North American Spine Society Journal (NASSJ) 10 (2022) 100113

Contents lists available at ScienceDirect

North American Spine Society Journal (NASSJ)

journal homepage: www.elsevier.com/locate/xnsj

Basic Science

Cortical bone trajectory fixation cause low compression force in anterior vertebral column

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ARTICLE INFO

Keywords:
Cortical bone trajectory
Intervertebral cage
Insertional torque
Interbody fusion

ABSTRACT

Background: The cortical bone trajectory (CBT) screws follow a caudocephalad and lateral path from the pedicle to the vertebral body. The bone fusion rate of CBT fixation is equal to or lower than conventional pedicle screw fixation. It remains unclear whether or not CVT screws exert equally compressive forces across the vertebral column. In this study, we intraoperatively examined the insertional torque of CBT screws, and investigated the compression loading and pressure distribution in conventional and CBT fixation using pig bones.

Methods: The insertional torque was measured for a total of 115 CBT screws. Detailed positions of these screws were retrospectively confirmed using CT scans. Screw loosening and interbody fusion were examined 1 year after surgery. In the experiment using pig bones, we inserted screws by conventional trajectory ($n = 3$) and CBT ($n = 4$).

Results: Multiple regression analysis showed that the total screw length, the distance from the screw to the medial border of the pedicle and the distance from the superior endplate of the vertebrae were significant independent factors affecting the insertional torque. There was no significant association between the insertional torque and the radiographic bone fusion rate 12 months after surgery. The average pressure and the compression loading in the anterior column were significantly lower in CBT group.

Conclusion: These results suggested that the long CBT screws as close to the endplate had high insertional torque, but the anterior column in CBT fixation showed low compression force leading to the insufficient holding intervertebral cage. CBT screws may cause the micromotion of cages, which lowers the bone fusion rate.

Introduction

The cortical bone trajectory (CBT) screw starts in the lateral part of the pars interarticularis and follows a caudocephalad and lateral path through the pedicle to maximize purchase of the cortical bone, from the pedicle to the vertebral body. Although CBT screw is effective for initial fixation [1–5], the bone fusion rate of CBT fixation is equal to or lower than conventional pedicle screw fixation [6–9].

The CBT screws place in the posterolateral part of vertebra body. While, the conventional screws cover lateral to medial and anterior to posterior axis in vertebra body. Thus, we considered that CBT screws caused unequally force distribution in vertebral column, leading to the less stabilization in CBT fixation.

The initial fixation of CBT screws depends on the insertional points, angles, and length. In this study, we examined the insertional torque, trajectory, screw loosening and bone fusion rate after posterior lumbar interbody fusion (PLIF) with CBT screws. Next, we investigated the experimental compressive loading and distribution in conventional and CBT fixation using pig bones.

Materials and methods

Patients

The insertional torque of CBT screws was measured intraoperatively in 25 patients (15 men, 10 women) who underwent PLIF for the treatment of lumbar degenerative spondylolisthesis (n = 9), lumbar canal stenosis (n = 14), or lumbar spondylolysis (n = 2). The mean age of patients at the time of surgery was 67.8 (range 45–86) years. The mean number of fused vertebral levels was 3.12 (range 2–5). We excluded L1 and L2 screws, because there was the morphological difference between spinal levels. Misplaced screws (n = 13) were excluded from this study using postoperative CT scans, and a total of 115 L3-5 screws were used to evaluate the maximum insertional torque.

