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Original Research Article

THORACIC PEDICLE MORPHOMETRY STUDY ON CADAVER AND CT SCAN WITH ITS CLINICAL APPLICATIONS

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ABSTRACT

Background: Morphometric measurements of a spine in the particular geographical area will help in proper implant selection during spinal surgeries, designing of best suited implant, understanding the biomechanics and pathoanatomy of the spine, precise clinical diagnosis and management of the population under consideration.

Methods: In this study sample size was 100 [58 male and 42 female] embalmed and preserved thoracic spine [T1 to T12] aged 35 to 80 years at the time of death. Chord length [CL]: Measured from the posterior cortical entry point of the pedicle to the anterior vertebral cortex along the axis of the pedicle. All the linear measurements like Vertical interpedicular distance [VIPD], Transverse interpedicular distance [TIPD], Sagital angle [SA] measured using digital vernier calipers with resolution [0.01mm].

Result: In pedicle width however there was no significance difference [$p > 0.05$] between direct measurement and CT measurement in T1, T2 and T10 and other vertebral level there was significance difference [$p < 0.05$] between DM and CT. Pedicle Hight of the thoracic spine showed no significant difference [$p > 0.05$] between the direct measurement and the CT measurement in T3 and T8, but in other vertebral level there is significant difference [$p < 0.05$] between direct measurement and CT. A significant difference [$p < 0.05$] between direct measurement and CT measurement sagital angle values in all the vertebral levels was observed.

Conclusion: Pedicle morphometry shows significant correlations in different parameters in most of the vertebral levels in direct measurement and in CT measurements. Also the multiple linear regressions was performed to obtain prediction equation taking direct measurement as dependant variable and CT scan measurements, age and gender as independent variables. The results of the present study can help in designing implants and instrumentations, understanding spine pathologies; and management of spinal disorder in this ethnic group.

KEY WORDS: Pedicle, Morphometry, Thoracic Vertebrae.

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INTRODUCTION

Transpedicular screw fixation in the thoracic spine remains an extensively debated topic among spinal surgeons. Importantly, this debate centers on the incidence,degree, and potential neurologic consequence of screw penetration through the medial pedicle wall.The thoracic spine has unique anatomical and biomechanical features. It is stiffer than the lumbar spine due to the restraining effect of both the rib cage

and its relatively thinner disks [1]. Morphometric measurements of a spine in the particular geographical area will help in proper implant selection during spinal surgeries, designing of best suited implant, understanding the biomechanics and pathoanatomy of the spine, precise clinical diagnosis and management of the population under consideration

The parameters such as pedicle height, pedicle width, sagittal angle, transverse angle, interpedicular distance and chord length measurements in the present study provides valuable information for the growing interest in the field of thoracic spine instrumentation and for better understanding of thoracic spine structure in a population. There is a demand for quantitative data concerning the thoracic pedicle using different measurement techniques. Computerized Tomography scan [CT] is preferred for evaluation of the morphometry of the thoracic spine. More precise measurements and dimensions of various anatomical parts of the selected vertebrae can be acquired from Computerized Tomography [CT]. However, there are a number of different effects that may be responsible for artifacts in CT [2]. Because, artifacts in CT arise as a result of the interaction between the subject and the machine, it is very essential to know about the artifacts by the nature of the error.

Hence, there is a need to study number of samples in order to correlate the morphometry of the pedicle with different techniques. Pedicle morphometry parameters show significant variations in different studies. This can be the result of different physical characteristics of the population such as biomechanical stress, musculoskeletal anatomy, regional demographical factors, influence of age and gender on thoracic pedicle morphometry, and osteoporosis-related vertebral deformities. Furthermore, the midthoracic region is predisposed to higher rotational stress, which may have a bearing on the rate of disc degeneration. These factors demand for studies of the thoracic pedicle morphometry in the population of different regions. Dakshina Kannada, located in coastal Karnataka has diverse population influenced by various environmental factors, socioeconomic factors, physical stress and genetic factors. Hence this study was undertaken to analyze the pedicle morphometry from a large dataset of CT scan and direct measurement with the following objectives: To determine the morphometry changes related to normal ageing and to analyze the difference between the genders and to develop a mathematical model for generating morphometry data from the CT scan for precise surgical procedures. Based on the correlation the mathematical model has been developed by obtaining the regression analyses. A thorough knowledge of thoracic spine anatomy is essential in the treatment of thoracic spine diseases.

MATERIALS AND METHODS

Data were collected from the cadavers from the six medical colleges in Mangalore. The discarded thoracic spine was used from the medical colleges; procure unclaimed cadavers from Government hospitals. The data collection started after obtaining Institutional Ethical Committee Clearance from Yenepoya University. In this study sample size was 100 [58 male and 42 female] embalmed and preserved thoracic spine [T1 to T12] aged 35 to 80 years at the time of death. These 100 samples were grouped as above 50 and below 50 years. Cadavers having congenital spinal deformities, had undergone surgical treatments [like implants], has history of spinal disease, were excluded from the study. The linear measurements were performed at the different vertebral levels with the digital Vernier calliper [resolution 0.01 mm] and the angular measurements performed with goniometer [resolution 1^0] and CT scanner [GE HEALTH CARE]. Morphometric anatomy of 1200 thoracic pedicles from 100 cadavers were studied using techniques namely direct measurement and CT scan measurement of same cadaveric group part with the intact spine has been seperated from the whole body. All the organs in the anterior part were removed. Dissection of the thoracic spine section was done in the upper back. Following measurement by the CT scan the direct measurement was carried out. The vertical interpedicular distance measured by the vernier caliper [direct measurement] with intact spine. For the measurement of other parameter each vertebrae separated from the intact spine.

