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Full Length Research Paper

The linear and angular dimensions of the L4-L5 facet in healthy adults: Measurements on the axial and parasagittal-oblique mri planes

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An understanding of the L4/L5 facet morphology should help in the design of facet instrumentation and decrease the risk of surgical complications. Despite the use of the axial plane, there are no reported normal values of the facet dimensions using the parasagittal-oblique plane on magnetic resonance imaging (MRI). The aim of this study was to document the L4/L5 facet joint dimensions in terms of angles and linear distances in healthy subjects using MRI, and to explore both the correlation between the morphological characteristics of the L4-L5 facet joint, and the association between these characteristics and the parameters of gender, height, and weight, of the subjects. 123 volunteers (51 males and 72 females) participated in this investigative study. The facet heights and widths were measured on the parasagittal-oblique MRI plane. Since the axial plane clearly depicted the facet joint, this plane was used for the mesurements of the sagittal and transverse facet angles. Intraobserver reliability was found to be high (intraclass correlation coefficient being 99.5 %). The male linear and angular parameters were larger than the female ones. There were significant differences between males and females in terms of the lengths and widths of the L4 facets ($p < 0.01$ and $p < 0.03$, respectively). No associations were found between the facet dimensions and the parameters of height and weight. This study provides baseline information about the morphological characteristics of the L4/L5 facet joint, which may well contribute to the success of related surgical interventions and also make possible the accurate simulation of this component of the segment of motion.

Keywords: Lumbar spine, facet joint, facet angle, MRI, functional spinal unit (motion segment)

INTRODUCTION

The facet (zygapophyseal) joints in the lumbar spine are important structural components which facilitate the controlled movement between the vertebrae, while protecting the discs from shear forces and excessive flexion and axial rotation. Thus, they contribute to the stability of the lumbar motion segments (Boden et al,1996; König et al, 2001; Mashawari et al, 2004; Williams et al, 1995; Zoltsin et al, 2000). It is important to gain in-depth knowledge on the linear and angular

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dimensions of the facets, as their sizes and shapes may be associated with the amount of stress hauled on the vertebral column, and thus may affect the kinematics and pathological conditions related to the motion segments in the spine (Boden et al, 1996; Zoltsin et al, 2000; Berlemann et al, 1998; Berven et al, 2002; Fujiwara et al, 2001; Grobler et al, 1993: Ko et al, 1997: Tischer et al, 2006).

Several studies have shown an association between the orientation of the facet joint and the degenerative changes in the lumbar spine such as disc herniation, degenerative spondylolisthesis, and osteoarthritis (Boden et al, 1996: Berven et al, 2002; Fujiwara et al, 2001; Dai, 2001). Since the L4/L5 facet constitutes a spinal functional unit (motion segment) which has the potential for giving rise to degenerative changes, these vertebrae were intentionally included in this study.

Recently, a large database was created, examining the facet angulation and its asymmetry in various planes (Boden et al, 1996; Berlemann et al, 1998; Berven et al, 2002; Fujiwara et al, 2001; Grobler et al, 1993; Dai, 2001; Cinotti et al, 1997; Ebraheim et al, 1997; Grogan et al, 1997; Iguchi et al, 2002; Kimura et al, 2001). There are some studies in which the morphometry of the facet in healthy subjects was measured using cross-sectional imaging (Berlemann et al, 1998; Berry et al, 1987; Mashawari et al, 2005; Panjabi et al, 1993; Patel et al, 2004). But, to the best of knowledge of the authors, the measurements of the facet dimensions using the parasagittal-oblique plane are not available in the literature. Although Ebraheim et al compared the male and female measurements of the thoracic facet, the correlation between the linear and angular dimensions of the L4/L5 facet, and the association between these dimensions and the parameters of gender, height and weight, have not been reported (Ebraheim et al, 1997).

