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MINIREVIEWS

Cortical bone trajectory screws in the treatment of lumbar degenerative disc disease in patients with osteoporosis

Song Guo, Kai Zhu, Mei-Jun Yan, Xin-Hua Li, Jun Tan

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Abstract

Lumbar degenerative disc disease (DDD) in the elderly population remains a global health problem, especially in patients with osteoporosis. Osteoporosis in the elderly can cause failure of internal fixation. Cortical bone trajectory (CBT) is an effective, safe and minimally invasive technique for the treatment of lumbar DDD in patients with osteoporosis. In this review, we analyzed the anatomy, biomechanics, and advantages of the CBT technique in lumbar DDD and revision surgery. Additionally, the clinical trials and case reports, indications, advancements and limitations of this technique were further discussed and reviewed. Finally, we concluded that the CBT technique can be a practical, effective and safe alternative to traditional pedicle screw fixation, especially in DDD patients with osteoporosis.

Key Words: Lumbar degenerative disc diseases; Cortical bone trajectory screw; Anatomy; Biomechanics; Indications; Clinical trials and case reports; Advancements

Core Tip: Some reviews in the literature have provided information that contributes to the anatomy, surgical technique, and biomechanics of cortical bone trajectory screws. However, the aim of this review is to report the recent clinical trials and case reports, indications, advancements and limitations of this technique. We concluded that the cortical bone trajectory technique can be a practical, effective and safe alternative to traditional pedicle screw fixation, especially in degenerative disc diseases patients with osteoporosis.

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INTRODUCTION

The incidence of lumbar degenerative disc diseases (DDDs) in the elderly has increased in recent years. The anatomy and curvature of the spine changes significantly with age. Hegazy and Hegazy[1] confirmed the change in morphology and dimensions of lumbar lordosis in aging adults, which suggested that the anatomy and curvature need to be given more attention during surgery[1]. Additionally, osteoporosis is quite common among elderly individuals. Therefore, another key treatment strategy for lumbar DDD in the elderly is the management of osteoporosis. Osteoporosis in the elderly can cause the loosening of internal fixation. A study showed that the rate of pedicle screw loosening in patients with osteoporosis was 12.8% to 25%. Additionally, the risks of proximal and distal junctional kyphosis also increase accordingly[2]. Therefore, the stability of internal fixation in osteoporosis patients should be enhanced during the operation by employing expansive pedicle screws, bone cement screws, or cortical bone trajectory (CBT) screws. Although expansive pedicle screws can increase the intensity of internal fixation, there are clear shortcomings, such as complicated placement, a high screw breakage rate, and limited clinical application. Bone cement screws have also been gradually applied in the treatment of DDD patients with osteoporosis. Zhang *et al*[3] showed that the loosening rate of bone cement screws is less than 4.3%, but intraoperative perfusion of bone cement increased the operation time and radiation exposure. Moreover, bone cement may leak into the spinal canal and blood vessels, leading to serious complications, such as neurological dysfunction and pulmonary embolism [3]. The CBT technique was proposed by Santoni *et al*[4] in 2009. Compared with the traditional technique, the CBT technique increases the contact surface between screws and cortical bone, and all screws used in the CBT technique are surrounded by the cortical bone. Therefore, this technique is more suitable for the treatment of lumbar DDD patients with osteoporosis[4]. Furthermore, in 2014, Mizuno *et al*[5] proposed the combination of this technique with lumbar posterior midline fixation and fusion in midline lumbar fusion (MIDLF) surgery. The CBT technique in MIDLF surgery has been widely used in lumbar DDD, adjacent vertebral diseases and postoperative revision due to its low invasiveness and high safety advantages[6].

