RESEARCH ARTICLE

Research of a Safe and Simplified Intertransverse Process Approach for the Lower Thoracic Interbody Surgery

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Objective: To assess a safe surgical approach for intertransverse process lower thoracic intervertebral body fusion (ITIF) based on measurements from enhanced three-dimensional CT reconstruction, cadaver simulated operation, and patient operation.

Methods: Enhanced three-dimensional CT image reconstruction was performed for 20 healthy volunteers on thoracic segments T8–T12. The length of the transverse process (LTP), distance between the upper and lower transverse processes (DULTP), remote distance of the transverse process (RDTP), height of the extraforaminal intervertebral space (HEIS), and oblique diameter of the intervertebral space (ODIS) were measured and recorded. The blood vessels of the intertransverse lower thoracic region were observed, and their internal diameters were measured. The rib-intervertebral space relationship for T10/11 and T11/12 was measured in 104 patients of the thoracic skeleton. Then, based on the data from the CT measurements, simulated surgery was performed on six human cadavers at the T11/12 level. An ankylosing spondylitis (AS) patient with a fracture of the T10/11 level was eventually operated on with the ITIF technique.

Results: No significant difference was found between the lengths of the left and right thoracic transverse processes. The relationship of the values of the LTP and RDTP for the measured vertebrae were found to be as follows:T8 > T9 > T10 > T11 > T12. For HEIS and DULTP, T8–9 < T9–10 < T10–11 < T11–12. The results for the ODIS were as follows: T8–T9 < T9–T10 < T10–T11 < T11–T12. The blood vessel inner diameter of T11–12 was less than that of T10–11, while there was no significant difference between the diameters for T8–9 and T11–12. Almost half of the volunteer's T10/11 intervertebral spaces were covered posteriorly by the 11th rib (45.19% on left and 41.35% on right), while for most patients, the T11/12 intervertebral space was not covered by the 12th rib (98.08%). According to the cadaver experiments, intervertebral bone grafting and ipsilateral pedicle screw fixation were performed to simulate the operation. One patient with a combined AS and T10/11 fracture was then operated on with the ITIF technique and followed up for 3 years with satisfactory results.

Conclusion: As verified by 3D CT reconstruction measurements, cadaver simulation surgery and patient operation with follow-up, the intertransverse process approach for some T10/T11 and almost all T11/T12 segments is a safe surgical pathway for operations such as ITIF, fracture bone grafting, clearance of focal lesions.

Key words: Cadaver; Intertransverse process approach; Intervertebral body fusion; Lower thoracic segment

Introduction

As a frequently occurring disease, low back pain is a major public health concern worldwide, resulting in vast societal and economic impacts.[1–5] In recent years, there has been a growing need for patients to undergo lumbar fusion surgery. However, according to previous studies, compared with those for lumbar vertebral fusion surgery, the indications for thoracic vertebral fusion surgery are limited, and thoracic vertebral dysfunction is rarely treated with interbody fusion surgery.[4,6,7] As the number of unstable thoracic fractures caused by car accidents, such as charge fractures, continues to increase, stringent requirements for the surgical treatment of spinal fractures in patients with ankylosing spondylitis (AS) are becoming more highly desired. Intervertebral fusion of the thoracic vertebrae is a new high-level surgical technique that could be used to treat such fractures.[8]

Traditional surgical approaches that can reach the thoracic intervertebral disc space include open thoracotomy, the thoracoabdominal approach, the anterior or lateral thoracoscopic approach, the lateral extended resection approach, the transverse rib process approach, and the transpedicular approach.[9,10] These approaches, however, remove some structural parts of the thoracic bone and could cause some instability. Despite the smaller number of thoracic fusion surgery approaches than lumbar fusion surgery approaches, the transforaminal thoracic interbody fusion (TTIF) surgical technique has been reported in recent studies.[11,12] TTIF is performed through the intervertebral foramen without damaging the thoracic spinal cord. This surgery avoids the need for wide exposure of the thoracic posterior tissue and is considered much safer than some existing thoracic vertebral fusion surgeries.[13] However, TTIF surgery still requires removal of the thoracic facet joint, destroying the bony stability of the corresponding operative segment. Additionally, the surgical area is still relatively close to the thoracic spinal cord, thus conferring a comparatively high risk of spinal cord injury, and careful and meticulous operation skills and electrophysiological monitoring are necessary.[14]

To achieve a higher fusion rate and fewer complications, we propose a new approach method through the intertransverse process space to perform lower thoracic interbody fusion (ITIF) and bone grafting if needed. In this technique, lower thoracic interbody fusion is performed through the transverse process space by a paravertebral approach and removal of the corresponding intervertebral disc. By avoiding removal of the lamina or articular facet joints and damage to the stability of the posterior column, this approach is useful for patients with certain surgical indications.

As ITIF is newly developed technique, this project was routinely designed and consisted of the following steps. First, the feasibility of the intertransverse process approach to the intervertebral body space was assessed. The lower thoracic spine is commonly considered to span from T8 to T12.[15] Unlike the lumbar intertransverse processes, there are ribs between the thoracic transverse processes and intervertebral body spaces for every segment. First, the researchers measured the bony length and space of the transverse process, intervertebral space, ribs, and so on. As nerves usually travel alongside blood vessels, enhanced CT can show the position and relationship of the nerve and bone. Thus, 3D CT reconstruction was used to illustrate the structure of the lower thoracic area. By obtaining measurements from a number of volunteers and patients, enough data was collected to determine the segment suitable for the ITIF technique. Second, the technique was tested with cadaver simulation surgery. Measurements can only provide some clues on the feasibility of ITIF for a particular segment, but conducting the surgical procedure is another matter entirely. Simulating surgery on cadavers further confirmed the feasibility of the approach and even served as a demonstration of the surgical technique with real surgical instruments and protocols. Third, with the positive results of simulating surgery, the technique was finally used clinically on real selected patients with real symptoms. Sufficient patient follow-up provided additional evidence for the quality of the surgical results.

