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Radiology Section

MR Morphometry of Lumbar Spine

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ABSTRACT

Introduction: Low back pain is the second most common complaint encountered by primary care physicians. Magnetic Resonance Imaging (MRI) is the modality of choice for evaluation of low backache due to its superior soft tissue contrast and safety. During last decade there have been considerable developments in the techniques of surgical treatment of spine for which detailed knowledge of spine morphometry is required. The available lumbar morphometric normograms are of few parameters which are based on cadaver or radiographs which cannot be directly applied on MRI to diagnose spinal stenosis or to plan surgical treatment. Very few studies of MR morphometry are available in world literature. Normal values for various dimensions by MRI in Indian Population are lacking.

Aim: Develop a database of Bony Spinal Canal Area (BSCA), Available Spinal Canal Area (ASCA), Pedical Length (PL) and Neural Foraminal (NF) area on MRI in Indian subjects and to determine difference between males and females for these measurements.

Materials and Methods: In this cross-sectional study lumbosacral was MRI performed on 50 volunteers in age group of 18-30 years with no history of any spinal injury/pathology/surgery. BSCA and ASCA, pedicle length and NF area were measured and tabulated. The data obtained was analysed by calculating mean, standard deviation and 95% confidence limit. The gender relationship was analysed by unpaired Student's 't'-test. A two tail p-value of <0.05 was taken as statistically significant.

Results: Normative morphological data for BSCA, ASCA, pedicle length and NF area were prepared for lumbar vertebra in a sample population of India. There was statistically significant difference in bony and ASCA at L1 and L2 level. There was no statistically significant difference on right and left side in either males or females for PL and neural foramina area.

Conclusion: A database of clinically relevant measurements of lumbar spine has been prepared and MRI can be used for these parameters without radiation risk

Keywords: Neural foramina, Normograms, Pedical length, Spinal canal area.

INTRODUCTION

Low back pain is the second most common complaint (after common cold) seen by primary care physicians and approximately 80% of the individuals will experience low back pain at some point of time in their life [1,2]. As per WHO, the incidence and prevalence of low back pain are roughly the same world over and low backache are amongst the most common cause of disability and inability to work and thereby affecting the quality of life. In most of cases, the cause of back pain is unknown but in few cases there is a direct link to some defined organic disease [3].

During the last decade there has been considerable development in the newer techniques of surgical treatment for low back pain and to stabilise and correct the human spine. Many approaches have been proposed for patient specific modelling of the human spine to explore the correction of spinal deformities, such as scoliosis. Multiple spinal instrumentation procedures are being developed. Knowledge of spine morphometry is vital not only for understanding biomechanical models of the spine and spinal implants but also for various spinal intervention procedures [4,5]. Accurate anatomical descriptions of the size, shape and orientation of the main structures of the human vertebrae and intervertebral discs are necessary for a variety of approaches and objectives.

MRI has become the most commonly applied diagnostic method for evaluating low back pain because it is non invasive and provides diverse information on the lumbar soft tissues, inter vertebral discs and various measurable areas [6].

Historically available normal dimensions were established by conventional radiography or on cadaver, that too mainly

from western population. These dimensions are being used for diagnostic evaluation of various spinal diseases. The available normograms are of few parameters which are based on bony landmarks on cadaver/radiographs which cannot be directly applied on MRI to diagnose spinal stenosis and plan surgical treatment. Furthermore, spinal canal area is more accurate rather than diameter of spinal canal and excellent soft tissue visualisation on MRI make us possible to measure ASCA. Very few studies are available in world literature on morphometry of lumbar spine and most of these studies are based on mid sagittal diameter, interpedicular distance and lateral recess and that too are CT based. Normal values for dimensions as demonstrated by MRI in Indian population are lacking. This prompted us to know the MR morphometry of lumbar spine in age group of 18-30 years to avoid confounding factors due to age related changes in vertebra and intervertebral discs. We included parameters like BSCA, ASCA, AP length of the pedicles and NF area which can be used for diagnosis of spinal stenosis and neural foramina stenosis. These measurements can be utilised for future development of spine biomedical engineering.