Surgical procedure

Through a midline incision, paraspinal muscles were dissected to the lateral margin of the isthmus of the lamina. Lateral fluoroscopy was used

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https://doi.org/10.1016/j.xnsj.2022.100113
Received 17 January 2022; Received in revised form 8 March 2022; Accepted 8 March 2022
Available online 18 March 2022

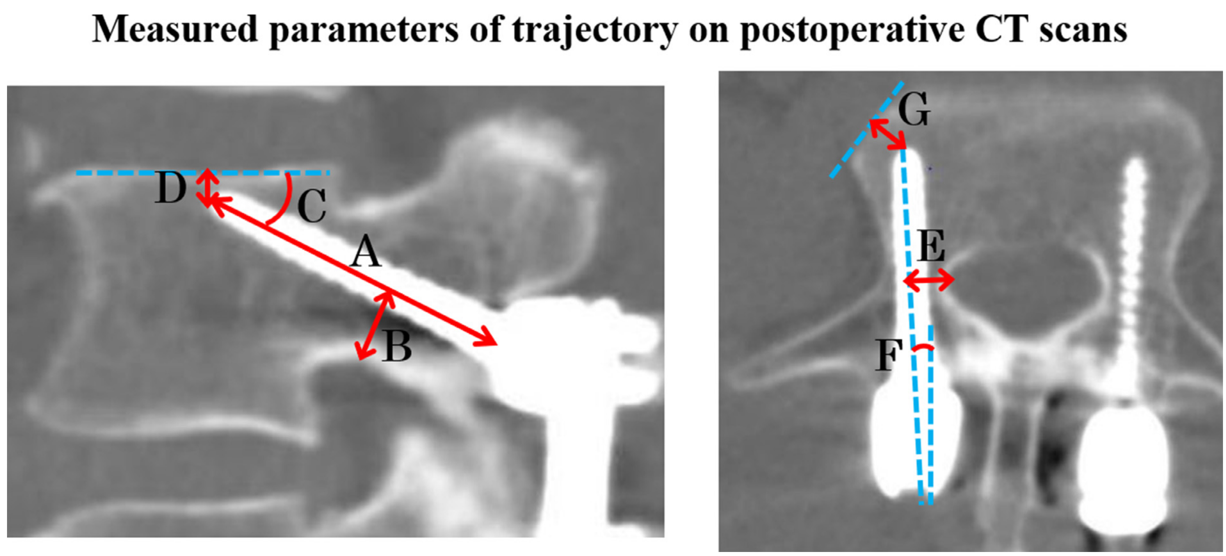

Fig. 1. Measured parameters of trajectory on postoperative computed tomography scans. (A) total screw length, (B) distance from the inferior border of the pedicle, (C) cephalad angle, (D) distance from the superior endplate of the vertebrae, (E) distance from the medial border of the pedicle, (F) lateral angle, (G) distance from the lateral wall of the vertebrae.

Table 1
Summary of all measured parameters.

	Total(n = 115)	L3(n = 31)	L4(n = 42)	L5(n = 42)	ANOVA	Multiple comparison by Tukey test
Age (yrs)	68.5 ± 9.2	69.9 ± 8.3	67.4 ± 10.1	68.5 ± 9.3	p = 0.713	
Sex, Male/Female	72/43	22/9	26/16	24/18	p = 0.487	
Lumbar BMD (g/cm^2)	1.07 ± 0.20	1.09 ± 0.20	1.06 ± 0.21	1.07 ± 0.21	p = 0.935	
Femoral BMD (g/cm^2)	0.71 ± 0.11	0.72 ± 0.10	0.69 ± 0.11	0.71 ± 0.11	p = 0.716	
Screw length (mm)	27.9 ± 4.9	28.7 ± 5.9	27.9 ± 5.1	27.3 ± 3.9	p = 0.465	
Lateral angle (°)	11.4 ± 5.5	9.0 ± 5.5	10.7 ± 5.1	13.8 ± 4.9	p = 0.0004	L3 vs L5**, L4 vs L5*
Cephalad angle (°)	18.6 ± 6.2	20.2 ± 6.8	20.8 ± 5.9	15.3 ± 5.0	P<0.0001	L3 vs L5**, L4 vs L5**
Distance from medial pedicle (mm)	5.5 ± 2.1	4.3 ± 1.5	5.5 ± 1.6	6.4 ± 2.4	P<0.0001	L3 vs L4*, L3 vs L5**
Distance from inferior pedicle (mm)	6.2 ± 1.6	5.8 ± 1.6	6.4 ± 1.6	6.4 ± 1.7	p = 0.235	
Distance from endplate (mm)	4.5 ± 2.1	5.0 ± 2.3	4.3 ± 1.9	4.2 ± 2.1	p = 0.204	
Distance from lateral wall (mm)	4.8 ± 2.4	5.3 ± 2.1	3.9 ± 1.9	5.4 ± 2.8	p = 0.0097	L3 vs L4*, L4 vs L5*
Torque (lbf·in)	11.6 ± 6.3	12.2 ± 6.9	12.0 ± 5.0	10.7 ± 7.0	p = 0.529	