Materials and Methods

Volunteer Selection and Measurement of the T8–12 Bone Structures

Ethical approval was granted by the Medical Ethical Committee of the Affiliated Hospital of Shandong University of Traditional Chinese Medicine (TCM), and the experimental protocol was approved by the institutional review board of the Affiliated Hospital of Shandong University of TCM. A written informed consent document was obtained from each participant. Enhanced three-dimensional CT scans were conducted on 20 volunteers (age range, 25–55 years; mean, 42.63 ± 10.42 years) without thoracic disorders on the lower thoracic segments, T8–T12.

Measurement of the LTP

The length of the transverse process (LTP) refers to the straight-line distance from the outermost end to the base of the transverse process (Fig. 1A). As demonstrated in Fig. 1A, the LTP is easily measured, spanning from the tip along the middle line of the transverse process to the base where the process joins the vertebral arc. The clinical significance of LTP lies in amount exposed during the intertransverse process approach; a sufficient LTP allows an easier operation.

Measurement of the RDTP

The remote distance of the transverse process (RDTP) refers to the straight-line distance from the tip of one transverse process to the other on the same vertebra; Fig. 1A shows this distance as well as the measurement technique, which is performed using the built-in scale in the picture archiving and communication system on the coronal plane of the lower thoracic segment. The RDTP allows the surgeon to develop a preoperative plan, since the width of the surgical field affects the length of the incision.
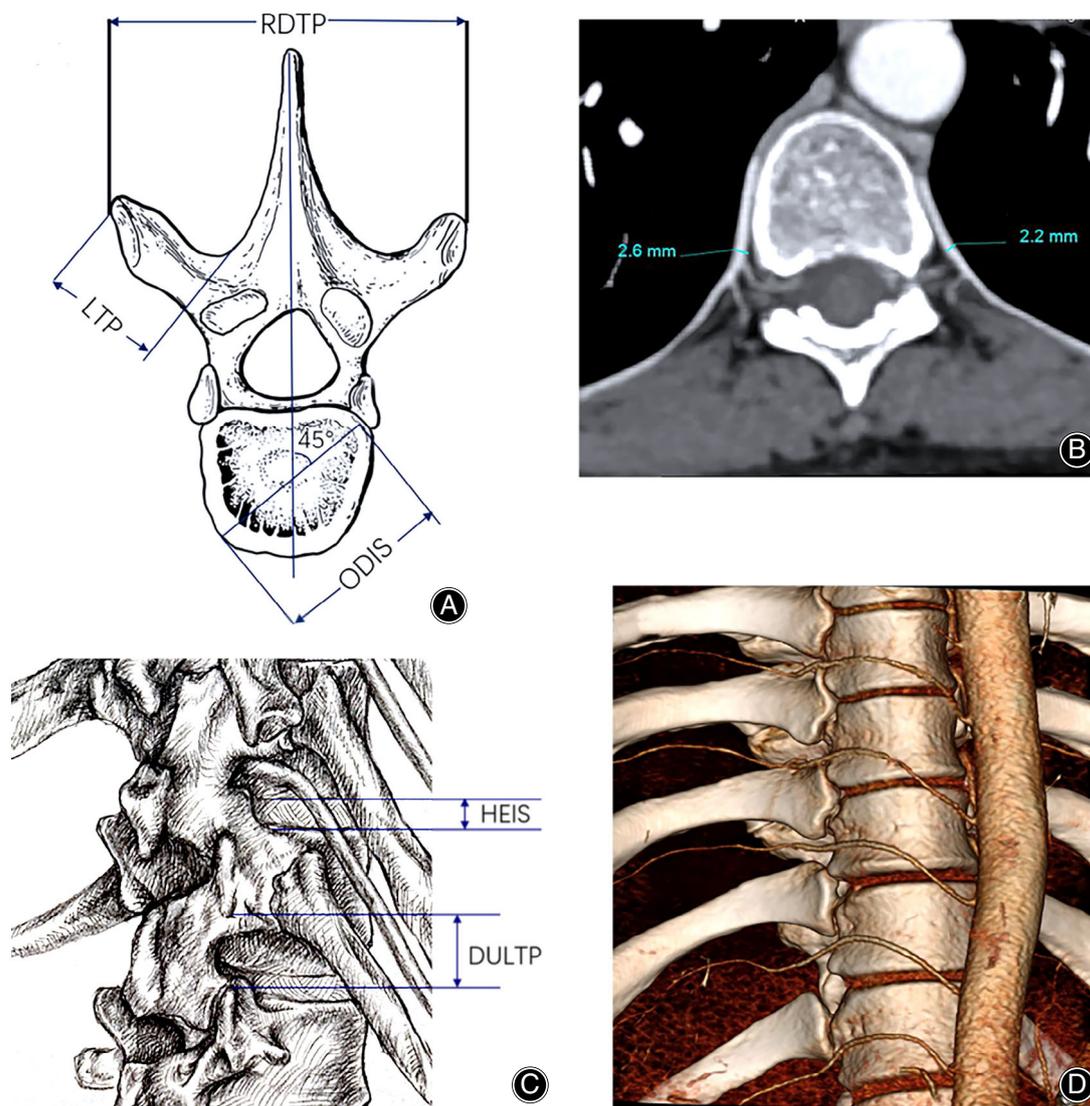
Fig. 1 (A) Measurement of the length of transverse process (LTP) and the remote distance of transverse process (RDTP), as well as the oblique diameter of intervertebral space (ODIS). (B) Measurement of blood vessel internal diameter. (C) Measurement of distance of upper and lower transverse process (DULTP) and the height of extra-foraminal intervertebral space (HEIS). (D) The enhanced 3D reconstruction of thoracic part showed the posterior intercostal artery and its dorsal branches. The relationship of intervertebral disc, rib, and blood vessels can be seen clearly

Measurement of the DULTP

The distance between the upper and lower transverse processes (DULTP) was defined as the vertical distance between the lower part of the upper thoracic transverse process to the upper part of the lower thoracic transverse process. As demonstrated in Fig. 1C, the key to determining the DULTP is to measure the base of the transverse process where it joins the vertebral arc. In fact, this is the most important measurement of the lower thoracic bone structure for conducting ITIF because this distance determines the space for the intervertebral fusion operation.