The understanding of the location, angulation, and dimensions of the facet serves as a useful data for the surgeon in the process of proper placement of the implant and in the design of instruments of intervention for the lumbar spine (Mashawari et al, 2004; Berry et al, 1987; Mashawari et al, 2005; Panjabi et al, 1993; Petit et al, 1998). The aims of this study were: a) to measure the linear (length and width) and angular (sagittal and transverse angles) dimensions of the L4/L5 facet using the axial and parasagittal-oblique planes on MRI in healthy volunteers, and then to document the normal values of this facet, and, b) to explore the correlation between the linear and angular dimensions of the L4/L5 facet, together with the association between these facet dimensions and the parameters of gender, height and weight. Thus, we investigated whether 1- the axial and parasagittal oblique planes would permit the quantitative analysis of the L4/L5 facet by providing clear anatomical landmarks; and 2- the facet dimensions claimed any dependency on the parameters of gender, height and weight.

MATERİALS AND METHODS

The data presented in this study are part of a series of morphometric studies of the lumbar spine in general, and the architecture of the facet joints in particular. One hundred and twenty-three healthy volunteers (51 males and 72 females) were recruited for this investigation. Individuals with the complaints of low back pain and disc or facet pathology were excluded from the study. The mean age was 32.9 ± 6.3 years, the mean height was 166.4 ± 8.8 cm, and the mean weight was 72.0 ± 12.5 kg. The research was approved by the hospital's ethical committee and performed according to the World Medical Association Declaration of Helsinki; and all subjects had given their informed consents prior to participating in this study.

MRI was conducted with a 0.2 T open system (Airis Mate, Hitachi, Japan) ,using a quadrant lumbar coil. All of the participants were investigated with a sagittal and an oblique-parasagittal T1-weighted spin-echo (SE) sequence, as well as an axial T1-weighted SE sequence, with scans passing through the facet joint levels. The parasagittal-oblique views were acquired by view planes passing through the facet joint spaces on these axial pilot scans. The parameters of MRI scanning were as follows: repetition time (TR)/echo time (TE): 450/25 msec; field of view (FOV): 330 mm; and slice thickness: 3 mm.

The linear measurements were made on the parasagittal-oblique plane, while the axial plane was used for the angular measurements. All measurements were made by the same radiologist to avoid any technical and/or inter-observer error and to maintain reproducibility. Measurement errors were assessed by using intraclass correlation coefficients (ICC). To assess measurement errors, the images of the fourth and fifth lumbar vertebrae from twenty subjects were randomly selected and all measurements were repeated on three consecutive days by the same observer. Data from these three sets of measurements were compared.

Lumbar facet length was appointed as the distance between the superior and inferior borders of the facet, and lumbar facet width as the distance between the anterior and posterior borders of the facet (Figure 1). On an axial MRI image, the sagittal angle (SA) was measured as the angle between a line drawn through the inter-articular gap of the facet joint and a midsagittal line (Figure 2). The two points of reference required to determine the midsagittal line were chosen as the center of the vertebral body and the center of the spinolaminar junction (Tischer et al, 2006) . The transverse angle was measured as the angle between a line drawn through the inter-articular gap of the facet joint and a line drawn coronally tangential to the anterior aspect of the vertebral body (Figure 2) (Berlemann et al, 1998; Cinotti et al, 1997). The sagittal angle can also be calculated by subtracting TA from 90° (SA= 90° - TA).

