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Original Article

Anatomical research on strength of screw track fixation in novel cortical bone trajectory for osteoporosis lumbar spine

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Abstract: Objectives: The cortical bone screw has good internal fixation effect on osteoporotic bone. In order to further increase the strength of screw track fixation in cortical bone trajectory, this study introduced a modified technique with novel insertion point and angle for cortical bone screw placement. Methods: Cortical bone screws were placed in four dry and six wet and intact lumbar specimens according to the modified technique. A total of 100 trajectories in specimens were confirmed by X-ray and CT scan to evaluate the safety, accuracy and practicability of screw fixation. The successful rate was 95% (38/40) in four dry specimens, and 88.7% (53/60) in six wet specimens. Conclusion: This study showed that the novel trajectory could be fixed more closely with cortical bone compared to traditional cortical bone trajectory technique, and thus it may reduce the surgical exposure to the elders and help them to recover quickly after the operation.

Keywords: Osteoporosis, lateral edge of isthmus, cortical bone trajectory

Introduction

Approximately 44 million people in the United States suffered from osteoporosis, and the total population aged over 65 in industrialized countries would increase by almost 30% within the next 20 years [1]. Similarly in China, an estimated 69 million people aged over 50 suffered from osteoporosis in 2006, and more than 200 million had low bone mass. The number of patients presenting with spinal conditions that involve osteoporotic bone is on the rise continuously [2], as well as the number of elderly patients who require surgery for their lumbar spine problems all over the world. Posterior fixation using pedicle screws is the mainstay of surgical instrumentation currently in use for patients with degenerative disorders of the lumbar spine [3]. Patients with osteoporosis have low bone density, and their trabecular bone structure is too weak to maintain the holding force of traditional lumbar pedicle screw [4, 5] and it leads to screw loosening easily. It is one of the reasons for postoperative failure of lumbar endoscopic surgery [6]. Previous study indicated that the occurrence of reoperation on lumbar degenerative spondylolisthesis in five years was 23.2% [7]. Furthermore, it is hard to achieve solid fixation under revision, which is another challenge in the clinic of orthopedics. Much effort was made to secure the stability of internal fixation for osteoporotic patients who receive lumbar spine revision surgery, e.g. constant improvement in screw configuration design and strength of screw tract. Experts have attempted to design various-shaped [8] or expandable vertebral pedicle screws [9]. In addition, hydroxyapatite coating was applied on the surface of screws [10], and to enhance the fixation effect of pedicle screws, allograft bone was used and bone cement reinforcing screws were applied during operation [11, 12]. However, the expandable screws and hydroxyapatite-coat screws are expensive, and

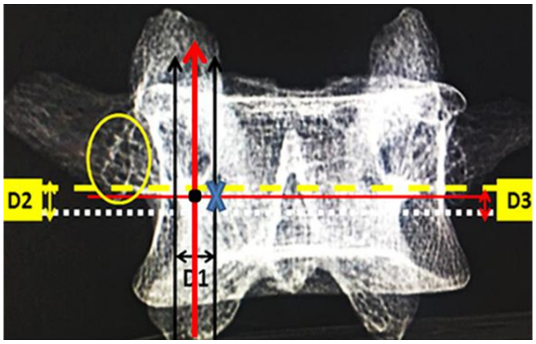

Figure 1. Diagram of screw insertion change of improved method [23]. Yellow dot lines indicate the inferior border of transverse process; while dot lines are connecting lines of isthmus tangent points; black dot indicates the starting point of traditional CBT [16]; × indicates the starting point of novel method described in the paper.

the allograft bone and bone cement have certain complications such as high exothermic polymerizing temperature, toxicity of the monomer, poor fatigue performance, and its permanence in the body which can cause a persistent immunologic response [13].

Cortical bone trajectory (CBT) is a new lumber screw trajectory proposed by Santoni in 2009 [14]. Compared with the traditional pedicle screw, CBT increases the contact surface between the screw and cortical bone, in where the screw is surrounded by dense cortical bone [15-18], and it does not deformation remarkably due to degeneration [7, 19]. CBT increases 30% uniaxial yield pullout load and equivalency in mixed loading [20], with a holding force 1.7 times that of the traditional screw trajectory [21]. Therefore, CBT screws are frequently used in elders suffering osteoporosis [3, 7, 14]. Additionally, it is a minimally invasive surgery and provides a new internal fixation option for lumbar and revision surgery, which has a certain values in orthopedic clinic [22]. How to further increase the strength of CBT screws on osteoporosis patient in elders and reduce the operation incisions are our aims which will be discussed in this paper.