Measurement of the HEIS

The height of the extraforaminal intervertebral space (HEIS) refers to the height of the intervertebral space from the extraforaminal angle. As shown in Figure 1C, to measure the HEIS, two straight lines are drawn along the cross section of the thoracic intervertebral space to measure the vertical distance between the upper and lower ends of the thoracic vertebrae (Fig. 1C). This is another very important measurement for the ITIF operation since the height determines the feasibility of intervertebral fusion with only a bone graft or cage.
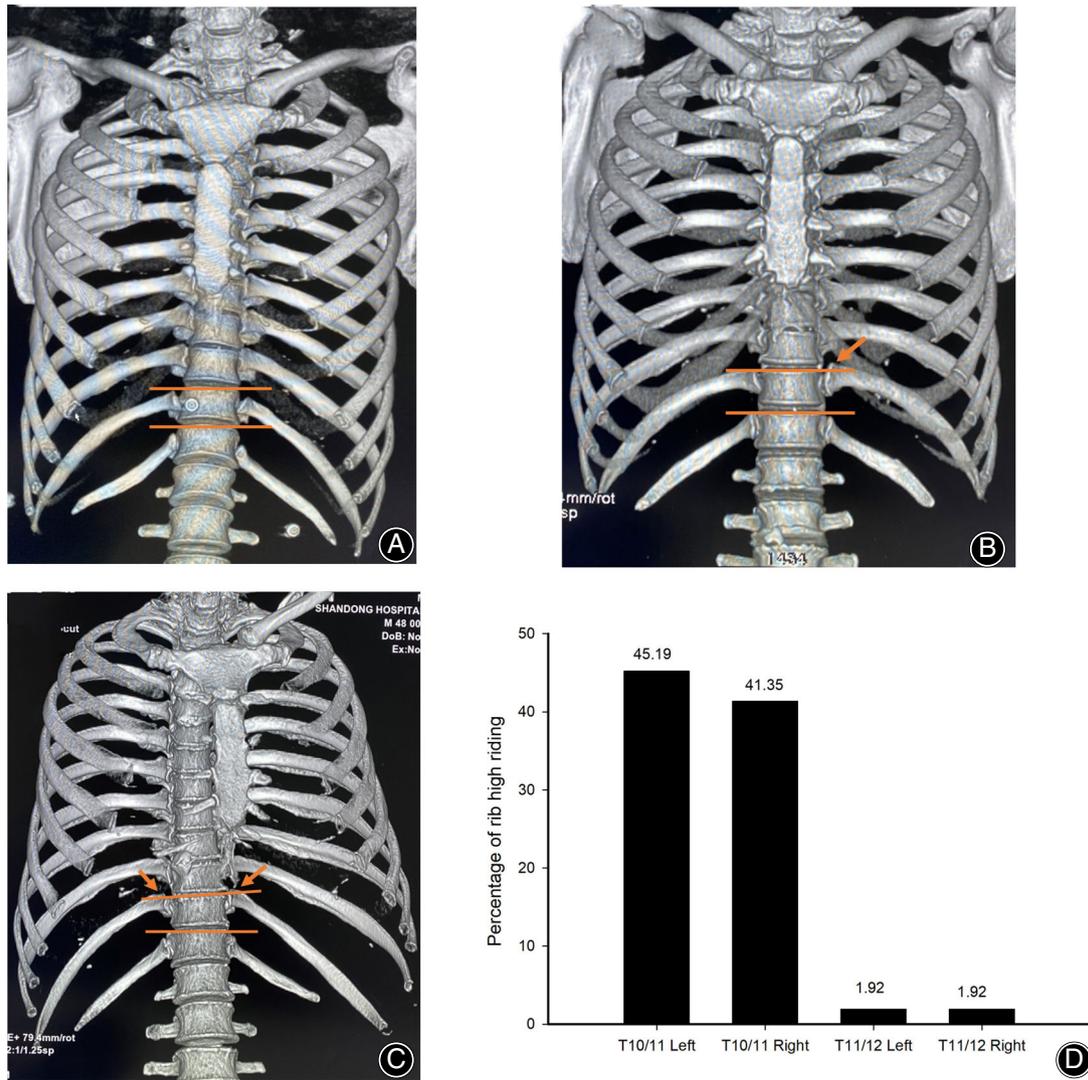
Fig. 2 3D reconstructed thoracic skeleton images were observed to define the rib-intervertebral disc space relationship of lower thoracic vertebrae T10/11 and T11/12. (A) Both sides of 11th and 12th rib are lower than the level of T10/11 and T11/12 intervertebral disc space. (B) The highest part of left 11th rib is higher than the lowest level of T10/11 intervertebral space (high riding). (C) Both sides of 11th rib is higher than the T10/11 intervertebral space (high riding). (D) Rib high riding percentage of T10/11 and T11/12 is demonstrated with the bar chart

Measurement of the ODIS

The oblique diameter of the intervertebral space (ODIS) refers to the diameter of the intervertebral space in its cross-section at an angle of 45° to the spinous process axis (Fig. 1A). The ODIS can be easily measured on cross-sectional CT, as shown in Fig. 1A. The magnitude of the ODIS can provide some guidance to the surgeon when performing discectomy and bone grafting or when inserting a cage. It can indicate the depth and range of the reamer necessary to avoid injury to both the blood vessels (caused by applying it too deeply) and spinal cord (caused by applying it too obliquely and too shallow).