Statistical analyses were performed by using the SPSS

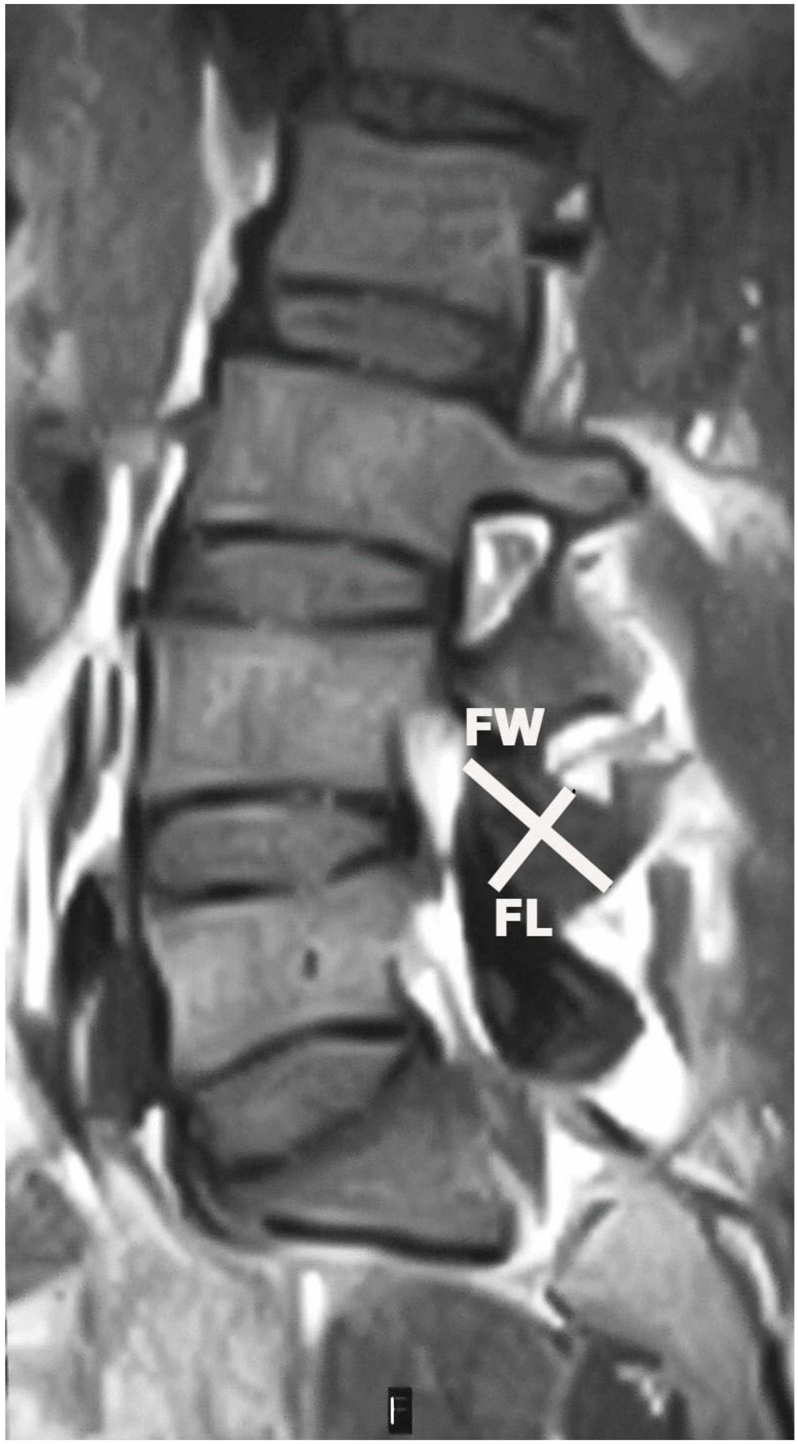

Figure 1. T1- weighted parasagittal-oblique MRI image. Lumbar facet length (FL) was defined as the distance between the superior and inferior borders of the facet, and lumbar facet width (FW) as the distance between the anterior and posterior borders of the facet.

