

Feasibility of Laminar Screw Placement in the Upper Thoracic Spine

Analysis Using 3-Dimensional Computed Tomographic Simulation

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Study Design. Evaluation using 3-dimensional screw trajectory software and computed tomographic scans.

Objective. To investigate the anatomic feasibility of laminar screw placement in the upper thoracic spine compared with pedicle screw placement.

Summary of Background Data. Although laminar screws have been suggested as an alternative to pedicle screws in the upper thoracic spine, previous anatomic feasibility studies have some limitations.

Methods. Four types of screws were simulated from T1 to T6: unilaminar screw (US), superior bilaminar screw (SBS), inferior bilaminar screw (IBS), and pedicle screw (PS). Maximum allowable screw dimensions and the success rates of 4.5-mm screw placement were compared for each level. Laminar screw dimensions with more than 90% success rate at each level were determined for reference.

Results. Computed tomographic scans of 132 patients were analyzed. Laminar screw diameters gradually increased from T1 (4.4–5.4 mm, for each type) to T6 (4.8–6.7 mm), whereas PS diameter steeply declined from T1 (5.9 mm) to T4 (3.4 mm) and then leveled off. At T1, PS had greater success rate of 4.5-mm screw

placement than laminar screws (US > IBS > SBS); at T2, US had greater success rate than IBS, followed by PS and SBS; and at T3 to T6, laminar screws (US > IBS > SBS) had greater success rate than PS in all comparisons. Except for SBS at T1, laminar screw diameters with more than 90% success rates were between 3.5 and 5.0 mm.

Conclusion. In view of their anatomic feasibility, laminar screws can be a viable alternative to PSs in the upper thoracic spine. Particularly at T3 to T6 where the pedicle width is inherently small, the success rates of laminar screw placement were significantly and consistently higher than those of PS placement. The comparable success rates of laminar screws using commercially available screw sizes further emphasize their potential clinical use.

Key words: thoracic laminar screws, thoracic pedicle screws, internal fixation, upper thoracic.

Level of Evidence: 2

Spine 2013;38:1146–1153

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Acknowledgment date: October 29, 2012. Revision date: December 18, 2012. Acceptance date: January 10, 2013.

The device(s)/drug(s) that is/are the subject of this manuscript is/are not FDA approved for this indication and is/are not commercially available for this purpose in the United States: thoracic laminar screw.

This manuscript includes unlabeled/investigational uses of the products/devices listed below and the status of these is disclosed in the manuscript: thoracic laminar screws.

No funds were received in support of this work.

Relevant financial activities outside the submitted work: payment for lecture, board membership, expert testimony, grants, royalties, stocks.

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DOI: 10.1097/BRS.0b013e31828aadf5

1146 www.spinejournal.com

Although pedicle screw (PS) fixation has been used as the standard method of stabilization in the thoracic spine, its use in the upper thoracic area has some limitations.^{1–9} In this area, the small pedicles,^{1–6} anatomical variations at the cervicothoracic junction,^{7,8} and inherently poor lateral radiographical visualization of the anatomical landmarks may pose some problems with PS insertion. This may be challenging or even impossible in cases with bony defects or obscured anatomical landmarks due to tumorous conditions or complex revisions.⁹ On occasions in which inadequate screw positioning, loosening, or cutout occurs, a salvage procedure may also be necessary. Furthermore, in patients with severe osteoporosis or those undergoing complex reconstructive surgery, augmentation of PSs may be necessary to ensure adequate stabilization. An effective and safe alternative to or augmentation of PSs can therefore enhance the surgeon's armamentarium, allowing for more individualized treatment strategies in such scenarios.

In order to overcome these limitations, laminar screws have been suggested as an alternative to PSs in the upper thoracic spine.^{10–17} Laminar screw insertion is technically easier because the starting points and trajectory are identified under direct visualization and palpation of the laminae.^{9–11}