MATERIALS AND METHODS

This cross-sectional study was performed in a Tertiary care Hospital of Bengaluru from December 2012 to September 2013 after approval from Institutional Ethical Committee. A batch of 100 under trainee students of nursing course of the hospital in the age group of 18-30 years with diverse ethnic group were enrolled after informed written consent. MRI was performed on individuals with no history suggestive of any spinal injury/pathology/surgery. Volunteers with MRI contraindication were excluded from study. Any structural spinal abnormality detected on MRI was also excluded from the study. Finally, 50 individuals (25 males and 25 females) were selected for morphometric analysis to make the study age matched and sex matched.

MR Imaging

MRI of lumbosacral region was performed on 1.5 Tesla (Siemens Magnetom Avanto Syngo MR B13). A spine coil was used in all patients. MR sequences were performed for lumbar spine in each volunteer [Table/Fig-1].

All the images from all the different MR sequences were evaluated by single observer and best image was taken for measurements by vendor provided software inbuilt in MRI console. BSCA, ASCA (excludes ligamentum flavum), AP length of the pedicles and NF area were measured as depicted in [Table/Fig-2a-d] respectively.

STATISTICAL ANALYSIS

The data obtained was analysed by calculating mean, standard deviation and 95% confidence limit. The gender relationship was analysed by unpaired student's 't'-test. A two tail p-value of $p<0.05$ was taken as statistically significant.

MRI Sequences	Parameters
TSE T1	Sagittal (Distance factor 10%, phase over sampling 100%, FOV read, 400 mm, FOV phase 100%, slice thickness 4 mm, TR-4220 ms, TE- 118 ms)
TSE T2	Sagittal (Distance factor 10%, phase over sampling 100%, FOV read 400 mm, FOV phase 100%, slice thickness 4 mm, TR-450, TE- 13 ms)
3D T2 SPACE Sequence	(Phase over sampling 69%, slice over sampling 25%, slice per slab 64, FOV read 380 mm, FOV phase 100%, slice thickness 1 mm, TR- 1200 ms, TE-143 ms, AVG -2)
TSE T1 and TSE T2 Axial	Five slice groups, one at each lumbar IV disc level with three slices at each IV discs with distance factor of 0% and slice thickness of 3 mm.

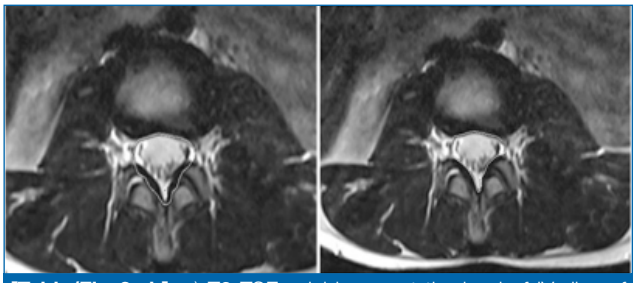
[Table/Fig-1]: Showing MRI sequences and their technical parameters used for lumbosacral spine MRI during study.
Note: TSE T1=turbo spin echo T1 weighted, TSE T2=turbo spin echo T2 weighted, 3D SPACE= 3D SPACE sequence, FOV= field of view, TR=time of repetition, TE=time of echo, AVG=number of averages

RESULTS

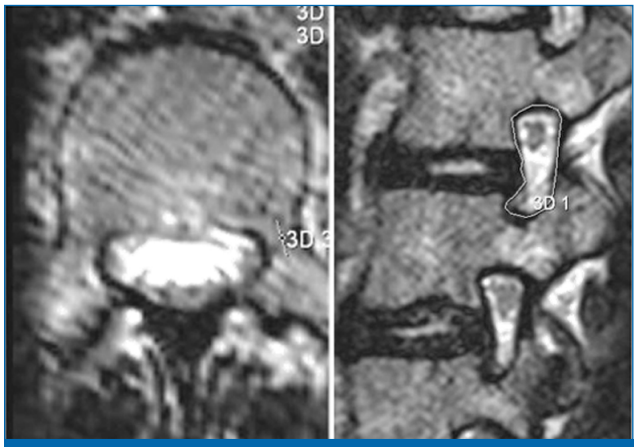
Total 50 volunteers with 25 males (mean age 22 years, mean height-168.16 cm and mean weght-62.8 Kg) and 25 females (mean age 21 years, mean height-160.4 cm and mean weght-53.52 Kg) were subjects for this study. Their BSCA, ASCA, AP Length of the Pedicles (PL) and NF area (NF Area) were measured and analysed.