Measurement of the Vascular Structure of the Intertransverse Lower Thoracic Vertebrae (BVID)

After examination by enhanced three-dimensional CT and image reconstruction, the intertransverse blood vessels of the lower thoracic region were observed, and the blood vessel internal diameter (BVID) in the intertransverse surgical area was measured (Fig. 1B). The ribs have a significant effect on the measurement of the thoracic vertebrae, so the positional relationship of ribs and the transverse process is also of vital importance, especially when assessing the intertransverse blood vessels of the lower thoracic region and measuring their internal diameter. According to the

AN INNOVATIVE APPROACH FOR LOWER THORACIC SURGERY

Fig. 3 Cadaver simulation of ITIF. (A) Exposure of transverse processes of T11 and T12. The thoracic nerve root was separated and demonstrated with hemostatic forceps. (B) The intervertebral disc area of T11/12 was exposed. (C) Measurement of operating space between the transverse process T11 and T12. (D) Nucleus pulposus and cartilaginous endplate was removed with curette. (E) Cage with the size 22 mm × 8 mm × 7.5 mm was inserted after proper bone grafting. (F) Pedicle screws placed into position with hand-free technique and rod attached to finish the fixation system

positional relationship between the ribs and transverse processes on the sagittal plane, the transverse process space can be divided into the posterior transverse process space, intertransverse space, anterior transverse process posterior costal space, intercostal space, and anterior costal space. The thoracic blood vessels were detected on CT, and the internal diameter of the blood vessels was measured. The dorsal branches of the intercostal artery were also identified on CT, and their positional relationship with the transverse process was recorded (Fig. 1D).

Rib-Intervertebral Disc Space Relationship Assessment (High Riding) for T10/11 and T11/12

The most significant difference between the thoracic and lumbar vertebral bodies is the costovertebral joint. As the ribs form a sort of thoracic cave and protected the internal organs, they also block surgical approaches from the intertransverse spaces. A total of 104 patients who underwent 3D CT scans of the thoracic skeleton from January 2018 to December 2019 in our hospital were selected for measurement. Ethical approval was granted by the Medical Ethical
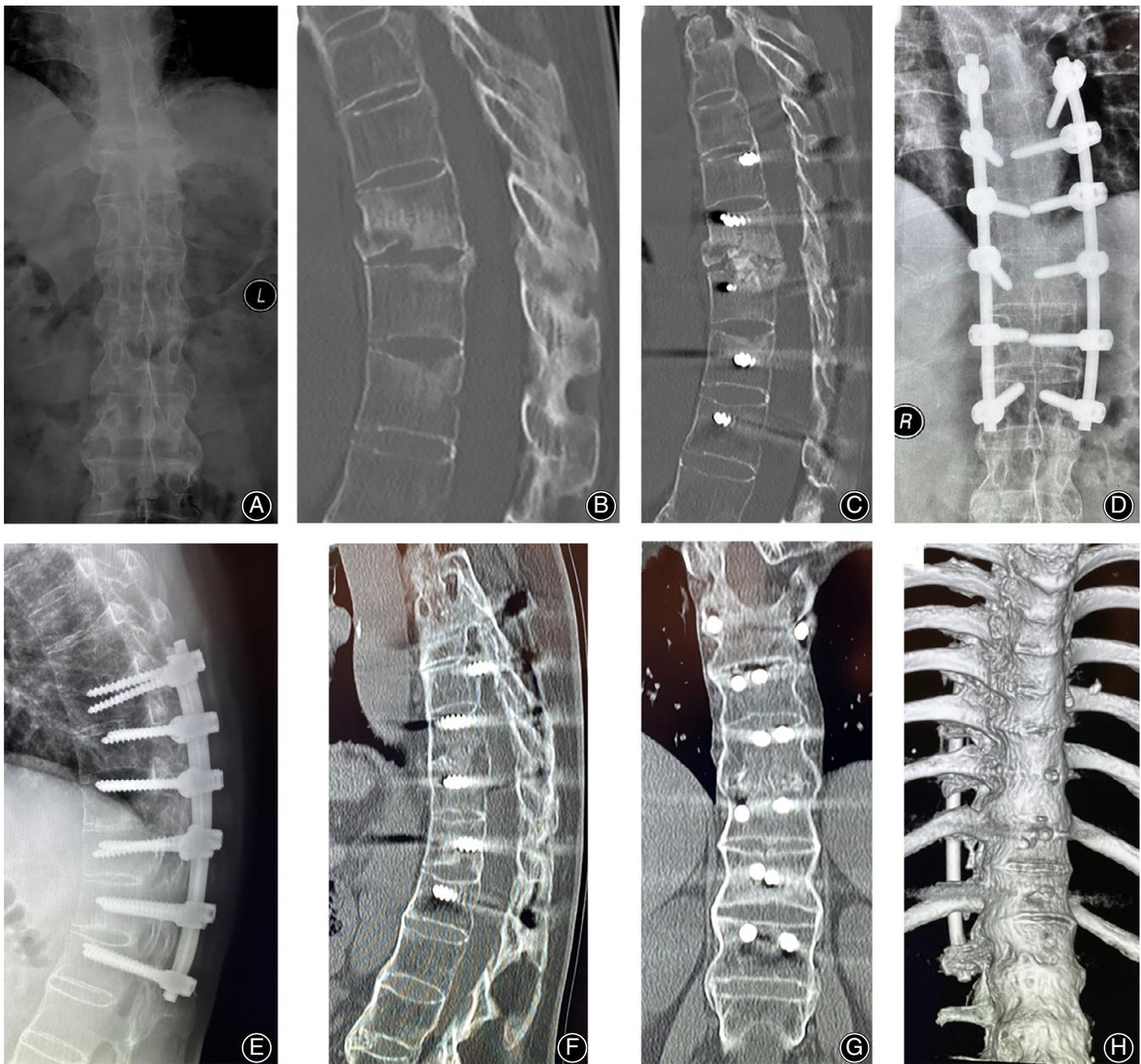
Fig. 4 Typical case report. F/51, ankylosing spondylitis with fracture of T10/11 underwent intertransverse approach autograft fusion and long segment internal fixation T8 - L1. (A) Anterior-posterior (AP) view preoperative showed typical bamboo like change of spine column with discontinuity of T10/11 level. (B) Sagittal plane view of CT reconstruction showed fracture places of anterior-inferior part of T10 vertebral body, posterior-superior part of T11 vertebral body, and posterior-interspinous process of T10/11 (not so obvious). (C) Two days post operation CT sagittal plane view showed autograft of iliac bone through intertransverse approach and the alignment after internal fixation of long segment rod and pedicle screws. (D) AP view of internal fixation 2 days post operation. (E) Lateral view of plain X ray on 3 year follow up showed almost perfect remodeling of fracture place T10/11. (F) Sagittal plane CT of 3 year follow-up further approved the union and remodeling of anterior and posterior part of T10/11 vertebral body. (G) Coronal plane CT of 3 year follow up showed the union and remodeling of both lateral part of T10/11 vertebral body. (H) Anterior view of 3D reconstruction of 3 year follow-up