ANATOMY AND BIOMECHANICS OF THE CBT TECHNIQUE

The CBT technique is performed at the intersection of the lateral isthmus of the pedicle and the lower edge of the transverse process. The entry point is at 5 o'clock on the left pedicle and 7 o'clock on the right pedicle. The ideal trajectory of placement is along the lower edge of the pedicle with a cranial incline of 25° to 30° and an external incline of 10° to ensure the maximum contact between the screw and cortical bone (Figure 1). Although the shape of the lumbar pedicles varies in different segments, the trajectory of placement remains unchanged. Four cortical bone surfaces are contacted using the standard CBT technique in the lumbar spine, namely, the isthmus, medial wall, lateral wall of the pedicle and anterior lateral wall of the vertebral body[7]. However, CBT screws are usually shorter and thinner than conventional pedicle screws. Matsukawa *et al*[8] measured the diameter and length of CBT in the adult lumbar spine using computed tomography (CT) and concluded that the diameter of the trajectory ranged from 6.2 ± 1.1 mm (L1) to 8.4 ± 1.4 mm (L5). The length of the trajectory at each vertebra was 36.8 ± 3.2 mm (L1), 38.2 ± 3.0 mm (L2), 39.3 ± 3.3 mm (L3), 39.8 ± 3.5 mm (L4), and 38.3 ± 3.9 mm (L5)[8]. Therefore, the biomechanical stability of the CBT technique has become a popular topic in research. Kojima *et al*[7] found that the bone CT value around CBT screws was four times higher than that around traditional pedicle screws, which indicated that the bone-screw interface strength of the CBT technique was greater[9]. Li *et al*[10] also showed that the CBT technique had better fatigue resistance stability, especially in osteoporotic vertebrae[10]. However, the CBT technique is less effective against lateral bending and rotation than the conventional pedicle screw technique, which may result in a lower

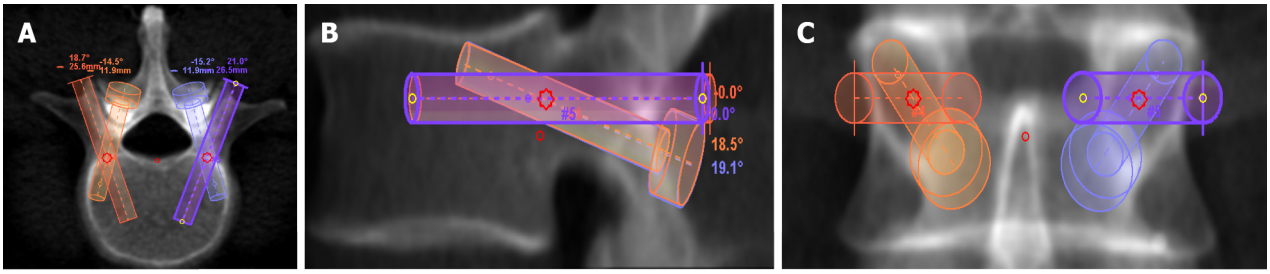

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Figure 1 Comparison of the cortical bone trajectory screw with the traditional pedicle screw trajectory. A: Axial view; B: Lateral view; C: Anteroposterior view.

interbody fusion rate using CBT screw fixation than that using traditional pedicle screw fixation[11,12]. Therefore, a transverse connection could be used to improve the anti-lateral bending and anti-rotational stability during CBT screw placement.

CBT TECHNIQUE IN LUMBAR DDD

As the CBT technique is applied closer to the posterior midline than the traditional pedicle screw technique, vertebral muscles and adjacent segment joints are less harassed; therefore, the CBT technique has many advantages, including less blood loss and fatty infiltration, a shorter hospital stay and a lower incidence of adjacent segment degeneration (ASD). Additionally, the trajectory of the CBT technique is away from important nerve and vascular tissues, which further decreases the risk of injury. The CBT technique combined with MIDLF surgery is minimally invasive and safer and has been widely used in the treatment of lumbar diseases. Studies have shown that the CBT technique combined with MIDLF in the treatment of DDD patients with osteoporosis can achieve similar clinical decompression effects to those of the traditional pedicle screw technique combined with transforaminal lumbar interbody fusion (TLIF) technology[13]. Mizuno *et al*[5] proposed that CBT screws combined with MIDLF in the treatment of patients with single-level lumbar spondylolisthesis achieved good clinical outcomes. Lumbar decompression, fixation and fusion can be completed by the CBT technique at the same time, which is in line with the concept of minimally invasive surgery. Takenaka *et al*[14] compared the CBT technique and the traditional pedicle screw technique combined with lumbar posterior interbody fusion (PLIF) in the treatment of lumbar DDD. They concluded that the operation time, intraoperative blood loss, postoperative drainage volume, bed rest time and postoperative hospital stay time in the CBT technique group were significantly lower than those in the traditional pedicle screw technique group. CBT screws combined with PLIF surgery can achieve a more minimally invasive treatment effect for DDD patients with osteoporosis[14]. Kasukawa *et al*[15] compared the clinical efficacy of CBT and conventional pedicle screw internal fixation in TLIF. They concluded that the CBT technique can achieve better clinical results, smaller incisions and faster postoperative recovery than the conventional pedicle screw technique.

