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ORIGINAL ARTICLE

Age- and sex-related changes in facet orientation and tropism in lower lumbar spine: an MRI study of 600 patients

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Abstract

Purpose We aimed to determine the age- and sex-related changes in facet orientation and facet tropism in lower lumbar spine.

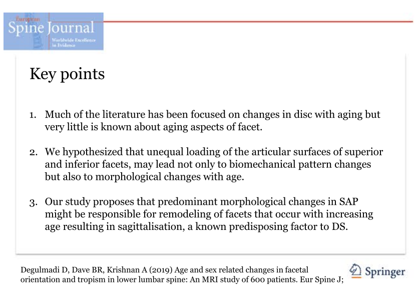
Methods Between June 2015 and December 2017, magnetic resonance imaging scans of the consecutive 600 patients performed in the outpatient department for low back pain were analyzed. The data were divided according to age into four groups: group A (< 30 years), group B (31–45 years), group C (46–60 years) and group D (> 60 years). The orientation of the facet angles at L3–4, L4–5 and L5–S1 was measured using the method described by Noren et al. Sagittal angles and tropism were determined at each level.

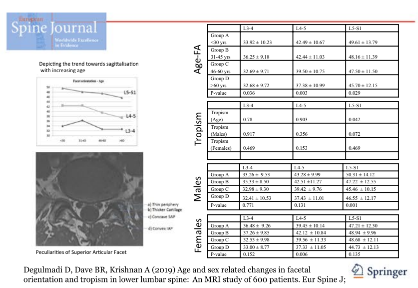
Results Average facet angle is noted to increase from L3–4 to L5–S1 level in all groups irrespective of age and sex. A positive correlation is noted between age and sagittal facet orientation at all levels across all groups. Tropism was noted to be statistically significant ($p < 0.05$) at L5–S1 level. L3–4 and L4–5 levels did not show a positive correlation with respect to age. Facet angle sagittalization was significantly associated in males at L5–S1 level ($p < 0.05$) and in females at L4–5 level ($p < 0.05$).

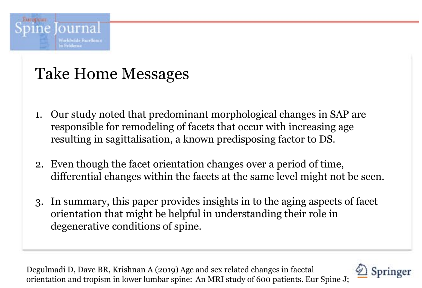
Conclusions Predominant morphological changes in superior articular process are responsible for remodeling of facets that occur with increasing age, resulting in sagittalization. Even though the facet orientation changes over a period of time, differential changes within the facets at the same level might not be seen.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords Lumbar · Facet · Remodeling · Degeneration · Listhesis

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Introduction

Facet joints, also known as zygapophyseal joints, play an essential role in balancing the segmental units of spine and control spinal kinematics [1–3]. Conditions such as degenerative disk disease, disk prolapse, degenerative spondylolisthesis and degenerative lumbar canal stenosis have been related to changes in facet orientation and tropism

[3–6]. Although sagittal facets have been associated with spondylolisthesis, relation between facet anatomy and other degenerative conditions has been always controversial [3–9]. It is well known that degenerative changes begin during second decade in disk; facets are usually secondarily affected [10]. Much of the literature has been focused on changes in disk with aging, but very little is known about aging aspects of facet. We hypothesized that unequal loading of the articular surfaces of superior and inferior facets may lead not only to biomechanical pattern changes but also to morphological changes with age. The present study focuses on the change in facet angle (FA) and its tropism (FT) with increasing age in lower lumbar spine.

Materials and methods

A total of 600 magnetic resonance imaging (MRI) scans of the consecutive patients performed in the outpatient department for low back pain between June 2015 and Dec 2017 were analyzed. Patients with previous history of trauma, back surgery, congenital anomalies, infection, deformity and tumors were excluded. FA of the lower lumbar vertebrae, namely L3–4, L4–5 and L5–S1, was measured. The data were grouped according to the predetermined criteria into four groups, 150 in each group. Group A consisted of patients less than 30 years of age, group B between 31 and 45 years of age, group C between 46 and 60 years of age and group D more than 60 years of age. No institutional ethical committee clearance was taken as it was a study on images only.