Committee of the Affiliated Hospital of Shandong University of TCM, and the experimental protocol was approved. Patient ages ranged from 13 to 91 years (mean ± SD: 55.21 ± 16.74 years), with 50 males and 54 females. The

reconstructed 3D bone thoracic images were analyzed from different angles to define the rib-intervertebral disc space relationships of lower thoracic vertebrae T10/11 and T11/12 (Fig. 2). If the upper part of the rib head was higher than the

lower level of the intervertebral space, then the rib was considered "high riding" for the space (Fig. 2B,C).

Cadaver Simulation of ITIF

Six cadavers were used for the experiment. ITIF was simulated with the following procedures (Fig. 3): (i) positioning—the cadaver was placed in the prone position, and the T11–T12 segment was located *via* anatomical markers; (ii) Incision—an approximately 10 cm incision was made 3–5 cm lateral to the midline of the back;. (3) exposure of the T11–T12 transverse process—fat and loosely connected tissues were separated, the thoracodorsal fascia was sectioned, and the muscles were exposed. The spinalis thoracis and longissimus thoracis were separated to access the transverse process area of T11 and T12; (iv4) Observation—the anatomical structures of the T11–12 transverse process area, such as the dorsal branch of the posterior intercostal artery and nerves, were observed and recorded; (v) exposure of the intervertebral disc—the intertransverse ligament was resected, and the thoracic nerve root was identified for protection (Fig. 3A). The space of the intertransverse area was enlarged to expose the intervertebral disc area of T11/12 (Fig. 3B,C); (vi) fusion—the annulus fibrosus was cut open with a pointed blade, and the majority of the nucleus pulposus was removed with a curette and nucleus pulposus forceps (Fig. 3D). All the endplate cartilage was removed, followed by bone grafting and insertion of a cage of appropriate size (Fig. 3E); and (vii) internal fixation—pedicle screws were placed ipsilaterally for fixation. Anatomical landmarks were used for entry point selection, and the screws were placed in position hands-free. A rod was attached to the screws to finish the fixation system (Fig. 3F).

Statistical Analysis

Data are presented as the means $\pm$ SD. Statistical significance was determined by Student's t test (SPSS™) and one-way analysis of variance followed by the Student–Newman–Keuls *post hoc* test. All tests were performed using SPSS 19.0 software (SPSS™, Chicago, IL, USA), and $P < 0.05$ was considered to indicate statistical significance. The intraclass correlation coefficient (ICC) value was used for the interobserver reliability and test–retest reliability. ICC = 0.91 showed that the consistency of the measuring process was reliable.

Typical Case Report

Following successful cadaver experiments, a patient with an appropriate indication for the ITIF technique was selected for the procedure after permission was obtained from the Ethics Committee of our hospital. The patient is a 51-year-old female who has been experiencing AS for 30 years and was injured by a car accident 3 days prior. Imaging findings verified a fracture of the T10/11 level with no obvious translation or dislocation of the fracture site(Fig. 4A,B). No nervous deficit was found. ITIF with long segment internal fixation of T8-L1 was performed as described previously. Briefly, the patient was placed in the prone position after general anesthesia induction. Then, the body surface projections of the T8 to L1 pedicles were marked, and an incision line was drawn along the midline of the surgical area. The transverse processes and facet joints were exposed from T8 to L1. After insertion of pedicle screws from T8 to L1, the intervertebral disc between T10 and T11 was treated using a left intertransverse approach, and an autograft with iliac bone was implanted. Then, a rod was placed to complete the fixation system(Fig. 4C).

Results

Measurement of the LTP and RDTP

There was no significant difference between the lengths of the left and right thoracic transverse processes. The relationship among the lengths of the different thoracic transverse processes were T8 > T9 ($t = 0.529$, $P = 0.603$), T9 > T10 ($t = 5.248$, $p = 0.000$), T10 > T11 ($t = 11.497$, $P = 0.000$), and T11 > T12 ($t = 10.150$, $P = 0.000$). The RDTPs also shared this relationship: T8 > T9 > T10 > T11 > T12. Among the RDTP values of the lower thoracic segment, the following pairs were significantly different: T8 > T9 ($t = 2.085$, $P = 0.051$), T9 > T10 ($t = 3.187$, $P = 0.005$), T10 > T11 ($t = 6.522$, $P = 0.000$), and T11 > T12 ($t = 4.133$, $P = 0.001$).