Material and methods

Study subjects

Four dry and six intact wet (including 3 males and 3 females) lumbar specimens (provided by Department of Anatomy, Xinjiang Medical University) were used for screw insertion. A lumbar vertebra was excluded if spondylosis, malformation, and tumor were observed. This study was approved by the ethical committee of Xinjiang Medical University (Ethical No: 2014141218-01).

Equipment and materials

Images were captured using 500 mA DR X-ray machine (Hitachi, Japan), computed tomography (CT) system (Siemens, Germany). Surgical drill with 2.50 mm and 2.70 mm bits, and Kirschner wires (1 mm, 1.5 mm, 2 mm, 2.5 mm, 3.5 mm) were used. Vernier caliper (0.02 mm accuracy) was used for measurement. 4.5 mm titanium alloy CBT screws (30 and 35 mm long) (Zheng Tian Medical Device, Tianjin, China) were used for placement.

Screw placement in anatomical spines

Screws were inserted into the CBTs in four dry and six wet lumbar specimens. The methods we used in this study were described in details in our previous study [23]. The lumbar isthmus tangent point was considered as a coordinate origin, and the insertion point (blue "×" in **Figure 1**) was determined through translating the distance of D1 value to the midline of the vertebral body horizontally and then vertically to the distance of D3 value. The black dot was the traditional insertion point (**Figure 1**) [23].

CBT assessment

All CBT were assessed visually by X-ray examination and CT scanning, and classified into three grades: Grade I, screws were inserted within the pedicle; Grade II, less than 50% of the screw diameter was penetrated into the pedicle. Grade III, more than 50% of the screw diameter was penetrated the pedicle [24]. Grade I was considered excellent positioned screws, Grades II and III were considered poorly positioned screws.

Statistical analysis

All data were recorded into Excel software for further analysis. Successful rate was calculated for both wet and dry samples. Successful rate was defined as the proportion of Grade I CBTs among all observed CBTs in L1-L5 lumber spines.

