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Shorter screw lengths in dynamic Dynesys fixation have less screw loosening: From clinical investigation to finite-element analysis

Fang-Chi Hsu[a], Chen-Sheng Chen[a], Yu-Cheng Yao[b,c], Hsi-Hsien Lin[b,c], Shih-Tien Wang[b,c], Ming-Chau Chang[b,c], Chien-Lin Liu[b,c], Po-Hsin Chou[b,c,*]

[a]Department of Physical Therapy and Assistive Technology, National Yang Ming Chiao Tung University, Taipei, Taiwan, ROC; [b]School of Medicine, National Yang Ming Chiao Tung University, Taipei, Taiwan, ROC; [c]Department of Orthopedics and Traumatology, Taipei Veterans General Hospital, Taipei, Taiwan, ROC

Abstract

Background: The dynamic Dynesys Stabilization System preserves lumbar mobility at instrumented levels. This study investigated the effect of screw length on screw loosening (SL) after dynamic Dynesys fixation and screw displacement during lumbar motion, using clinical investigation and finite-element (FE) analysis.

Methods: Clinical data of 50 patients with degenerative spondylolisthesis treated with decompression and Dynesys fixation in 2011 were analyzed retrospectively. Horizontal sliding displacement and vertical displacement of screw tips at L4 were analyzed postoperatively using displacement-controlled FE analysis at the L4-L5 level with screw lengths 45 (long screw), 36 (median screw), and 27 (short screw), and 6.4 mm in diameter, under flexion, extension, lateral bending, and rotation.

Results: In 13 patients (13/50, 26%), 40 screws (40/266, 15%) were loose at mean follow-up of 101.3 ± 4.4 months. Radiographic SL at 35, 40, 45, and 50 mm were 7.7%, 10.7%, 12.1%, and 37.5%, respectively, regardless of the fixation level ($p = 0.009$). FE analysis revealed that the long screw model with corresponding longer lever arm had maximal horizontal sliding displacement under all directions and maximal vertical displacement, except for lateral bending.

Conclusion: Shorter screws in Dynesys fixation may help avoid dynamic SL. Clinically, 50 mm screws showed the greatest SL and median screw screws demonstrated the least displacement biomechanically.

Keywords: Finite-element analysis; Fracture fixation; Internal; Lumbar vertebrae; Pedicle screw; Prosthesis failure

1. INTRODUCTION

With the rapid increase in older adults in the global population, the number of aging patients needing spine surgery has increased as the average lifespan increased.[1] Degenerative lumbar spondylolisthesis (LDS) with lateral recess and foraminal stenosis is a common pathologic condition in the aging spine,[2] for which decompression along with spinal fusion is the gold standard for those who have failed conservative treatment.[3] Fusion of rigid pedicle screws significantly reduces range of motion (ROM) at the fused segments.[4] The dynamic Dynesys Stabilization System (Zimmer Inc., Warsaw, IN) is one of the most frequently used posterior motion-preserving implant methods,[3] designed to preserve mobility at instrumented levels with satisfactory clinical outcomes.[5,6]

Screw loosening (SL) is not uncommon after Dynesys instrumentation.[7–9] The overall incidence of SL in the Dynesys system was 11.7% (range 0% to 76.5%) in a systematic review of the literature, with a mean 30 months of follow-up,[10] although the included studies had inconsistent radiologic criteria for SL. Being older with osteoporosis was a risk factor associated with higher incidence of SL.[8] Consequently, surgeons must focus on avoiding SL in patients after Dynesys fixation. In spine fusion surgery, increasing screw length[11,12] is one method used to improve pullout strength and enhance bony fusion.[7] Currently, most surgeons continue to use longer lumbar pedicle screws for the dynamic Dynesys system, as recommended in fusion surgery.[11,12]

Biomechanically, the intact lumbar rotation center (LRC) is located at the posterior margin of the intervertebral disc bordering the superior endplate of the posterior margin of each vertebrae.[13] Moreover, the lumbar spine after decompression and Dynesys fixation retains a rotation center similar to that of an intact lumbar spine specimen.[14] Most surgeons do not take the LRC into consideration when placing the dynamic Dynesys, although we believe that considering the LRC may improve clinical outcomes. However, few studies have investigated the effects of different screw lengths on the displacement of screws after Dynesys fixation based on the LRC as the fulcrum point.

* Address correspondence. Dr. Po-Hsin Chou, Department of Orthopedics and Traumatology, Taipei Veterans General Hospital, 18F, 201, Section 2, Shi-Pai Road, Taipei 112, Taiwan, ROC. E-mail address: choupohsin@gmail.com (P.-H. Chou).

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However, we believe that the displacement at the screw tip of Dynesys in vitro may explain the mechanism of radiographically identified SL in vivo.

When LRC is used as the fulcrum point, top-loading of Dynesys at one side and the screw tip at the other side forms a seesaw between the two sides in vivo. We hypothesized that longer screws may be located farther away from the LRC at the instrumentation level and have a longer lever arm, producing a greater arc of micromotion, or vertical displacement (VD), during lumbar motion. Moreover, the longer screws may also have greater horizontal displacement. The objective of this study was to investigate the effects of different screw lengths on the vertical and horizontal displacement at the screw tip based on LRC as the fulcrum point during lumbar motion.