CBT TECHNIQUE IN LUMBAR REVISION SURGERY

Recently, the incidence of failed back surgery syndrome and ASD has increased with the extensive application of spinal internal fixation, leading to a high proportion of lumbar revision surgeries[16]. In revision surgery, the exposure risk of the nerve structure and blood vessels is significantly increased due to hypertrophic scar tissue and unclear spinal anatomy. Another advantage of the CBT technique is the reduction in exposure risk in revision surgery. During revision surgery, the internal fixation of the original operation usually needs to be replaced when the adjacent segment is decompressed and fixed. However, the replacement of internal fixation can not only increase the operation time and surgery risk but also result in more blood loss. Therefore, decompression, fixation and fusion on the adjacent segments without removing the internal fixation of the original surgery has become a key technique for the treatment of ASD. The CBT technique, which has a unique entry point and trajectory, can complete screw placement, decompression and fusion of adjacent segments through a small incision while retaining the original internal fixation, thereby avoiding extensive dissection and reducing the operation time and risk. In addition, the CBT technique can be used to place two groups of screws in the same vertebral body[17]. A study by Takata *et al*[18] showed that the CBT technique combined with MIDLF in lumbar revision surgery has the advantages of less soft tissue injury, fewer postoperative complications and better stability of internal fixation compared with traditional revision surgery[18].

CLINICAL TRIALS AND CASE REPORTS OF USING THE CBT TECHNIQUE

We performed an online database search on PubMed using the terms "cortical bone trajectory", "clinical trials", and "case reports". Only papers published in English until June 10, 2022 were reviewed. Finally, seventeen articles were identified and included in Table 1[3,9,18-32]. There were thirteen retrospective cohort studies, two retrospective cohort comparative studies, and two prospective cohort studies. Most studies in this table indicated that the CBT technique offered good clinical outcomes with shorter incision length.

INDICATIONS FOR THE CBT TECHNIQUE

CBT screw fixation not only provides more stable internal fixation strength for patients with osteoporosis but can also be combined with a variety of minimally invasive procedures to reduce the risk of injury and intraoperative exposure. Especially for patients with obesity or diabetes, the application of CBT screw fixation can significantly reduce the incidence of postoperative complications. The following indications for CBT screw fixation were determined by comprehensive analysis of the anatomical characteristics, biomechanical characteristics and technical advantages of the CBT technique: (1) Lumbar disc degenerative diseases, especially combined with osteoporosis; (2) Obesity and high iliac crest; (3) ASD after traditional pedicle screw placement; (4) Salvage screw placement after failure of traditional pedicle screws; (5) Diseases mainly characterized by the destruction of the anterior and middle columns of the vertebral body, such as lumbar tuberculosis and intervertebral space infection; (6) Thoracolumbar fracture; and (7) Lumbar scoliosis correction and internal fixation with osteoporosis. However, CBT screw fixation is not suitable for bone destructive diseases with the absence of isthmus or spinal deformity characterized by rotation.