BMD indicates bone mineral density. *p<0.05 **p<0.01.

to verify the trajectory for screw placement and choose the screw length longer than possible. In our previous study on CBT, we used the isthmus as an anatomical landmark for entry [10,11]. Screws were placed 3 mm inside the isthmus and inserted in a cephalad and lateral direction. Same-size tapping was performed for all screws. The screw diameter was 4.5 mm (ZODIAC polyaxial screw, Alphatec Spine, Tokyo, Japan), and the screw lengths were 25, 30, 35, and 40 mm. Titanium cages or polyetheretherketone (PEEK) cages were used in all cases. When the screw reached the end of replacement checking the position by lateral fluoroscopy, the maximum insertional torque of the screw rotation was measured using an Inline dial indicator 584100 (Holmed Corporation, Franklin, USA). Its scale was modified by Alphatec Spine to measure 0–55 in-lb (1 in-lb = 0.113 Nm) in increments of 1 in-lb.

Measured parameters and radiological evaluation

We confirmed the detailed positions of these screws using postoperative CT scans. The following parameters were measured using three-dimensional reconstruction software (AquariusNET; TeraRecon, San Mateo, CA, USA): total screw length, cephalad and lateral angle of the trajectory, distance from the long axis of the screw to the medial and inferior border of the pedicle, and distance from the screw end to the superior endplate and lateral wall of the vertebrae (Fig. 1). We measured the BMD of the femoral neck and lumbar vertebrae by dual-energy x-ray absorptiometry preoperatively. The BMD of 11/25 patients was missing. Additionally, we examined screw loosening and bone fusion 12 months after surgery using CT images. We determined the screw loosening was determined if postoperative radiolucent zones around the screws was found. Bone fusion was based on a 3-grade system as defined by the Brantigan, Steffee, Fraser (BSF): BSF-1 (radiographic pseudarthrosis), BSF-2 (radiographic locked pseudarthrosis) and BSF-3 (radiographic fusion).[10] We defined BSF-3 as bone fusion.

Experiment using pig lumbar vertebrae

We inserted screws (Depuy Synthes) for lumbar vertebrae of pig bones by traditional trajectory (n = 3) and CBT (n = 4) using fluoroscopy. Then we placed the pressure measurement film (PRESCALE; Fujifilm, Tokyo, Japan) into the intervertebral space, and compressed with the same force (196N). PRESCALE makes it possible to measure pressure balance, distribution, and size. The color appears red where pressure is applied, and the color density varies according to the amount of pressure. Using this film, we analyzed the initial compression loading and distribution.

Statistical analysis

All results are shown as mean ± standard deviation (SD). All measured parameters were analyzed by one-way ANOVA and Tukey's test (α = 0.05). Pearson correlation coefficient (R) was used for single regression analysis to assess how the maximum insertional torque changes

