Int. J. Morphol.,
28(3):841-847, 2010.

Evaluation of Lumbar Vertebral Body and Disc: A Stereological Morphometric Study

Evaluación del Cuerpo y Disco Vertebral Lumbar: Estudio Morfométrico Estereológico

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GOCMEN-MAS, N.; KARABEKIR, H.; ERTEKIN, T.; EDIZER, M.; CANAN, Y. & IZZET DUYAR, I. Evaluation of lumbar vertebral body and disc: a stereological morphometric study. ***Int. J. Morphol., 28(3)***:841-847, 2010.

SUMMARY: Anterior access to the L1-L5 vertebrae and disc spaces can be technically challenging, frequently requiring the use of an approach to a surgeon for an adequate exposure. The technique is used for lesion excision, corpectomy, vertebral body reconstruction with cages, realignment, and/or plating or screwing. For a successful anterior approach and a suitable instrumental design via screw, adequate morphometric knowledge about body of lumbar vertebrae and disc spaces and standardized volumetric data are also required for neurosurgeons. We aimed morphometric and volumetric evaluation of lumbar bodies and discs to contribute to a safe anterior approach during surgery. We evaluated vertebral body and disc morphometry using stereology in right-handed 25 adult subjects on MRI in the same population with no history of vertebral fractures and degenerative spinal disease. The shape, defining concavity index and volumetric measurements of the body L1-L5 vertebrae, morphometric parameters such as length, height, width of the vertebral body were measured. Also morphometric and volumetric analysis of discs between L1 and L5 were evaluated selected axial and sagittal slices. As expected, the average dimensions of male vertebrae are greater than those of females, but most of them do not differ statistically. Only three dimensions, the mean difference between anterior and central heights of L3, L4 and L5 showed statistically significant difference, indicating smaller central height in both males and females.The transverse and anterior-posterior diameters of the vertebral body, intervertebral disc height and volume displayed no sexual dimorphism ($p>0.05$). But, the intervertebral disc height and volume increased from L1 to L5 ($p<0.01$). Concavity indexes for all lumbar vertebrae for both sexes did not differ statistically. The method is important to estimate applying implant size and amount in decompression operations for neurosurgeons.

KEY WORDS: Lumbar vertebra; Body; Morphometry; Volumetry; Stereology; Anterior access.

INTRODUCTION

Human lumbar vertebrae support the weight of the upper body. The vertebrae which are five bones are the largest vertebrae in dynamic part of the spinal column. Loads lifted and carried by the upper extremities cause significant loading stress to the vertebral bodies. In between the body of vertebrae are intervertebral discs made of fibrous cartilage that act as shock absorbers and allow the back to move (Moore, 1992). Wide individual variations within common patterns of body and disc anatomy may appear. These force the surgeon to understand the individual anatomy of the patient, in order to achieve clinical success, and to appreciate the patterns of lumbar vertebrae anatomy during anterior approach.

In recent years, anterior lumbar interbody fusion, in association with a variety of methods to stabilize both the implant and motion segment, has increased in popularity. Expandable vertebral body replacement material can provide solid anterior column constructs with restoration of height and sagittal alignment (Arts & Peul, 2008). The anterior route provides direct access to most spine diseases and allows optimal neural decompression and the possibility of adequate

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realignment and strong reconstruction/fixation. Stability of the vertebral column is achieved, resolution of clinical pain is rapid and almost complete, and the rate of surgical complications is very low (D'Aliberti *et al*., 2008). For a successful surgery and a suitable instrumental design using screw, adequate morphometric knowledge about body of lumbar vertebrae, disc spaces and anatomical data is also required. Morphometric studies published by many authors established that the vertebrae undergo continuous growth and remodeling throughout life, presumably in response to the changing needs of the body. The height of an intervertebral disc is influenced by several factors. There has been a tendency in earlier reports to classify this steady biochemical and histologic transformation of the disc as degenerative, but the accounts of Humzah and Soames and Oda *et al*. (cited by Shao *et al.*, 2002), suggest that irreversible changes of disc height are associated with the adaptation of the intervertebral discs to alterations in the prevailing functional conditions within the vertebral column during aging.