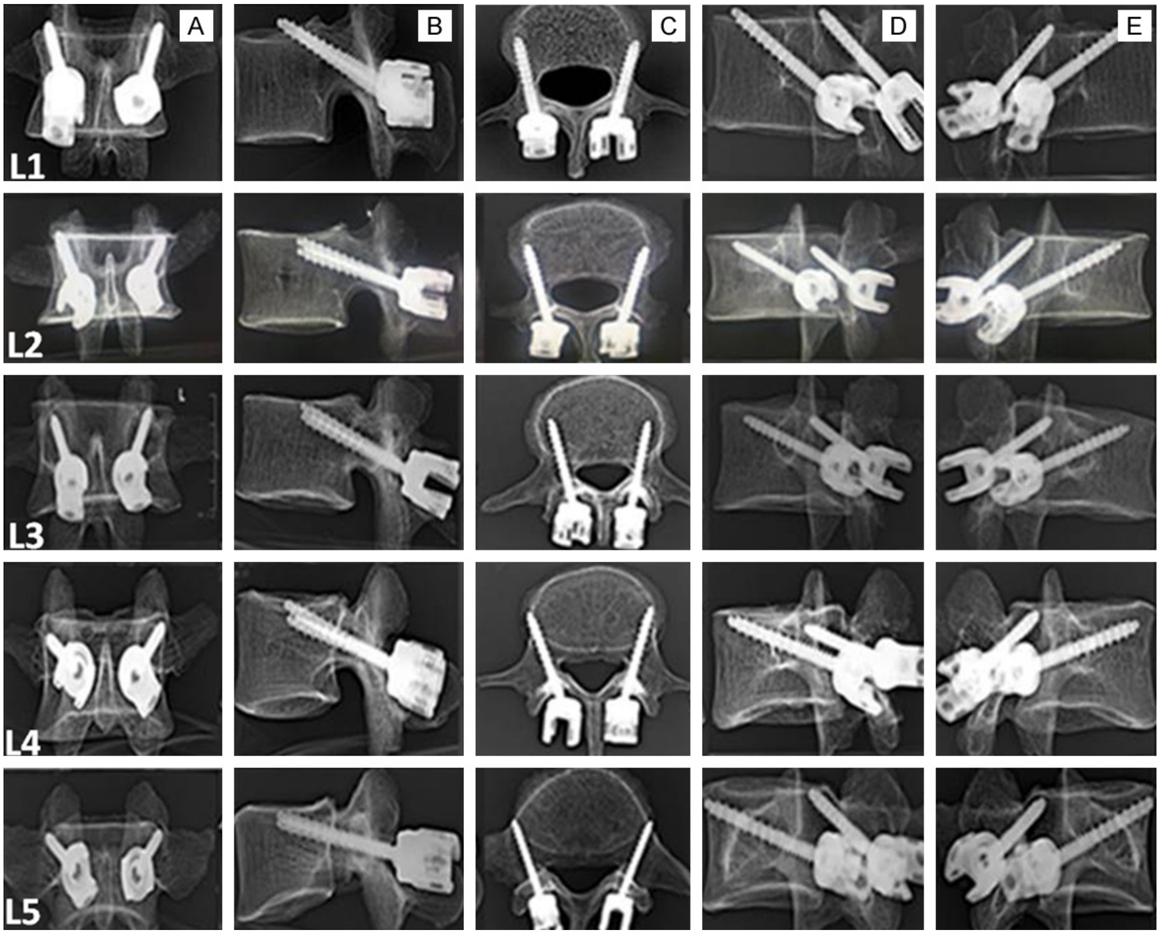

Figure 2. X-rays of placement of CBT screws into dry spines at different vertebral levels [23]. A. Xial; B. Lateral; C. Over look; D. Right oblique; E. Left oblique.

Results

X-ray and CT examinations

X-ray and CT scans of CBTs were obtained and are shown in wet and dry spine specimens. 100 CBTs were assessed and classified into three categories (**Figures 2**-**5**). The successful rates were 88.7% and 95% for the wet and dry samples, respectively. Except for L5 in the wet spines, the successful rates were all above 87% (**Table 1**) [23].

Discussion

Cortical bone does not deform and degenerate with aging obviously; however in patients with osteoporosis, cancellous bone mass would decrease significantly and lose its stability, which results in degeneration, and thus cortical bone is relatively preserved [4-7, 19]. Zdeblick pointed out that the torque was the best predictor of the failure of the bone and screw interface when the screw was inserted into the bone, that was, the bone strength determined whether the screw was loose or not [18]. The purchase of cancellous bone compromises screw-bone interface strength [4], which may lead to early loosening and the development of pseudarthrosis [20].

The traditional pedicle screws used for fixation are generally inserted along the axis of the pedicle of the vertebral body. When this entry route is used, the screw does not come into contact with the cortical bone of the pedicle, but is inserted into the cancellous bone. However, bone density especially cancellous bone declines in the elderly, pedicle screw pullout strength is significantly lower in vertebral bodies with lower bone density [20].

CBT was considered as a novel entry trajectory for pedicle screws which maximize the area