2. METHODS

To investigate the effect of different screw lengths on SL, the study consisted of clinical investigation, finite-element (FE) analysis, and a comparison of the two. The clinical study was used to collect clinical data for statistical analysis to understand the possibility of SL occurring. The FE analysis aimed to study the mechanical behavior of SL under the conditions of different external movements of the lumbar spine.

2.1. Clinical analysis

2.1.1. Ethical considerations

The present clinical study was conducted in accord with international standards and the study protocol was approved by the hospital Institutional Review Board (2020-12-011CC). Signed informed consent of the included patients was waived due to the retrospective nature of the radiographic analysis, in which patients were deidentified.

2.1.2. Study design and enrolled population

Between January 2011 and December 2011, the data of 78 consecutive patients diagnosed with grade I LDS with lateral recess and/or foraminal stenosis who were treated with lumbar-stability preserving decompression and Dynesys fixation due to neurogenic claudication or radiculopathy and failure to respond to conservative treatment for at least 3 to 6 months were screened. A preoperative computed tomography (CT) scan was used to evaluate the degree of stenosis. The exclusion criteria were degenerative scoliosis with Cobb's angle >10° in the anteroposterior view, prior spine surgery, or adult degenerative deformity. To avoid the confounding effect of osteoporosis or poor bone quality on clinical SL, those with Hounsfield unit (HU) values <110 at the index level for instrumentation, previously identified as an independent risk factor for SL,[15] were excluded.

Preoperative dual-energy x-ray absorptiometry (DXA) was also not routinely prescribed for each patient, but each did receive a routine preoperative lumbar CT scan. Preoperative HU values of the vertebral body at the planned instrumented levels in the standard CT scan were used rather than the T-score to represent the preoperative regional bone quality.

HU values were obtained using thin slices (thickness: 2.5 mm) with multiplanar reconstruction. According to the protocol described by Schreiber et al,[16] HU scores were obtained from the circular regions of interest (ROIs) of mid-sagittal axial CT slices. ROIs were the largest possible elliptical regions that excluded the cortical margins to prevent volume averaging (Fig. 1A, B). HU values were obtained three times by one of the authors (P.-H.C.), with the arithmetic mean recorded as our data.

The HUs at the index operation levels were all measured using the picture archiving and communication system (PACS) (Smart Viewer 3.2; Taiwan Electronic Data Processing Cooperation, Taipei, Taiwan). To assess the inter-reliability of the HU measurement, one author (P.-H.C.) measured the HU in a random sample of 10 patients on two separate occasions. Interobserver reliability was obtained with an absolute agreement intraclass correlation coefficient (ICC) analysis using a two-way random effects model. The interobserver reliability of the HU measurements was excellent (ICC = 0.982).

In total, 28 patients were excluded from the study. Nine patients had incomplete final follow-up, two developed degenerative scoliosis preoperatively, three had revision surgery, and nine had HU values <110 at the index instrumented level. The screw diameter in our FE analysis was 6.4 mm, so the five patients with screws of 6.0 mm in diameter were also excluded.

Finally, the data of 50 patients were included for retrospective analysis, with the results compared between the preoperative examination and the final follow-up in 2020. Following the policy of the National Health Insurance of Taiwan, post-operative CT scanning was not routinely used to evaluate screw position or SL, so as to reduce costs, reduce radiation exposure and prevent artifacts in the image due to metallic implants.

The mean age at index surgery was 58.3 ± 5.15 years (range: 47–65 years) and the mean follow-up duration was 101.3 ± 4.4 months (range: 97–106 months). Thirty patients were male and 20 were female. The Dynesys system was inserted for a one-level motion segment in 24 patients, two-level in 19 patients, and three-level in seven patients, with 266 screws inserted (Table 1). The mean HU value at the instrumented index levels was 154.1 ± 21.9 HU (range: 123.03–244.06 HU), which indicated good-to-fair bone quality at the instrumented levels. All surgeries were performed by the same senior surgeon (C.-L.L.) using the conventional midline approach. The traversing and existing nerve roots were confirmed by probe as having adequate decompression. Posterior tension of the supra- and interspinous ligaments was preserved at the most cranial level.

All lengths and trajectories of pedicle screws were evaluated based on preoperative CT scan and correlated with intraoperative portable fluoroscopy. All diameters of pedicle screws were 6.0 or 6.4 mm and purchase made with the Roy-Camille method. The constructs of cord and spacer were assembled as recommended by Dynesys. A drain was placed in the subfascial layer, and the wound was primarily closed layer by layer with sutures. Patients were encouraged to ambulate after drain removal and to wear soft lumbar orthosis for at least three months.

Table 1

Patient demographic data

Parameters	Values
No. of patients	50
Male/female	20/30
Mean age ± SD (y)	58.3 ± 5.15 (47–65)
Surgery (motion segment)	
1-level	24
2-level	19
3-level	7
Total numbers of screws	
L2	14
L3	50
L4	100
L5	96
S1	6
Mean follow-up ± SD (range), mo	101.3 ± 4.4 (97–106)

SD = standard deviation.