TABLE 1 Measurement of transverse process (LTP) and the RDTP ($\bar{X} \pm s$, mm)							
	LTP						
Vertebrae	Right LTP	Left LTP	T value	p value	RDTP	t value	P value
T8	23.10 ± 2.29	23.25 ± 2.15	0.529	0.603	58.65 ± 5.05	2.085	0.051
T9	22.95 ± 2.24	23.10 ± 2.40	5.248	0.000	57.55 ± 4.36	3.187	0.005
T10	21.05 ± 2.09	21.30 ± 2.30	11.497	0.000	55.20 ± 5.28	6.522	0.000
T11	17.05 ± 1.54	16.93 ± 2.20	10.150	0.000	50.65 ± 4.38	4.133	0.001
T12	12.75 ± 2.51	13.00 ± 2.47	–	–	46.05 ± 6.53	–	–

There was no difference between left and right side of LTP. t and P value are T8 compared with T9, T9 compared with T10, T10 compared with T11, and T11 compared with T12.; LTP, length of transverse process; RDTP, remote distance of transverse process.

AN INNOVATIVE APPROACH FOR LOWER THORACIC SURGERY

TABLE 2 Measurement of DULTP and HEIS ($\bar{X} \pm s$, mm)

Segment	DULTP				HEIS			
	Right	Left	T value	p value	Right	Left	T value	p value
T8/9	14.20 ± 2.53	14.25 ± 2.15	0.326	0.748	2.51 ± 0.57	2.44 ± 0.68	0.12	0.905
T9/10	14.05 ± 2.06	14.55 ± 2.26	−4.884	0.000	2.53 ± 0.60	2.50 ± 0.67	−3.108	0.006
T10/11	16.10 ± 2.15	15.95 ± 2.19	−2.994	0.007	2.97 ± 0.69	2.95 ± 0.66	−2.826	0.011
T11/12	18.30 ± 3.85	18.45 ± 3.35	–	–	3.30 ± 0.63	3.29 ± 0.68	–	–

There was no difference between left and right side, t and P value are T8/9 compared with T9/10; T9/10 compared with T10/11; T10/11 compared with T11/12.; DULTP, distance of upper and lower transverse process; HEIS, height of extraforaminal intervertebral space.

The quantitative data for the LTP and RDTP values are shown in Table 1.

Measurement of DULTP and HEIS
The relationship among the DULTP was as follows: T8/T9 and T9/T10 < T10/T11 < T11/T12. Among the DULTP values of the lower thoracic segment, T8/T9 < T9/T10 ($t = 0.326$, $P = 0.748$); T9/T10 < T10/T11 ($t = 4.884$, $p = 0.000$); and T10/T11 < T11/T12 ($t = 2.994$, $P = 0.007$). Among the HEIS values of the lower thoracic segment, T8/T9 < T9/T10 ($t = 0.120$, $P = 0.905$); T9/T10 < T10/T11 ($t = 3.108$, $P = 0.006$); andT10/T11 < T11/T12 ($t = 2.826$, $P = 0.011$). The quantitative data for the DULTP and HEIS are shown in Table 2.

Measurement of ODIS
The relationship among the ODIS values was T8/T9 < T9/T10 < T10/T11 < T11/T12 ($p < 0.05$), T8/T9 < T9/T10 ($t = -2.901$, $P = 0.009$), T9/T10 < T10/T11 ($t = -6.610$, $P = 0.000$) and T10/T11 < T11/T12 ($t = -6.347$, $P = 0.000$). The quantitative data for the ODIS are shown in Table 3.

Anatomy and Distribution of the Main Blood Vessels of the Intertransverse Surgical Area and Measurement of the BVID
Reconstruction of the three-dimensional CT images clearly demonstrated the blood supply of the lower thoracic intertransverse area. The blood supply of the lower thoracic intertransverse areas, including T8–T9, T9–T10, T10–T11, and T11–T12, originated from the posterior intercostal artery and its dorsal branches (Fig. 1B,E). The right posterior intercostal arteries of T8–T9, T9–T10, and T10–T11 were located in the middle intercostal space level. Moreover, the right posterior intercostal arteries of T11–T12 and T12–L1 were found at the middle intercostal space level, and the artery of T8–T9 was located at the upper intercostal space level. Arterial circuities were found in the lower thoracic intertransverse area. Similarly, the left posterior intercostal arteries of T8–T9 were identified at the middle intercostal space level, and the artery of T9–T10 was located at the lower intercostal space level. Generally, artery circuities and variations of the arterial trunk were found in the lower thoracic intertransverse area.

The BVID values of the intertransverse surgical area were also evaluated on reconstructions of the enhanced three-dimensional CT images (Fig. 1B). The relationship among the values of the BVID in the intertransverse surgical area was T8/T9 and T11/T12 < T9/T10 and T10/T11 overall. Specifically, T8/T9 < T9/T10 ($t = 1.155$, $P = 0.262$), T9/T10 < T10/T11 ($t = 0.702$, $P = 0.491$), and T10/T11 > T11/T12 ($t = 1.635$, $P = 0.118$). The quantitative data for the BVID are shown in Table 3.

Rib High Riding Percentages for T10/11 and T11/12
As shown in Fig. 2D, 45.19% of the ribs on the left side and 41.35% of the ribs on the right side of T10/11 were high riding according to the intervertebral level. The equivalent percentages for T11/12 were only 1.92% for both sides.

Cadaver Simulation of ITIF and the Case Report
ITIF of T11/12 was successfully performed on all six cadavers, all with cages measuring 22 mm × 8 mm × 7.5 mm. The operation for the patient was successful, with no infection or other complications. Following their experience with the six cadaver simulations, the surgeons were strongly recommended to maintain a safe instrument angle when operating on the intervertebral discs and bone grafts. Intraoperative fluoroscopy was necessary to ensure that the spinal cord was not impacted. The 3-year follow-up showed very good bone union and remodeling of the fracture site (Fig. 4D–H).