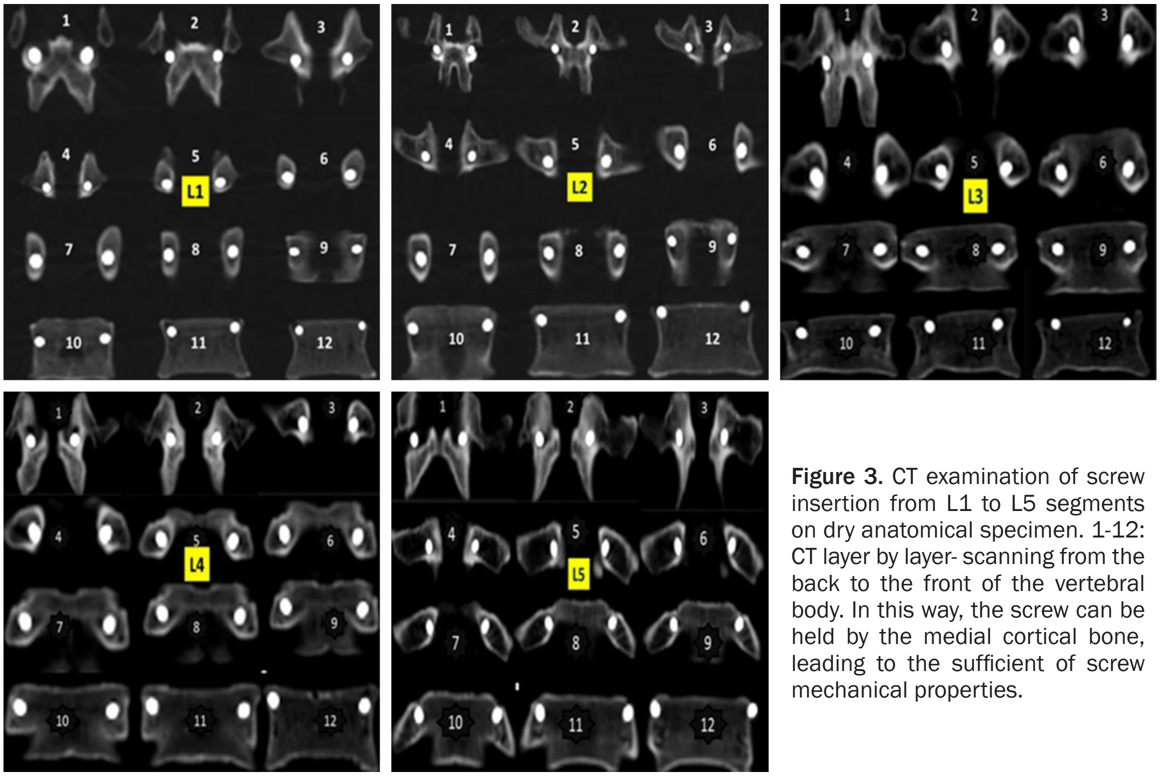

Figure 3. CT examination of screw insertion from L1 to L5 segments on dry anatomical specimen. 1-12: CT layer by layer- scanning from the back to the front of the vertebral body. In this way, the screw can be held by the medial cortical bone, leading to the sufficient of screw mechanical properties.

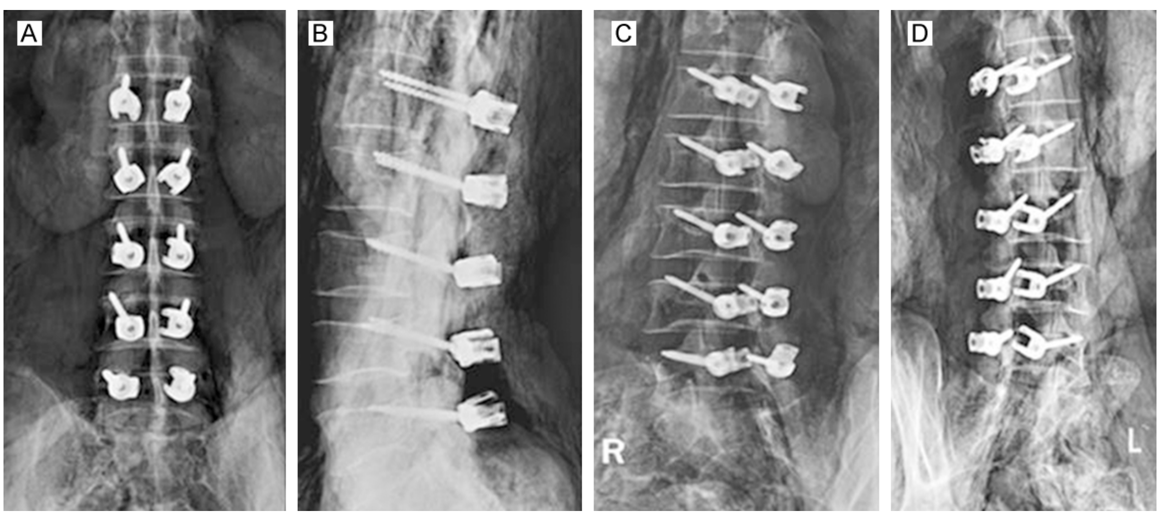

Figure 4. X-rays of placement of CBT screws into wet spines at different vertebral levels [23]. A. Axial; B. Lateral; C. Right oblique; D. Left oblique.