Chord length [CL]: Measured from the posterior cortical entry point of the pedicle to the anterior vertebral cortex along the axis of the pedicle.

Vertical interpedicular distance [VIPD]: Vertical distance between the two pedicles of two vertebrae at the midpoint.

Transverse interpedicular distance [TIPD]:

Transverse distance between the two pedicle at the midpoint.

Transverse angle [TA] of the pedicle was measured by the angle between the pedicle axis and a line parallel to the vertebral midline measured in the transverse plane

Sagital angle [SA] of the pedicle was measured as angle between the sagittal pedicle axis and the superior border of the vertebral body in the sagittal plane.

All the linear measurements were made using digital vernier calipers with resolution [0.01mm]. Angles were measured by a goniometer [resolution 1^0] and confirmed using a protractor after tracing the outline of the vertebrae onto a paper.

RESULTS

Assessment and comparison of direct measurement and Computerized Topographic [CT] scan measurement of cadaver

Chord length [CL]: The CL had maximum mean value of 38.00 ± 6.63 mm at T12 level in whole series and the minimum mean value was observed at T1 level [26.24 ± 3.92 mm] in direct measurement. In the CT measurement the CL had maximum mean value of 37.43 ± 6.14 mm at T12 level and minimum mean value at T1 [25.02 ± 3.99 mm]. The CL increased from T1 towards T12 and this observation was consistent in both CT and direct measurements. We observed in the chord length a significant difference [$p < 0.05$] between the two measurements for all the thoracic vertebral level [T1-T12] and it is inferred that direct measurement value is higher compared with CT value.

Pedicle height [PH]: The mean PH was maximum at T12 vertebral level with a value of 11.50 ± 0.19 mm and minimum value of 8.33 ± 0.38 mm at T2 vertebral level in direct measurement. CT showed maximum mean value

Vertebral level		Chord Length			Pedicle Height			Pedicle Width		
		Mean & Standard devotion	T Test P value		Mean & Standard deviation	T Test P value		Mean & Standard deviation	T Test P value	
T1	CD	26.245±3.916	0	Sig	8.383±.362	0.016	Sig	7.650±.362	0.202	NS
	CT	25.016±3.989			8.447±.464			7.636±.464		
T2	CD	28.225±4.800	0	Sig	8.335±.386	0	Sig	5.672±.386	0.056	NS
	CT	27.800±4.311			7.824±.575			5.707±.575		
T3	CD	29.060±4.902	0	Sig	8.467±.165	0.719	NS	4.581±.165	0	Sig
	CT	28.730±4.301			8.477±.416			5.167±.416		
T4	CD	30.612±5.024	0	Sig	8.505±.172	0	Sig	4.497±.172	0	Sig
	CT	29.684±5.031			8.538±.156			4.601±.156		
T5	CD	30.418±5.942	0	Sig	8.485±.184	0	Sig	4.521±.184	0.003	Sig
	CT	29.902±5.586			8.531±.191			4.572±.191		
T6	CD	32.638±7.060	0	Sig	9.438±.188	0	Sig	4.608±.188	0	Sig
	CT	32.056±6.689			9.554±.211			4.532±.211		
T7	CD	34.003±7.365	0	Sig	9.495±.182	0	Sig	4.588±.182	0	Sig
	CT	33.504±7.054			9.705±.198			4.885±.198		
T8	CD	35.704±7.796	0	Sig	9.538±.154	0.143	NS	4.610±.154	0	Sig
	CT	35.285±7.363			9.556±.188			4.803±.188		
T9	CD	35.975±7.345	0	Sig	9.522±.186	0.041	Sig	5.599±.186	0	Sig
	CT	35.833±7.216			9.548±.173			5.671±.173		
T10	CD	36.849±6.857	0	Sig	10.557±.182	0	Sig	7.379±.182	0.182	NS
	CT	36.092±6.564			10.668±.211			7.398±.211		
T11	CD	37.089±6.613	0	Sig	10.576±.194	0	Sig	7.611±.194	0	Sig
	CT	36.608±6.107			10.603±.183			8.471±.183		
T12	CD	38.000±6.626	0	Sig	11.503±.195	0	Sig	7.519±.195	0	Sig
	CT	37.434±6.139			11.532±.229			7.639±.229		

of 11.53 ± 0.22 mm at T12 and minimum mean value at T2 [7.824 ± 0.575] mm. Increase in the PH was observed from T2 to T12 in both measurement techniques. PH of the thoracic spine showed no significant difference [p > 0.05] between the direct measurement and the CT measurement in T3 and T8, but in other vertebral level there is significant difference [p < 0.05] between direct measurement and CT.**Pedicle width [PW]:** Mean PW was maximum at T11 vertebral level with value of 8.47 ± 0.54 mm in the CT measurement and 7.65 ± 0.13 mm in the direct measurement and minimum mean value was observed at T4 [4.50 ± 0.17 mm] in the direct measurement and 4.53 ± 0.24 mm in CT measurement.PW in the upper and lower thoracic vertebra level were higher compared to mid thoracic level. In pedicle width however there was no significance difference [p > 0.05] between direct measurement and CT measurement in T1, T2 and T10 and other vertebral level there was significance difference [p < 0.05] between DM and CT.