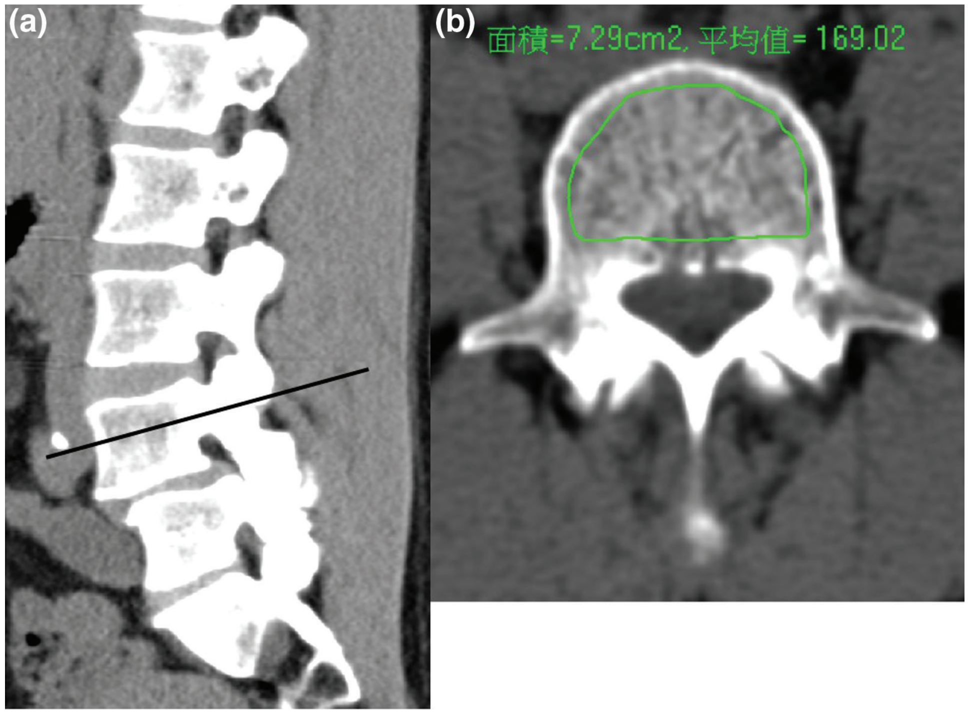

Fig. 1 Illustration of measurement of HUs in the computed tomography images at the mid-sagittal axial cut. A, Slice was taken at the mid-sagittal level in the sagittal view. B, The number 169.02 indicates the HU value at the L4 index level. HUs = Hounsfield units.

2.1.3. Radiographic definition of SL

To evaluate SL, we looked for the radiographic "halo zone sign"[17] and "double-halo sign"[18] on the latest anteroposterior plain radiograph of the spine in the PACS system. Confirmation of either of the radiographic signs indicating SL was determined by agreement of two independent experienced spine surgeons (P.-H.C. and S.-T.W.). Any discordance was resolved by consultation and agreement with a third experienced spine surgeon (C.-C.L.).

The radiographic determination of SL was evaluated mainly from the anteroposterior view on a plain radiograph of the spine rather than the lateral view, due to better visualization provided by this view.[18] However, bowel air or body mass still introduced some bias. Displacement of the pedicle screw was evaluated from a lateral radiograph of the spine. Any displacement found at the final follow-up was defined as SL.

2.1.4. Statistical analysis

One-way ANOVA was used to determine the effects of screw length on SL.

All statistical analysis was performed using the SPSS for Windows statistical package, version 22.0 (IBM Corp., Armonk, NY). The level of significance was established as $p < 0.05$.

2.2. FE analysis

2.2.1. FE model of the intact lumbar spine

A three-dimensional L1–L5 intact lumbar spine (INT) FE model was built using ANSYS 14.5 software (ANSYS Inc., Canonsburg, PA). The INT model includes the vertebrae, intervertebral discs, endplates, posterior bony elements and all 7 ligaments (anterior and posterior longitudinal ligament, flavum ligament, facet capsules, intertransverse, interspinous and supraspinous ligaments). The cortical bone, cancellous bone, endplate, posterior bony element, and annulus ground substance were simulated by the 8-node solid element. The cortical and cancellous bones were modeled using homogeneous and orthotropic material property. For the disc, the nucleus was defined as 43% of the disc based on the range reported in a previous study (30%–50%).[19] The 8-node fluid element was used to simulate the nucleus pulposus as an incompressible fluid. Twelve double cross-linked fiber layers were embedded in the ground substance. Fiber stiffness increased proportionally in a radial direction.[20] The nonlinear annulus ground substance was modeled by a hyper-elastic Mooney-Rivlin formulation. All seven ligaments were constructed according to anatomic direction and modeled by the 2-node tension-only link element. Contact behavior at the facet joint was simulated by contact elements (CONTA174) and target elements (TARGE170). The facet joint transmitted only compressive forces, and the coefficient of friction was set at 0.1. The initial gap between a pair of facet surfaces was within 0.5 mm. The INT model comprised 112 174 elements and 94 162 nodes. The INT model has been described in greater detail in previous studies.[21,22]

2.2.2. FE model of the Dynesys dynamic stabilization system (Dynesys model)

The Dynesys model was inserted bilaterally into the L4–L5 segment of the INT model (Fig. 2A, B). The material properties of the Dynesys components are listed in Table 2, as previously described.[23] The threads of the screw were ignored and the contact behavior between the screws and bone was modeled as standard contact. The coefficient of friction was set at 0.3.