that contact cortical bone, and provide strength equivalent to or greater than that achieved by traditional pedicle screw method [3]. CBT application is anticipated in patients with reduced bone quality due to osteoporosis and other conditions [25]. A favorable internal fixation effect of cortical screw trajectory makes it more suitable for patients with osteoporosis than traditional screw method [22].

Improvement of anatomical reference of traditional CBT insertion

Previously, the junction of the center of the superior articular process and 1 mm inferior to the inferior border of the transverse process was proposed to be the CBT starting point [3, 14, 26], although we believe the use of these anatomical references to define the site of CBT

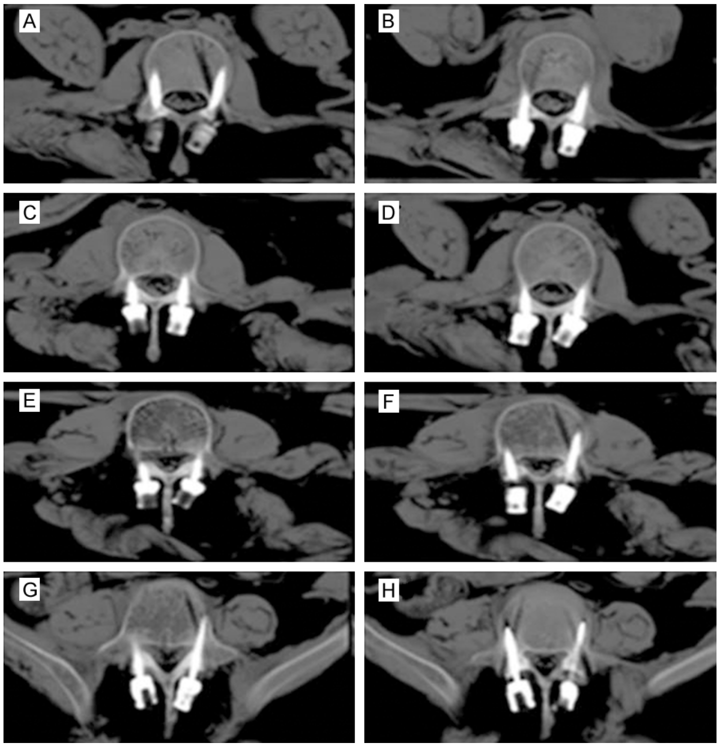

Figure 5. CT images of placement of CBT screws into wet spines at different vertebral levels [23]. A. L1; B. L2; C. L3; D. L3; E. L4; F. L4; G. L5; H. L5.

Table 1. Evaluation of CBTs in anatomic spines

Spine Level	I	II	III	Successful rate (%)
Wet				
L1	10	1	1	88.3 (10/12)
L2	11	0	1	91.7 (11/12)
L3	12	0	0	100 (12/12)
L4	11	1	0	91.7 (11/12)
L5	9	2	1	75.0 (9/12)
Total	53	4	3	88.3 (53/60)
Dry				
L1	7	1	0	87.5 (7/8)
L2	7	1	0	87.5 (7/8)
L3	8	0	0	100 (8/8)
L4	8	0	0	100 (8/8)
L5	8	0	0	100 (8/8)
Total	38	2	0	95 (38/40)

The table is quoted from the author previously article. Rexiti P, Abudurexiti T, Abuduwali N, Wang S, Sheng W. Measurement of lumbar isthmus parameters for novel starting points for cortical bone trajectory screws using computed radiography. Am J Transl Res 2018; 10: 2413-2423 [23].

screw starting point has certain limitations. For examples, previous studies showed that zygapophyseal joints were prone to degeneration, which occured in 89.2% of people aged between 60 and 69 [27, 28]. If the starting point was positioned based on the midlines of easily degenerated zygapophyseal joints as reported in the previous studies, the screws might hurt the nearby nerves [29]. Furthermore, the inferior border of the transverse process is often upward turned, but not horizontal as assumed. Therefore, it would be very challenging to use it as reference to locate the starting point due to the variability in the baseline of the transverse process. Besides, for patients who had inter-transverse process fusion surgery, it is difficult to locate the inferior border of the transverse process for revision surgery.

