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Digital Anatomical Measurement for Anterolateral Fixation of Middle and Lower Thoracic Vertebrae

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Background: The key to its successful application is to determine the best entry point for the vertebral screw(s). This study aimed to provide a reference for clinical anterolateral fixation through digital measurement of computed tomography (CT) data to identify relevant anatomical positions in the middle and lower thoracic vertebrae (T4–T12) of 30 adults.

Material/Methods: We performed digital measurement of anatomical positions in the middle and lower thoracic vertebrae (T4–T12) of 30 adults. Abbreviations: Left height of vertebral body, LHV; Right height of vertebral body, RHV; Anterior height of vertebral body, AHV; Middle height of vertebral body, MHV; Posterior height of vertebral body, PHV; Superior sagittal diameter of vertebral body, SSDV; Superior transverse diameter of vertebral body, STDV; inferior sagittal diameter of vertebral body, ISDV; Inferior transverse diameter of vertebral body, ITDV; (1) Left (right) height of vertebral body, [L(R)HV]; Anterior (middle, posterior) height of vertebral body [A(M,P)HV]; Superior (inferior) sagittal diameter of vertebral body, [S(I)SDV]; Superior (inferior) transverse diameter of vertebral body, [S(I)TDV].

Results: The transverse diameters of vertebral bodies were always larger than the sagittal diameter for 3~4 mm. The distance between 2 vertebrae (interval of 1 vertebra) range were (52–56) mm for T4–T7 and (44–48) mm for T8–T12, and the surgeons could collate these data to choose a suitable stick length.

Conclusions: Bone graft should prune into laterigrade cuboid, it can recover A-P and bilateral physiological functions load, and the height of the vertebral body increased from T4 to T12.

MeSH Keywords: Anatomy • Computers • Screw Fixation Techniques • Thoracic Vertebrae

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Background

In the past 30 years, anterolateral spinal fixation has been widely used to treat vertebral fractures, cancer, tuberculosis, and other severe spinal diseases that compress the spinal cord. The key to its successful application is to determine the best entry point for the vertebral screw(s). Malposition of the screw into the spinal canal or intervertebral space can result in serious clinical consequences. There have been many reports on appropriate entry points in adults [1–3], but no concrete analyses of specific circumstances have been provided. Moreover, vertebral morphology differs greatly among races/ethnicities and spinal segments, and screw location also varies. This study aimed to provide a reference for clinical anterolateral fixation through digital measurement of computed tomography (CT) data to identify relevant anatomical positions in the middle and lower thoracic vertebrae (T4–T12) of 30 adults.

Material and Methods

Search strategy

This study was funded by the National Natural Science Foundation of China (H0601), the Natural Science Foundation of Inner Mongolia (2012MS1117), and the Initial Fund for Scientific Research of Doctors from the Medical University of Inner Mongolia.

Clinical data

Spine (T1–L1) CT data were collected from 30 patients (25–43 years old; mean age, 34 years) at the Radiology Department of the First Affiliated Hospital of Inner Mongolia Medical University. None of the patients had spinal diseases or osteoporosis. All patients had heights and weights within the normal ranges for Chinese people and provided informed consent. The experiment was approved by the Inner Mongolia Medical University Ethics Committee (No. 20140514)

Spiral CT scan

A Philips Medical System Brilliance 16-slice CT scanner (Eindhoven, The Netherlands) was used with the following scanning conditions: voltage, 120 Kv; current, 150 mA; thickness, 1.25 mm; and matrix size, 512×512. A TOSHIBA PC (Tokyo, Japan; Intel Pentium® dual T2370, CPU, 2G RAM, Windows XP) with Mimics12.0 software (Materialise, Leuven, Belgium) was employed to analyze the data.

The subjects were in supine position, and the longitudinal body axis was kept vertical against the plane during scanning of the middle and lower thoracic spine (T4–L1).

CT image processing and downloading

Clear tomographic bone window images were acquired by adjusting the gray scale, increasing the contrast, and making other image adjustments on the CT workstation before they were saved in DICOM format on a CD.

CT image processing and three-dimensional vertebrae modeling

After reconstruction in Mimics12.0, three-dimensional models of T4–T12 were saved in STL format.

Measurement of relevant vertebral parameters

Image registration was performed in the horizontal, coronal, and sagittal panels on Mimics12.0 to determine the measurement point. The Tools toolbar was activated, and the Distance Measure Tool was used to measure the distance between 2 measurement points by clicking twice on the image (Figure 1).

(1) Left (LH) and right (RH) heights of the middle and lower thoracic vertebrae: Linear distances between the superior and inferior borders on the left and right sides of the vertebrae in the median coronal plane.

