CLINICAL ARTICLE

Pedicle Morphology of Lower Thoracic and Lumbar Spine in Ankylosing Spondylitis Patients with Thoracolumbar Kyphosis: A Comparison with Fracture Patients

Ji-chen Huang, MD, Wen-bin Xuan, MD, Bang-ping Qian, MD, Yong Qiu, MD, Bin Wang, MD, Yang Yu, MD, Ze-zhang Zhu, MD

Division of Spine Surgery, Department of Orthopaedic surgery, Nanjing Drum Tower Hospital, The Affiliated Hospital of Nanjing University Medical School, Nanjing, China

Abstract

Objective: The pedicle morphology of ankylosing spondylitis (AS)-related thoracolumbar kyphosis patients may be different from that of individuals with normal spine due to the ectopic ossification and kyphotic deformity. However, there was no literature analyzing the pedicle morphology of AS patients with thoracolumbar kyphosis. Therefore, the present study aimed to investigate the pedicle morphology of lower thoracic and lumbar spine (T9-L5) in ankylosing spondylitis (AS)-related thoracolumbar kyphosis patients.

Methods: A retrospective review of AS patients with thoracolumbar kyphosis (AS group) and the patients with spinal or rib fracture (fracture group) who underwent CT scans of the lower thoracic and lumbar spine between February 2017 and September 2018 was performed. Patients with spinal tumor, spinal tuberculosis, severe degenerative spinal diseases including degenerative scoliosis, degenerative spondylolisthesis, degenerative spinal stenosis or history of previous spine surgery, or AS patients with pseudarthrosis which influenced the measurement of pedicle parameters were excluded. The measured parameters on CT images included transverse pedicle angle (TPA), transverse pedicle width (TPW), chord length (CL), pedicle length (PL), and sagittal pedicle angle (SPA). The intraclass correlation coefficient (ICC) was used to evaluate the agreement of radiographic parameters between observers. The independent sample t test was applied for the comparison of pedicle parameters between the two groups. The gender distribution between the two groups were compared using the Fisher’s exact test.

Results: A total of 1444 pedicles of 53 AS-related thoracolumbar kyphosis patients and 30 patients with fracture were analyzed. TPA was significantly smaller in AS group (p < 0.05). Significantly larger TPW was found in AS group in the lumbar spine (p < 0.05). TPW ≥ 7.5 mm was observed in 95.3%–98.1% of the pedicles at the levels of L3-L5 in AS group. The CL and PL were significantly larger in AS group at the levels of T9-L5 (p < 0.05). The CL ≥ 50 mm was found in 84.0%–96.2% of the pedicles in mid-to-lower lumbar spine in AS group. Significantly smaller SPA was found in AS group at the levels from L3 to L5 (p < 0.05).

Conclusions: Pedicle screws with relatively large diameter of 7.5 mm and length of 50 mm could be used in mid-to-lower lumbar spine in the majority of AS-related thoracolumbar kyphosis patients. Also, the insertion angle of pedicle screws in both the transverse and sagittal plane should be appropriately reduced in these patients. This study may help surgeons select the pedicle screws of appropriate size in AS patients.

Key words: ankylosing spondylitis; lower thoracic spine; lumbar spine; pedicle morphology; thoracolumbar kyphosis

Address for correspondence Bang-ping Qian, MD, Affiliated Drum Tower Hospital, Medical School of Nanjing University, Zhongshan Road 321, Nanjing, China 210008 Tel: 0086-25-6818-2202; Fax: 0086-25-6818-2202; Email: qianbangping@163.com

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**Introduction**

Pedicle screws have been widely used in posterior spinal surgeries. They are useful in achieving and maintaining the desired correction in the corrective surgery for spinal deformity including the ankylosing spondylitis (AS)-related thoracolumbar kyphosis owing to the strong pullout strength and superior biomechanical stability. However, accurate pedicle screw insertion, especially in the deformed spine, remains technically demanding because the deformity may alter the anatomy of the pedicles and the pedicle screws cannot be inserted in a conventional trajectory. Malpositioned pedicle screws may damage the neurologic or vascular structures around the pedicles or vertebral bodies and cause disastrous consequences. Therefore, a clear understanding of pedicle morphology is helpful and essential for the determination of pedicle size and trajectory.