A Dynesys system, consisting of two conical titanium alloy screws (diameter: 6.4 mm; length: 45 mm), a polycarbonate urethane spacer (diameter: 12 mm; length: 30 mm) and a polyethylene terephthalate (PET) cord, was used, as shown in Figure 2C. The conical screws and the spacer were simulated by the 8-node solid element. The PET cord was modeled by the 2-node tension-only link element. Both sides of the PET cord connected precisely to the screw heads at L4 and L5. The cord pretension of 300 N was controlled by a linking element using an initial strain.

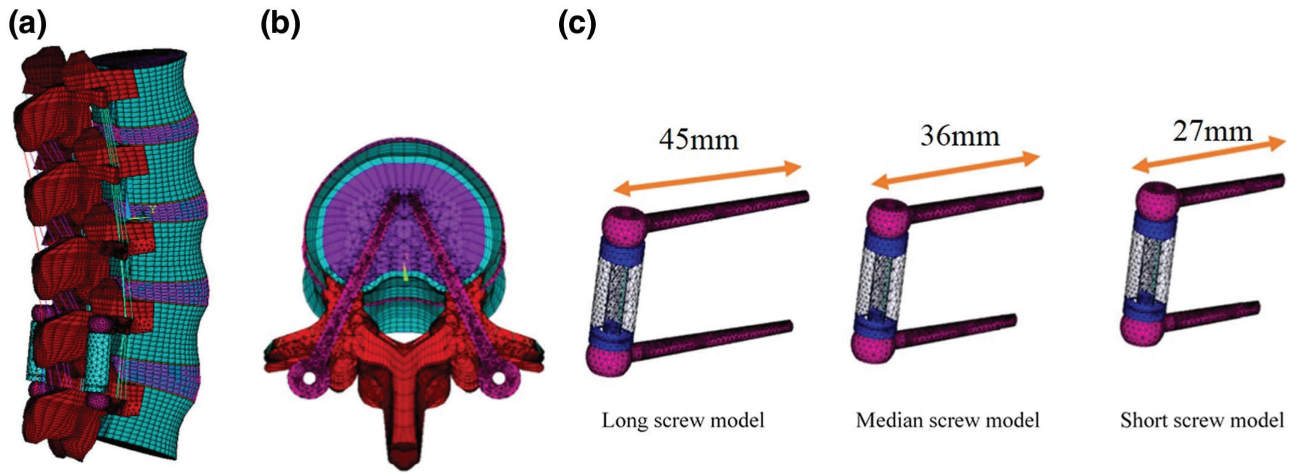

Fig. 2 The finite-element model of the lumbar spine with the Dynesys system implanted. A, The Dynesys was implanted into the standard position at the L4–L5 levels. B, The Dynesys was inserted using a medialized screw trajectory. C, The Dynesys system contains a PET cord, a PCU spacer, and pedicle screws. The three models of screw length were defined as 45 (left, LS), 36 (middle, MS), and 27 mm (right SS), respectively. The cord pretension of 300 N was controlled by link elements using an initial strain. LS = long screw; MS = median screw; PCU = polycarbonate urethane; PET = polyethylene terephthalate; SS = short screw.

Table 2

Material properties of Dynesys components

Components	Young's modulus (MPa)	Poisson's ratio
Titanium alloy screw	111 000	0.28
PCU spacer	68.4	0.4
PET cord	1500	0.4

PCU = polycarbonate urethane; PET = polyethylene terephthalate.

To investigate the effects of screw length on screw displacement, different screw lengths were modeled in the Dynesys system. Dynesys with screw length of 45 mm was defined as the long screw (LS) model and consisted of 166 422 elements and 126 090 nodes. The median Dynesys screw length, which was 0.8 times the normal size (36 mm), was defined as the median screw (MS) model and consisted of 187 560 elements and 107 759 nodes. A short screw length (27 mm) was 0.6 times the normal size, defined as the short screw (SS) model and consisting of 186 854 elements and 107 333 nodes (Fig. 2C).

2.2.3. Convergence test and model validation

For the convergence test, the loading condition was 10 Nm moment, and a 150 N preload acted on the superior surface of the L1 vertebra. Three mesh densities (coarse: 4750 elements/4960 nodes; normal: 27 244 elements/30 630 nodes; fine: 112 174 elements/94 162 nodes) were selected to test the changes in ROM in the INT model, and the finest mesh density was selected because changes between the normal model and fine model were within 1.03% in flexion (<0.28), 4.39% in extension (<0.58), 0.01% in torsion (<0.28) and 0.001% in lateral bending (<0.18). As a result, the element size was approximately 2.5 mm, as reported in previous studies.[21,22]

In terms of model validation, FE results of the intact lumbar spine were compared with the results of the in vitro cadaveric tests for the same loading conditions. The ROM for the five levels of the intact model has been previously validated in cadaveric in vitro tests.[21,22] The FE intact model displayed stiffer behavior in flexion, with an ROM value that was 4° less than that described in the in vitro study of Rohlmann et al. In addition, softer results were obtained in torsion compared with the in vitro test data; however, these differences were still within 2°. Overall, the discrepancy between the in vitro tests and our FE simulation was within one standard deviation. The ROMs for four physiological movements fell within similar ranges, and the trends agreed well with the experimental results.