(2) Anterior (AH), middle (MH), and posterior (PH) heights of the middle and lower thoracic vertebrae: AH: linear distance between the superior and inferior borders of the anterior vertebrae in the median sagittal panel; MH: linear distance between the upper and lower points on the middle of the vertebrae; PH: linear distance between the upper and lower edges of the posterior vertebrae in the median sagittal panel.

(3) Superior sagittal (SSD) and transverse (STD) diameters of the middle and lower thoracic vertebrae: SSD: distance between the points of intersection between the median sagittal plane and the anterior and posterior borders of superior endplate of the vertebrae; STD: distance between the points of intersection between the median coronal plane and the left and right borders of superior endplate of the vertebrae.

(4) Inferior sagittal (ISD) and transverse (ITD) diameters of the middle and lower thoracic vertebrae: ISD: distance between the points of intersection between the median sagittal plane and the anterior and posterior borders of inferior endplate of the vertebrae; ITD: distance between the points of intersection between the median coronal plane and the left and right borders of inferior endplate of the vertebrae.

Statistical analysis

We used SPSS13.0 (SPSS, Chicago, IL) for all statistical analyses. LH and RH of the vertebrae in the median coronal plane were

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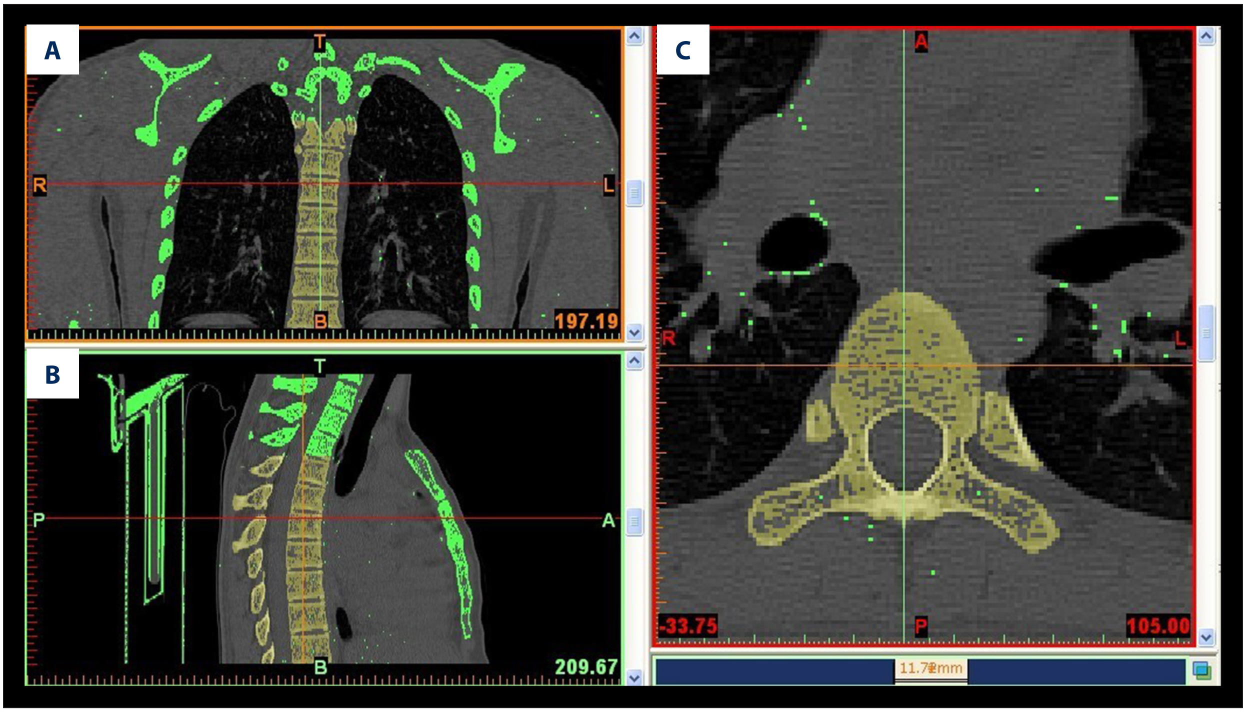

Figure 1. The true-up of different sections (**A**: coronal plane; **B**: sagittal plane; **C**: horizontal plane).

compared using paired *t* tests. Anterior, middle, and posterior vertebrae heights in the median sagittal panel were compared using repeated measures analysis of variance. Correlations between the measurement results and vertebral level were tested with bivariate Spearman rank correlation analysis.