The orientation of the FA was measured in degrees on the axial T2-weighted MRI images using the method described by Noren et al. [7]. On T2 axial image that bisected the intervertebral disk, the first line was drawn in the mid-sagittal plane of the vertebra passing through the center of the disk and center of base of spinous process and the second line was drawn between the anteromedial and posterolateral edges of the superior articular facets bilaterally (Fig. 1). All the cases with abnormal spinous process angle (deformity) were excluded. FA was calculated as angle between the oblique line and the sagittal plane on both the sides. MB Angle software (Markus Bader-MB software solutions version 5.3) was used to calculate the left and right facet joint angles. The degrees of two angles (left and right) were averaged and considered as the orientation of the facet joints. All values were measured by two authors and the average value was used for analysis. The cutoff angles of 36° at L3–4, 42° at L4–5 and 45° at L5–S1 were taken for labeling as sagittally aligned facet (SAF) joints [7]. Facet tropism (FT), difference between right and left angles, was calculated and categorized into mild (< 7°), moderate (7°–15°) and severe (> 15°) [11].

Statistical analysis

Continuous variables were expressed as mean ± standard deviation. The correlation analysis was performed with Pearson's method. Descriptive statistics were summarized as frequencies and percentage of categorical variables as mean and SD for continuous variables. Fischer's exact test was performed to determine the statistical significance. The criterion for statistical significance was $p < 0.05$. Intra-class correlation coefficient (ICCs) was calculated to determine the reliability/agreement between the two observers for the measurement of facet angle. All the statistical analysis was performed using SPSS (Statistical Package for Social Sciences), version 17.

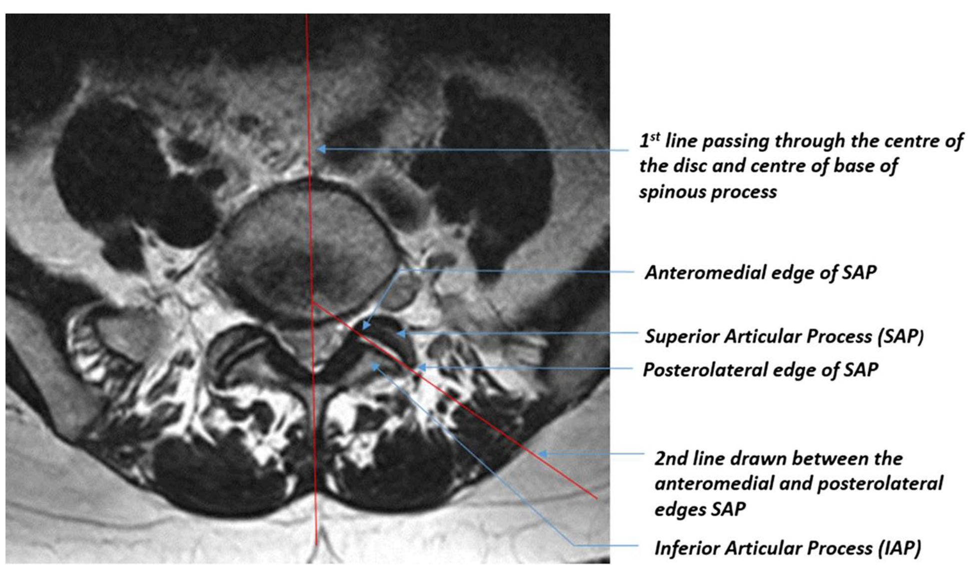

Fig. 1 Angle measurement technique

Table 1 Mean facet angles in different age groups

	L3–4	L4–5	L5–S1
Group A <30 years	33.92 ± 10.23	42.49 ± 10.67	49.61 ± 13.79
Group B 31–45 years	36.25 ± 9.18	42.44 ± 11.03	48.16 ± 11.39
Group C 46–60 years	32.69 ± 9.71	39.50 ± 10.75	47.50 ± 11.50
Group D >60 years	32.68 ± 9.72	37.38 ± 10.99	45.70 ± 12.15
p value	0.036	0.003	0.029