ADVANCEMENTS OF THE CBT TECHNIQUE

Although CBT screws are widely used in a variety of lumbar diseases, placing CBT screws is extremely demanding. Freehand techniques have a risk of exiting nerve root injury and lead to a high failure rate during screw placement. Because the anatomical entry point is hard and not evident, the placing instruments can easily slip and cause pedicle, isthmus and upper endplate injuries during surgery. The failure rate of the freehand placement technique is as high as 33.1%[33]. Second, the entry point and trajectory of the CBT technique are different from those of traditional screw placement. Surgeons cannot rely on tactile feedback to place screws, which will inevitably increase the amount of intraoperative X-ray exposure and operation time. To reduce complications and ensure screw placement safety and accuracy, researchers have begun to use 3D-printed guide plates, navigation, and robots to assist in CBT screw placement. The 3D-printed guide plate, navigation and robot-assisted placement of CBT screws successfully compensated for the disadvantages of freehand screw placement and improved the safety and accuracy of CBT screw placement for internal fixation. Marengo *et al*[34] used a 3D-printed guide plate to assist in the placement of CBT screws, and they concluded that 85.2% of the screw entry points were within 2 mm of the planned entry points. Buza *et al*[35] compared the surgical effects of MIDLF assisted by the Mazor spinal robot and free-hand MIDLF and found that the Mazor spinal robot improved the accuracy of CBT screw placement with less intraoperative blood loss and shorter hospital stays and operation times. Le *et al*[36] compared the free-hand CBT screw technique with the CBT screw technique assisted by the Tianji orthopedic surgery robot and found that the robot-assisted CBT screw technique reduced the incidence of adjacent segment facet joint injury. The accuracy of robot-assisted CBT screw placement was higher than that of the freehand group, and the acceptable screw placement in the robot-assisted group was 98.3%, which was significantly higher than that in the freehand group (84.5%). Additionally, the blood loss, operation time and radiation exposure dose of the robot-assisted group were significantly lower than those of the freehand group. Three-dimensional navigation technology is used to assist and monitor the trajectory of CBT screws in real time, which maximizes the contact between screws and the cortical bone interface and reduces the risks of screw placement (Figure 2). Navigation-assisted CBT screw placement can reduce the incidence of superior facet joint injury[17]. Khan *et al*[37] compared the accuracy of CBT screw internal fixation in the treatment of lumbar DDD with osteoporosis using a 3D guide plate, navigation and freehand[37], and they concluded that the accuracy rate of screw placement in the 3D-printed guide group and the navigation group was 100%. The accuracy rate of screw placement in the freehand group was only 87.5%. Although the application of spinal robotic and three-dimensional navigation technology has significantly improved the accuracy of CBT screw placement, there are still some shortcomings in this technology. Systematic errors are related to the patient's position change, image registration errors and screw skidding. Additionally, the angle and position of the screw may be shifted during implantation due to differences in surgeons' experience and learning curves. Therefore, it is necessary to probe the trajectory and perform intraoperative fluoroscopy to confirm the accuracy and safety of CBT screws as in the

Table 1 Clinical trials and case reports of the cortical bone trajectory screw fixation

Ref.	Country/region	Study design	Number of cases	Indication	Technique	Revision surgery	Accuracy	Outcomes	Fluoroscopy X-ray dose	Complications	Incision length
Crawford CH 3rd *et al*[19], 2019	United States	RCCS	56	Spondylolisthesis and foraminal stenosis	Navigated CBT-pedicle screw (29) traditional open TLIF (27)	NA	NA	Lower ODI and less back pain in navigated CBT group	NA	Late reoperations for adjacent segment disease were significantly greater in the traditional open TLIF group	NA
Hsu *et al* [20], 2020	Taiwan	ROS	12	Thoracolumbar osteoporotic compression fracture	Short-segment CBT instrumentation with vertebroplasty	None	NA	The average blood loss and VAS scores were significantly improved; the average sagittal Cobb angle significantly increased from 15.4° preoperatively to 18.8° postoperatively	NA	None	NA
Noh *et al* [21], 2021	South Korea	ROS	200	Spinal stenosis, spondylolisthesis, degenerative disc diseases	Open surgery with CBT screw instrumentation	5 cases with adjacent segment disease	NA	Symptom and quality of life significantly improved after surgery	NA	5 cases with ASD, 1 case with screw loosening, 8 cases with dura tear	NA
Takata *et al* [18], 2014	Japan	ROS	6	Degenerative spondylolisthesis	Hybrid CBT-pedicle screw	NA	NA	Mean operative time 175.8 min. Blood loss 70–200 mL	NA	One had a mild infection after surgery	Around5-6 cm, shorter than that of the conventional PS
Zheng *et al* [22], 2022	China	RCCS	48	Traumatic thoracolumbar fractures without neurologic defects (type A)	Percutaneous CBT (PCBT 24) OPPS 24	No	NA	VAS scores improved after operation. Blood loss and hospital stay were better in PCBT group	NA	No complications in PCBT group, four cases with complications in OPPS group	PCBT group was better than OPPS group
Petrone *et al*[23], 2020	Italy	ROS	238	Degenerative lumbosacral disease	First group: 43 cases without CT planning-Second group: 158 cases with CT planning. Third group: 37 cases with 3D printed guide	NA	Screws entirely within the cortex of the pedicle were 78.9%, 90.5% and 93.9% in the three groups	All patients' symptoms improved after surgery mean operation time was 187, 142 and 124 min in the three subgroups	NA	The total amount of complications were 4.2% (16.3%, 3.8%, 0.0% respectively)	NA
Dayani *et al*[24], 2019	United States	POS	22	Lumbar degenerative disease and spinal instability	Early experience (first 11 patients) late experience (last 11 patients)	NA	Early experience phase: 66.7% (4/6) of medial pedicle breaches; 100% of lateral vertebral body breach	Late phase: greater efficiency	NA	Incidence of complications decreased in the late phase	NA