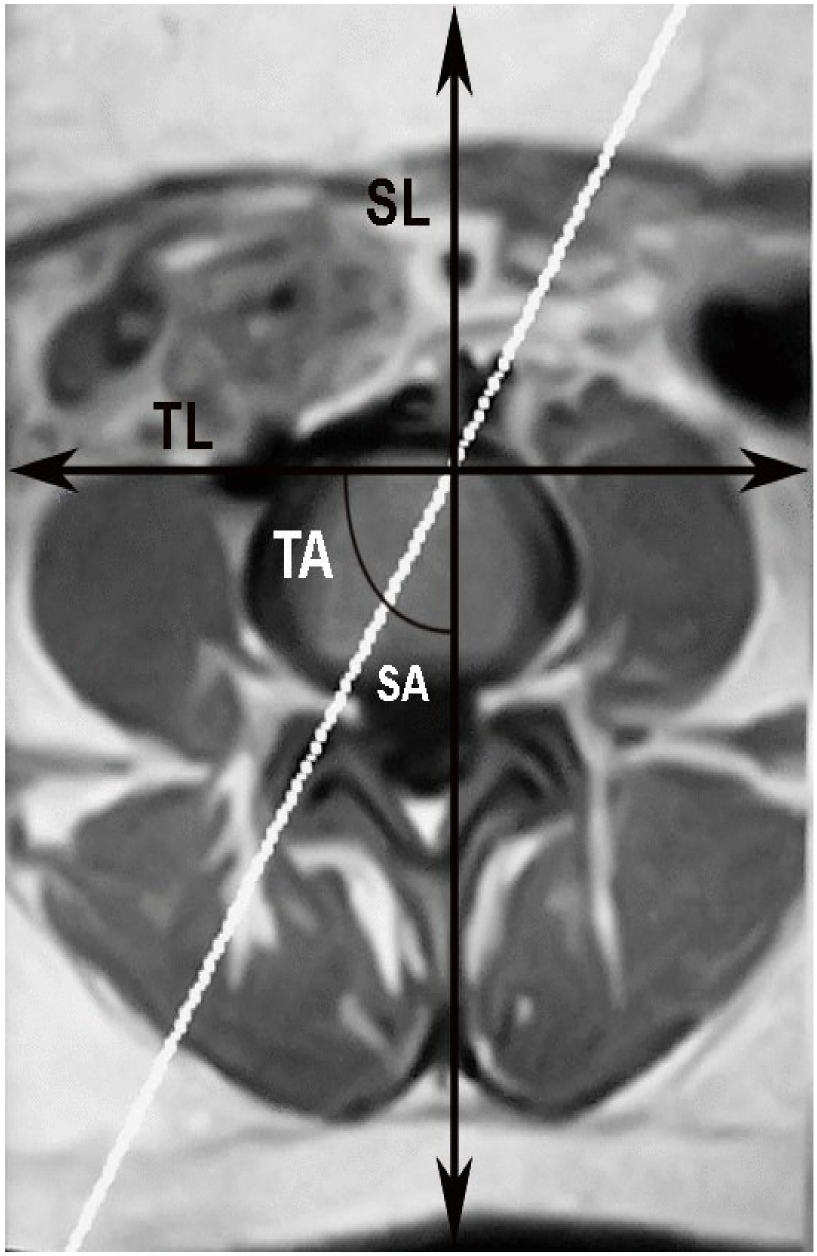

Figure 2. The axial MRI plane image. The midsagittal angle (SA) was defined as the angle between a facet line drawn through the inter-articular gap of the facet joint (white line) , and a midsagittal line (SL). The transverse angle (TA) was defined as the angle between the midsagittal line and a transverse line (TL) drawn coronally tangential to the anterior aspect of the vertebral body.

11.0 statistical software. Descriptive statistics were carried out for all measurements. The comparison of dimensions between the male and female subjects were analyzed using the Student's t test. Pearson's correlation coefficient was calculated for the investigation of the associations between the various parameters. The criterion for statistical significance was $p < 0.05$; $p < 0.05$ and $p < 0.01$ were considered significant and highly significant, respectively.

RESULTS

The parasagittal-oblique and axial MRI planes were found to be capable of enabling the localization of the facet joint and acquiring accurate measurements. The measurements of the mean values ± standard deviations (SD) of the measurements are shown in Table 1. The mean height of the individuals was 166.4 ± 8.8 cm, males being significantly taller than females (172.4 ± 7.8 cm vs

Table 1. The means and standard deviations of the dimensions and angles of the L4-L5 facet.