In order to make up for the deficiency mentioned above and further increase the strength of screw placement, we modified the insertion point and track of CBT. Without changing the Horizontal axis, the vertical axis of the insertion point of the cortical bone screw was moved from the conventional mid-perpendicular line of the articular process (the 5 o'clock orientation in the left pedicle and the 7 o'clock orientation in the right) [16] to the tangent line of the median wall of the pedicle. Through anatomical and imaging study, the results showed the improved method was safe and effective.

The location of the improved insertion point and its difference from the original CBT have been clearly explained in the previously published CBT imaging article by author [23].

The influence of modified CBT method on screw fixation strength

Notably, the most important factor affecting the insertion torque was the length of the cortical screw in the lamina (the black double arrow), not the length in the vertebral body or the total length of the screw (**Figure 6**). The cortical bone was mainly located in the lower or the lower edge of the pedicle [30].

Effective fixation of cortical bone trajectory depends on three points: the entry site of CBT,

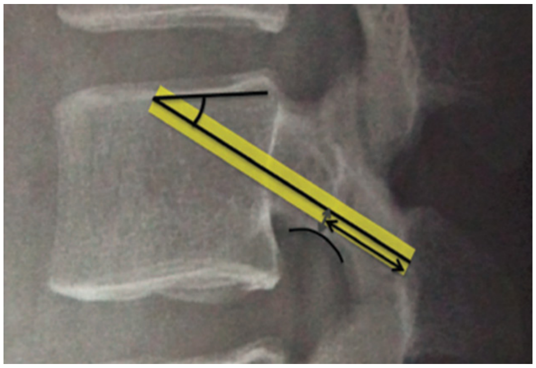

Figure 6. The length of the screw in the vertebral plate affects the mechanical torque of the cortical bone screw [30].

the medial side of the pedicle of the vertebral arch, and the cranio-lateral side of the pedicle of the vertebral arch [3]. In order to enhance the holding power between the screw threads and the cortical bone of the lamina and pedicle, we used modified CBT screw which was different from the traditional CBT pedicle screw. We believe that the improved CBT technology has the particular advantages in increasing the biomechanical properties of the screw; and the details will be discussed in this part.

According to previous research, we believe that the improved CBT technology has the following advantages in increasing the biomechanical properties of the screw:

(1) One intraoperative complication was cortical bone fracture at the site of screw compression [31, 32]. We found that vertebrae bodies, especially the L1 and L2, were prone to crack or fracture at the isthmus because the cortical bone at the rounding edge of the screw was too thin. As a result, the stability of the screw was undermined, which might cause postoperative discomfort due to constricting of fractures on adjacent nerve roots.

In this modified method, the novel insertion point of CBT was as close as possible to the inner wall of the pedicle; therefore the cortical bone which contacted with the screw tail was thicker at the lateral edge of isthmus, which avoided the bone from being broken because of screw insertion. In addition, the modified method also increased the stability of the screw and its holding force with the lateral edge of the isthmus (**Figure 7**).

(2) According to previous research, the appropriate angle was about 10° [14-16, 22, 30]. An excessively laterally directed path may penetrate the lateral wall of the pedicle or fail to support the vertebral column, inducing loss of holding power [15]. The novel cortical bone trajectory at insertion point was thicker as mentioned above, and thus the CBT screws could be placed at a greater external angle in our modified method. This method could also increase the actual effective length in the vertebral plate and the mechanical properties of the CBT screw according to geometry (**Figure 6**) [15, 30]. In general, cortical screws used in orthopedic surgery have a dense thread with a smaller bite (difference between the outer and root dimeters). The increased distance in modified method may not be noticeable, however, in this distance there will be more cortical screw threads contacting the high density bone in the vertebral plate, which will increase the screw track strength.