Discussion

Anatomical Structure of the Lower Thoracic Area Measured by Enhanced CT
Ordinary CT examinations are widely used in the diagnosis and treatment of various orthopedic disorders because of their clear demonstration of the structure of human skeleton and have also been used to measure the bone structures of the cervical vertebrae, thoracic vertebrae and lumbar vertebrae in basic and clinical research.[16,17] In the current study, the lower thoracic intertransverse area anatomy was comprehensively described with reconstruction of enhanced three-dimensional CT images, and the posterior intercostal artery and its second branches were measured with great precision.

TABLE 3 Measurement of ODIS and BVID ($x \pm s$, mm)

Segment	ODIS				BVID			
	Right	Left	t value	P value	Right	Left	t value	P value
T8/9	32.20 ± 3.46	32.55 ± 3.55	−2.901	0.009	2.17 ± 0.39	2.20 ± 0.39	−1.155	0.262
T9/10	33.45 ± 3.17	34.05 ± 3.02	−6.610	0.000	2.29 ± 0.40	2.30 ± 0.41	−0.702	0.491
T10/11	36.05 ± 3.53	36.60 ± 3.65	−6.347	0.000	2.34 ± 0.36	2.40 ± 0.37	1.635	0.118
T11/12	38.30 ± 3.83	38.95 ± 3.80	–	–	2.21 ± 0.29	2.24 ± 0.34	–	–

There was no difference between left and right side, t and P value are T8/9 compared with T9/10; T9/10 compared with T10/11; T10/11 compared with T11/12.; BVID, blood vessel internal diameter; ODIS, oblique diameter of intervertebral space.
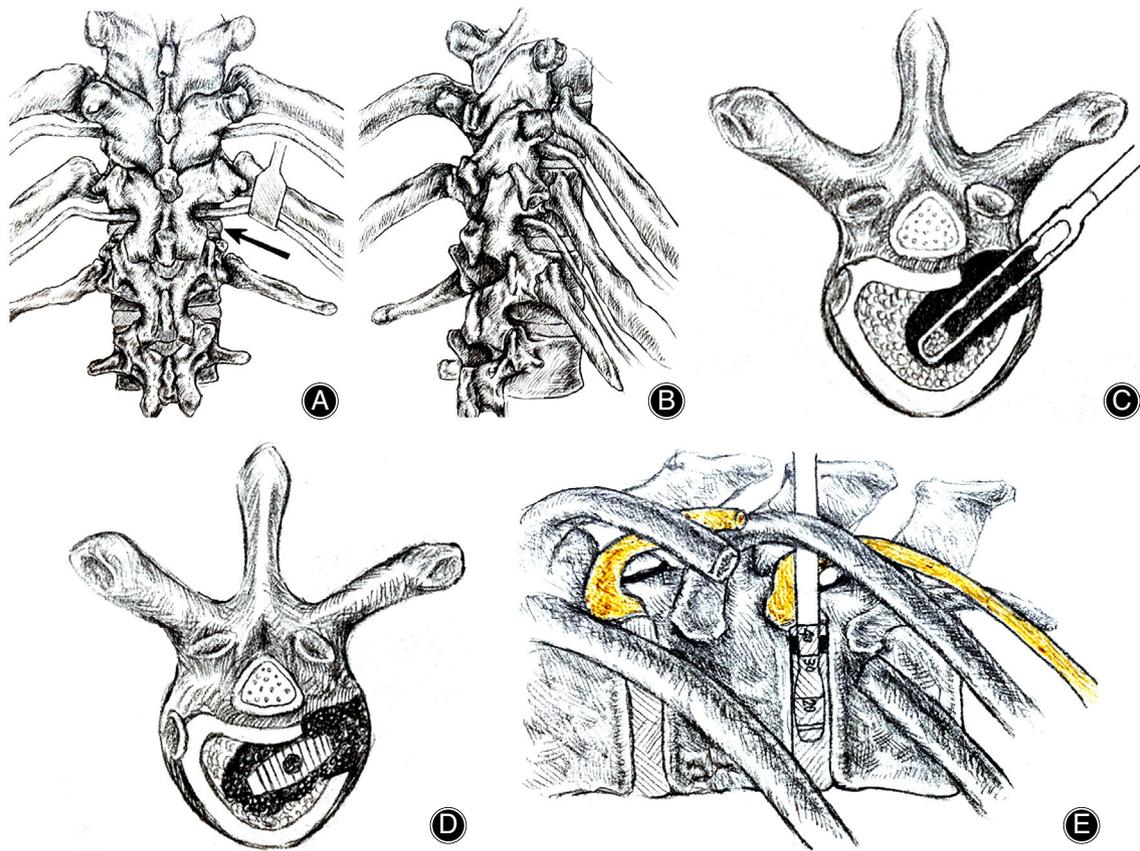
Fig. 5 (A) Posterior view of lower thoracic segment T10/11 and T11/12. (B) Oblique view of lower thoracic segment so the relationship of transverse process, rib, nerve (and blood vessel, since it travels along with nerve) and intervertebral disc space could be demonstrated more clearly. (C) Prone lateral view simulating operation of intervertebral body fusion with cage and autograft. (D) Illustration of discectomy of lower thoracic segment T11/12. (E) Illustration of autograft and cage insertion to fulfill the fusion

Compared to that with traditional autopsy, arterial demonstration of the thoracic intertransverse area with enhanced three-dimensional CT image reconstruction is regarded to be more intuitive, efficient, and easier to manage.[18] Therefore, enhanced three-dimensional CT image reconstruction technology has great clinical application value for anatomical research on the human skeletal structure and blood vessel distribution of the lower thoracic intertransverse area.