[Table/Fig-3,4] shows mean, SD and 95% confidence limit of BSCA, ASCA, right and left PL and right and left NF area at different levels of lumbar vertebra in males and females respectively.

Unpaired student's 't'-test was carried out to know the two tail p-value and significance level of gender variance in measured parameters. The $p<0.05$ was taken as statistically significant. [Table/Fig-5] shows gender difference and test of significance of BSCA, ASCA. There is no statistically significant difference ($p>0.05$ at all lumbar levels) between right and left PL and NF area in either males or females.



[Table/Fig-2a,b]: a) T2 TSE axial image at the level of IV disc of lumbar vertebra showing bony spinal canal area. This includes ligamentum flavum; b) T2 TSE axial image at the level of IV disc of lumbar vertebra showing available spinal canal area. This excludes ligamentum flavum.



[Table/Fig-2c,d]: c) Axial reconstructed image of a 3D Space image sequence showing AP length of left pedicle; d) Sagittal 3D space image showing neural foramina area.

Parameter	BSCA (in cm^2)	ASCA (in cm^2)	PL (Rt) (in mm)	PL (Lt) (in mm)	NF Area (Rt) (in cm^2)	NF Area (Lt) (in cm^2)
L1 Vertebra						
Mean	3.440	2.738	7.968	7.576	1.678	1.694
SD	0.425	0.397	1.244	0.990	0.2278	0.2288
95% CL	2.606-4.274	1.959-3.516	5.528-10.407	5.634-9.517	1.231-2.124	1.246-2.143
L2 Vertebra						
Mean	3.308	2.579	7.928	7.572	1.716	1.706
SD	0.394	0.3817	1.311	1.073	0.266	0.255
95% CL	2.535-4.081	1.831-3.327	5.710-10.145	5.468-9.675	1.194-2.239	1.205-2.207
L3 Vertebra						
Mean	3.018	2.328	7.844	7.512	1.602	1.548
SD	0.509	0.482	1.105	0.969	0.2973	0.262
95% CL	2.110-4.107	1.383-3.274	5.676-10.011	5.611-9.412	1.020-2.185	1.033-2.063
L4 Vertebra						
Mean	3.208	2.514	7.712	7.316	1.400	1.376
SD	0.6418	0.664	1.329	1.266	0.285	0.255
95% CL	1.950-4.466	1.212-3.815	5.106-10.317	4.834-9.797	0.840-1.959	0.875-1.878
L5 Vertebra						
Mean	3.865	2.786	6.656	6.324	1.380	1.336
SD	0.775	0.787	1.873	1.782	0.2566	0.231
95% CL	2.345-5.305	1.242-4.329	2.984-10.327	2.830-9.818	0.877-1.882	0.883-1.789

[Table/Fig-3]: Showing mean, SD and 95% confidence limit of Bony Spinal Canal Area (BSCA), Available Spinal Canal Area (ASCA), Pedical Length (PL) and Neural Foraminal area (NF Area) at different levels of lumbar vertebra in males.

Parameter	BSCA (in cm^2)	ASCA (in cm^2)	PL (Rt) (in mm)	PL (Lt) (in mm)	NF Area (Rt) (in cm^2)	NF Area (Lt) (in cm^2)
L1 Vertebra						
Mean	3.157	2.446	7.840	7.608	1.618	1.625
SD	0.3193	0.299	1.178	1.213	0.222	0.153
95% CL	2.519-3.795	1.848-3.044	5.484-10.196	5.182-10.034	1.174-2.062	1.319-1.931
L2 Vertebra						
Mean	3.020	2.313	7.630	7.402	1.686	1.652
SD	0.382	0.37	1.58	1.538	0.314	0.304
95% CL	2.256-3.784	1.573-3.053	4.47-10.79	4.326-10.478	1.058-2.314	1.044-2.26
L3 Vertebra						
Mean	3.012	2.234	7.100	6.960	1.660	1.636
SD	0.507	0.382	1.461	1.500	0.270	0.264
95% CL	2.910-3.113	1.47-2.998	4.178-10.02	3.96-9.96	1.12-2.2	1.108-2.144
L4 Vertebra						
Mean	3.102	2.311	6.652	6.632	1.460	1.460
SD	0.694	0.58	1.400	1.400	0.233	0.217
95% CL	1.714-4.49	1.151-3.471	3.852-9.452	3.832-9.432	0.994-1.926	1.026-1.894
L5 Vertebra						
Mean	3.586	2.660	6.624	6.532	1.368	1.352
SD	1.010	0.916	1.515	1.590	0.250	0.217
95% CL	1.566-5.606	0.828-4.492	3.59-9.654	3.356-9.716	0.868-1.868	0.918-1.786