There is no concensus about age and gender related changes on disc or body height and also what are the norms of the heights of the intervertebral discs. Published methods to measure disc or body height yield, except for some exceptional cases, inaccurate results. Reasons for this are the variation of exposure geometry in a clinical environment, inadmissible simplifications and assumptions when interpreting the radiographic image, and subjective errors inherent in the different methods. Reference values of disc or body height, suitable for quantitative comparison with a given them, have yet to be established (Al-Hadidi *et al.,* 2001; Prêteux *et al*., 1985; Eriksen, 1976). Besides, in literature there is no data about intervertebral disc volumetry of lumbar vertebrae using stereological method. We calculated the concavity index for each lumbar vertebra in adults, as well. Concavity index was established for each vertebral body by dividing the "central" vertebral height by the anterior vertebral height. These data mirror the changes in disc convexity index and emphasize the importance of interaction at the disc–vertebral interface (Shao *et al.*).

Delineating the normal lumbar vertebra morphometry and its neurosurgical importance interested in both the anatomists and the spinal surgeons. A validation study was performed to evaluate vertebral body and disc morphometry using stereology in the adult subjects using MRI (magnetic resonance imaging) in the same population with no history of vertebral fractures and degenerative spinal disease.

MATERIAL AND METHOD

Morphometric parameters of lumbar vertebrae and intervertebral disc and also volumetric data about bodies and intervertebral disc spaces were obtained from 25 healthy, right-handed adult individuals (13 males, 12 females) aged between 22 and 49 were evaluated, retrospectively. Measurements of the vertebrae from L1 to L5 were taken. Both body of lumbar vertebrae and discs volumetry were evaluated via stereological method on MR images. All subjects were admitted to the Department of Neurosurgery in Afyon Kocatepe University, Faculty of Medicine. Participants were admitted Neurosurgery clinic due to lowback pain complaint and no neuroradiological pathologies were encountered. The official permissions and inform consents were taken. The subjects with disc herniation, vertebral fractures, congenital or acquired bone deformities, and tumors were excluded by patient history records and neurological examinations. Consecutive 2 mm thick serial MRIs from sagittal and axial T1 weighted with SE T1A (TR 500–700 ms; TE 10–30 ms) was obtained to estimate intervertebral disc and lumbar vertebral body. The whole body of vertebra and disc volumes estimated from each image using the point-counting technique by two anatomists and antropologists. All measurements were performed blinded to subject details and the results of any other measurements.

Table I. Mean value of anterior and central heights of L1-L5 vertebrae have been shown in female and male subjects as centimeters.

Vertebrae	Males (n=13)				Females (n=12)					
	Anterior Height (Ha) Mean ± SD	Central Height (Hc) Mean ± SD	Sig. P_{Ha-Hc}	Concavity index (Hc/Ha)	Anterior Height (Ha) Mean ± SD	Central Height (Hc) Mean ± SD	Concavity index (Hc/Ha)	Sig. P_{Ha-Hc}	Sig. $P_{SEX (Ha-Hc)}$	Sig. $P_{SEX (Ha-Hc)}$
L1	2.29 ± 0.23	2.28 ±0.13	ns	0.99	2.42 ± 0.16	2.29 ± 0.14	0.97	ns	ns	Ns
L2	2.45 ± 0.35	2.36 ±0.24	ns	0.96	2.57 ± 0.15	2.38 ± 0.21	0.93	ns	ns	Ns
L3	2.51 ± 0.28	2.35 ± 0.17	<0.05	0.94	2.65 ± 0.25	2.31 ± 0.27	0.87	<0.001	ns	Ns
L4	2.52 ± 0.18	2.22 ± 0.12	<0.001	0.88	2.69 ± 0.28	2.25 ± 0.16	0.84	<0.001	ns	Ns
L5	2.59 ± 0.13	2.27± 0.16	<0.001	0.88	2.74 ± 0.24	2.28 ± 0.19	0.83	<0.001	ns	Ns