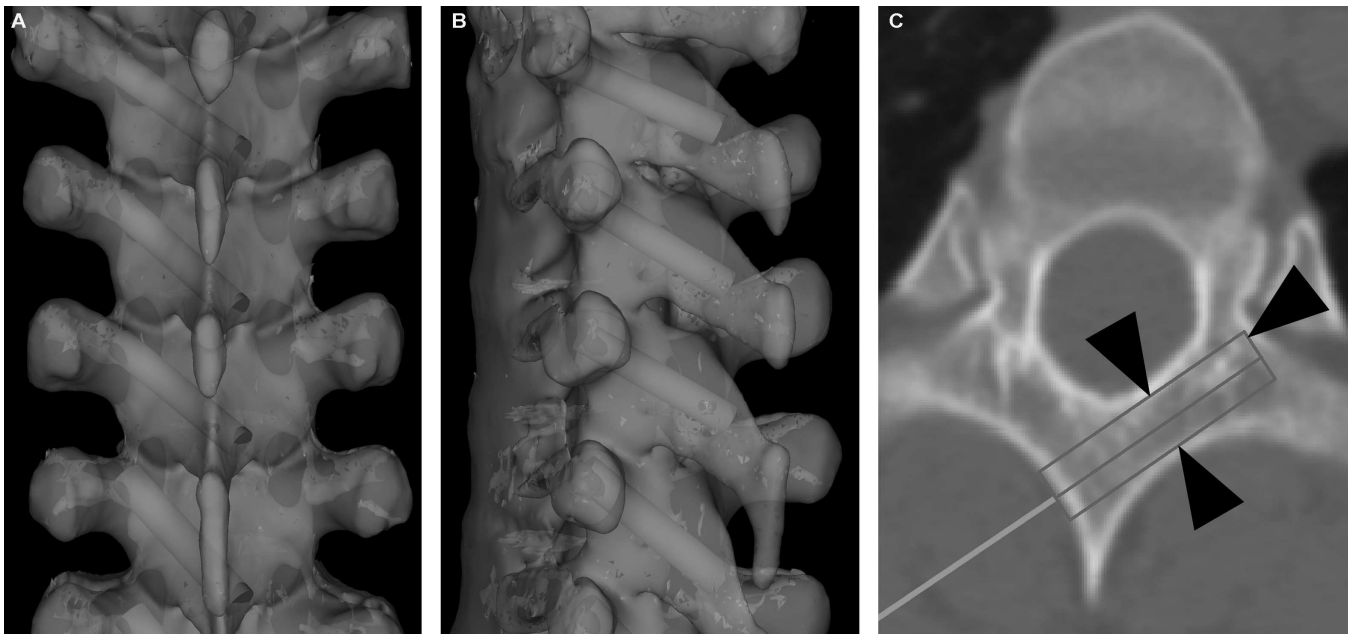


Figure 1. The trajectories of unilaminar screws are shown in posterior (A) and left posterior oblique (B) views of a 3-dimensional model and in an oblique axial image reconstructed along the screw trajectory (C). Screws were placed within the interior cortical margins: the margin between the cortical and the cancellous bone (black arrowheads), instead of the exterior cortical margins (C).

Despite several studies that have shown that the biomechanical properties of laminar screws in the upper thoracic spine are comparable with that of PSs,^{12–14} previous anatomic feasibility studies of upper thoracic laminar screws have some limitations. For example, in the only cadaveric study found in the literature,¹⁴ the authors measured laminar and pedicle widths in only 9 T1 and 11 T2 vertebrae because they were assessing the biomechanical property at the same time. In addition, in the 4 studies that used computed tomographic (CT) scans,^{14–17} the sample size was small,^{14,15} the axial image intervals were too large (3 mm)^{15,17} or not described,¹⁶ only T1

and T2 were evaluated,^{14,17} or a direct comparison with PSs was not done.^{15,16} Furthermore, all these studies^{14–17} evaluated only 2-dimensional CT scans. Moreover, none of them^{14–17} have evaluated the feasibility of bilateral screw placement, which requires a larger trajectory window when compared with unilateral screw fixation.¹⁸ Therefore, the purpose of this study was to investigate the anatomic feasibility of the placement of both unilateral and bilateral laminar screws in the upper thoracic spine and to compare it with the placement of PS using a large number of 1.0-mm interval CT scans and 3-dimensional screw insertion simulation software. Of note,