[Table/Fig-4]: Showing mean, SD and 95% confidence limit of Bony Spinal Canal Area (BSCA), Available Spinal Canal Area (ASCA), Pedical Length (PL) and Neural Foraminal area (NF area) at different levels of lumbar vertebra in females.

DISCUSSION

Low backache is very common problem for which patient presents to imaging department. Up to 80% of all individuals will experience low back pain at some point in their lives [1,2]. Radiographs, CT and MRI are commonly available modalities for evaluation of back pain. Knowledge of spine morphometry is vital not only for evaluation of low back pain, understanding biomechanical models of the spine and spinal implants but also for various spinal intervention procedures [4,5]. Accurate anatomical descriptions of the size, shape and orientation of the main structures of the human vertebrae and intervertebral discs are necessary for a variety of approaches and objectives [4,5].

Several authors like Larsen JL et al., and Hall LT et al., [7,8], Huizinga J et al., [9], Eisenstein [10] and Postacchini F et al., [11], Amonoo-Kuofi [12] have measured human vertebrae. But it was difficult for them to obtain several cadaver specimens

Parameter	Male	Female	Mean Difference	p-value	Significance
L1 Vertebra					
BSCA (cm^2)	3.44	3.157	0.283	0.010	S
ASCA (cm^2)	2.738	2.446	0.292	0.005	S
L2 Vertebra					
BSCA (cm^2)	3.308	3.02	0.288	0.011	S
ASCA (cm^2)	2.579	2.313	0.266	0.015	S
L3 Vertebra					
BSCA (cm^2)	3.018	3.012	0.006	0.507	NS
ASCA (cm^2)	2.328	2.234	0.094	0.448	NS
L4 Vertebra					
BSCA (cm^2)	3.208	3.102	0.106	0.577	NS
ASCA (cm^2)	2.514	2.311	0.203	0.255	NS
L5 Vertebra					
BSCA (cm^2)	3.865	3.586	0.279	0.278	NS
ASCA (cm^2)	2.786	2.66	0.126	0.604	NS

[Table/Fig-5]: Showing gender difference of Bony Spinal Canal Area (BSCA), Available Spinal Canal Area (ASCA) at different lumbar levels. S=statistically significant; NS=statistically not significant; $p<0.05$ is statistically significant.

and to provide accurate measurements from cadaver because they undergo postmortal changes. Some of the previous studies were on direct measurements of morphometric parameters from plain radiographs or computed tomography (CT) scans [13,14]. Aly T et al., reported data applicable to the Egyptian Lumbar spine that were obtained from CT scans, but these measurements do not necessarily apply to the spine in the normal Indian population [13].

On compressive literature review it was found that previous lumbar morphometric studies are mainly on cadavers or radiograph which cannot be accurate. A few CT based morphometric studies are there but there are very few MRI based studies [13,14]. MRI has all the advantage of CT based study with added advantage of no radiation risk and excellent soft tissue visualisation. MRI is preferred modality for evaluation of spine due to its excellent soft tissue delineation [15]. It allows accurate measurement of BSCA and ASCA [15]. Furthermore, most of these studies have measured mid sagittal diameter [12,14,16,17] interpedicular distance [13,18] and lateral recess [13] which were mainly centred for spinal stenosis evaluation. Mid sagittal diameter cannot reliably diagnose spinal stenosis because spinal canal is not a circular structure. Our study included BSCA as well as ASCA as pure bony canal area cannot account for ligamentum flavum hypertrophy, osteophytes, disc disease which are very common in any age group in present day scenario and which actually cause spinal stenosis. The prevailing literature reveals MRI to remain the modality of choice on spinal evaluation due to its non radiation based modality. No normogram available for various parameters taken for this study in Indian population and MRI based parameters is the need of the hour for better understanding of pathoanatomy in low backache and will be a boon to biomedical engineering.