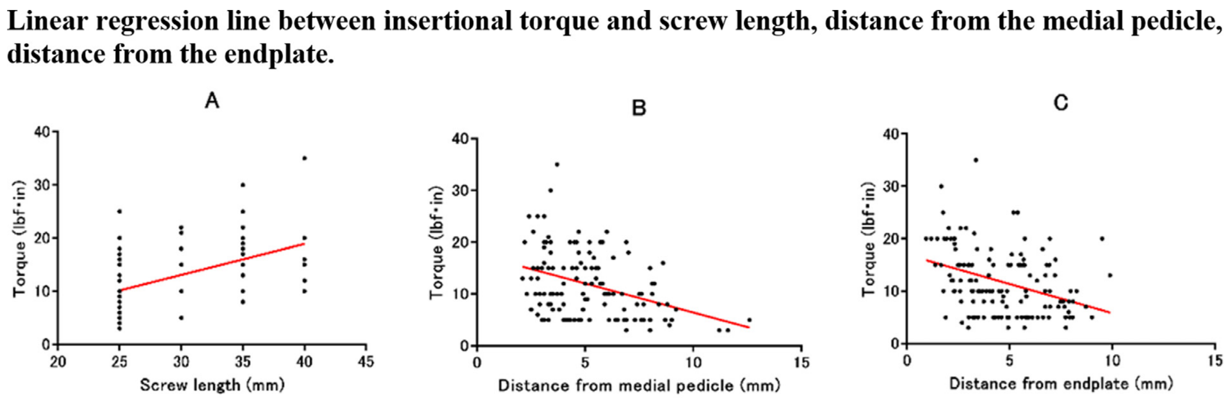

Fig. 2. Linear regression line between insertional torque and (A) screw length, (B) distance from the medial pedicle, (C) distance from the endplate.

Table 2
Single regression analysis of insertional torque.

Parameters	R	p value
Age	0.109	0.245
Lumbar BMD	0.154	0.228
Femoral BMD	0.076	0.520
Screw length	0.466	<0.01
Lateral angle	-0.393	<0.01
Cephalad angle	0.144	0.125
Distance from medial pedicle	-0.392	<0.01
Distance from inferior pedicle	-0.233	<0.05
Distance from endplate	-0.277	<0.01
Distance from lateral wall	0.042	0.621

R indicates correlation coefficient; BMD, bone mineral density.

with the positions of the screws. Then, using variables with P value less than 0.05 in the single regression analysis, multiple regression analyses were performed through a forward stepwise selection to examine the variables that affect the insertional torque. The mean insertional torque classified by screw loosening and bone fusion and the mean BMD classified by screw loosening were compared using the unpaired t-test. The interbody pressure distribution in lumbar vertebrae of pigs was also compared using the unpaired t-test. We used GraphPad Prism 7 (GraphPad Software, Inc., La Jolla, CA, USA) for all analyses, and significance was defined as p value of less than 0.05.

Results

All measured parameters are shown in Table 1. The lateral angle, cephalad angle, distance from medial pedicle, and distance from lateral wall showed significant difference. The results of the single regression analysis are shown in Table 2. This showed that the insertional torque exhibited significant correlation with the total screw length (R = 0.466, p < 0.01), lateral angle (R = -0.393, p < 0.01), distance from the medial pedicle (R = -0.392, p < 0.01), distance from the inferior pedicle (R = -0.233, p < 0.05), and distance from the endplate (R = -0.277, p < 0.01). Multiple regression analyses were performed through a forward stepwise selection (Table 3). This showed that total screw length (β = 0.280, p < 0.01), distance from the inferior pedicle (β = -0.995, p < 0.01), and distance from the endplate (β = -0.992, p < 0.01) were significant independent factors affecting the insertional torque Fig. 2. shows the linear regression line between the insertional torque and the screw length (Fig. 2A), the distance from the medial pedicle (Fig. 2B), the distance from the endplate (Fig. 2C).

The mean insertional torque classified by screw loosening and bone fusion is shown in Fig. 3. Significantly few screws of high insertional torque resulted in loosening (p < 0.01). There was no significant association between insertional torque and radiographic bone fusion. Parameters other than the insertional torque classified by screw loosening are shown (Supplementary Table 1). There was a significant association between screw loosening and screw length, lateral angle, and distance from the endplate.