The axial and sagittal slices on MRI for imaging vertebral bodies and intervertebral disc spaces were selected. The shape, vertebral body and disc length, width, height, and also volumetric data about the L1-L5 vertebrae and intervertebral disc spaces were analyzed by stereological method. The concavity indexes of L1, L2, L3, L4, and L5 vertebrae were also examined to evaluate its effects on intervertebral disc morphology in all of the cases. On all scans and radiographs anterior (Ha) and mid as central (Hc) vertebral heights were measured and wedge (Ha/Hc) ratios (a concavity index) calculated for each vertebral body, ideally from L1 to L5. The height of the lumbar discs was measured according to the Leivseth protocol (Leivseth *et al.*, 1999). The calculation of concavity index in vertebrae, as described previously (Shao *et al.*) was established for each vertebral body by dividing the Hc by the Ha (Hc/Ha).

Measurement parameters of each vertebra and disc in both male and female subjects as follows: (1) transverse diameter of vertebral body, (2) anterior-posterior diameter of vertebral body, and (3) anterior and (4) lateral (central) height of the body on the midsagital slice, (5) anterior intervertebral disc height on the midsagital slice, (6) volumes of each body lumbar vertebra, (7) and intervertebral disc (Fig. 1), (8) concavity index of the each vertebra. Original MR images were exported as jpeg image files and further stereological analysis were done for volumetric analysis using these image sets with the aid of Image-J software. All vertebral measurements were standardized relative to each other, and means and standard deviations were calculated using a statistical fitting procedure derived from volume and concavity index. A uniform point-grid with a point-associated area of 0.156 cm^2 was randomly superimposed on each MRI slices using the ''Grid'' plug-in of Image-J. Points hitting the lumbar vertebra and intervertebral disc space were manually counted for area estimation of the profiles (Fig. 1). Automated area estimation by manual perimeter tracing is generally took too much time and hence, more rapid point counting method was preferred. Volume estimation was accomplished by the Cavalieri's principle as described previously (Gocmen-Mas *et al*., 2009; Sahin & Ergur, 2006) using the formula given below:

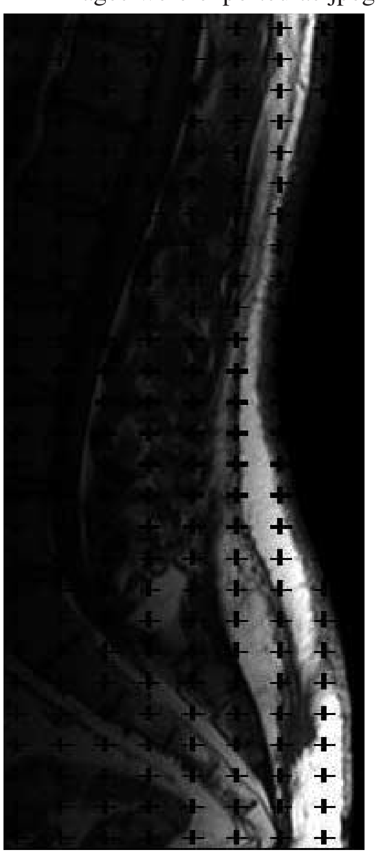

Fig. 1. Point hittings on intervertebral disc space and body of lumbar vertebrae have been demostrated for area estimation on the T1-weighted sagital MRI image.

V = t x [((SUx d)/ SL] 2 x ?P

where t is the section thickness, SU is the scale unit, d is the distance between two points in the point grid, SL is the scale length and ∑P is the number of points counted. SU and SL are used to include the linear magnification in the final estimate. All data have been entered to a previously prepared Microsoft Excel spread sheet for automatic calculation of both the results of the above formula and the statistical evaluation parameters including the nugget variance and the coefficient of error (CE). All the measurements were performed blinded to subject details and the results of any other measurements, and were done three times in each trial by the researchers. The data set were analyzed by two factor repeated measure analysis and Pearson correlation analysis test for defining age and height of disc space.