Vertebral level		Sagital angle			Transverse angle		
		Mean & Standard deviation	T Test P value		Mean & Standard deviation	T Test P value	
T1	CD	16.179±.241	0.027	Sig	30.524±.210	0	Sig
	CT	16.203±.272			29.654±.317		
T2	CD	17.431±.368	0	Sig	23.479±.160	0	Sig
	CT	17.566±.342			23.569±.285		
T3	CD	17.425±.268	0	Sig	18.532±.185	0	Sig
	CT	17.286±.095			18.587±.199		
T4	CD	17.804±.226	0	Sig	16.519±.168	0.725	NS
	CT	17.731±.303			16.515±.248		
T5	CD	17.38±.079	0	Sig	15.535±.152	0	Sig
	CT	17.360±.071			15.608±.206		
T6	CD	15.979±.337	0	Sig	14.551±.176	0	Sig
	CT	15.906±.359			14.520±.171		
T7	CD	16.374±.159	0	Sig	14.566±.203	0	Sig
	CT	16.508±.264			14.626±.197		
T8	CD	15.290±.294	0	Sig	13.552±.246	0	Sig
	CT	15.433±.255			13.646±.249		
T9	CD	10.402±.489	0	Sig	11.566±.325	0.001	Sig
	CT	10.465±.358			11.650±.141		
T10	CD	10.539±.237	0	Sig	10.537±.218	0	Sig
	CT	10.325±.153			10.026±.566		
T11	CD	7.606±.307	0	Sig	9.483±.177	0	Sig
	CT	7.471±.129			8.877±.463		
T12	CD	5.543±.349	0	Sig	8.547±.181	0	Sig
	CT	4.611±.481			8.585±.222		

Sagittal pedicle angle [SPA]: The SPA between T1 to T8 vertebra with the values ranging between to 15.4 degree to 17.8 degree both in direct measurement and CT and it gradually decreased to minimum value at T12 vertebra with the mean value of 5.54 ± 0.34 degree in direct measurement and 4.6 ± 0.48 degree in CT measurement for whole series of cadaver samples. Maximum sagittal pedicle angle was 17.43 ± 0.36 degree at T2 vertebral level in direct measurement and 17.56 ± 0.34 degree in CT measurement. A significant difference [p < 0.05] between direct measurement and CT measurement values at all the vertebral levels was observed.

Transverse pedicle angle [TPA]: The maximum TPA was at T1 level with mean value of 30.52 ± 0.21 degree and 29.65 ± 0.31 degree for direct measurement and CT respectively. The TPA decreased from T1 to attain a minimum value at T12. The mean values of TPA for T12 were 8.54 ± 0.18 degree in DM and 8.58 ± 0.22 degree in CT. A significant difference [p < 0.05] between direct measurement and CT measurements in the TPA was observed except at the level of T4.

Vertebral level		Transverse inter pedicular distance			Vertical inter pedicular distance		
		Mean & Standard devotion	T Test P value		Mean & Standard devotion	T Test P value	
T1	CD	23.390±.089	0.014	sig	21.694±.148	0	sig
	CT	23.413±.171			21.283±.678		
T2	CD	23.834±.206	0	sig	22.635±.142	0.741	NS
	CT	22.975±.501			22.638±.159		
T3	CD	19.239±.165	0	sig	23.328±.241	0	sig
	CT	19.522±.307			23.383±.183		
T4	CD	18.375±.086	0	sig	23.749±.717	0	sig
	CT	18.575±.225			23.420±.315		
T5	CD	18.396±.121	0	sig	23.407±.167	0	sig
	CT	18.580±.222			23.466±.155		
T6	CD	23.460±.082	0	sig	24.365±.177	0	sig
	CT	23.694±.225			24.530±.258		
T7	CD	25.744±.165	0	sig	25.425±.179	0	sig
	CT	24.751±.270			25.344±.151		
T8	CD	26.845±.173	0	sig	26.580±.133	0.007	sig
	CT	26.608±.275			26.620±.247		
T9	CD	27.781±.223	0.02	sig	27.387±.207	0.228	NS
	CT	27.750±.309			27.405±.220		
T10	CD	28.293±.227	0	sig	28.794±.233	0	sig
	CT	27.737±.348			28.737±.243		
T11	CD	29.296±.198	0	sig	29.358±.175	0	sig
	CT	30.107±.033			29.534±.174		
T12	CD	31.676±.222	0	sig	30.275±.206	0	sig
	CT	31.802±.130			30.465±.346		

Transverse inter pedicular distance [TIPD]: The maximum TIPD was at T12 vertebral level with mean value of 31.67 ± 0.22 mm in direct measurement and 31.80 ± 0.13 mm in CT measurement. The minimum mean value was at T4 18.37 ± 0.86 mm in the direct measurement and mean value of 18.57 ± 0.22 mm in CT measurement. It is increased from the vertebral level T4 to T12 with the range between 19.23 ± 0.165 mm to

31.67 ± 0.22 mm in direct and CT measurements respectively. In the transverse interpedicular distance there was significance difference [p < 0.05] between direct measurement and CT measurement of TIPD.