Marengo *et al*[25], 2018	GER	ROS	101	Degenerative lumbo-sacral disease	CT planning	32 patients (31.6%)	NA	Symptom and quality of life improved after surgery; mean procedural time 187 min; mean hospital stay 3.47 days; mean blood loss 383 mL	1.60 mg cm2	4 screws misplaced; 1 wound infection; 1 pseudmeningocele	NA
Chen *et al* [26], 2018	Taiwan	ROS	6	Lumbar adjacent segment disease	C-arm guidance	Revision surgery:6 cases	NA	Symptom and quality of life improved after surgery	NA	No post-operative complication	NA
Orita *et al* [27], 2016	Japan	POS	40	Degenerative spondylolisthesis or lateral lumbar disc herniation; stenosis	Percutaneous CBT (pCBT 20); traditional PPS arms (20); C-arm fluoroscope guidance	NA	NA	Clinical outcome regarding LBP and lower limb pain improved with no significant difference between the two groups	Shorter duration of fluoroscopy in PCBT group	No complications	Shorter incision length in PCBT group
Snyder *et al*[28], 2016	United States	ROS	79	Degenerative lumbosacral disease	Navigation guide	Revision surgery: 20 cases (25.3%)	NA	Mean length of stay was 3.5 days; mean operative blood loss was 306.3 mL	NA	9 complications (8.9%) including hardware failure, pseudarthrosis, DVT, pulmonary embolism, epidural hematoma, wound infection. No complications by misplaced screws	NA
Mai *et al* [9], 2016	United States	ROS	22	Lumbar spine disease	NA	NA	NA	NA	NA	Screw loosening: 2 intra-operative dural tear: 1. Both a pedicle fracture and screw loosening: 1	NA
Ninomiya *et al*[29], 2016	Japan	ROS	21	Degenerative spondylolisthesis	Conventional PS (10) CBT (11). C-arm fluoroscope guidance	NA	NA	Symptom and quality of life improved after surgeryboth techniques showed good slip reduction	NA	NA	NA
Elmekaty *et al*[30], 2018	Sweden	ROS	59	Lumbar spondylolisthesis	MIS-PLF: 22; MIS-TLIF: 15; MIDLF: 22	NA	NA	MIDLF: shorter operation time, less bleeding amount, lower values of CRP and CK than the other two techniques; symptom and quality of life of all the patients improved after surgery	NA	Screw loosening. MIS-PLF: 10%. MIS-TLIF: 7.14%. MIDLF: 4.76%	MIDLF with a small, single posterior midline incision (3.5 cm)
Zhang *et al* [3], 2021	China	ROS	52	Lumbar tuberculosis	CBT group: 27. PS group: 25	NA	NA	All patients achieved good clinical outcomes; incision pain in CBT group is better than PS group on the 1st day and 3 rd day after surgery	NA	All patients have no intraoperative complications	NA
Wochna *et al*[31], 2018	United States	ROS	71	Traumatic thoracolumbar fractures	ORIF PS: 39; MIS PS: 20; CBT: 12	NA	NA	EBL was 337.50 mL for CBT, 184.33 mL for MIS,	NA	1 case of construct failure; 1 case of incisional site	NA

								and 503.33 mL for ORIF; LOS was 4.06 days fewer for CBT compared to ORIF		infection in the PS group; but none were found in the CBT group	
Laratta *et al*[32], 2019	United States	ROS	134	Degenerative spondylolisthesis mechanical collapse with foraminal stenosisdegenerative scoliosis adjacent segment disease	Navigation with intraoperative CT	Revision surgery: 26.9%	Accuracy rate was 98.3%. The accuracy within 1 mm of error was 99.2%	NA	NA	Lateral breaches: 3 (0.5%); medial breaches: 7 (1.1%)	NA

ROS: Retrospective cohort study; RCCS: Retrospective cohort comparative study; POS: Prospective cohort study; TLIF: Transforaminal lumbar interbody fusion; PS: Pedicle screw; CBT: Cortical bone trajectory; LBP: Lower back pain; PLF: Posterolateral fusion; MIDLF: Midline lumbar fusion; MIS: Minimally invasive spine; EBL: Estimated blood loss; LOS: Length of stay; ORIF: Open reduction internal fixation; OPPS: Open posterior pedicle screw.

conventional pedicle screw placement technique.