RESULTS

The following data that was obtained from MRI for each vertebra and disc has been showed in Table 1-4. As expected, the average dimensions of male vertebrae are greater than those of females, but most of them do not differ statistically. Only three dimensions, the mean difference between anterior and central heights of L3, L4 and L5 showed statistically significant difference, indicating smaller central height in males and females. The anterior measurements and anterior-posterior diameters of the vertebral body, intervertebral disc height and volume displayed no sexual dimorphism (p>0.05). The intervertebral disc height and volume increased from L1 to L5 (p <0.01). Anterior height of lumbar 1 (p <0.05) , 2 and 3 (p<0.01) discs spaces were linearly decreased with regard to the aged and correlation coefficients were statistically significant (Pearson correlation coefficients of anterior height of L1= -0.48, L2= -0.55 and L3= -0.53, respectively). There was no statistically significans between male and female with regard to age (p>0.05). Concavity indexes for all lumbar vertebrae in both sexes did not differ statistically. Correlation between age and the concavity index of the vertebrae was shown in Table I.

Table II. Mean value of transverse diameter of L1-L5 vertebrae in female and male subjects

Vertebrae	Males (n=13) Transverse diameter (TD) Mean ± SD	Females (n=12) Transverse diameter (TD) Mean ± SD	Sig. P_{SEX}
L1	4.88 ± 0.37	4.78 ± 0.54	ns
L2	5.23 ± 0.31	5.21 ± 0.42	ns
L3	5.39 ± 0.43	5.36 ± 0.25	ns
L4	5.65 ± 0.25	5.64 ± 0.36	ns
L5	5.73 ± 0.44	5.72 ± 0.31	ns

Table III. Mean values of anterior-posterior diameter of L1-L5 vertebrae in female and male subjects

Vertebrae	Males (n=13) Anterior-posterior diameter (APD) Mean ± SD	Females (n=12) Anterior-posterior diameter (APD)	Sig. P_{SEX}
L1	3.46 ± 0.21	3.37 ± 0.24	ns
L2	3.61 ± 0.30	3.53 ± 0.27	ns
L3	3.72 ± 0.32	3.61 ± 0.20	ns
L4	3.33 ± 0.25	3.79 ± 0.35	ns
L5	3.95 ± 0.34	3.88 ± 0.18	ns

Table IV. Means and standard deviations of anterior intervertebral disc heights and disc space volumes.

Intervertebral disc	Males (13)		Females (12)		Sig. $P_{SEX\ (DHa)}$	Sig. $P_{SEX\ (DV)}$
	Anterior intervertebral disc height (DHa) Mean ± SD	Intervertebral space volume (DV) Mean ± SD	Anterior intervertebral disc height (DHa) Mean ± SD	Intervertebral disc volume (DV) Mean ± SD	Sig. $P_{SEX\ (DHa)}$	Sig. $P_{SEX\ (DV)}$
L1-L2	0.88±0.16	17.69 ± 3.84	0.88±0.17	15.17 ± 1.34	ns	ns
L2-L3	0.95±0.15	20.36 ± 4.15	0.98±0.13	16.23 ± 1.27	ns	ns
L3-L4	1.10±0.21	21.58 ± 4.07	1.08±0.18	18.40 ± 1.89	ns	ns
L4-L5	1.16±0.43	22.16 ± 3.85	1.20±0.33	19.28 ± 2.12	ns	ns

DISCUSSION

The use of technologies for the treatment of degenerative spinal diseases, traumatic body of vertebra dislocation, tumors has undergone rapid clinical and scientific development. Lumbar interbody fusion can be performed using a posterior, anterior or combined approach (Schleicher *et al*., 2008). It has been extensively studied in combination with various techniques for spinal stabilization from anterior approach.

Much clinical research on anterior fixation technique is aimed at representing a management of vertebra and disc pathologies such as fractures, degenerative disease with fractures, neoplasms, and spinal infections etc. (D'Aliberti *et al.*; Komemushi *et al*., 2005). The technique was used for lesion excision, corpectomy, vertebral body reconstruction with cages, realignment, and/or plating or screwing (D'Aliberti *et al.*), but there is considerable disagreement about defining normality. Degenerative disease or instability in the lumbar vertebrae and discs may necessitate fusion and stabilization supplemented by instrumentation between lower thoracic vertebrae and the sacrum. However, screw placement in a reasonable position is more difficult to achieve because of inadequate anatomical knowledge about the lumbar vertebrae.