Vertical interpedicular distance [VIPD]: VIPD increased from T1 vertebral level to T12 vertebral level where the maximum mean value was seen at T12 level with the value of 30.27 ± 0.20 mm in the direct measurement and 30.46 ± 0.34 mm in the CT measurement. The minimum mean value was at T1 with 21.69 ± 0.15 mm in the direct measurement and 21.23 ± 0.68 mm with CT measurement. In the Vertical interpedicular distance there was significance difference [p value < 0.05] between direct and CT measurement at all vertebral level except at T2 and T9, there is no significant difference [p > 0.05].

Analyses of reliability of the data using direct measurement and CT measurement Intra class correlation coefficient, ICC

Chord length			
Vertebral level	ICC	95% Confidence Interval	
		Lower Bound	Upper Bound
T1	0.974	0.823	0.995
T2	0.994	0.975	0.998
T3	0.993	0.986	0.996
T4	0.991	0.204	0.998
T5	0.996	0.956	0.999
T6	0.997	0.955	0.999
T7	0.998	0.965	0.999
T8	0.998	0.991	0.999
T9	0.999	0.999	1
T10	0.996	0.767	0.999
T11	0.997	0.982	0.999
T12	0.996	0.963	0.999

Pedicle height			
Vertebral level	ICC	95% Confidence Interval	
		Lower Bound	Upper Bound
T1	0.887	0.828	0.925
T2	0.786	0.652	0.841
T3	0.769	0.656	0.845
T4	0.961	0.9	0.981
T5	0.969	0.771	0.989
T6	0.905	0.802	0.977
T7	0.734	0.646	0.93
T8	0.853	0.782	0.901
T9	0.867	0.802	0.911
T10	0.886	0.852	0.967
T11	0.986	0.945	0.994
T12	0.981	0.953	0.991

Chord length [CL]: A strong agreement between direct measurement and CT measurement of CL in all the vertebral levels from T1 to T12 was evident as the Intra class correlation coefficient was above 0.9 in all the vertebral levels.

Pedicle height [PH]: In T2, T3 and T7 levels of thoracic spine the agreement between direct measurement and CT measurement was good as ICC was between 0.7 to 0.8, whereas rest of the vertebral levels [T1 T4 T5 T6 T8 T9 T10 T11 T12] of thoracic spine showed strong agreement between direct measurement and CT measurement as ICC was > 0.8

Pedicle width			
Vertebral level	ICC	95% Confidence Interval	
		Lower Bound	Upper Bound
T1	0.899	0.85	0.932
T2	0.854	0.782	0.902
T3	0.703	0.602	0.748
T4	0.827	0.701	0.936
T5	0.876	0.806	0.919
T6	0.925	0.697	0.969
T7	0.708	0.625	0.904
T8	0.773	0.628	0.899
T9	0.935	0.474	0.979
T10	0.978	0.967	0.985
T11	0.69	0.587	0.758
T12	0.906	0.855	0.975

Sagital angle			
Vertebral level	ICC	95% Confidence Interval	
		Lower Bound	Upper Bound
T1	0.955	0.932	0.97
T2	0.905	0.632	0.96
T3	0.611	0.506	0.801
T4	0.938	0.821	0.97
T5	0.911	0.816	0.951
T6	0.973	0.874	0.989
T7	0.804	0.752	0.925
T8	0.881	0.702	0.96
T9	0.953	0.922	0.971
T10	0.787	0.693	0.839
T11	0.686	0.3	0.835
T12	0.761	0.644	0.782

Pedicle width [PW]: A good correlation between direct measurement and CT measurement of PW at T3, T7, T8 and T11 as ICC was between 0.7 to 0.8. A strong correlation between direct measurement and CT measurement of pedicle width at T1, T2, T4, T5, T6, T9, T10, T12 as ICC > 0.8

Transverse Angle			
Vertebr al level	ICC	95% Confidence Interval	
		Lower Bound	Upper Bound
T1	0.838	0.805	0.898
T2	0.85	0.642	0.923
T3	0.952	0.768	0.981
T4	0.928	0.892	0.951
T5	0.876	0.62	0.943
T6	0.971	0.92	0.986
T7	0.931	0.776	0.969
T8	0.95	0.199	0.986
T9	0.69	0.511	0.8
T10	0.741	0.673	0.802
T11	0.725	0.624	0.73
T12	0.964	0.914	0.981