The INT model was validated by comparing the results of ROM, facet contact force and intradiscal pressure with seven other FE models and the in vitro approach.[24] Differences in the results between the FE models and the in vitro test were within one standard deviation. The ROM was similar for all four physiological motions, and the trends agreed well with previous experimental tests.[21,22,24]

2.2.4. Loading and boundary conditions

Previous studies have indicated that the displacement control method is more reasonable than the loading control method for measuring ROM.[22] Maintaining a constant ROM clinically predicts the effects in the adjacent region. Therefore, the ROM values under flexion, extension, rotation and lateral bending were 20°, 15°, 8°, and 20°, respectively, in this study. A 150 N preload was placed perpendicular to the top of the L1. All FE models were constrained at the bottom of the L5 vertebra.

To compare the three screw length models, the results of ROM, horizontal sliding displacement (HSD) and VD at the L4 level. The HSD of the screw was defined as the horizontal displacement along the screw parallel axis (Fig. 3A). The VD of the screw was defined as the vertically displaced distance at the screw tip (Fig. 3A).

3. RESULTS

3.1. Clinical analysis

Clinically, in 13 patients (13/50, 26%), 40 screws (40/266, 15%) were loose based on radiographic criteria. The incidence of SL in screw lengths of 35, 40, 45, and 50 mm was 7.7%, 10.7%, 12.1%, and 37.5%, respectively (Table 4). Longer screws had a significantly higher incidence of radiographically identified SL at the last follow-up (p = 0.009).

A similar trend was found in results between the in vitro biomechanical FE analysis and the clinical investigation in the present study, although screw lengths of 50 or 55 mm were not involved in FE analysis due to breaking through the anterior vertebral body during simulation.