Measurements of size and volumetric definition for body of lumbar vertebrae and intervertebral discs are of importance for preventing complications after anterior approach such as cage dislocations and adjacent level vertebral body fractures after placement of expandable cages (Chou *et al*., 2008).

Most methods for measuring vertebral body morphometry use radiographic analysis (Cyteval *et al*., 2002), but there was no volumetric data about both body of lumbar vertebrae and intervertebral discs using stereological technique. Komemushi et al. aimed to evaluate the relationships between volume of vertebral bodies via CT on the cases with compression fracture before percutaneous vertebroplasty. The authors declerated that average vertebral body volume was 26.3 +/- 8.1 cm3 (Komemushi *et al*.). The observations presented here have defined many of the anatomical and volumetric parameters that should be taken into consideration for screw fixation to avoid injury of vascular and neural structures during spinal instrumentation involving the lumbar vertebrae and intervertebral discs.

According to Davis (1961), there is a reduction in the surface area of L5 as compared to L4. Pal & Routal (1987) found that the body surface area gradually increases from L1 to L4, indicating that from above downwards more is borne by the anterior column. The significantly smaller area of L5 body as compared to L4 indicates that some of the compressive force from L5 is diverted before it reaches to its inferior surface. We found that the mean body volume showed a gradual increase from above downwards in males and females, but there was no significant differences releated with gender. The anatomic and volumetric findings related with the intervertebral discs are rarely seen in the medical literature (Liu *et al*., 2006; Al-Hadidi *et al*.). There is a general agreement that changes induced by aging lead to alterations in the thickness of the disc, but there are differences in the accounts of the effect of aging on the thickness of the lumbar discs. Published methods to measure disc space height yield, except for some exceptional cases have inaccurate or non standardized results. Because disc space changes greatly with age, it is important to obtain enough data for each age. For that reason we searched for the correlation between disc space for each level and age in the adult cases. Reference values of disc height and concavity index of lumbar vertebra bodies, suitable for quantitative comparison with a given disc and lumbar vertebral body, have yet to be established (Shao *et al.*). Mean normative values demonstrated an increase in disc height between L1/L2 and L4/L5 and a constant or decreasing disc height between L4/L5 and L5/S1. However, this "physiological sequence of disc height in the statistical mean" was observed in only 36% of normal males and 55% of normal females (Biggemann *et al.,* 1997). In the current study, we investigate the reliability of MRI for normal references determination about vertebrae and disc morphometry, concavity index and also volumetry. We found that, the intervertebral disc heights and volumes increased from L1 to L5 ($p<0.01$), but there were no sexual dimorphism. A limitation of the present study is to be the relatively small sample size, absence of decade and weight parameters. Hovewer, we aimed to obtain data of volumetry in both the lumbar vertebrae and discs using stereological technique according to gender in adult healthy subjects and also the concavity index.

Shao *et al*. found that the heights of lumbar discs on x-ray T12-L1, L1-L2, L2-L3, L3-L4, L4-L5, and L5-S1 of men and women within the age 20-69 years increased with increasing age (4.6-6.9% in men and 4.7-8.4% in women). We found the anterior heights of lumbar discs were increased with increasing level for both gender.

The authors claimed that, the concavity index of vertebrae T12, L1, L2, L3, L4, and L5 of men within age 20-87 years and of women within age 20-92 years decreased linearly with increasing age (0.9-1.5% in men and 1.6-3.2% in women). In other words, the vertebral body endplates became more concave with age (Shao *et al*.). Al-Hadidi *et al.* declared that, in relation to age, midpoint disc heights displayed a non-linear, alternating increase/decrease pattern, which was of higher magnitude and statistically significant in males, but less evident and statistically insignificant in females. Maximum values were reached during the 6th decade in males while during the 5th decade in females. The relative height indices were similar in both sexes and remained fairly constant between age groups at all levels (Al-Hadidi *et al.*). Changes in the concavity index reflected a general trend to increased concavity in old age in both sexes. Considering the data for all lumbar vertebrae, the trend was significant. There was no significant change from L1 through to L5 in terms of the concavity index (Twomey *et al.,* 1983).