Data are presented as means ± standard deviations

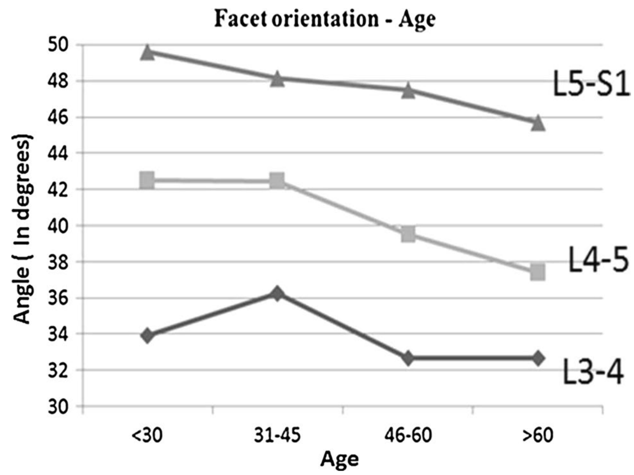

Fig. 2 Trend toward sagittalization with increasing age

Results

Patient characteristics

Out of 600 subjects, 51% were males and 49% were females. The male/female ratio was greater than 1 in all patient groups (1.12–3.83). Minimum age of 15 years and maximum age of 88 years were included in study. All the patients were grouped into respective groups accordingly (150 in each group).

Measurement reproducibility

The intra-class correlation coefficient was found to be 0.918, which shows excellent agreement between the two observers for facet angle measurement. However, the degrees of two angles (left and right) were averaged and considered as the orientation of the facet joints (single reading) for statistical purposes.

Subgroup analysis

Average facet angle is noted to increase from L3–4 to L5–S1 level in all groups irrespective of age and sex. Table 1 summarizes the facet angles at all lower lumbar levels in different groups.

Relation to age

Though the trend toward sagittalization is seen in all the lumbar levels, a positive correlation is noted between age and sagittal facet orientation at all levels across all groups (Fig. 2). Statistical significance ($p < 0.05$) was noted at all the levels across all the groups with respect to facet angle (Table 1). Tropism was noted to be statistically significant ($p < 0.05$) at L5–S1 level. L3–4 and L4–5 levels did not show a positive correlation with respect to age (Table 2).

Table 2 *p*-values of facet tropism in relation to age and sex

	L3–4	L4–5	L5–S1
Tropism (age)	0.78	0.903	0.042
Tropism (males)	0.917	0.356	0.072
Tropism (females)	0.469	0.153	0.469

Data are presented as means ± standard deviations

Table 3 Mean facet angles in different age groups in males

	L3–4	L4–5	L5–S1
Group A	33.26 ± 9.53	43.28 ± 9.99	50.31 ± 14.12
Group B	35.33 ± 8.50	42.51 ± 11.27	47.22 ± 12.55
Group C	32.98 ± 9.30	39.42 ± 9.76	45.46 ± 10.15
Group D	32.41 ± 10.53	37.43 ± 11.01	46.55 ± 12.17
p-value	0.771	0.131	0.001

Data are presented as means ± standard deviations

Relation to sex

Facet angle sagittalization was significantly associated in males at L5–S1 level ($p < 0.001$) (Table 3) and in females at L4–5 level ($p < 0.05$) (Table 4). However, tropism did not show any significance at any of the levels with respect to sex (Table 2).

Table 4 Mean facet angles in different age groups in females

	L3–4	L4–5	L5–S1
Group A	36.48 ± 9.26	39.45 ± 10.14	47.21 ± 12.30
Group B	37.26 ± 9.85	42.12 ± 10.84	48.94 ± 9.96
Group C	32.53 ± 9.98	39.56 ± 11.33	48.68 ± 12.11
Group D	33.00 ± 8.77	37.33 ± 11.05	44.73 ± 12.13
p-value	0.152	0.006	0.135

Data are presented as means ± standard deviations

Discussion

Growing trends in spinal degenerative pathologies and the role played by facets invoke us to study the aging patterns in orientation of facets. Such knowledge is a prerequisite to understand various spinal aging problems. Despite the work that has been done thus far to understand the role of facets in causation of multiple degenerative conditions, we are not aware of any large studies describing the changes in facet orientation in relation to age. To our knowledge, ours is the first study that focused on the age- and sex-related changes in FA and FT of lower lumbar spine.