Transverse interpedicular distance			
Vertebral level	ICC	95% Confidence Interval	
		Lower Bound	Upper Bound
T1	0.86	0.787	0.907
T2	0.703	0.616	0.765
T3	0.793	0.73	0.836
T4	0.736	0.631	0.8
T5	0.845	0.728	0.876
T6	0.66	0.632	0.733
T7	0.81	0.703	0.842
T8	0.84	0.728	0.873
T9	0.936	0.898	0.955
T10	0.886	0.808	0.997
T11	0.635	0.526	0.751
T12	0.747	0.605	0.898

Vertical interpedicular distance			
Vertebral level	ICC	95% Confidence Interval	
		Lower Bound	Upper Bound
T1	0.739	0.708	0.844
T2	0.887	0.832	0.924
T3	0.922	0.83	0.958
T4	0.742	0.276	0.879
T5	0.914	0.662	0.964
T6	0.74	0.671	0.901
T7	0.889	0.73	0.962
T8	0.833	0.745	0.89
T9	0.846	0.772	0.896
T10	0.955	0.862	0.979
T11	0.746	0.716	0.93
T12	0.802	0.79	0.93

Sagittal angle [SA]: A good agreement between direct measurement and CT measurement of SA at T3, T10, T11 and T12 vertebral levels as ICC > 0.7. A strong correlation between direct and CT measurement of sagital angle at T1, T2, T4, T5, T6, T7, T8, T9 as ICC > 0.9

Transverse angle [TA]

TA in all the thoracic vertebral level showed a strong agreement between direct measurement and CT measurement as ICC > 0.9 except at T9, T10, T11 vertebral level there is a good agreement between direct and CT measurement as ICC > 0.7.

Transverse Interpedicular Distance

Transverse inter pedicular distance [TIPD] Intra class correlation coefficient between direct and CT measurement for TIPD was significant [ICC > 0.9] at T1,T5,T7,T8,T9,T10 vertebral level and the ICC > 0.8 in direct measurement and CT measurement at T2, T3, T4, T6, T11, T12

Vertical interpedicular distance [VIPD]: Intra class correlation was between 0.64 to 0.75 for direct and CT measurement for VIPD at T1 T4, T6, T11, T12 vertebral level and the ICC between direct and CT measurement for VIPD was significant as ICC > 0.9 at T2, T3, T5, T7, T8, T9, T10 vertebral level.

Variation between measurement of male and female thoracic vertebra in direct and CT measurements

Chord Length [CL]: CL increased from T1 to T12 vertebral level in males and females groups in direct and CT measurement. Male cadaver had larger mean CL than female cadaver at all thoracic spine levels in both the techniques and chord length had maximum mean value at T12 with 43.61 ± 0.08 mm in males and 30.25 ± 0.18 mm in females at direct measurement and 42.63 ± 0.28 mm in males and 30.26 ± 0.15 mm in CT measurement and observed minimum mean value at T1 with 28.38 ± 0.39 mm in males and 20.36 ± 0.16 mm in females in CT measurement and 29.56 ± 0.19 mm in males 21.68 ± 0.19 mm in females at direct measurements. The differences were statistically significant [p < 0.05] at the spine levels from T1 to T12.

Pedicle height [PH]: PH was maximum at T12 vertebral level in direct measurement and CT measurement in males [11.46 ± 0.16 mm in DM], [11.59 ± 0.26 mm in CT] and in females [11.55 ± 0.219 mm in DM] [11.48 ± 0.19 mm in CT] and

PH increased from T2 to T12 vertebral level in male and female subject groups.PH was more in females compare to males at all the vertebral levels. There was no significant difference [p > 0.05] between males and females expect at T10 and T12 there is the significant difference [p < 0.05] between males and females.

Pedicle width [PW]: PW was maximum at T1 in males [7.63 ± 0.18 mm in DM] [7.60 ± 0.21 mm in CT] and females [7.67 ± 0.14 mm in DM] [7.67 ± 0.22 mm in CT] and maximum value observed at T11 in males 7.58 ± 0.17 mm and females 7.64 ± 0.205 mm in direct measurement and T12 in males [7.63 ± 0.21 mm] and females [7.64 ± 0.25 mm] in CT measurement. Minimum value observed at T5 in males 4.49 ± 0.18 mm and at T4 vertebral level in females 4.49 ± 0.17 mm in direct measurement, whereas minimum value observed in males [4.50 ± 0.16 mm] and females [4.57 ± 0.30 mm] in CT measurement at T6 vertebral level .The PW was higher at upper and lower thoracic level compare to mid thoracic region in males and females in direct and CT measurements. There was no significant difference [p > 0.05] between the males and females in all the vertebral level except at T8 [p < 0.05]

Sagittal angle [SA]: SA showed significant difference [p < 0.05] between males and females in all vertebral levels except T2,T3,T11,T12. SA was maximum at T4 vertebral level in males in direct measurement [17.84 ± 0.24 degree] and in CT measurement [17.78 ± 0.26 degree] and in females direct measurement showed maximum value of [17.75 ± 0.23 degree] and CT measurement [17.59 ± 0.39 degree] at T4 vertebral level.