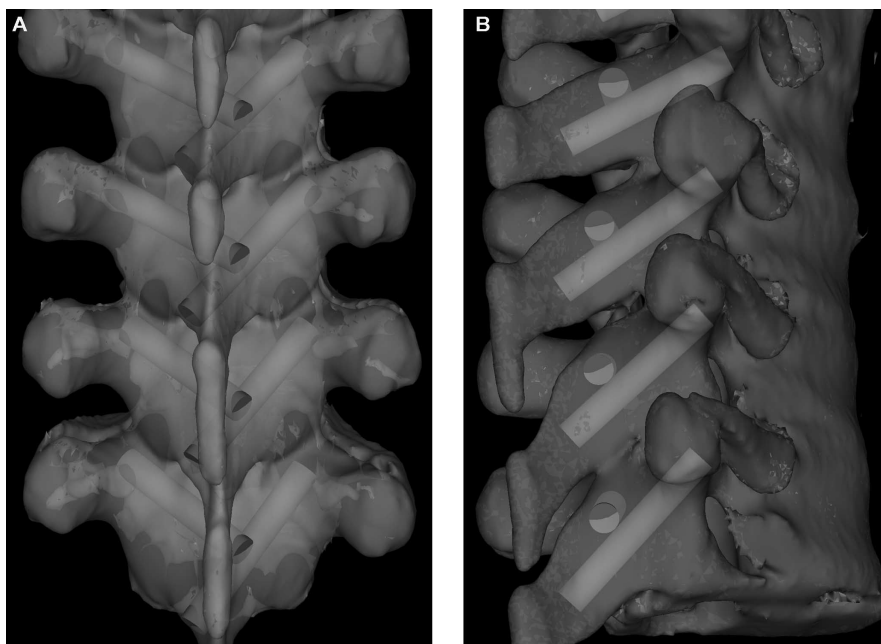


Figure 2. The trajectories of bilaminar screws are shown in posterior (A) and right posterior oblique (B) views of a 3-dimensional model. A, Superior bilaminar screws have more horizontal trajectories and thus shorter lengths than inferior bilaminar screws. B, No collisions or overlaps between the screws on both sides are seen.

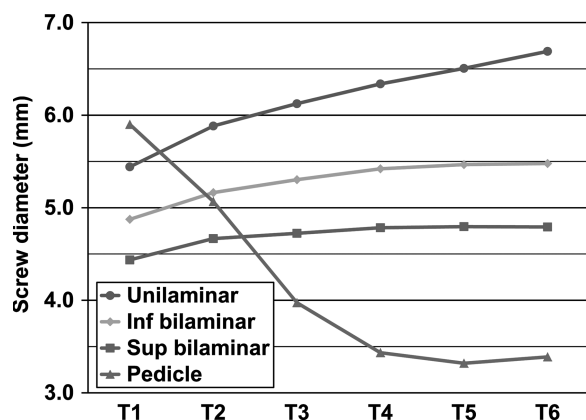


Figure 3. Mean values of maximum allowable diameters of the 4 types of screws at each level.

laminar screw placement in the thoracic spine is not approved by the US Food and Drug Administration.

MATERIALS AND METHODS

Inclusion and Exclusion Criteria

This study was approved by our institutional review board. Thoracic spine 1.0-mm interval CT scans (Mx8000 IDT; Philips Medical Systems, Best, the Netherlands) obtained at a single institution between January 2005 and May 2012 were

initially included for analyses. Exclusion criteria included (1) CT scans of patients younger than 20 years, (2) those with unsatisfactory imaging of T1 to T6, (3) postoperative CT scans, and (4) those with fractures, infection, tumor, deformities, or congenital anomalies. Among those fulfilling the selection criteria, equal number of consecutive patients were selected for each sex.

Computer Simulation

Screw insertion was simulated using 3-dimensional screw trajectory simulation software (Vworks; Cybermed, Inc., Reston, VA), which had a function similar to preoperative planning software used for intraoperative navigation. After loading the axial CT scan files in the software, sagittal and coronal images and a 3-dimensional model of the spine were reconstructed. Screw insertion was simulated simultaneously using those images as reference (Figures 1 and 2). The entry point, trajectory, diameter, and length of each screw could be determined using this software.

Screw Trajectories and Measurement of Screw Dimension

Placement of 4 screw types was simulated at T1 to T6: unilaminar, superior bilaminar, inferior bilaminar, and PSs. Trajectories of laminar screws were determined from a pilot simulation study using 30 cases. The entry point of a unilaminar

TABLE 1. Maximum Allowable Screw Diameters*

	T1	T2	T3	T4	T5	T6
Unilaminar screw (U)						
Male (mm)	5.6 ± 1.3	5.9 ± 1.3	6.0 ± 1.2	6.2 ± 1.2	6.3 ± 1.1	6.5 ± 1.1
Female (mm)	5.3 ± 1.2	5.8 ± 1.1	6.2 ± 1.1	6.5 ± 1.1	6.7 ± 1.1	6.9 ± 1.1
All (mm)	5.4 ± 1.3	5.9 ± 1.2	6.1 ± 1.2	6.3 ± 1.2	6.5 ± 1.1	6.7 ± 1.1
Inferior bilaminar screw (I)						
Male (mm)	4.8 ± 0.8	4.9 ± 0.8	5.0 ± 0.8	5.1 ± 0.8	5.1 ± 0.8	5.0 ± 0.9
Female (mm)	5.0 ± 1.1	5.4 ± 0.9	5.6 ± 1.0	5.7 ± 1.0	5.8 ± 1.1	5.9 ± 1.1
All (mm)	4.9 ± 1.0	5.2 ± 0.9†	5.3 ± 0.9	5.4 ± 1.0	5.5 ± 1.0	5.5 ± 1.1
Superior bilaminar screw (S)						
Male (mm)	4.6 ± 1.1	4.7 ± 0.8	4.8 ± 0.9	4.8 ± 0.9	4.8 ± 0.9	4.7 ± 0.9
Female (mm)	4.3 ± 1.0	4.6 ± 0.8	4.7 ± 0.7	4.7 ± 0.7	4.8 ± 0.8	4.9 ± 0.8
All (mm)	4.4 ± 1.0	4.7 ± 0.8	4.7 ± 0.8	4.8 ± 0.8	4.8 ± 0.8	4.8 ± 0.9
Pedicle screw (P)						
Male (mm)	6.1 ± 1.2	5.4 ± 1.1	4.2 ± 1.2	3.6 ± 1.3	3.4 ± 1.2	3.6 ± 1.2
Female (mm)	5.7 ± 1.1	4.7 ± 1.1	3.8 ± 1.1	3.3 ± 1.1	3.2 ± 1.1	3.2 ± 1.2
All (mm)	5.9 ± 1.2	5.1 ± 1.2†	4.0 ± 1.1	3.4 ± 1.2	3.3 ± 1.2	3.4 ± 1.2
Post hoc comparison‡	P > U > I > S	U > I = P > S	U > I > S > P	U > I > S > P	U > I > S > P	U > I > S > P