A functional spine unit is a three-joint complex consisting of two facet joints and one intervertebral disk. These take part in load sharing and affection of one may influence the biomechanics of other articulations [2, 12]. While the intervertebral disk is the main load bearing structure in flexion, the two facet joints bear the major load in extension posture. The facet joints play a critical role in maintaining the stability of the lumbar spine by sharing load in compression and extension, thereby protecting the disk from excessive shear and rotational forces [13, 14]. In the lumbar region, the facet joints are inclined to a nearly vertical orientation and are curvilinear, shape that highlights their role in preventing rotation as well as forward displacement [15]. In normal subjects, the sagittal orientation of the facet joints increases progressively from L5–S1 to the upper lumbar levels. At L1–2 segment, a 30-degree angle between the L1–L2 articular facets resists rotation and allows flexion/extension. At L4–S1, angle varies from 30° to 90° creating more resistance to forward displacement of the superior articular process (SAP) during flexion and extension but allowing more rotation as the lumbar spine transition to sacrum [9].

Due to contribution in weight bearing of lumbar spinal column, even subtle misalignments of these paired articulations may induce degenerative changes [1]. Over the course of adult life, the superior and inferior facets of a typical lumbar vertebra exhibit different patterns of changes, reflecting the different stresses placed upon these parts of the joint [16]. According to our proposed hypothesis, unequal loading of SAP and inferior articular process (IAP) may lead not only to biomechanical pattern changes but also to morphological changes with age. We noticed few probable mechanisms that contribute to facet remodeling. With the erosion of SAP, the starting point to measure the facet angle seems to move more laterally and the joint articulation was observed to be more vertical. As the erosion continues, the angle might change over the time dynamically and tends to become more sagittal over the years, as observed in this study. Such findings were more statistically significant at lower lumbar levels where predominant mobility occurs.

Disk degeneration usually begins in the early 1920s, further loading the facets in the posterior column [10]. A loss of disk height leads to laxity of facet capsule, leading to loss of capsular restraint and thus increased mobility at that spinal unit complex. Abnormal increased mobility causes excessive movement between two articular processes of the facet and may subsequently lead to cartilage erosion and arthritis of facet joint complex [17]. Movement in a facet joint complex of a motion segment is such that the IAP of cranial vertebra glides to a controlled extent against SAP of caudal vertebra and the facet joint capsule [18]. Normally SAP of caudal vertebra neutralizes the shear vector promoted by IAP of cranial vertebra. The anterior coronal portion of SAP at this point acts as a weight bearing structure. The static area of contact of SAP against the gliding IAP leads to higher erosion of SAP over the years as compared to IAP. With the continuous flexion–extension cycles occurring over the lifetime period and age-related degeneration, there is gradual remodeling of anterior part of SAP [16]. Any change in one part of the articulating surface of a joint leads to change in the orientation of that joint angle. Such degenerative changes lead to sagittalization and thereby degenerative listhesis. However, differential changes between the two facets at the same level also need to be looked into as tropism is also implicated in many of the degenerative conditions. In our study, tropism did not show statistical significance with aging except for L5–S1 ($p < 0.05$). This finding showed that even though the facet orientation changes over a period of time, differential changes (tropism) within the facets at the same level might not be seen.

Unlike disks, facets do not show an age-related loss of proteoglycans or a consequent decrease in the resistance to a compressive load [19]. Peculiar features of SAP include thicker cartilage, peripheral thin portions, concavity, higher fixed charge density and higher water content in contrast to IAP that is convex (Fig. 3). The biomechanical properties of cartilage depend to a large extent on its ability to maintain hydration and tissue thickness under the mechanical stresses encountered during normal activities. Arthritis of facet joint like any other joint in the body leads to remodeling of articulating surfaces. The cartilage of the SAP is thicker than that of IAP and has a higher fixed charge density [19]. As SAP is concave, the peripheral portions being thinner are more worn out that lead to a change in the orientation. At the same