Results

LH and RH

Both LH and RH gradually increased from T4 to T12 (Table 1). LH increased from 18.73±2.01 mm at T4 thorough 20.55±1.18 mm at T8, to a maximum of 24.12±1.65 mm at T12. Similarly, RH increased from 18.68±2.17 mm at T4 thorough 20.83±1.38 mm at T8, to a maximum of 24.03±2.18 mm at T12. No significant difference was found between LH and RH at any level except T6, where a difference of 0.38±0.92 mm was recorded (Table 1). The Spearman correlation coefficients between LH and vertebral level and RH and vertebral level were 0.728 and 0.703, respectively (both $P<0.001$). These results demonstrate a significant positive correlation of LH and RH with vertebral level. In other words, LH and RH increased at lower vertebral levels.

AH, MH, and PH

AH increased from 17.86±1.76 mm at T4 to 20.03±1.65 mm at T8 to a maximum of 24.12±1.65 mm at T12. MH increased from 17.31±1.77 mm at T4 to 19.42±1.65 mm at T8, to a maximum of 22.67±2.11 mm at T12. PH increased from 18.09±1.36 mm at T4 to 20.74±1.50 mm at T8, to a maximum of 24.68±1.74 mm at T12 (Table 2). Significant differences were found between AH and MH at all levels, expect T4, T5, and T7; between PH and MH at all levels; and between AH and PH at all levels, expect T4, T10, and T12 (Table 3). The Spearman correlation coefficients with the vertebral level were 0.777 for AH, 0.688 for MM, and 0.800 for PH (all $P<0.001$). The findings indicate significant positive correlations of AH, MH, and PH with vertebral level.

SSD and ISD

SSD increased from 21.99±2.20 mm at T4 to 28.05±2.00 mm at T8, to a maximum of 31.83±2.17 mm at T12. Similarly, ISD increased from 22.97±2.20 mm at T4 to 28.89±2.77 mm at T8, to a maximum of 32.24±3.25 mm at T12. Significant differences were found between SSD and ISD for T4, T6, T8, T9, and T11 (SSD >ISD) (Table 4). The Spearman correlation coefficients with vertebral level was 0.814 for SSD and 0.711 for ISD (both $P<0.001$), indicating significant positive correlations of SSD and ISD with vertebral level.

STD and ITD

STD increased from 24.88±2.64 mm at T4 to 31.72±2.57 mm at T8, to a maximum of 38.70±3.16 mm at T12. ITD exhibited similar changes, increasing from 27.15±2.54 mm at T4 to

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Table 1. The vertebral body height of left and right ($\overline{\chi}$±S, mm ,n=30).

Vertebrea	The vertebral body height of left	The vertebral body height of right	d-value	t	*P*
T_4	18.73±2.01	18.68±2.17	0.04±1.94	0.123	0.093
T_5	19.25±1.74	19.54±1.93	−0.28±1.31	−1.171	0.251
T_6	19.95±1.11	19.57±1.27	0.38±0.92	2.252	0.032
T_7	19.96±0.97	19.85±1.34	0.12±0.93	0.715	0.480
T_8	20.55±1.18	20.83±1.38	−0.28±0.94	−1.645	0.111
T_9	21.14±1.31	21.34±1.31	−0.20±0.87	−1.260	0.218
T_{10}	22.23±1.75	22.45±1.61	−0.22±1.08	−1.109	0.277
T_{11}	22.79±1.54	23.09±1.93	−0.29±1.51	−1.043	0.306
T_{12}	24.12±1.65	24.03±2.18	0.09±1.39	0.349	0.729

Table 2. Anterior (AH), middle (MH), and posterior (PH) heights of the middle and lower thoracic vertebrae ($\overline{\chi}$±S, mm ,n=30).

Vertebrea	AHV	MHV	PHV
T_4	17.86±1.76	17.31±1.77	18.09±1.36
T_5	17.90±1.54	17.24±2.49	18.81±1.65
T_6	18.50±1.36	18.02±1.50	19.15±1.58
T_7	18.85±1.51	18.43±1.25	19.74±1.50
T_8	20.03±1.65	19.42±1.65	20.74±1.50
T_9	20.97±1.62	20.02±1.65	21.59±1.58
T_{10}	21.68±1.89	20.61±1.76	22.05±1.49
T_{11}	22.69±2.05	21.24±3.03	23.36±1.65
T_{12}	24.53±2.69	22.67±2.11	24.68±1.74

Table 3. The difference values between AHV&MHV& PHV ($\overline{\chi}$, mm ,n=30).