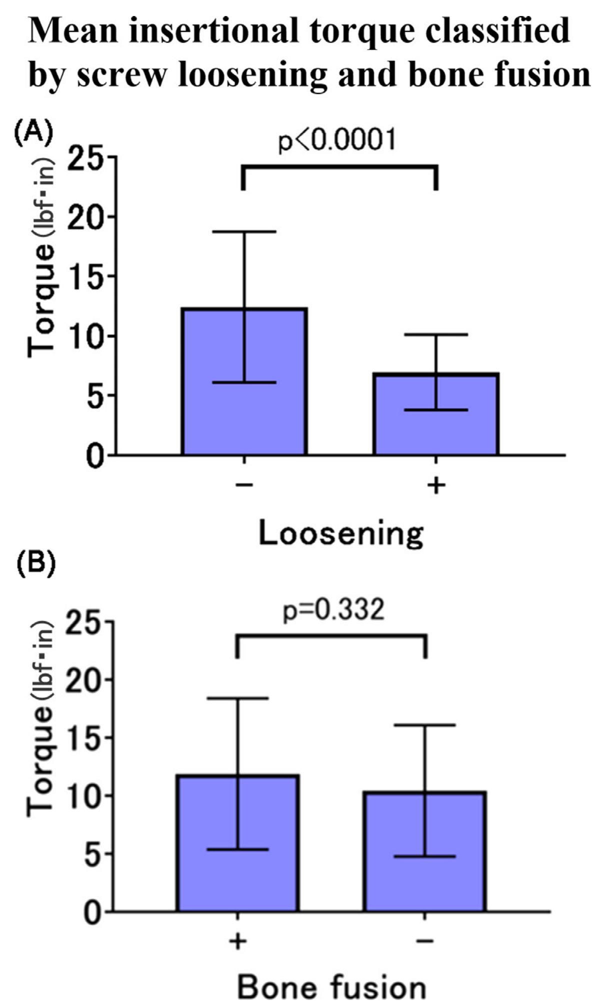

Fig. 3. (A) Mean insertional torque classified by screw loosening and bone fusion. (B) Significantly few screws of high insertional torque resulted in loosening.

We inserted screws for lumbar vertebrae of pig bones by traditional trajectory (n = 3) and CBT (n = 4) using fluoroscopy (Fig. 4) Fig. 5. pre-

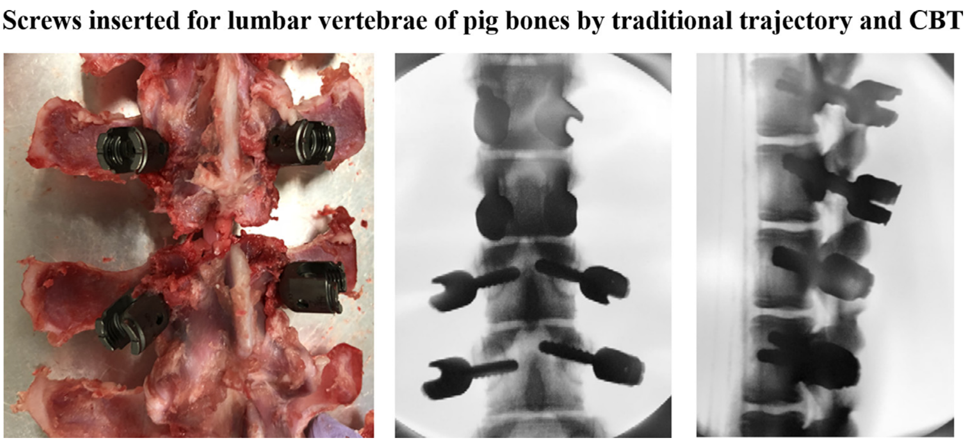

Fig. 4. Screws were inserted for lumbar vertebrae of pig bones by traditional trajectory and CBT using fluoroscopy.