Anthropometric and Demographic Characteristics

Most of the previous morphometric study had wide range of age distribution like 23-60 years in Amonoo-Kuofi HS et al., [12], 19-67 years in study by Imad GS et al., which can itself be a confounding factor. This study was designed for age group of 18-30 years to avoid various age related changes in lumbar spine [19].

Our volunteers are nursing under trainee of the hospital and are of nearly same age group with mean age of 22 years in males and 21 in females with mean height of 168.1 cm in males and 160.4 cm females. They are of diverse ethnic group. Mean weight of 62.8 Kg males and 53.52 Kg females suggestive of nearly similar demographic characteristics of our study sample.

Bony Spinal Canal Area and Available Spinal Canal Area

The area of cross section of vertebral canal has been studied by Zinat M et al., at L3 and L4 which was 2.29 and 2.81 sq cm respectively [18] while it was 2.88 and 3.50 sq cm in Gouzien study [20]. We measured the BSCA and the mean values at the level of L1, L2, L3, L4 and L5 are 3.440, 3.308, 3.018, 3.208 and 3.865 sq cm respectively in males and 3.1576, 3.02, 3.012, 3.102 and 3.586 sq cm respectively in females in our study. Our study is MR based and showed lowest measurements in L3 and highest in L5. We found that mean values of BSCA decreases from L1 to L3 vertebra followed by increase in mean values from L3 to L5.

No normogram is available on ASCA to our knowledge. We found that ASCA showed decrease in mean values from L1 to L3 vertebra followed by increase in mean values from L3 to L5.

The mean difference between males and females of BSCA and ASCA and their test of significance are shown in [Table/Fig-5]. The findings reveal slightly higher values in males than females. The BSCA, ASCA shows statistically significant difference in L1 and L2 but not at L3, L4 and L5 levels.

Pedical Length

Transpedicular spinal fixation has gained importance these days throughout world but there is requirement of precise knowledge of morphology of pedicles and its relation with neural structures for safe and efficient surgery. Our study reveals PL decreases from L1 to L5 in both males and females. Our study shows that PL ranges from 6.6 to 7.9 mm in both males and females on both sides. This is in contrast to Mohamed AM, study which showed that PL is approximately 5 cm at all levels [21]. PL as measured in Torun F et al., in cadavers is 15.3±2.2 cm [22]. This large difference between our study and Torun F study was due to different method of PL measurement used [22]. He had included the adjacent laminar length in measuring pedicle. His study showed longest pedicle is of L2 and shortest pedicle of L4. This difference of pattern of pedicle length may be due to difference in method of measurement or may be due to racial difference. In our study there was no statistically significant difference in the measured values in right and left side in both genders.

Furthermore, presently CT is the modality of choice for computing various measurements for transpedicular fixation. We found that all relevant measurements can be done by MRI accurately thus avoiding unnecessary radiation risk.

Neural Foramina Area

Haswgawa T et al., has measured intervertebral foramen height [23] and Devi R et al., studied vertical and transverse diameter of neural foramina at all lumber levels [24] but we think that height cannot be considered as a measure of neural foramina stenosis as the plain height at maximum level cannot account for ligamentous hypertrophy. Therefore, we measured NF area. Our study revealed that NF area increases from L1 to L2 then decreases from L2 to L5. Our pattern of neural foramina is similar to Devi R et al., study who had measured vertical diameter which increased from L1 to L2 and then decreased thereafter from L2 to L5. There was no statistically significant difference in the measured values in right and left side in both genders.

LIMITATION

Our Study has included 25 male and 25 female volunteers of Indian origin. To establish a normogram, a large sample size study will be better.

CONCLUSION

Low back pain is a common problem and MRI is the diagnostic method of choice. Spinal canal and NF evaluation is important for evaluation of organic cause of back pain. Spinal morphometry is the need of the hour for diagnosis of cause of back pain and development for various implants and instruments due to recent advances in spinal interventional procedures. Most of the available morphometry is cadaver based, radiograph based or CT based. MR based data of spinal morphometry is lacking in world literature. We performed lumbar morphometry by MRI and a database of clinically relevant measurements of lumbar spine viz BSCA, ASCA, PL and NF area of Indian population were prepared and their gender variations were evaluated. It has been found that MRI can be used for all these measurements without any radiation risk .This study can be taken as pilot study and a large population based study with different age groups can be done for generation of spinal morphometric map.

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