Vertebrea	AHV & MHV	*P*	MHV & PHV	*P*	AHV & PHV	*P*
T_4	0.55	0.059	0.78	0.017	0.23	0.538
T_5	0.66	0.161	0.91	0.001	0.91	0.001
T_6	0.48	0.033	1.13	0.000	0.66	0.004
T_7	0.42	0.062	1.31	0.000	0.89	0.000
T_8	0.61	0.014	1.32	0.000	0.71	0.009
T_9	0.96	0.001	1.58	0.000	0.62	0.006
T_{10}	1.07	0.000	1.44	0.000	0.37	0.122
T_{11}	1.45	0.002	2.12	0.000	0.68	0.007
T_{12}	1.86	0.000	2.01	0.000	0.15	0.597

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Table 4. The compared between SSDV & ISDV ($\overline{\chi}$±S, mm ,n=30).

Vertebrea	SSDV	ISDV	D-value	t	*P*
T_4	21.99±2.20	22.97±2.13	−0.97±1.99	−2.677	0.012
T_5	23.80±2.10	24.04±1.82	−0.24±1.73	−0.774	0.445
T_6	25.05±2.35	26.57±2.00	−1.52±1.99	−4.184	0.000
T_7	27.71±3.36	28.31±2.45	−0.60±2.66	−1.238	0.226
T_8	28.05±2.00	28.89±2.77	−0.83±2.00	−2.281	0.030
T_9	28.79±2.40	29.68±3.03	−0.89±1.68	−2.904	0.007
T_{10}	29.97±2.79	30.16±2.59	−0.19±2.51	−0.410	0.685
T_{11}	31.40±1.94	29.76±2.68	1.64±2.62	3.425	0.002
T_{12}	31.83±2.17	32.24±3.25	−0.42±3.14	−0.729	0.472

Table 5. The compared between STDV & ITDV ($\overline{\chi}$±S, mm ,n=30).

Vertebrea	STDV	ITDV	d-value	t	*P*
T_4	24.88±2.64	27.15±2.54	−2.27±3.23	−3.845	0.001
T_5	26.35±2.67	28.32±2.50	−1.97±2.84	−3.806	0.001
T_6	28.18±2.54	29.76±2.34	−1.58±2.35	−3.684	0.001
T_7	29.90±2.39	30.67±2.91	−0.77±2.36	−1.795	0.083
T_8	31.72±2.57	32.51±3.10	−0.80±2.02	−2.163	0.039
T_9	32.10±3.06	34.82±3.07	−2.72±3.27	−4.561	0.000
T_{10}	34.37±2.27	37.59±3.24	−3.23±2.23	−7.908	0.000
T_{11}	36.71±2.30	39.03±3.63	−2.32±3.47	−3.670	0.001
T_{12}	38.70±3.16	42.96±5.60	−4.27±3.98	−5.875	0.000

32.51±3.10 mm at T8, to a maximum of 42.96±5.60 mm at T12. Significant differences were found between STD and ITD at all levels, except T7 (SSD >ISD at all levels) (Table 5). The Spearman correlation coefficients with vertebral level were 0.875 for STD and 0.824 for ITD (both $P<0.001$), demonstrating significant positive correlations of STD and ITD with vertebral level.

Discussion

Given the extensive clinical use of orthopedic spinal implants and research progress in spinal biomechanics since the late 1960s [4], great progress has been made in the treatment of spinal fractures, tuberculosis, tumors, and other diseases complicated with paraplegia. As such, there has been a general transition from traditional conservative treatment to more effective and aggressive surgical treatment.

Middle and lower thoracic compression fractures and spinal tuberculosis and tumors can affect the posterior spinal cord, nerves, and other important structures to cause paraplegia. Fixation via the anterolateral approach enables clearing of damaged segments under direct vision and secure fixation after bone grafting. This is the only approach to prevent surgical error-related damage to the surrounding blood vessels, nerves, and other tissues. The most important principle of external fixation is effective reduction and secure fixation. As injuries, tumors, and other diseases can completely destroy vertebral segment shape, it is imperative to determine the appropriate height of bone graft (titanium mesh) to achieve "relative anatomical reduction" and to identify a protocol to evaluate preoperative grading and postoperative efficacy for vertebral compression fractures.

Radiographic measurement of vertebral height is an important indicator for preoperative grading and determining postoperative efficacy in patients with vertebral compression fractures,

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and it has important implications for the clinical practice of spinal surgery and biomechanical research. Although there are many relevant reports in the literature, they all have some disadvantages.

