the spondylolisthetic levels increased progressively as the sagittal orientation of the facets decreased, and vice versa. However, while in patients with markedly sagittal facet joints the spondylolisthetic vertebra was hypomobile or hypermobile, in all patients with coronally oriented facets the spondylolisthetic vertebra was hypermobile. This suggests that in patients with a marked sagittal orientation of the facets, the main predisposing factor to vertebral slipping is the reduced frontal area of the facet joints. In these patients, the superior facets of the vertebra below have a reduced capacity to arrest the tendency of the vertebra above to slip forward during flexion. When the disc fails, vertebral slipping occurs. In patients with coronally oriented facet joints, spondylolisthesis may occur if the vertebra is hypermobile. It is possible that hypermobility causes the posterior vertebral arch to undergo abnormal mechanical stress, causing remodelling processes in the pars interarticularis and/or in the facet joints. The latter would tend to become more horizontal in the sagittal plane, thus allowing the spondylolisthetic vertebra to slip forward. This hypothesis is supported by radiographic and anatomical observations indicating that in DS there is an increase of the angle in the sagittal plane between the pedicle and the inferior articular processes of the spondylolisthetic vertebra [5, 6, 24].

The surgical treatment of degenerative spondylolisthesis includes decompression [2, 16] and decompression and fusion, with or without internal fixation [8, 15, 21]. The criteria for choosing the most appropriate treatment have not been determined, though it would be important to identify which sub-group of patients may be treated with decompression alone, considering the morbidity associated with fusion [19, 20], particularly when this is supplemented with internal fixation [4, 23, 31]. It has been suggested that patients with coronally oriented articular facets could undergo decompression alone, since in this situation partial facetectomy would not compromise the stabilizing action of the facets to a critical extent [11, 13]. Our findings cast doubt on this assumption. Most of our patients with coronal orientation of the facet joints showed marked hypermobility of the spondylolisthetic vertebra, and this was probably the main cause of the spondylolisthesis. In these cases de-

compression alone may give poor results because of an increase of instability after surgery. On the other hand in patients with sagittal orientation of the facets, decompression alone may cause an increase ofolisthesis because the residual portion of the facets may not be able to prevent further vertebral slipping. Our study suggests that both the orientation of the facet joints and the degree of motion of the spondylolisthetic vertebra should be considered in the choice of surgical procedure.

An abnormal sagittal orientation of the facet joints and hypermobility of the spondylolisthetic vertebra play major roles among predisposing factors in degenerative spondylolisthesis. The abnormal sagittal orientation of facet joints appears to be related to both constitutional factors and to remodelling of the facets. Sagittal orientation of the facets and vertebral hypermobility are inversely related and each condition can be responsible for vertebral slipping. Evaluation of these factors can be helpful in identifying the subgroup of patients with DS who can be treated successfully with simple decompression.

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