Table 3
Multiple regression analysis of insertional torque.

Parameters	*β*	95% CI	*P* value
Screw length	0.280	0.0162 0.543	<0.01
Distance from medial pedicle	-0.995	-1.522 -0.467	<0.01
Distance from endplate	-0.992	-1.517 -0.466	<0.01

β indicates standardized regression coefficient; CI, Confidence interval.

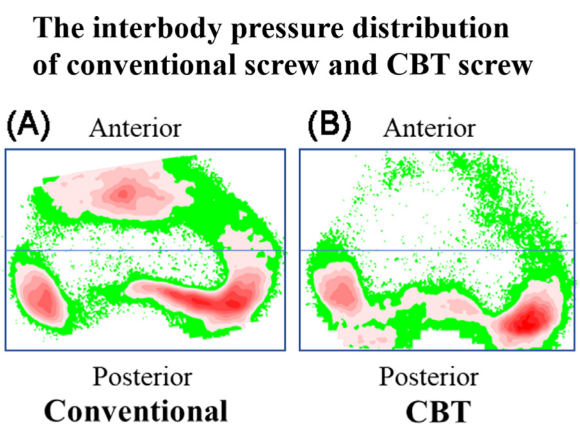

Fig. 5. The interbody pressure distribution of (A) conventional screw and (B) CBT screw in lumbar vertebrae of pigs using PRESCALE.

sented the interbody pressure distribution in lumbar vertebrae of pigs using PRESCALE. Red and green color represented high and low pressure, respectively. This showed that the CBT screw had a lower pressure in the anterior column than the conventional screw. Quantitative evaluation of the average pressure and the compression loading in the anterior column were shown in Fig. 6. They were significantly lower in CBT group ($p = 0.0044$, $p = 0.0016$, respectively).

Discussion

In this study, the insertional torque of CBT screws was measured intraoperatively. Detailed positions of these screws, screw loosening and interbody fusion were examined using CT scans. Our results show that the total screw length should be longer and as close to the endplate as possible. The insertional torque of the pedicle screw is highly correlated with pullout strength [12–16]. The high insertional torque of screws should reduce screw loosening. However, there was no significant association between the insertional torque and the bone fusion. The bone fusion rate was involved in the cage type and cage size, endplate preparation, and bone graft [17–20].