Transverse angle [TA]: The TA decreased from T1 to T12 vertebral levels in males and females. The maximum TA observed at T1 vertebral level [30.51 ± 0.16 degree] in males in direct measurement and [29.59 ± 0.17degree] in CT measurement and [30.54 ± 0.26 degree] in females in direct and [29.73 ± 0.44 degree] in CT measurements. Minimum TA observed in T12 vertebral level in males [8.53 ± 0.19 in DM] [8.55 ± 0.25 degree in CT] and females [8.56 ± 0.15 degree in DM] [8.61 ± 0.17 degree in CT].There was no significant difference [p > 0.05] between the males and females in the TA at all the vertebral level except at T9 and T11 it was significant [p < 0.05]

Transverse inter pedicular distance [TIPD]: The TPD was increased from T4 to T12.The maximum TIPD was at T12 vertebral level in males [31.73 ± 0.20 mm in DM, 31.82 ± 0.12 mm in CT] and females [31.59 ± 0.22 mm in DM, 31.77 ± 0.13 in CT].The minimum TIPD was observed at T4 vertebral level in males [18.36 ± 0.06 mm in DM] [18.55 ± 0.19 mm in CT] and females [18.39 ± 0.11 mm in DM][18.60 ± 0.26 mm in CT].There was significant difference [p < 0.05] between males and females in all the vertebral level as except at T4, T5, T6 it was not significant as p > 0.05

Vertical Inter Pedicular Distance [VIPD]: The VIPD was increased from T1 to T12 in males and females. There was minimum value of VIPD in males [21.70 ± 0.16 mm in DM, 21.40 ± 0.58 in CT] and females [21.69 ± 0.13 mm in DM, 21.11± 0.76 mm in CT] was at T1. A significant difference [p < 0.05] between males and females were at T3, T6, T7, T9, T12 vertebral level and there was no significant difference [p > 0.05] between males and females at T1, T2, T5, T8, T10, T11 vertebral levels.

CONCLUSION

The present study was undertaken to gain a detailed knowledge of the vertebral morphometry of thoracic spine in Dakshina Kannada population and the observations from the present study were compared with the previous published studies from India [3,4], Asia [5-8] and western world [8-15]. It included more number of cadaveric specimens in comparison to other studies which included 6-40 cadaveric specimens. The previous studies done in India in this regard by Datir and Mitra [16] was based on 18 cadaveric specimens, by Chadha *et al* [17] on 31 patients and recently published study by Acharya *et al* [18] on 50 patients. All of these studies have focused primarily on pedicle morphometry and except for Datir and Mitra [16] two studies have only studied lower thoracic pedicles.

A comprehensive data set has been presented, providing quantitative pedicle morphometry of thoracic pedicle, and it may be used to predict pedicle instrumentation. Pedicle morphometry shows significant correlations in different

parameters in most of the vertebral levels in direct measurement and in CT measurements. While comparing data obtained from this study with available literature from different ethnic groups it is clear that there is considerable variation in pedicle morphometry. This can be the result of different physical characteristics of the population. Based on the findings from this study, we conclude that 26 mm screw length is appropriate for the upper thoracic region and in lower thoracic region 36 to 37mm screw length would be appropriate as per the chord length measurements. Average Pedicle height among 100 cadavers studied in present study found to be 8.3 mm to 11.5 mm from upper and lower thoracic region respectively. There was increase or decrease of 0.5 to 1.0 mm in each parameter when it is compared with each cadaver in direct and CT measurements. Various authors documented that cross section of the pedicle is oval; hence the sagittal pedicle isthmus width is always greater than the transverse pedicle isthmus width which is the limiting factor in choosing the diameter of the pedicle screws.

In this study minimum mean value of pedicle width was 4.6 mm at T4 in the CT measurement and 4.4 mm at T4 in the direct measurement. Vaccaro *et al* [19], Datir and Mitra [16], and Zindrick *et al* [28] had minimum value at T5 level which were all around 4.5 mm. whereas Ugur *et al* [20] and Ebraheim *et al* [7] had minimum value at T4 level as our study. This trend of change in size of the pedicles may be varying indifferent ethnic group and it is due to transition of force from a more mobile cervicothoracic junction to relatively fixed mid-thoracic region and again to a mobile thoracolumbar junction putting differential stress on the facet joints and pedicles. Transverse diameter of the pedicle is the important dimension as this decides size of the screw to be inserted. Pedicle width decreased from T1 to T5 and gradually increased from T6 to T12 in the present study. Pedicle width is 4.52 ± 0.21 mm at T5 vertebral level which is narrowest diameter when we compare to upper and lower thoracic level. In the present study, values of PW was less than 5 mm observed at T4 to T8 similar to other studies reported in the literature [17,18]

whereas some other studies in the literature reported higher values at all levels and at no level the width was less than 5 mm [18]. Then 35% of all pedicles, 48% of those from T4 through T8 and 68% of those at T6, measured less than 5 mm in a study reported by Cinnotti *et al* [3]. In another study by McLain *et al* [9] 25% of T1 pedicles, 17% of T2 pedicles, 42% of the T3 pedicles, 61% of T4 pedicles, 67% of T5 pedicles and 75% of T6 pedicles were too small to accept a 5.5 mm screw.