(3) As shown in the **Figures 7** and **8**, the traditional CBT insertion point was relatively outward to the insertion point suggested in our modified method. Therefore, the screw head of traditional method was located in the pedicle cancellous bone when it moved from the insertion point to the lateral side of vertebral body. So the screw could not be held by the medial cortical bone of pedicle and result in insufficient screw mechanical properties.

Anatomically, in order to increase the holding force of the cortical bone screw, the cortical bone screw insertion point should be as close as possible to the inner wall of the pedicle, and moved inward from the midline of the original articular process of traditional CBT to the tangential line position of the inner wall of the pedicle. In this way, the CBT screws in the modified method could contact the medial wall bone of the pedicle more closely (**Figures 2-5**) [23].

(4) The thickness change of bone cortex in vertebral arch was greater in inner wall than outer wall (**Figure 8**) [33]. CBT screw in the modified method would not break through the thinner lateral wall of pedicle mentioned above (**Figures 2-5**) [23], since insertion point was closer to the thick inner side and far away from the lateral wall, avoiding the decrease of screw stability.

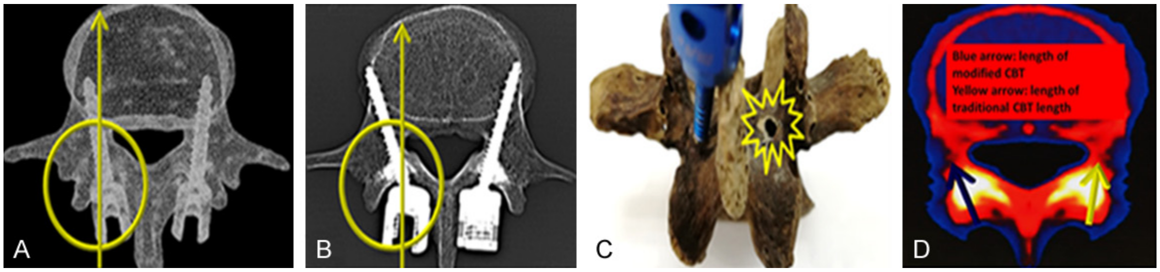

Figure 7. Improved CBT technique increases the thickness of the marginal cortex at the screw insertion point and the stability of the screw by contacting with inner wall of pedicle and the lateral side of the upper endplate with longer screw length, especially increase the effective length in vertebral plate, and attach the level of the middle column of the vertebral body thus dispersive stress on the CBT screw effectively. A. The traditional CBT insertion technique [14-30]. B. Modified CBT insertion technique by the author [23]. C. Modified CBT technique increase the thickness of cortical bone which contact with the screw tail, thus preventing the bone broken during screw insertion. D. The difference between the actual effective length of traditional CBT (yellow arrow) and modified CBT technology (blue arrow) in the vertebral plate. The latter is significantly longer than the former [15, 23, 30].