Parameters	Male (n=51)		Female (n=72)		Total (n=123)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Age (year)	32.4 ± 6.8	18-45	33.2 ± 6.0	19-45	32.9 ± 6.3	18-45
Height (cm)	172.4 ± 7.8*	150 - 192	162.2 ± 6.7	149 - 180	166.4 ± 8.8	149 - 192
Weight (kg)	76.0 ± 12.4*	53 - 98	69.2 ± 11.9	47 - 90	72.0 ± 12.5	47 - 98
L4 Facet length (mm)	18.9 ± 2.4*	12.8 - 24.6	18.0 ± 2.4	13.6 - 23.9	18.4 ± 2.4	12.8 - 24.6
L4 Facet width (mm)	24.5 ± 2.5*	19.9 - 32.7	23.4 ± 2.7	18.3 - 31.4	23.8 ± 2.7	18.3 - 32.7
L5 Facet length (mm)	18.8 ± 2.7	13.1 - 25	18.4 ± 2.2	13.3 - 23.6	18.6 ± 2.4	13.1 - 25.0
L5 Facet width (mm)	24.5 ± 2.7	17.2 - 30.9	23.6 ± 2.6	17.9 - 29.7	24.0 ± 2.7	17.2 - 30.9
L4/L5 Transvers angle (°)	51.90 ± 8.3	21.6 - 69.1	54.1 ± 6.0	40.0 - 68.9	53.3 ± 7.1	21.6 - 69.1
L4/L5 Sagital angle (°)	38.0 ± 8.3	20.9 - 68.4	35.8 ± 6.0	21.1 - 50.0	36.7 ± 7.2	20.9 - 68.4

* Difference statistically significant with respect to females ($p < 0.05$)

162.1 ± 6.7 cm, respectively; $p < 0.001$). The mean weight of the individuals was 72.0 ± 12.5 kg, males being significantly heavier than females (76.0 ± 12.4 kg vs 69.2 ± 11. 9 kg, respectively; $p < 0.003$). Intraobserver reliability was found to be high (intraclass correlation coefficient being 99.5%) for all measurements and time intervals.

No significant differences were found in facet dimensions with regard to body height and weight. However, the length and width dimensions of the L4 facet were significantly bigger in males compared to females ($p < 0.01$, and $p < 0.03$ respectively). The angles of the facet did not show any significant alterations in comparison to its linear dimensions.

DİSCUSSİON

This study was structured on the quantitative analysis of the L4/L5 facet joint, and it well demonstrated that the anatomical landmarks can be defined accurately by using the axial and parasagittal-oblique planes of MRI. The normal values of the dimensions of the L4/L5 facet joint were obtained at the end of the study. Thus, the results of this study provide a basis for designing a facet instrument and defining the normal and abnormal sizes of the facet.

One of the limitations of this study is the fact that a single radiologist performed all of the measurements, and thus the interobserver reliability coefficients were not calculated. However, several morphologic studies of the lumbar facet have also not included interobserver reliability (Fuwiwara et al, 2001; Patel et al, 2004; Petit et al, 1998). The other limitation is that the influence of age could not be evaluated, since approximately two-thirds of the volunteers were between 27 and 39 years.