Previous studies have investigated the pedicle morphology of individuals with normal spine or scoliosis by direct measurement using specimens or radiological measurement using computed tomography (CT) or magnetic resonance imaging (MRI). However, to the best of our knowledge, there was no English literature analyzing the pedicle morphology of AS patients with thoracolumbar kyphosis.

In the advanced stage of AS, patients may present with severe thoracolumbar kyphosis. Corrective osteotomy with long segment instrumentation is usually performed for the kyphosis correction and sagittal realignment. Solid pedicle screw fixation is helpful for both achieving satisfied intraoperative deformity correction and decreasing the loss of correction during the follow-up. The fixation strength of pedicle screws is related to the screw length and diameter. The pedicle screws with the largest length and diameter that can be safely accommodated by a pedicle are usually recommended to be used for maximizing the fixation strength and minimizing the screw-related implant failure. The osteoporotic cancellous bone is not uncommon in advanced AS due to the long-standing inflammation and reduced outdoor exercise; therefore, theoretically larger pedicle screws are needed to be inserted to provide sufficient fixation strength in AS. However, there is an upper limit to the diameter and length of pedicle screws because oversized screws will breach the walls of pedicles and vertebral bodies which may injure the surrounding structures. Furthermore, the pedicle screw trajectory in AS-related thoracolumbar kyphosis patients may be different from that in individuals with normal spine due to the ectopic ossification and kyphotic deformity. In thoracolumbar kyphosis patients secondary to AS, the chronic inflammation and new bone formation may change the morphology of pedicles. Moreover, the indistinct anatomic landmarks due to spinal inflammation and ossification make it more challenging to insert the pedicle screws in AS. Therefore, a comprehensive investigation and thorough understanding of pedicle morphology is necessary for the successful placement of pedicle screws in AS-related thoracolumbar kyphosis.

The aims of the present study were: (i) to assess the pedicle morphology of lower thoracic and lumbar spine in AS patients with thoracolumbar kyphosis based on CT scans; (ii) to compare the pedicle parameters (including pedicle diameters, pedicle parameters associated with the pedicle screw insertion depth, and insertion angle of pedicle screws) between the patients with AS-related thoracolumbar kyphosis and fracture.

**Methods**

Patients

A retrospective review of AS patients with thoracolumbar kyphosis and post-traumatic patients who sought treatment in our institution between February 2017 and September 2018 was performed. The inclusion criteria were (i) AS patients with thoracolumbar kyphosis (the diagnosis of AS was made according to the modified New York criteria); (ii) post-traumatic patients with spinal fracture or rib fracture which was confirmed by CT scan; (ii) age >18 years; and (iii) availability of CT images of the lower thoracic (T9–T12) and lumbar spine (L1–L5). The exclusion criteria were (i) patients with spinal tumor, spinal tuberculosis, severe degenerative spinal diseases including degenerative scoliosis, degenerative spondylolisthesis, or degenerative spinal stenosis; (ii) with history of previous spine surgery; (iii) AS patients with pseudarthrosis which influenced the measurement of pedicle parameters were also excluded. Finally, 53 AS patients with thoracolumbar kyphosis (AS group) and 30 post-traumatic patients with fractures (fracture group) were included in this study. The present study was approved by the Nanjing Drum Tower hospital ethics committee (No. is 2011052).

**Radiographic Measurements**

The radiographic measurements of pedicles in lower thoracic (T9–T12) and lumbar spine (L1–L5) were performed on both axial and sagittal CT images (Discovery CT750 HD 64-slice spiral CT, Figures 1 and 2). The measured parameters on axial CT images included: (Figure 1):

Transverse pedicle angle (TPA)

It was defined as the angle between the pedicle axis perpendicular to the transverse isthmus and the vertebral midline, which indicated the insertion angle of pedicle screws in the transverse plane.

Transverse pedicle width (TPW)

It was measured as the medial-lateral outer cortical diameter at the narrowest part of the pedicle, which indicated the upper limit to the diameter of pedicle screws;

Chord length (CL)

It was the distance measured between the anterior margin of the vertebral body and the posterior margin of the vertebral arch on a line perpendicular to the transverse isthmus, which indicated the upper limit to the length of pedicle screws.
Pedicle length (PL)
It was defined as the distance between the posterior longitudinal ligament and the posterior margin of the vertebral arch along the axis of the pedicle.