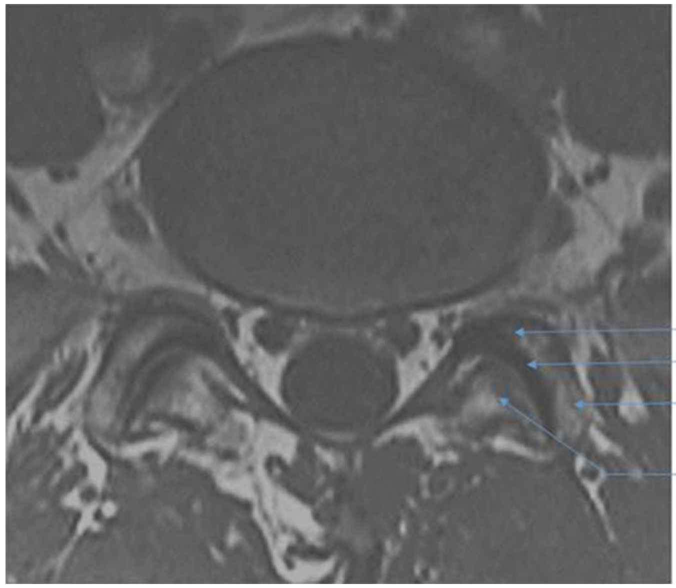

Fig. 3 Various peculiarities of superior articular facet

time, SAP has a higher water content, which is known to accompany damage of the collagen network and cartilage degeneration [19].

In previous studies, Boden et al. [3] mentioned that disk degeneration would induce changes like subluxation of joints and thereby cartilage alteration. Small bone fractures and OA of facets leading to alteration in facets were reported by Fujiwara et al. [20], but the exact mechanism was not clearly mentioned. Wang et al. [21] in his paper reported that increased stress on facet joints leads to changes in facet orientation. Love et al. [22] found that older adults have a significantly greater mean sagittal angle of the facets than those in the younger group. In their study, the presence of more sagittally orientated facet joints in patients with degenerative spondylolisthesis did not show that the sex difference can be explained by the morphology of the facet joint. Few studies also concluded that the increased angle of the facet joint is the result of arthritic remodeling and not the primary cause of degenerative spondylolisthesis [3, 21, 22]. L5–S1 in males and L4–5 in females showed statistical significance in terms of facet sagittalization in our study. This finding coincides with the literature in which L4–5 level is suggested to be the commonest level of spondylolisthesis. Degenerative spondylolisthesis is reported to be four times more common in females; this study supports the fact with L4–5 level showing statistical significance in females.

There were several limitations in the current study. Firstly, this was a cross-sectional observational study only. It will be practically impossible to take consecutive MRI (longitudinal study) in same patient with time. As the radiological parameters were not followed longitudinally over time, it is not possible to prove our hypothesis. Although the measurement of facet joint angle from MRI axial T2-weighted image is less accurate than measurement from computed tomography (CT) image, the authors found the reliability of this measurement method was comparable and consistent with several previous studies. The primary source of error could be in the identification of the reference plane and the margins of the facet joint, which is operator dependent. The characteristic of hypertrophic "lipping" of superior facet can cause error in the measurement of facet joint angle; still an established method was used to measure with interobserver reliability studies done earlier with established consistency. The discrepancy of SAF or FT cutoff angles has been described in the literature in variance, and we have used only one methodology which is the only possible way of studying. Neither did we include sagittal balance, lumbar lordosis, other pelvic and angular parameters, BMI and other demographic features which may have a role individually. The strengths of the present investigation include the use of a large sample. We have analyzed the facet orientation and tropism to different age groups that have highlighted new concepts that will be useful in future longitudinal studies. The measurement technique was highly reproducible and the actual measurements were consistent with values available from several previous studies in which CT scans were used. Our methodology provided normative data as well as insight for additional studies of degenerative conditions of spine.

Conclusions

Our study proposes that predominant morphological changes in SAP might be responsible for remodeling of facets that occur with increasing age resulting in sagittalization, a known predisposing factor to DS. Even though the facet orientation changes over a period of time, facet tropism does not seem to change with increasing age. In summary, this paper provides insights into the aging aspects of facet orientation that might be helpful in understanding their role in degenerative conditions of spine.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest

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