By measuring the vertebrae of 124 dry bone specimens collected from northern China, Li et al. [5] obtained measurement data of various diameters of C3–L5 and identified sex and regional differences in the various diameters. However, due to dehydration, efflorescence, and cancellous bone atrophy, all of which alter bone shape, the measured values of dry bone specimens vary from those in the living body. Therefore, clinical operation cannot be performed based solely on dry bone measurement data.

Dai et al. [6] performed X-ray measurements of the anterior, middle, and posterior heights of thoracic and lumbar vertebrae in 124 normal subjects to calculate normal reference values for Chinese patients in clinical studies. However, the magnification differences between X-ray measurements and *in vivo* values will lead to errors in measurement results.

In this study, the CT imaging data were imported into a powerful interactive medical image control system where they were reorganized and analyzed through established procedures and displayed on 3 different panels. The built-in measurement tool modules can automatically eliminate the magnification effect of imaging data according to the scanning data. Therefore, the results will be a true reflection of changes in vertebrae diameters in the living body, which are more valuable for clinical use.

Anterior fixation of bone grafts in the middle and lower thoracic vertebrae are mostly performed on the lateral side of vertebrae, and the anterolateral screw to fix the graft passes through the vertebrae. After determining vertebral screw length, its location and direction are also key factors that affect fixation. According to Kaneda et al. and Rao et al. [7,8], the ideal location of the vertebral screw should be as follows: the screw does not pass into the spinal canal and should be parallel to the upper and lower cartilage endplates of the corresponding vertebra and coronal plane of the spine and the screw tip just penetrates into the contralateral cortical bone; therefore, the transverse diameter of vertebra determines the vertebral screw length. A vertebral screw that is too long can damage the contralateral tissues and organs, while one that is too short cannot reach the contralateral cortical bone, which will impair the orthopedic force and internal fixation effects [9,10].

According to the measurement results of the transverse diameters of superior and inferior endplates in this study, for screw placement at the superior border of the vertebra, a 25-mm screw should be selected for T4–T5, a 30-mm screw for T6–T9, and a 35-mm screw for T10–T12. For screw placement at the inferior border of the vertebra, a 30-mm screw should be selected for T4–T9, a 35-mm screw for T9–T11, and a 40-mm screw for T11–T12.

With regard to comparisons of sagittal and transverse diameters between the superior and inferior endplates of the same vertebra:

(1) There was no significant difference in the sagittal diameter between the superior and inferior endplates at T5, T7, T10, or T12, meaning that the superior and inferior endplates had similar sagittal diameters, while the sagittal diameter was significantly greater for the superior endplate than the inferior endplate at other levels.
(2) The transverse diameter was significantly greater for the inferior endplate than the superior endplate at all levels except T7. These conclusions are valuable for the manufacture and improvement of artificial vertebrae. As the transverse diameter is 3–4 mm greater than the sagittal diameter in the middle and lower thoracic vertebrae, it is recommended that cancellous bone grafts are trimmed into a cuboid to be placed in the transverse direction (with the length 3–4 mm greater than the width) to enable maximum recovery of anterior-posterior and left-right physiological loads for the damaged vertebrae.

For anterior fixation in the middle and lower thoracic vertebrae, emphasis should be placed on the length of the longitudinal needle during device design [11]. A too-short screw cannot sufficiently prop the compressed segments [12], and it is easy to damage the surrounding blood vessels, nerves, and other tissues during spinal flexion and extension with a too-long screw [13]. According to the measurement data of vertebral heights, most segments in the middle and lower thoracic vertebrae took the shape of an elliptical cylinder that was slightly higher at the edges and slightly lower in the middle (for some segments, the anterior edge was at a similar height as the posterior edge or the middle part). Moreover, the vertebral height gradually increased with lower vertebral levels, and the distance between 2 vertebrae (with 1 vertebra between them) was 52–56 mm for T4–T7 and 44–48 mm for T8–T12. An appropriate longitudinal needle should be selected in reference to the above data for lateral fixation of lower thoracic vertebrae.

Of course, many researchers [14,15] have found from measurements of dry bone that all vertebral diameters vary with race, height, sex, and age. Therefore, to determine ideal vertebral screw placement parameters, CT scanning should be performed for the patient's affected segments, and measurements and preoperative simulations should be conducted using software with powerful post-processing functions, such as Mimics, to develop an individualized surgical plan. These steps can improve surgery success rates and facilitate rapid recovery.

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Conclusions

1. Bone graft should prune into laterigrade cuboid, it could recovery anterior-posterior and bilateral physiological functions load.
2. Height of vertebra body increased from T4 to T12. The distance between two vertebra (interval one vertebra) range were (52–56) mm for T4–T7, (44–48) mm for T8–T12, the surgeons could collate these data to choose suitable stick length.

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