On sagittal CT images, sagittal pedicle angle (SPA) and pedicle height (PH) were measured (Figure 2). SPA
It was the angle between a line perpendicular to the sagittal isthmus and the superior border of vertebral body in the sagittal plane, which indicated the insertion angle of pedicle screws in the sagittal plane.

PH
It was defined as superior–inferior outer cortical height of the pedicle.

Each radiographic parameter was measured on both left and right pedicles and the left and right parameter values were averaged. Moreover, global kyphosis (GK) was measured on full-length standing radiographs.
GK
It was defined as the angle between the superior endplate of maximally tilted upper end vertebra and the inferior endplate of maximally tilted lower end vertebra, which indicated the overall severity of thoracolumbar kyphosis.

Statistical Analysis
Each radiographic parameter of both left and right pedicles was measured by two independent observers and the measured value by these two observers was averaged. The intraclass correlation coefficient (ICC) was used to evaluate the agreement of radiographic parameters between observers. ICC values of 0 to 0.20, 0.21 to 0.40, 0.41 to 0.60, 0.61 to 0.80, and 0.81 to 1.0 indicated slight, fair, moderate, substantial, and excellent agreement, respectively. The independent sample t test was applied for the comparison of pedicle parameters between AS group and fracture group. The gender distribution between the two groups were compared using the Fisher’s exact test because one cell had an expected count of less than 5. Quantitative variables were expressed as mean ± standard derivation and qualitative variables were expressed as raw numbers. A value of P < 0.05 was considered statistically significant.

Results

Demographic data
Totally, 83 patients (72 males and 11 females) with a mean age of 36.9 ± 10.9 years (range, 19–67 years) were included in this study. Fifty-three patients were in AS group and thirty patients were in fracture group. There was no significant difference in age between AS group and fracture group (35.9 ± 10.4 years vs 38.7 ± 11.7 years, t = −1.113, p = 0.269). Also, the male-to-female ratio was similar between the two groups (46/7 in AS group vs 26/4 in fracture group, p > 0.999).

Comparison of Pedicle Morphology between AS Group and Fracture Group
In AS group, a morphometric analysis of 954 pedicles from T9 to L5 was performed. In fracture group, a total of 490 pedicles from T9 to L5 were analyzed; other 50 pedicles (T9: 2; T11: 8; T12: 8; L1: 10; L2: 8; L3: 10; L4: 4) were not measured because the fracture of vertebral body influenced the measurement of pedicle morphology.

On the axial CT images, the TPA was significantly larger in AS group (T9, t = −3.162, p = 0.002; T10, t = −2.365, p = 0.020; L1, t = −2.905, p = 0.005; L2, t = −3.027, p = 0.003; L3, t = −2.387, p = 0.019; L4, t = −2.507, p = 0.014; L5, t = −2.329, p = 0.022; Figures 1, and 3A). Significantly larger TPW was observed in AS group at the levels of L1–L5 (L1, t = 2.299, p = 0.027; L2, t = 2.156, p = 0.034; L3, t = 2.087, p = 0.040; L4, t = 2.451, p = 0.016; L5, t = 2.163, p = 0.033; Figures 1, and 3B). The CL (T9, t = 3.607, p = 0.001; T10, t = 3.964, p < 0.001; T11, t = 4.432, p < 0.001; L1, t = 5.828, p < 0.001; L2, t = 3.559, p = 0.001; L3, t = 3.206, p = 0.002; L4, t = 4.651, p < 0.001; L5, t = 5.196, p < 0.001) and PL (T9, t = 2.712, p = 0.008; T10, t = 3.175, p = 0.002; T11, t = 2.028, p = 0.046; T12, t = 2.180, p = 0.032; L1, t = 2.130, p = 0.036; L2, t = 2.576, p = 0.020; L3, t = 2.118, p = 0.037; L4, t = 4.733, p < 0.001; L5, t = 3.486, p = 0.001) were significantly larger in AS group at all levels from T9 to L5 (Figures 1, and 3C,D).