Hence, it is suggested from the study a small screw with 4mm should also be used with great care in mid thoracic region. Thus, we agree with Datir and Mitra [18] that even a 4-mm screw should be used carefully at the mid-thoracic level; 5-mm screw seems to be safe at upper and lower levels of the thoracic spine. Tan *et al* [21] also explained that except for T1 and T10-T12, the pedicle width was not wide enough to accommodate a 5-mm transpedicular screw. Lieu *et al* [22] reported that the 67.8% male and 94.4% females had transverse outer pedicle diameter less than 5-mm at T4; and 62.2% males and 90.0% females at T5 level. We also agree with other studies that the pedicles between T4 and T8 should be measured on computed tomography scans before surgery after correcting magnification error and artifacts because they might not be suitable to instrumentation with pedicle screws due to their narrow width [17,18,20,23]

Islam *et al* [23] emphasized most vertebrae have a real minimal diameter, which is the smallest diameter of the pedicle and they reported the ratio of vertical or transverse diameter to minimal diameter for each level to estimate real minimal diameter. The axis of minimal diameter which is the smallest is generally oblique and is different from the vertical and transverse axes, although it is sometimes superimposed on either [24]. Considering the small size of pedicles in thoracic spine, some authors proposed extravehicular fixation within the pedicle unit to avoid medial wall violation [24,25]. In pedicle width however there was no significance difference between DM and CT measurement in T1, T2 and T10. But other vertebral level there was significance difference between DM and CT.

In the present study the PH gradually increased

from T1 to T12. Similar trend seen in the Christodoulou *et al* [12] which showed gradual increase from T1 to T12. The mid pedicle height of the present study was lower than the other studies [12,17,26] Similar trend was also seen in studies of Datir and Mitra [16] and Zindrick *et al* [28], but not in the study by Vaccaro *et al* [19] whose PH dimensions were lower than present study. Comparison of PW and PH explains the oval shape of pedicle in the cross section except for 1st pedicle which is cylindrical with more or less equal width and height [7.7 mm and 8.6 mm] [17]. Since the PH is more than pedicle width at all levels, it does not limit the size of the screw to be used. The PH is more towards the lower thoracic vertebra because the force of transmission towards the lower thoracic vertebrae is more than the upper thoracic vertebral level. In our study PH of the thoracic spine showed no significant difference between the direct measurement and the CT measurement in T3 and T8, but in other vertebral level there is significant difference between direct and CT measurement was observed indicating the consistency in two techniques.

Pedicle angle were sagittal angulated in cephalic direction with narrow range between T1 to T9 [15 to 17 degree] .The angle for T10 was 10^0 while it decreased to 4^0 for T12.The pedicular angles play an important role in the overall stability of the fixation. This is important in accurate screw placement as inferior migration of screw may result in injury to the nerve root. Inaccurately placed screw along the sagittal axis can injure the nerve root, which is very close to the inferior border of the pedicle. With a suitable choice of insertion angles, screw triangulation is possible along the entire spine.

Transverse PA was decreased from T1 to T10 in the present study compared to other studies. The pedicles were angulated more medially initially and around T12 vertebral level it faced more laterally at T12 in the present study. In Indian study by Datir and Mitra [16] the pedicles reached neutral position rather earlier and at no levels the pedicle were facing laterally. In a study by Chadha *et al* [17] the pedicles were facing laterally at lower end but less compared to our study. In the published study by Acharya *et al* showed at the lower thoracic spine, pedicles faced more laterally [13]. Going for pedicle screw instrumentation on the basis of other study groups would have lead to the risk of injury to cord and other neural structures. Because of the more lateral angulation of T12 pedicle the CL of the T12 vertebra was also less as compared to other lower thoracic vertebrae.

Sagittal angle in the current study [CT and direct method] were significantly larger than those reported by Zindrick *et al* [28]. Sagital pedicle angle in the current study decreases from T1 to T12. In the present study the pedicles were sagittal angulated in cephalic direction with a narrow range between T1-T9 [15-17.6°]. When we compare with other studies the cephalic angle decreased from T10-T12 with more than 50% of T12 having sagittal angle of 0°. Compared to Datir and Mitra [16] the present study group had more cephalic angulation but the trend being the same. The present study group had maximum sagittal angle at T4 level [17.8° in DM and 17.7 in CT], where as Zindrick *et al* [28] and Datir and Mitra [16] had maximum value at T2 level [17.5° and 11.8° respectively]. Sagittal and transverse angles show a significant difference between DM and CT measurements except T4 level