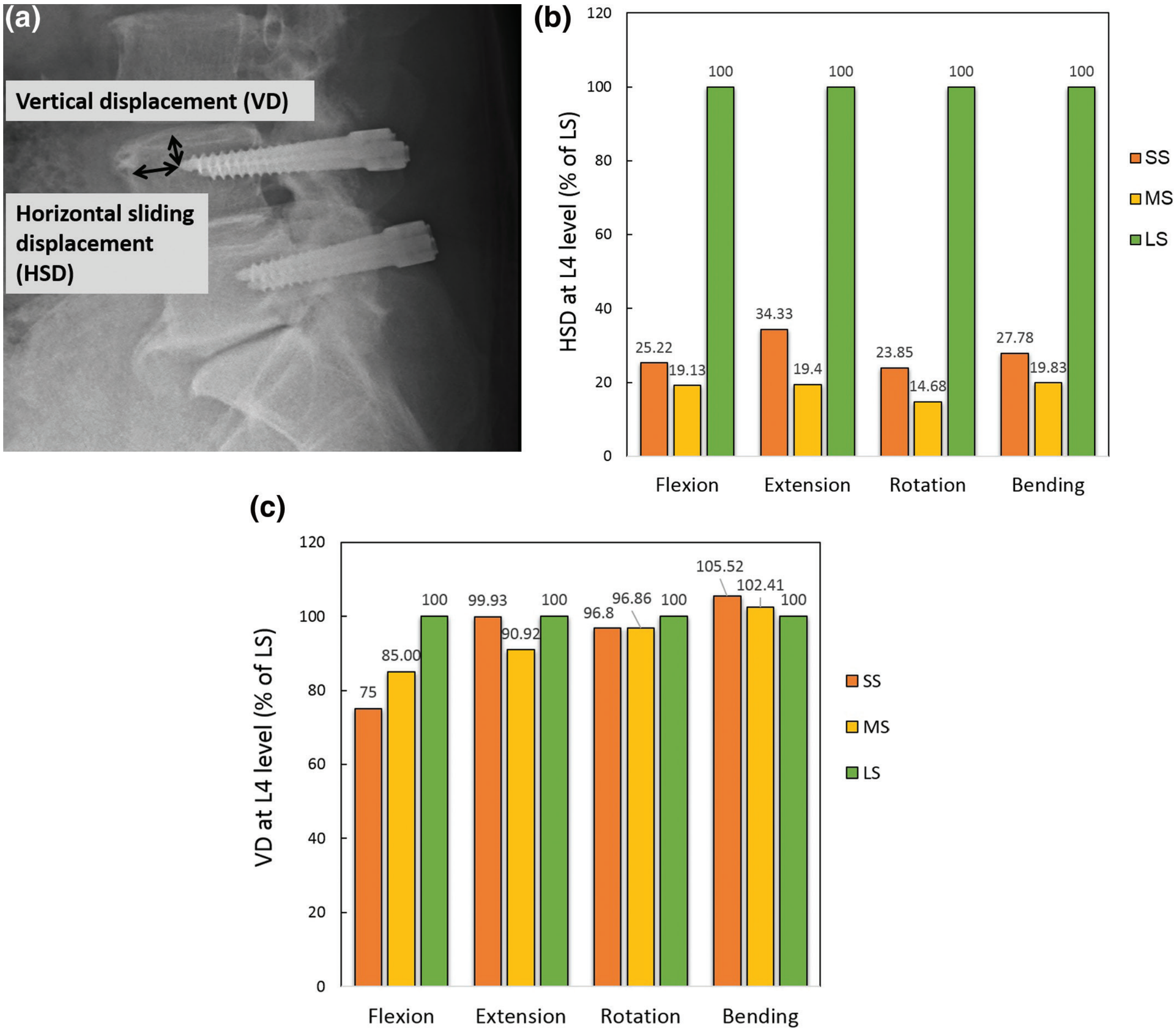

Fig. 3 Illustration of HSD and VD at the L4 level among models of different screws lengths. A, Definition of HSD and VD (arrows). HSD (longer arrow) was defined as the horizontal displacement along the screw axis at the screw tip. VD (shorter arrow) was defined as the vertically displaced distance at the screw tip. B, HSD at L4 level for different directions of motion. The bar indicates the ratio of HSD divided by the LS model (45 mm) (green bar) for the MS (36 mm) and SS (27 mm) models, respectively. C, VD at L4 level for different directions of motion. The bar indicates the ratio of VD divided by the LS model (green bar) in the MS and SS models, respectively. The three models had similar VD in all directions of movement, except in the flexion movement. The VD decreased approximately 33.8% in the SS model and 17.8% in the MS model. HSD = horizontal sliding displacement; LS = long screw; MS = median screw; SS = short screw; VD = vertical displacement.

3.2. FE analysis

3.2.1. ROM following Dynesys fixation in FE analysis

ROM at the surgical region of the Dynesys models was lower than in the INT model. The ROM in the flexion direction declined from 74% to 77%. In other directions, ROM decreased by 30%–35% in extension, 25% in rotation and 55%–59% in lateral bending (Supplementary Table and Figure, http://links.lww.com/JCMA/A172; http://links.lww.com/JCMA/A174). At the supraadjacent level, ROM increased after implantation of the Dynesys: 30% in flexion, 13%–15% in extension, 13% in rotation and 16% in lateral bending (Supplementary Table and Figure, http://links.lww.com/JCMA/A173; http://links.lww.com/JCMA/A174). ROM at the instrumented and supraadjacent levels differed within 5% in all directions of ROM, regardless of the screw length model.

3.2.2. HSD and VD at the L4 level

The maximum HSD value at the L4 level was observed in the LS model; the minimal HSD value at the L4 level was found in the MS model. The result implied that the MS model (screw length: 36 mm) had the least displacement at the screw tip along the screw parallel axis as evaluated by FE analysis (Table 3). The HSD of the MS model decreased obviously from 80% to 85% as compared with the LS model in all directions of motion (Fig. 3B).

The sum of VD in four directions of motion in the LS, MS, and SS models were 6.1, 5.67, and 5.67 mm, respectively (Table 3). The LS model had the greatest sum value of VD in four directions of motion; the SS and MS models had a similar sum value of VD. Compared to the LS model, VD decreased approximately 33.8% in the SS model and 17.8% in the MS model under flexion motion (Fig. 3C). However, VD in the other directions of motion were similar between all three models.

Table 3

HSD and VD for three finite-element models of different screws length

	HSD (mm)		
	LS	MS	SS
Flexion	0.12	0.02	0.03
Extension	0.067	0.013	0.023
Rotation	0.109	0.016	0.026
Lateral bending	0.116	0.023	0.031
Total	0.412	0.072	0.110
	VD (mm)		
Flexion	1.78	1.51	1.33
Extension	1.53	1.39	1.53
Rotation	1.50	1.45	1.45
Lateral bending	1.29	1.32	1.36
Total	6.1	5.67	5.67

HSD = horizontal sliding displacement; LS = normal screw model (45 mm); MS = median screw model (36 mm); SS = short screw model (27 mm); VD = vertical displacement.

Table 4

Screws length and incidences of SL

Screw length (mm)	Number of inserted screws	Number of SL	Incidence of SL (%)
35	26	4	7.7
40	84	9	10.7
45	124	15	12.1
50	32	12	37.5

SL = screws loosening.

3.3. Comparison of clinical data and FE data

The relatively small differences (0.43 mm) in the sum of VD in the four directions of motion were investigated between the three models. However, the minimal HSD and VD in the MS model resulted in a significantly greater difference after long-term Dynesys fixation, which clinically implied less screw micromotion or displacement in all directions of motion. Theoretically, this result may explain the possible mechanism for a lower incidence of radiographically identified SL in the MS model.

4. DISCUSSION

In the present study, the L1 to L5 lumbar spine FE model was used to evaluate the biomechanical effect of screw length on lumbar repair with Dynesys. Results showed that ROM in FE models decreased at the index level and increased at the supra-adjacent level compared to the INT model. The results were in good agreement with results of previous studies showing that Dynesys reduced ROM at the index level and increased ROM at the supraadjacent level because of compensation.[25–27] The ROM in all FE models were similar at the index and supraadjacent levels. This similarity implies that differences in screw length were less important in terms of ROM at the index and supra-index levels.