On the sagittal CT images, significantly smaller SPA was observed in AS group at the levels of L3–L5 (L3, t = −2.343, p = 0.022; L4, t = −3.477, p = 0.001; L5, t = −4.044, p < 0.001, Table 1, Figure 2). There was no significant difference in the PH between the two groups (T9, t = 0.801, p = 0.426; T10, t = 0.183, p = 0.855; T11, t = 0.254, p = 0.800; T12, t = 0.191, p = 0.849; L1, t = 0.365, p = 0.717; L2, t = −1.262, p = 0.211; L3, t = −0.103, p = 0.918; L4, t = 1.210, p = 0.230; L5, t = 1.094, p = 0.277). According to the GK, the enrolled AS patients were classified into two groups (GK ≤ 70°, n = 16; GK > 70°, n = 37). Patients with severe kyphotic deformity (GK > 70°) had significantly smaller SPA at the level of L5 (−4.3° vs −2.4°, t = 2.325, p = 0.024). Although the patients with severe kyphotic deformity (GK > 70°) had smaller SPA at the level of L3 (−1.2° vs −0.6°) and L4 (−3.0° vs −1.7°), the difference did not reach the statistical significance (L3, t = 0.919, p = 0.362; L4, t = 1.712, p = 0.093).

The TPW and CL in AS group
There was a steady increase of TPW in the lower thoracic spine from T9 to T12 (Figure 3B). Then a slight decline of TPW was observed at the level of L1 (Figure 3B), followed by a continuing increase from L2 to L5 (Figure 3B). The TPW ≥ 7.5 mm was found in 95.3% (101/106), 97.2% (103/106), and 98.1% (104/106) of the pedicles at the levels of L3–L5, respectively.

Regarding the CL in AS group, the largest one in lower thoracic spine was at T12 (Figure 3C). The largest CL in lumbar spine was observed at L3 (Figure 3C). The CL ≥ 50 mm was found in 96.2% (102/106), 86.8% (92/106), and 84.0% (89/106) of the pedicles at the levels of L3–L5, respectively.

Inter-observer Reliability for the Radiographic Measurements
The inter-observer analysis of the total 1444 pedicles from 83 enrolled patients was performed, revealing excellent agreement between the two independent observers regarding all the measured radiographic parameters (SPA left, ICC = 0.977; SPA right, ICC = 0.979; PH left, ICC = 0.821; PH right, ICC = 0.856; TPW left, ICC = 0.976; TPW right, ICC = 0.977; TPW left, ICC = 0.918; TPW right, ICC = 0.899; CL left, ICC = 0.935; CL right, ICC = 0.943; PL left, ICC = 0.862; PL right, ICC = 0.865; p < 0.001, Table 3).

Discussion

Pedicle diameters between patients with AS-related kyphosis and fracture
The pedicle diameters include TPW and PH. The TPW is often smaller than PH in thoracic and lumbar spine15,22,23.
In the present study, the average PH was larger than TPW in both AS group and fracture group from T9–L4 (Table 2 and Figure 3B), which was consistent with the previous findings by Zindrick et al. and Lien et al. showing that the value of PH was higher than that of TPW in the thoracic and lumbar spine (except L5) in their study cohort. Therefore, TPW is the limiting factor which determines the diameter of pedicle screws. Use of a larger size screw will contribute to the medial or lateral pedicle wall breach and may cause neurologic compromise. In the present study, the widest pedicle of lumbar spine in fracture group was seen at L5 and the narrowest pedicle of lumbar spine was seen at L1, which was in agreement with the results of study by Zindrick et al. However, the width of lumbar pedicles in this study (from 7.6 mm at L1 to 14.2 mm at L5) were all smaller than that in Zindrick et al. study (from 8.7 mm at L1 to 18.0 mm at L5), probably due to the racial difference. Therefore, racial difference should be taken into consideration when selecting the appropriate screw size. In this study, the TPW was significantly larger in AS group from L1–L5 (p < 0.05, Figure 3B), which may be caused by the new bone formation around the pedicles, making it possible to choose pedicle

![Fig. 3](image-url)

Comparison of radiographic parameters measured on axial CT images between AS group and fracture group. Comparison of TPA between the two groups (A); Comparison of TPW between the two groups (B); Comparison of CL between the two groups (C); Comparison of PL between the two groups (D). *Indicates a statistically significant difference between the two groups (p < 0.05). TPA indicates transverse pedicle angle; TPW, transverse pedicle width; CL, chord length; PL, pedicle length; AS, ankylosing spondylitis