The common imaging methods used for the evaluation of the facet joint are standard radiographs, computed tomography (CT), and MRI. Standard radiographs, especially without oblique views, are of limited value. The facet joints are in an oblique position and have a curved configuration. Even on oblique views, only the portion of each joint that is oriented parallel to the X-ray beam may be visible. This poor visibility of the facet joints on conventional radiographs may be the major reason for the limited number of studies conducted on the facet joint shape and orientation. CT is a well-known modality that provides better image representations for the analysis of the facet joints (Petit et al, 1998). Among several imaging tools used to evaluate the alignment and configuration of the lumbar spine, MRI offers the best option, possessing no radiation exposure risks, and providing limitless choices of imaging planes (Kimura et al, 2001). MRI is also the imaging method of choice in certain pathological conditions such as degenerative disk disease, spinal stenosis, infection, and neoplasia of the lumbar spine (Weishaupt et al, 1999) . As health care resources are limited, imaging should be directed to obtaining the maximum information in as few steps as possible. This was an impetus for us to obtain the image of the facet joint in detail by using the parasagittal–oblique plane of MRI, without giving any discomfort to the individual.

Comparison of the findings of this study with the reported data on facet joint shapes and orientations shows a good correspondence with only minor differences in facet dimensions as well as facet angles (Table 2). This suggests a proper viewing and evaluation of the location, dimensions and orientation of the facet joint on the parasagittal-oblique MRI plane, for normal individuals. The measurements of the lengths and widths of the facet obtained in this study were greater than those of Mashawari et al, and Panjabi et al (Mashawari et al, 2005; Panjabi et al, 1993). These alterations may be attributed to the differences in the parameters of sample size, sample type, and age, together with the differences in the utilized procedures , measuring devices, and anatomic landmarks .

Various methods have been used to measure the angle of the facet joint. A more practical and clinically useful

Table 2. Comparison of the data of this study with those from various other studies.

Parameters	Current study (n=123)	Panjabi et al (n=276)	Mashawari et al Dry vertebrae	Karacan et al	Patel et al Dry vertebrae	Cinotti et al (n=27)	Love et al 37 women 35 men
Age (years)	32.9 ± 6.34	46.3	20 - 80 (range)	37.8 ± 6.9		54 -75 (range)	Women mean = 68.5 Men mean = 69.6
Height (cm)	166.4 ± 8.8			163.3 ± 8.2			
Weight (kg)	72,0 ± 12,5			73.0 ± 10.7			
L4 Facet length (mm)	18.4 ± 2.4		14.81 ± 2.32 (n=233)				
L4 Facet width (mm)	23.8 ± 2.7		15.45 ± 2.32 (n=235)				
L5 Facet length (mm)	18.6 ± 2.4	18.4	15.30 ± 3.22 (n=209)				
L5 Facet width (mm)	24.0 ± 2.7	16.3	14.03 ± 2.65 (n=209)				
Transvers angle of L4/L5 (°)	53.3 ± 7.07	86.0		50.7 ± 10.0 (n=30)		47	44.51 (women) 46.11 (men)
Sagital angle of L4/L5 (°)	36.7 ± 7.17	154.8	41.9 ± 12.4 (n=240)	39.8 ± 10.6 (n=30)	41 ± 12.9 (n=50)		

method is to measure the angle of the articular surfaces as seen on CT and/or MR images (Grogan et al, 1997). The angle may be measured with reference to the sagittal or coronal plane. The facet angle between the facet and the midsagittal lines was defined as the sagittal angle, by certain authors (Ko et al, 1997; Grogan et al, 1997; Patel et al, 2004; Karacan et al, 2004). The angle measured with respect to a coronal reference plane on the posterior wall of the vertebral body was defined as the transverse facet angle, by certain other authors (Boden et al, 1996; Berlemann et al, 1998; Dai, 2001; Cinotti et al, 1997). In our study, the sagittal facet angle was defined as the angle between the midsagittal line and a line drawn through the inter-articular gap of the facet joint, and the transverse angle was measured as the angle between a line drawn through the inter-articular gap of the facet joint and a line drawn coronally tangential to the anterior aspect of the vertebral body (Figure 2).