IPD in direct and CT method in the current study was similar at all levels when it is compared with the values reported by Ugur *et al* [20] and Chaynes *et al* [21]. Mean IPD values from the current study and those mentioned by Chaynes *et al* [21] increased gradually from above downwards. Ugur *et al* [20] has reported IPD, decreased gradually from T1 to T7 followed by gradual increase upto T12. Scoles *et al* [13], Panjabi *et al* [14] and Berry *et al* [10] also reported similar trend as mentioned in our study. Transverse interpedicular distance decreased from T1 to T5 in our study. So in the midthoracic region, TIPD is less and it is the important zone and critical vascular zone for the spinal cord. It has the narrowest opening and blood supply to the spinal cord is least perfuse also the surgical situation in this site is further compounded by the fact that this is the area of least pedicle width. Any misdirection of the pedicle screw at this region can cause neural damage, dural tears, and spinal cord damage. The vertical interpedicular distances determine the distance

between the holes of plates and the length of the transfixators related to the TIPD. In the present study, TIPD decreased from T1 to T5 in DM and CT .Then gradually increased from T6 to T12 with in DM and CT. The similar trend was observed by Ugur *et al* [20], Panjabi *et al* [14], Scoles *et al* [13], Berry *et al* [10], Tan *et al* [21] and Mc Cormack *et al* [15]. However, the studies by Datir and Mitra [16] and Chaynes *et al* [29] showed similar values at all levels and with uniformly increasing trend from T1 to T12. The mid-thoracic region is important because it is critical vascular zone for the spinal cord. It has the narrowest opening, and blood supply to the spinal cord is least perfuse [29]. In the Transverse interpedicular distance there was significance difference between DM and CT measurement of transverse interpedicular distance and in the Vertical interpedicular distance there was significance difference between DM and CT at all vertebral level except at T2 and T9 there was no significant difference.

The interpedicular distance was also found to be higher in females in all levels except at T1, T2 and T7 vertebrae. Thus, it was observed that the vertebral canal in female vertebrae was wider than male vertebrae in the present study group. This was in contradiction to other dimensions where values in male vertebrae were found higher than female vertebrae values. The female horizontal and vertical diameters of the pedicles have shown a tendency to increase throughout normal aging [18, 23]. Due to normal ageing, the intervertebral disc height decreases and consequently causes the facet joints to place an increased pressure on each other. This type of overloading is the most common causes of facet hypertrophy [an enlargement of the facet joint] and is also thought to increase the growth of osteophytes in the facet joints [31]. Also this is reflected in our analyses. Understanding this effect is of particular importance with respect to spinal stenosis where a narrowing of the spinal canal causes the impingement of the spinal nerve. So most of the changes in the parameters from T1 to T12 can be explained on the basis of local musculoskeletal anatomy and biomechanical stress.

Chord length for the current study population was significantly smaller in direct measurement compared with the values reported by Hou and colleagues [31] and Vaccaro *et al* [19] at almost all levels. In the current study CL was significantly smaller when we compared with Scoles *et al* [12] in the direct measurements. To avoid violation of anterior cortex of the vertebral body, the pedicular screw length of 25 mm at the upper thoracic level and 30 mm at mid and lower thoracic levels should be safe. Furthermore the fact that there is significant difference between the males and females in each spinal levels in direct and CT measurements. In the present study the pedicle dimensions in the thoracic level vertebrae of females were lower than those of the same vertebrae in males, also the age has been considered as important variables in describing the pedicular morphometry. The assessment and comparison of direct and CT measurements showed in the chord length a significant difference between the two measurements for all the thoracic vertebral level [T1-T12] and it is inferred that direct measurement value is higher compared with CT value.

The relationship between the two techniques were described by Karl Pearson's correlation analysis indicating uniformity of the technique and positive correlation between the two measurements were observed almost in all vertebral levels. Also the multiple linear regressions was performed to obtain prediction equation taking direct measurement as dependant variable and CT scan measurements, age and gender as independent variables. Further, this data on the regional population shows the morphometry variation among the subjects as it is distinct from other ethnic groups. The data obtained is of immense application in the orthopedic surgeries with advance technology in imaging for invasive procedures in the treatment of spinal disorders and deformities.

There is a positive correlation between the direct measurement and CT measurements in most of the vertebral levels for the cadavers used in this study. But it is not 100 percent in all the parameters in different vertebral levels. This can be described by presence of periosteum which is the fibrous membrane of connective tissue that covers all thoracic vertebrae which is not considered in CT image. An attempt was made to establish a relationship between the two

measurements [direct and CT measurements] so as to estimate true pedicle morphometry from CT measurements for all the parameters in the different vertebral levels. The CT method was able to increase the reliability of vertebral measurements on the different planes and should be recommended for use in clinical practice. The magnification error and artifacts in the CT scan should be considered and corrected prior to the procedure in the patients. The detector array design of multichannel CT scanners allows faster scanning, thinner sections, and the generation of a higher X-ray tube current. The faster scanning times result in reduced motion artifacts, very thin sections create a scanned volume of isotropic voxels with equivalent image resolution in all planes, and higher milliamper-age-second exposures may result in better penetration of metal hardware and reduction of artifacts [2]. Based on these criteria it may be validated, since its accuracy and precision were substantially better as compared to the manual method. However in clinical practice, direct measurement is impractical and preoperative imaging must be relied upon to determine whether or not this technique can be safely used. The results of the present study can help in designing implants and instrumentations, understanding spine pathologies; and management of spinal disorder in this ethnic group.

A high positive correlation will provide measurement with certainty and when it does not correlate with expected levels assumption of possibility of error in CT technique or musculoskeletal variation, any developmental abnormality of the spine can be predicted. This will enable the clinical decision maker to take appropriate measure before any invasive interventions.

Conflicts of Interests: None

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