LIMITATIONS OF THE CBT TECHNIQUE

Although CBT screws combined with the MIDLF technique have been widely used in clinical practice, relevant studies are still lacking. (1) The screws used in various biomechanical studies have different specifications, so the results have not been uniformly concluded; (2) Most clinical studies are retrospective case studies with small sample sizes and short follow-up times. Therefore, long-term, large-sample and prospective studies are still needed to further reveal the long-term complications and long-term fusion rate; (3) CBT screws are mostly used in patients with short-segment lumbar DDD. For patients with long segments, lumbar DDD and thoracic disease are rarely reported and need further research; and (4) To date, research on the corresponding relationship between the degree of osteoporosis and the choice of internal fixation methods is limited. The focus of further studies should be the correlation between the degree of osteoporosis and various internal fixation enhancement techniques to ensure the best selection of the internal fixation under different degrees of osteoporosis.

CONCLUSION

CBT can be used as a practical and effective alternative to traditional pedicle screw fixation. It has obvious advantages in the treatment of lumbar DDD, especially in patients with osteoporosis under strict mastery of the indications and contraindications.

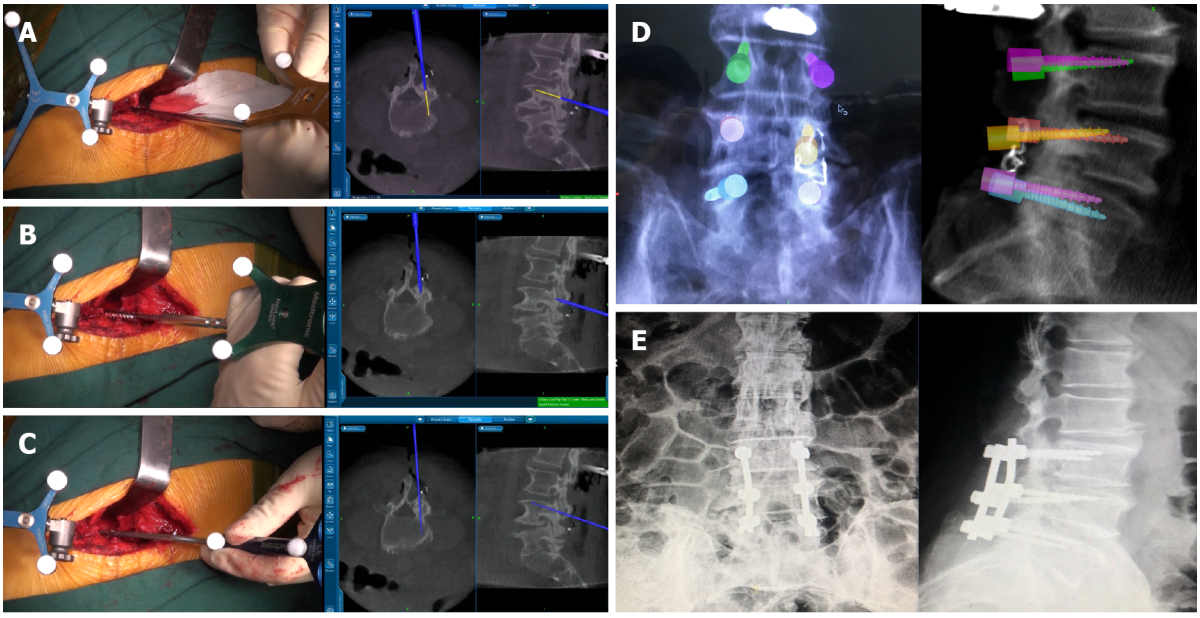

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Figure 2 Implantation of the cortical bone trajectory screw assisted by the navigation system. A: Feeling the entry point of the cortical bone trajectory (CBT) screw in L4 with the assistance of the navigation system; B: Awl of the CBT screw in L4 with the assistance of the navigation system; C: Tapping of the CBT screw in L4 with the assistance of the navigation system; D: Fluoroscopy showed the placement of CBT screws during the surgery; E: X-ray showed the implantation of CBT screws after surgery.

FOOTNOTES

Author contributions: Guo S performed most of the writing; Zhu K performed data accusation, writing and prepared the figures and tables; Yan MJ provided the input in writing the paper; Li XH designed the outline and coordinated the writing of the paper; Tan J contributed to the conception of the study.

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