The use of longer screw fixation is appropriate only for instrumented fusion surgery. However, the concept has not been validated clinically in the use of the dynamic system for pedicle screw fixation. Because Dynesys is a dynamic pedicle screw system, top-loading of the construct may force the screws to move within the pedicle and lose their bone purchase.[18] Moreover, the LRC in the lumbar spine is located at the posterior border of the vertebrae. Based on using the LRC as the fulcrum center, the pedicle screw in the dynamic Dynesys system at one side and the top-loading force at the other side each have their own lever arm to create the "seesaw effect" during lumbar motion, which leads to further micromotion or displacement at the pedicle screw site. Based on our FE results, the MS model (screw length: 36 mm) had the smallest HSD. In contrast, the longest lever arm

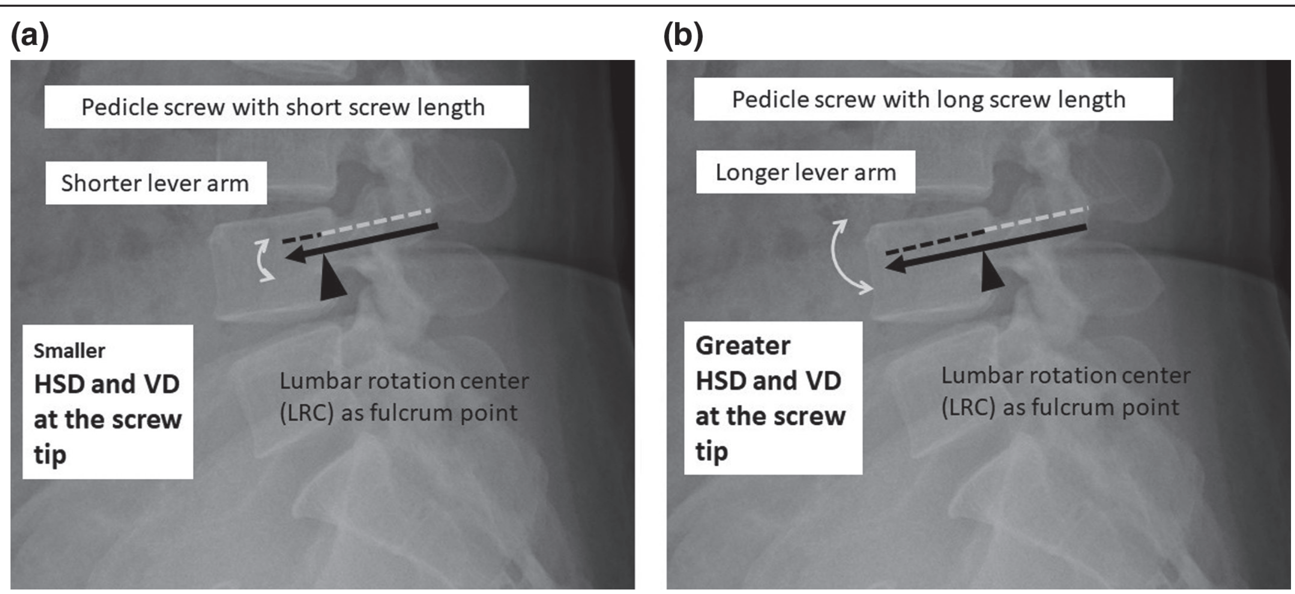

Fig. 4 Greater seesaw effect may be the possible mechanism for the higher incidence of screw loosening in longer screw fixation of Dynesys in terms of the LRC. A, MS length model (36 mm). B, LS length model (45 mm). The black triangle is the LRC as the fulcrum point. The solid black lines with arrows represent the different screw lengths, the LS model and the MS model. The dotted black and gray lines represent the corresponding lever arms at both sides based on the fulcrum point (left: screw tip; right: top-loading along with lumbar motions). The solid gray lines represent HSD and VD at the screw tips, respectively (ie, the longer the line, the greater the displacement). With LRC as the fulcrum point, the longer lever arm on one side of the LS created greater displacement at the screw tip during dynamic Dynesys motion than in the MS model. We defined the greater "seesaw" effect in the LS model as taking LRC into consideration. Moreover, the longer screw also had greater HSD as well. LRC = lumbar rotation center; HSD = horizontal sliding displacement; LS = long screw; MS = median screw; SS = short screw; VD = vertical displacement.

of the LS model (screw length: 45 mm) resulted in much more VD. The greater degree of VD may lead to a clinically greater degree of screw-bone interface displacement or micromotion at the screw tip, resulting in the formation of the so-called radiographic "halo sign." Apparently, fixation of longer screws with longer lever arms resulted in a correspondingly greater VD at the screw tip, when referencing LRC as the fulcrum point. Biomechanically, the greater "seesaw" effect in the LS model was taken as an effect of the larger LRC (Fig. 4), which may explain the mechanism of SL in terms of screw length.

Older age (mean age: 64.8 years) is a potential risk factor for SL in dynamic Dynesys system fixation; older adult patients experience SL within an average of 6.6 months following the index surgery.[8] Moreover, osteoporosis is a well-known risk factor for SL in Dynesys instrumentation.[8] According to biomechanical studies,[28] the bone–screw interface in the osteoporotic spine is unstable, leading to reduced pullout force and cutout force. In the present study, to eliminate the confounding factors of age and osteoporosis, HU values were taken from the CT scan, shown to be a reliable and accurate technique for assessing regional bone quality.[16] HUs have also been used to correlate regional bone mineral density with surgical outcomes such as SL.[15] Zou et al[15] reported that patients with HU values <110 at the index level had a significantly higher incidence of SL regardless of DXA-determined T-scores or age. Accordingly, the authors adopted a cutoff HU value of 110 to exclude the effect of regional bone quality on SL. Under rigid instrumentation, the pedicle screws must provide initial stability until a solid posterolateral and/or interbody fusion is achieved. Theoretically, a higher incidence of SL in the dynamic Dynesys system may require longer follow-up. Our medical center started using dynamic Dynesys fixation in late 2010, and we selected for study those who received lumbar surgery in 2011, to obtain the longest possible follow-up period.