But, according to our results the concavity index of vertebrae decreased linearly from L1 through to L5 for both gender (0.99-0.88% in men; 0.97-0.83% in women) in adult cases.

Cyteval *et al*. claimed that there was a strong correlation between volume and medial area of vertebral bodies (Pearson correlation coefficient 0.95) and a constant relationship between the medial area of vertebral bodies for each subject (coefficient of variation 5.6%) (Cyteval *et al*.). In the present study instead of medial area we measured that volumetry and concavity index of lumbar vertebrae. We aimed to contribute to neurosurgeons for safe surgical intervention by these data.

We believe that calculation of various parameters in different human populations from both Western and Eastern countries is useful for correct screw selection in various spinal stabilization procedures. The stereological volume analysis technique is simple, reliable, unbiased and inexpensive.

Further studies are needed with larger samples in order to support our data. As a result, more real and accurate implant size choosing might be provided using this method. This study has been conducted to evaluate lumbar vertebrae anatomy of the Western Anatolian population in terms of morphometric measurements in healthy cases as well as giving a guidance to the surgeons during anterior approach.

GOCMEN-MAS, N.; KARABEKIR, H.; ERTEKIN, T.; EDIZER, M.; CANAN, Y. & IZZET DUYAR, I. Evaluación del cuerpo y disco vertebral lumbar: estudio morfométrico estereológico. ***Int. J. Morphol., 28(3)***:841-847, 2010.

RESUMEN: El acceso anterior a las vértebras L1-L5 y espacios entre los discos puede ser técnicamente difícil, con frecuencia requiere la participación de un cirujano para una exposición adecuada. La técnica se utiliza para la extirpación de la lesión, corpectomía, la reconstrucción del cuerpo vertebral con jaulas, realineamiento y / o placas o tornillos. Para un enfoque exitoso anterior y un diseño adecuado instrumental a través de tornillo, un acabado conocimiento sobre la morfometría del cuerpo de las vértebras lumbares y de los espacios entre los discos y la evaluación volumétrica son necesarias para el neurocirujano. El objetivo fue la evaluación morfométrica y volumétrica de los cuerpos lumbares y los discos, para contribuir al abordaje seguro durante la cirugía. Se evaluó en 25 sujetos adultos, diestros, sin antecedentes de fracturas vertebrales y de enfermedad degenerativa espinal, el cuerpo vertebral y la morfometría del disco mediante estereología con RM. La forma de las vértebras, el índice de concavidad y la definición de las medidas volumétricas de los cuerpos L1-L5. Además, se midieron los parámetros morfométricos como longitud, altura, ancho del cuerpo vertebral. Se efectuó un análisis morfométrico y volumétrico de loss cortes axiales y sagitales de los discos entre L1 y L5. Como era de esperar, las dimensiones promedio de las vértebras en los hombres fueron mayores que en las mujeres, pero la mayoría de ellos no son estadísticamente significativas. Sólo tres dimensiones, la diferencia promedio entre la altura anterior y central de las vertebras L3, L4 y L5 mostraron diferencias estadísticamente significativas, indicando menor altura central tanto en los hombres como en las mujeres. Los diámetros transversal y anteroposterior del cuerpo vertebral, la altura del disco intervertebral y el volumen no mostraron dimorfismo sexual (p>0,05). Sin embargo, aumentaron la altura del disco intervertebral y el volumen de L1 a L5 (p<0,01). Los índices de concavidad, de todas las vértebras lumbares, para ambos sexos, no diferían estadísticamente. El método es importante para el neurocirujano, para estimar el tamaño y cantidad del implante y su aplicación en las cirugías de descompresión.

PALABRAS CLAVE: Vértebra lumbar; Cuerpo; Morfometría; Volumetría; Estereología, Acceso anterior.

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Received: 21-12-2009
Accepted: 16-05-2010