To avoid traction injury of the spinal cord, thoracic intertransverse bone grafting is performed during the spinal fusion surgery; however, the surgical physicians often have to contend with vascular damage in the lower thoracic intertransverse surgical area, the narrowness of the surgical field and the high incidence of postoperative hematoma.[19] The blood supply of the lower thoracic intertransverse area, including T8–T12, originated from the posterior intercostal

artery and its dorsal branches. At the intervertebral foramen level, the posterior intercostal artery, located in the upper intertransverse space, supplies the dorsal branches along with the intercostal space.[20,21] Arterial circuities and variations of the arterial trunk were found in the lower thoracic intertransverse area. At the intervertebral foramen level, the dorsal branches of the arterial trunk were found in the upper intertransverse space, and the arterial distribution of the lower thoracic intertransverse area demonstrated some regularity. Knowledge of the anatomical structure of the surgical area also helped minimize intraoperative blood loss and increase the safety of the operation.

Feasibility and Limitations of ITIF

Spinal fusion surgery, as reported by Albee,[22] has been performed for the treatment of spinal disorders, including spinal tuberculosis, spinal fracture, spinal congenital malformation, spondylarthritis, and spinal degenerative diseases.[23,24] In recent research, traditional spinal surgical approaches used to reach the thoracic intervertebral disc space have included the thoracoabdominal approach, open thoracotomy, the anterior or lateral thoracoscopic approach, the lateral extended resection approach, and the transpedicular approach.[25] According to research by Kim *et al.* and Karmakar and Ho, the anterior surgical approach provided an excellent thoracic operative region and intervertebral disc tissue exposure; however, it was often associated with significant respiratory and surgical incision-related complications.[26,27] Through the posterior surgical approach, surgeons have been shown to reach the intervertebral space with a low incidence of complications, but the surgical field exposure was limited posteriorly by the spinal cord, especially in the lateral extended resection operative approach.[28] TTIF was performed for thoracic vertebral interbody fusion through the vertebral foramen without damage to the thoracic spinal cord. However, this procedure requires extremely high-level, skilled manipulation and a complex surgical protocol for removing the thoracic facet joint, breaking the bone stability of the corresponding vertebral segment.[29] In the current study, we report ITIF for the treatment of thoracic vertebral disorders (Fig. 5). The ITIF technique, which involves a lower thoracic lateral approach, does not require removal of the thoracic vertebrae, transverse processes or ribs, thus preserving the posterior column structure of the thoracic vertebrae. Compared with that of TTIF, the operating zone of ITIF in the current research could be created further from the spinal cord, which means that this approach is safer, more stable and more reliable. The aforementioned data suggest that ITIF, when conducted through the intertransverse surgical area, could serve as a potential treatment for thoracic vertebral disorders. Based on the data from three-dimensional CT image reconstruction, the DULTPs of T10–T11 and T11–T12 were larger than those of T8–T9 and T9–T10. Likewise, the thoracic intervertebral disc spaces of T10–T11 and T11–T12 were greater than those of T8–T9

and T9–T10. However, according to our assessment of the number of high riding ribs of the lower thoracic area, approximately half of the T10/11 and almost all of the T11/12 segments are not blocked by ribs. Unfortunately, almost all ribs are high riding above these two segments, and ITIF therefore is not feasible.

Cadaver Simulation and Clinical Usage Report

Six cadavers were used to compare different approaches to the intertransverse area from the muscle space. The longissimus pectoralis and pectoral spinous muscle space was found to be more suitable than the space between the longissimus pectoralis and pectoral iliac costal muscles. The reason is that more muscles are attached in the area of the pectoral iliac costal muscle contains a larger number of attached muscles and more traveling blood vessels; hence, the surgical trauma and operative time and expenses are larger. Cage insertion can be performed at a range of angles to adapt to the position of the intervertebral space, and preparation of the cartilage endplate must be adequate. The entry point of the pedicle screw can be slightly more lateral than usual, but the tilt angle on the transverse plane must be adjusted accordingly. Some studies about the biomechanics of lower thoracic spinal fusion and instrumentation[30,31] can be used for reference.

For the patient in the case report, there was no need for laminectomy for decompression since no space occupation in the vertebral canal and no nervous deficits were found. Intervertebral body autografts can restore anterior column stability and promote fusion, although some authors may argue that autografts are not absolutely necessary. The intertransverse approach showed significant advantages in not disturbing the spinal cord, and the patient demonstrated very good results at the 3-year follow-up. ITIF has been performed by our medical team for 5 years for patients with similar indications, and we expect to publish a clinical report with a very large number of cases in the future.

Some authors[31,32] have mentioned that the lower thoracic spine is not destabilized by sequential unilateral decompression procedures. The lower thoracic spine is not significantly different from the upper thoracic spine in terms of flexion-extension and lateral bending after decompression despite the lack of true ribs. ITIF will then be well indicated if bilateral decompression is needed or discectomy must be performed while maintaining the height of the disc. There is much more to be studied regarding ITIF, but to the best of our knowledge, no other group are investigating this surgical procedure.

Some may argue that the indications for ITIF are quite limited given the high riding nature of the ribs over level T10. It is true that only two levels of the 11 thoracic intervertebral spaces are suitable for the technique according to our research, but we still consider it to be innovative, even if it only provides a small improvement for spinal surgery.

Conclusion

Enhanced three-dimensional CT image reconstruction provided a clear demonstration and precise measurement of the lower thoracic vertebral and vascular structures. There is some regularity in the artery distribution of the lower thoracic intertransverse area, which could help minimize intraoperative blood loss and improve the safety of the operation. ITIF, performed through the intertransverse surgical area, simulated by cadaver operations, and verified by a clinical case, was shown to be a potential treatment for thoracic vertebral disorders. Intertransverse lower thoracic interbody fusion in half of the T10–T11 and almost all of the T11–T12 segments is feasible.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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