### TABLE 1 Comparison of SPA (°) between AS group and fracture group

|       | AS    | fracture | t    | p    |
|-------|-------|----------|------|------|
| T9    | 14.1 ± 1.1 | 14.5 ± 1.8 | -1.093 | 0.281 |
| T10   | 14.3 ± 1.0 | 14.5 ± 3.0 | -0.351 | 0.728 |
| T11   | 12.0 ± 1.3 | 12.8 ± 2.7 | -1.396 | 0.173 |
| T12   | 10.6 ± 1.1 | 11.3 ± 2.1 | -1.489 | 0.146 |
| L1    | 5.7 ± 1.5  | 6.0 ± 2.3  | -0.472 | 0.640 |
| L2    | 3.4 ± 1.4  | 3.7 ± 1.2  | -0.347 | 0.717 |
| L3    | -1.1 ± 2.2 | 0.4 ± 3.0  | -2.343 | 0.028*|
| L4    | -2.6 ± 2.6 | -0.4 ± 2.9 | -3.477 | 0.001*|
| L5    | -3.7 ± 2.9 | -1.2 ± 2.5 | -4.044 | <0.001*|

Abbreviations: AS, ankylosing spondylitis; SPA, sagittal pedicle angle.; * Indicates a statistically significant difference between AS group and fracture group (p < 0.05).

### TABLE 2 Comparison of PH (mm) between AS group and fracture group

|       | AS     | fracture | t    | p    |
|-------|--------|----------|------|------|
| T9    | 13.5 ± 1.1 | 13.3 ± 1.5 | 0.801 | 0.426 |
| T10   | 14.2 ± 1.3 | 14.1 ± 1.6 | 0.183 | 0.855 |
| T11   | 15.0 ± 1.4 | 14.9 ± 1.6 | 0.254 | 0.800 |
| T12   | 14.8 ± 1.4 | 14.7 ± 1.8 | 0.191 | 0.849 |
| L1    | 13.8 ± 1.1 | 13.7 ± 1.6 | 0.365 | 0.717 |
| L2    | 13.6 ± 1.7 | 14.1 ± 1.5 | -1.262 | 0.211 |
| L3    | 13.3 ± 1.6 | 13.4 ± 1.6 | -0.103 | 0.918 |
| L4    | 14.2 ± 1.2 | 13.9 ± 1.2 | 1.210 | 0.230 |
| L5    | 13.6 ± 1.4 | 13.2 ± 1.8 | 1.094 | 0.277 |

Abbreviations: AS, ankylosing spondylitis; PH, pedicle height.; * Indicates a statistically significant difference between AS group and fracture group (p < 0.05).
screws with relatively large diameter in the lumbar spine in corrective surgery for AS-related thoracolumbar kyphosis. Usually, 6.5-mm diameter pedicle screws were used for lumbar spinal fixation. However, 6.5-mm diameter screws in mid-to-lower lumbar spine may not afford sufficient fixation strength for AS-related thoracolumbar kyphosis patients based on our clinical experience, which may be due to the osteoporotic cancellous bone. Therefore, 7.5-mm diameter screws were routinely used in L3–L5 segments for these patients to enhance fixation strength in our practice. The results of the current study indicated that TPW ≥ 7.5 mm was observed in an overwhelming majority (95.3%–98.1%) of the pedicles at the levels of L3–L5 in AS group, which supported the use of 7.5-mm diameter screws in mid-to-lower lumbar spine of AS-related thoracolumbar kyphosis patients. What should be noticed is that some AS patients may have small pedicles and carefully studying their anatomy on preoperative CT is necessary for choosing the appropriate pedicle screw size.

CL and PL

The pedicle parameters associated with the pedicle screw insertion depth include CL and PL, of which CL dictates the upper limit to the length of pedicle screws. On the one hand, CL was correlated with the fixation strength of pedicle screws. On the other hand, the CL limited the length of pedicle screws; the use of screws longer than CL will lead to perforation of the anterior vertebral cortex and may cause damage to the thoracic or abdominal aorta anterior to the thoracic or lumbar spine. The current study showed that the CL of lumbar spine was all larger than that of thoracic spine, which is in agreement with the study by Zindrick et al. In the present study, both CL and PL were significantly larger in AS group (Figure 3C,D, p < 0.05), which may result from hyperplasia of the articular process, transverse process, and vertebral body. The relatively large CL in AS group supported the use of relatively long pedicle screws in these patients. Moreover, the CL ≥ 50 mm was found in most pedicles (84.0%–96.2%) in mid-to-lower lumbar spine and therefore the pedicle screws with the length of 50 mm were recommended to be used at L3–L5 in most of the AS-related thoracolumbar kyphosis patients.