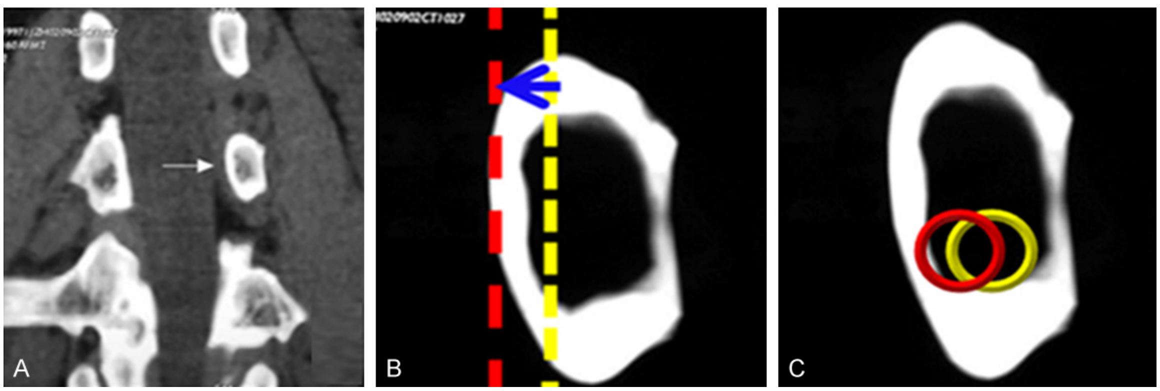

Figure 8. The relationship between traditional CBT and modified CBT technique screws with the median wall of pedicle [16, 23, 33]. A. Morphological image of lumbar pedicle on CT scan. B. The yellow vertical line indicates the traditional CBT screw insertion projection line (The 5 o'clock orientation in the left pedicle and the 7 o'clock orientation in the right [16]), and the red vertical line indicates the tangent line of the medial wall in modified CBT method, which moves toward to the central line of lumbar spine (blue arrow shows) [23]. C. The difference of screw trajectory between modified method (red circle) with traditional CBT (yellow circle) in the course of pedicle insertion.

(5) Under the influence of the median insertion point and great external angle of the screw insertion, the screw in modified CBT technique could easily reach the cortical bone at the lateral edge of the upper endplate of vertebral and increase the holding power of the screw (**Figures 2**, **3**).

(6) Based on point two and five above, in modified CBT technique, screws were inserted in longer length, and more threads on screw contacted with the cortical bone in the trajectory, not only limited to the vertebral plate (30), which would increase the holding force of the CBT screw efficiently.

(7) The improved CBT screw technique facilitated the uniform distribution of mechanical loads along the long length of screw, and attached the level of the middle column of the vertebral body thus dispersive stress on the CBT screw effectively, while the traditional CBT technique cannot achieve the above mechanical effects [15, 30, 34, 35].

(8) Screws inserted in longer length in improved CBT technology may penetrate the lateral side of upper endplate of vertebral body where the lumbar disc annulus edge exists, however in the traditional method, the nucleus of lumbar disc might be damaged when screw penetrate upper endplate, and lumbar disc would degenerate more quickly and might result in adjacent-level disc protrusion in the future.

(9) Furthermore, the modified technique also reduced the influence of the cortical bone screw tail on the facet joint and avoided postop-

erative acceleration and degeneration of articular processes of adjacent joints (**Figure 7**).

In conclusion, we believe that if modified method of CBT was applied in clinic, the most important factor affecting the insertion torque would be the total length of the screw which contacted cortical bone tightly from beginning to the end during insertion, not limited to the length in the lamina (**Figure 6**) [30], since in traditional method only this part of screw in the lamina actually holds the cortical bone effectively, but other parts of screw still contact with cancellous bone.

The significance of modified CBT in minimally invasive surgery

Paraspinal muscle degeneration plays important role in loosening of screw in spine surgery [36]. Although pedicle screw fixation is a common and reliable method, there are several disadvantages such as invasive nature of traditional placement [37].

The cortical trajectory is considered less invasive than the traditional screw trajectory. The initial insertion point is located medial on the pars interarticularis, which translates into smaller initial incisions and less muscle dissection and retraction. Peri-operatively, this advantage theoretically leads to a reduction in intraoperative and postoperative blood loss, postoperative pain, duration of hospitalization and an enhancement of postoperative recover, and preventing screw from loosening especially in elder osteoporotic patients [38-42].

While in traditional CBT method, in order to identify the x axis of the site which is 1 mm inferior to the inferior border of the transverse process, the entire inferior border of the transverse process near the intervertebral foramen needs to be exposed, leading to increased surgical invasiveness. Compared with the lower edge of the transverse process, the left and right sides of the isthmus were more symmetrical, and the tangential points on both sides of the isthmus were basically on the same straight line. With the proposed method, there was no need to expand the surgical exposure during surgery, which protects paraspinal muscles, reduces soft tissue injury and bleeding, and shortens operation time. It shows the advantages of being more practical, less invasive and more convenient, and thus is very important for aged people who received the lumbar internal fixation operation.

Conclusion

This study partially improved the traditional CBT technology, especially its biomechanical property and clinic significance on minimally invasive surgery, which would further increase screw strength in osteoporotic patients. However, the proposed method is still in the anatomical research stage, and no corresponding surgical treatment was carried out in clinical cases. Therefore, biomechanical tests are needed to compare the mechanical properties of the two methods, and the practical application of the technology should be further verified in subsequent clinical practice.

Disclosure of conflict of interest

None.

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