In a systematic review of 1,166 patients in 21 studies[10] in Dynesys fixation, 11.7% and 1.6% of patients had SL and fracture, respectively, with a mean 30-month follow-up (range: 16–54 months) regardless of the criteria used in each study to diagnose SL. However, neither Wu et al[8] nor Pham et al[10] investigated the role of screw length in SL with dynamic Dynesys fixation. In the present series, 40 screws (40/266, 15%) in 13 patients (13/50, 26%) had SL based on radiographic criteria during a mean follow-up of 101.3 months. Screws of 35 mm had less incidence of loosening based on our radiographic criteria for SL, a result which was compatible to those found in our FE analysis.

In clinical practice, the common diameters used in the Dynesys system are 6.0 and 6.4 mm. We sometimes choose a smaller diameter and shorter length of screw fixation because of the smaller pedicle diameter and shorter pedicle, midline axis and transverse pedicle axis distance in the Taiwanese population as compared to Caucasian populations.[29] A larger diameter of screw may lead to pedicle breach of the medial wall and jeopardize the nerve root, and a longer screw may produce anterior vascular injury. Moreover, a screw length of 50 or 55 mm was deemed not appropriate for our FE model due to breaking through of the anterior vertebral body during simulation. Consequently, in order to correlate the clinical investigation and our FE analysis correctly, patients with screw diameters of 6.0 mm were excluded.

Despite recent advances in spinal fusion, the optimal pedicle screw for fixation within a bone of compromised quality remains a concern,[30] especially in older adults. Increasing the screw length[12] is one method used to improve the pullout strength in spine fusion surgery. Both a clinical investigation[12] and an in vitro FE study[31] have shown that increasing the screw length may increase stability and pullout strength; however, screw length is ultimately limited by the anatomy of the vertebrae and the potential for vascular injury.[32]

The present study identified the smallest HSD and VD in the MS model. These results suggest that using a median length screw may reduce the horizontal and VD at the screw tip and possibly reduce the occurrence of SL. The present results differ in some points from the previous FE analysis reported by Jendoubi et al,[33] who found that longer screw length was associated with better pullout resistance. However, that earlier study did not take into consideration the movement of the screws at the instrumented level. Screws with greater HSD and VD in FE analysis may have more bone destruction at the screw tip in vivo, which will then increase radiographic SL.

VD was lower in the MS model than in the LS model. These results imply that a median-length screw results in less of a seesaw effect and further reduces the degree of bone–screw interface destruction compared to using a longer screw. Screws of median length also had better pullout resistance than shorter screws, based on the FE analysis reported by Jendoubi et al.[33] Based on the present FE analysis of HSD and VD, and the pullout resistance shown by Jendoubi et al,[33] we may conclude that, compared to longer screws, using median length screws will reduce the possibility of SL. Our clinical findings also support the results of our in vitro biomechanical FE analysis.

The study collected clinical data to undertake statistical analysis to determine the possibility of SL and understand the phenomenon using several samples from our clinic. Step-by-step analysis was used to determine the amount of force transferred under movement in the lumbar spine in screws of different lengths and FE analysis was used to estimate the mechanical change which occurred when using screws of different lengths. Combining statistical science (clinical analysis) and computer science (FE analysis) allowed us to determine the extent of SL in the clinic. The study considered only one kind of disc degeneration and ignored other situations like delamination, dehydration and reduction in disc height. The lumbar spine model used was simplified and lacked a sacrum. Without a sacrum, the effect of the lower adjacent region is unknowable. In terms of the simplification of material properties, the nonlinear property of spinal ligaments and the viscoelasticity of the disc were not considered. In addition, the implant model did not include the screw threads. The model included a friction coefficient to measure the generated friction force to represent the effect of the screw thread; however, it was still a different measure. Threads may change the value and region of screw stress in a theoretical study differently from in a clinical study, because different pathways of force may be involved. Future studies may investigate the results obtained from a detailed screw thread model. Also, the ROM in the present study was smaller than that needed for movements in daily life.[34] Lack of the muscle would cause small ROM in the FE study and less stiffness in the lumbar model. Despite these study limitations, the FE model can still be used to evaluate the likelihood of SL with different screw lengths. Clinically, the retrospective analysis may contribute bias to the results. Neither adjacent segment degeneration nor functional outcome evaluation were performed in the clinical investigation. Moreover, the detection of SL using lumbar CT scans is more specific and accurate. However, if a halo sign or double-halo sign on radiographs is used, the diagnosis may be influenced by bowel gas, radiograph beam angulation, or radiographic contrast.

In conclusion, FE analysis revealed that the smallest HSD and VD were in the MS model. With minimal values of HSD and VD in the MS model, less screw displacement or micromotion at the screw tip was apparently achieved, suggesting that use of this screw length may potentially minimize the destruction at the screw-bone interface and reduce the possibility of SL. Clinically, fixation using longer screws may result in a higher incidence of dynamic SL, regardless of the fixation levels. Choosing shorter screws for Dynesys fixation may help to avoid SL when addressing the LRC.

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APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://links.lww.com/JCMA/A172, http://links.lww.com/JCMA/A174, and http://links.lww.com/JCMA/A173.

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