**TPA and SPA**

Safe screw placement without violation of adjacent vital structures relies not only on the selection of screws with appropriate size, but also on the direction of the screws. TPA and SPA reflects the insertion angle of pedicle screws in the transverse plane and sagittal plane, respectively. In the present study, the TPA decreased gradually from T9 to T12 and then progressively increased from L1 to L5. This trend was in consistent with the results of study by Zindrick et al. The results of this study revealed that the TPA was significantly smaller in AS group (p < 0.05, Figures 1 and 3A), which meant that the insertion angle of pedicle screws in the transverse plane should be properly reduced in AS-related kyphosis patients. Furthermore, the mean value of SPA at the levels of L3–L5 in AS group was negative and smaller than that in fracture group (p < 0.05, Table 1, Figure 2), which indicated that the caudal insertion angle of pedicle screws in the sagittal plane should be decreased in the mid-to-lower lumbar spine in AS-related thoracolumbar kyphosis patients and sometimes should even be inserted in a cephalad direction. The change in the insertion angle of pedicle screws in the sagittal plane may result from the loss of lumbar lordosis, subsequent lumbar kyphotic deformity, and pelvic retroversion in AS patients with thoracolumbar kyphosis.

**Clinical Relevance**

With regard to the clinical relevance, the results of this study actually provided a theoretical basis that the pedicle screws with relatively large diameter of 7.5 mm and length of 50 mm could be used in mid-to-lower lumbar spine in the majority of AS patients. Also, the insertion angle of pedicle screws in both the transverse and sagittal plane should be appropriately reduced in these patients.

**Limitations**

The limitations to this study need to be acknowledged. Firstly, this was a single-center study with retrospective design; Secondly, the height, weight, disease duration, and severity of kyphotic deformity may have influence on the pedicle morphology and therefore subgroup analysis based on these stratified factors should be performed in future studies with larger sample size.

**Conclusion**

The results of this study demonstrated that the pedicle screws with relatively large diameter (7.5 mm) and length (50 mm) could be used in mid-to-lower lumbar spine in the

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**TABLE 3 Inter-observer reliability for the radiographic measurements**

|               | ICC   | p       |
|---------------|-------|---------|
| SPA left      | 0.977 | <0.001* |
| SPA right     | 0.979 | <0.001* |
| PH left       | 0.821 | <0.001* |
| PH right      | 0.856 | <0.001* |
| TPA left      | 0.976 | <0.001* |
| TPA right     | 0.977 | <0.001* |
| TPW left      | 0.918 | <0.001* |
| TPW right     | 0.899 | <0.001* |
| CL left       | 0.951 | <0.001* |
| CL right      | 0.943 | <0.001* |
| PL left       | 0.862 | <0.001* |
| PL right      | 0.865 | <0.001* |

Abbreviations: CL, chord length; ICC, intraclass correlation coefficient; PH, pedicle height; PL, pedicle length; SPA, sagittal pedicle angle; TPA, transverse pedicle angle; TPW, transverse pedicle width; * Indicates a statistically significant correlation (p < 0.05).
majority of AS patients. The insertion angle of pedicle screws in the transverse plane should be appropriately reduced to prevent the medial pedicle wall violation in AS patients. Moreover, the insertion angle in the sagittal plane should also be decreased in the mid-to-lower lumbar spine in these patients. Future research with larger sample size could focus on subgroup analysis based on stratified factors (height, weight, disease duration, and severity of kyphotic deformity) to help surgeons apply more individualized pedicle screw placement design.

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Author contribution

HCJ made substantial contributions to the analysis and interpretation of data for the work and drafted the work; XWB made substantial contributions to the analysis and interpretation of data for the work; QBP and QY made substantial contributions to the conception and design of the work and revised it critically for important intellectual content; WB, YY and ZZZ made substantial contributions to the acquisition of data for the work.

Ethics statement

This study was approved by the Medical Ethics Committee of our Hospital (the ethics approval number provided by the board was 2011052). Written informed consent was obtained from all patients prior to testing.

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