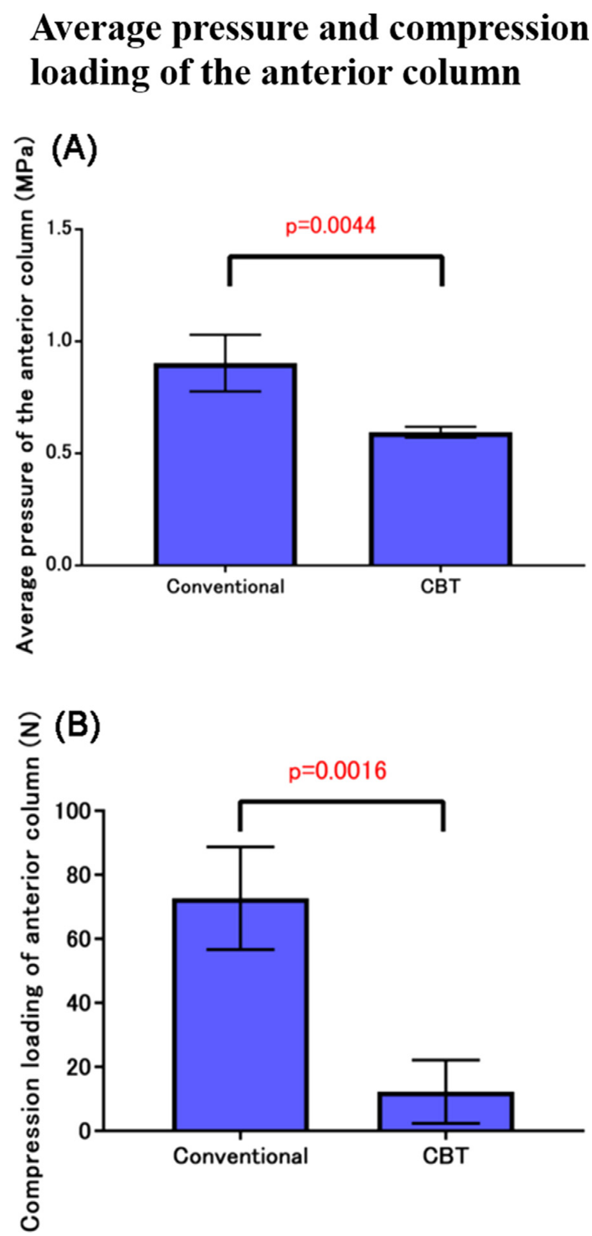

Fig. 6. Average pressure and compression loading of anterior column. (A) The average pressure and (B) the compression force of the anterior column in CBT screw fixation were significantly lower than traditional screw fixation.

We investigated the compressive loading distribution in conventional and CBT fixation using pig bones. The CBT screws place in the posterolateral part of vertebra body. The conventional screws cover lateral to medial and anterior to posterior axis in vertebra body. Our experimental compressive loading and distribution study revealed that the compression force of the anterior column of intervertebral space was significantly lower in CBT than traditional trajectory. These results suggested that CBT screws caused unequally force distribution in vertebral column. CBT fixation also has low stiffness during axial rotation and lateral bending [21]. Thus, CBT screws may cause the micromotion of cages, which lowers the bone fusion rate.

The initial fixation of CBT screws depends on the insertional points, angles, and length. We have reported isthmus-guided CBT technique previously [10,11]. Supplementary Fig. 1 presented the spline regression curves between the insertional torque and trajectory angle. This showed that screws of high insertional torque were directed 0° to 10° laterally and 15° to 25° cranially. We occasionally experienced two misplaced CBT screws and measured insertional torque of these CBT screws intraoperatively. These screws were deviated from the lateral margins of the vertebral body. The insertional torque of misplaced screws was approximately 30% lower than properly placed screws. These findings suggested that it was necessary to place the screws along an appropriate trajectory to obtain high insertional torque.

CBT is effective for patients with osteoporosis [1–5]. Femoral bone mineral density (BMD) was a significant independent factor affecting insertional torque of CBT screws [22]. In current study, there was no significant association between BMD and screw loosening. There was no significant correlation with age ($R = 0.109$, $p = 0.245$), lumbar BMD ($R = 0.154$, $p = 0.228$), femoral BMD ($R = 0.076$, $p = 0.520$), cephalad angle ($R = 0.144$, $p = 0.125$), and distance from the lateral wall ($R = 0.042$, $p = 0.621$). This indicates that CBT enables insertional torque of screws to be high, even if the patients have low BMD.

This study had some limitations. It was a retrospective study, not a prospective, randomized controlled trial. The screw diameter was fixed at 4.5 mm; hence, we could not investigate the relationship between insertional torque and screw diameter. The BMD of some patients was not measured. There was a significant difference regarding the trajectory angle and the distance from medial border of the pedicle between the levels of vertebrae. A short-term follow-up might be another limitation. Thus, additional studies with a longer follow-up, and larger sample size need to be conducted.

Conclusion

This study suggested that the long CBT screws as close to the endplate had high insertional torque, but the anterior column in CBT fixation showed low compression force. CBT screws may cause the micromotion of intervertebral cages leading to the lowering bone fusion.

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. This study received ethics committee approval of Osaka University Hospital (approval no.17098), and all patients provided signed informed consent.

Declarations of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

No funding.

Acknowledgments

We thank Dr. T. Okawa-Arita, and K. Ninomiya for assistance with surgical technique. We also thank Dr. A. Nishi for experimental assistance.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.xnsj.2022.100113.

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