The transverse and sagittal facet joint angles measured in this study were smaller than those reported by Panjabi et al (Panjabi et al, 1993). It is not clear how such differences can be reconciled, except to speculate that the differences in measurement techniques and specimens used must be the reason. Boden et al reported that the mean transverse facet angle was 41 degrees (37.6 - 44.6 degrees, 95 % confidence interval) in asymptomatic volunteers (Boden et al, 1996). Dai found that the facet joint angle relative to the coronal plane at L4-L5 ranged from 35° to 49° (average ± standard deviation, 42.3° ± 3.95°) in normal control subjects (Dai, 2001). Grogan et al measured the facet joint angles with respect to the sagittal plane on CT scans using 104 lumbar facet joints from 21 cadavers (Grogan et al, 1997). They found that the left and right individual facet joint angles ranged from 10° to 77°. The sums of the two angles for one level ranged from 28° to 154°.

Facet joint orientation has been defined as the average of the angles of the right and the left facet (Grogan et al, 1997; Panjabi et al, 1993). Facet joints have diarthrodial synovial articulations, and undergo degenerative changes seen in other synovial articulations (Grobler et al, 1993; Tischer et al, 2006). Several studies have shown an association between the orientation of the facet joint and the degenerative changes which take place in the lumbar spine, such as disc herniation, degenerative spondylolisthesis, and osteoarthritis (Boden et al, 1996; Berven et al, 2002; Fujiwara et al, 2001; Dai, 2001; Grogan et al, 1997; Iguchi et al, 2002; Karacan et al, 2004; Love et al, 1999; Mashawari et al, 2007; Sato et al, 1989). Several other studies focused on the role of facet-joint alignment and reported a pronounced sagittal orientation (Berlemann et al, 1998; Dai, 2001; Sato et al, 1989) . Karacan et al also described that the smaller the facet angle between the facet line and the midsagittal line, the more sagittally-oriented the facet joint was; and, the larger this angle , the more coronally-oriented the facet joint was (Karacan et al, 2004). Panjabi et al have reported large variations in the orientation of the facet joints in normal subjects (Panjabi et al, 1993). Boden et al also suggested that the increased facet angles in asymptomatic volunteers represent variations in anatomy rather than a secondary result of spondylolisthesis (Boden et al, 1996).

The biomechanical implications of the current results are beyond the scope of this paper. However, biomechanical theoretical interpretations may be done in relation to the functional requirements in the L4/L5 region of the spine, in the light of the previously reported analytical and experimental researches. The facet joints have a significant role in providing stability to the spine, and thus keeping control of motion. The intervertebral disc and both facet joints make up a three-joint complex (functional spinal unit or motion segment), each structure of which affects the biomechanics of the other structures. Mobility between the two adjacent motion segments is determined by the orientation of the planes of these facet joint articulations. The concave superior facet (superior articular process) and the convex inferior facet (inferior articular process) are both composed of a ventral and more frontally-oriented part; and a dorsal and more sagittally-oriented part. Compared with the other portions of the spine, the sagittally-oriented lumbar facets facilitate anteroposterior movement (flexion and extension of spine) while limiting axial rotation (Zoltsin et al, 2000; Ko et al, 1997; Mashawari et al, 2007; Pal et al, 1999; Sharma et al, 1995). The sagittally-oriented curved articular processes are also well adapted to bear the load hauling at the lumbar facet joints (Berlemann et al, 1998; Sharma et al, 1995; Kowalski et al, 2005). Facet size partially determines the amount of movement permitted in the facet joints (as in any other articular surface of any other joint). Clinicians seeking to improve spinal function should be aware of the asymmetry in facet size (henceforth, the anatomic limitation in range of motion), consequently leading to variations in the range of motion (Petit et al, 1998).

Based on the clear anatomic landmarks on MRI planes which were used, the goals of this study were achieved by making possible the documentatiton of the size and position of the L4 –L5 facet joint in the healthy subject. This study provides an understanding of the lumbar facet morphology and the relationship of the facet dimensions with the parameters of gender, height and weight. In addition to its probable contribution to the successful planning of the surgical technique, this study also possesses the potential to be of value in the design of lumbar facet instrumentations for mathematical modelers.

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