*The values given are the mean ± standard deviation.

†P = 0.700 in post hoc Tukey test.

‡Post hoc Tukey test after repeated measures 1-way analysis of variance test, for all patients, including male and female; P < 0.05 in all comparisons except for one indicated as " = ".

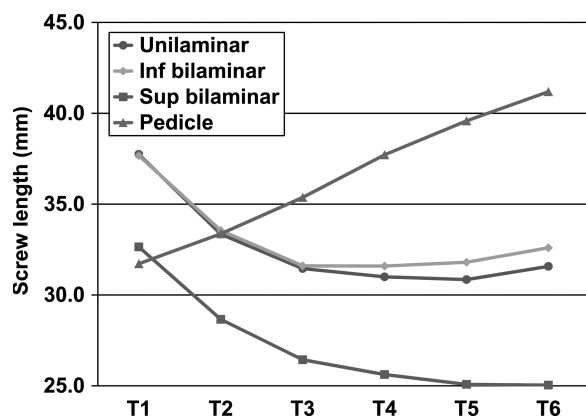


Figure 4. Mean values of maximum allowable lengths of the 4 types of screws at each level.

screw (US) was the craniocaudal midpoint of the spinolaminar junction or at a point slightly caudal to it (Figure 1A, B). The screw trajectory was aimed at the proximal third of the junction of the contralateral transverse process and lamina on the posterior view of the 3-dimensional image. The screw was inserted following the slope of the contralateral lamina, without violating either the ventral or the dorsal cortices of the lamina (Figure 1C). “Cortical breach” was defined as any violation of the interior margin of the cortical bone, that

is, the margin between the cortical and the cancellous bone (black arrowheads in Figure 1C). The maximum allowable screw diameter without cortical breach of the dorsal and ventral laminae was measured for each screw. The maximum allowable screw length in the absence of cortical breach of the transverse process and superior articular facet surface was measured.

For bilaminar screws, the entry points were moved to the upper third of the spinolaminar junction for the superior bilaminar screw (SBS) and to the lower third for the inferior bilaminar screw (IBS), in order to avoid collision between the screws, as shown in Figure 2. For both screws, the screw was aimed at the proximal third of the junction of the contralateral transverse process and lamina on the posterior view of the 3-dimensional image, as with US. The maximum allowable diameters and lengths of the bilaminar screws in the absence of any cortical breach and overlap of screws on both sides (Figure 2B) were measured.

PSs were inserted bilaterally using the straightforward trajectory.^{19–21} The entry point was set at the craniocaudal midpoint of the junction of the transverse process and lamina at the lateral pars at T1 and T2 and was progressively shifted to a more medial and cephalad point at the more caudal thoracic levels.¹⁹ The screw trajectory followed the pedicle axis in the axial plane and remained parallel to the superior endplate in the sagittal plane.²¹ The maximum allowable screw diameters

TABLE 2. Maximum Allowable Screw Lengths*

	T1	T2	T3	T4	T5	T6
Unilaminar screw (U)						
Male (mm)	39.3 ± 1.9	34.6 ± 2.1	32.7 ± 1.9	32.1 ± 2.0	31.5 ± 1.8	32.3 ± 2.0
Female (mm)	36.2 ± 2.2	32.1 ± 2.1	30.2 ± 1.8	29.9 ± 1.7	30.2 ± 1.8	30.9 ± 1.8
All (mm)	37.7 ± 2.6†	33.3 ± 2.4‡	31.5 ± 2.2§	31.0 ± 2.2	30.8 ± 1.9	31.6 ± 2.1
Inferior bilaminar screw (I)						
Male (mm)	39.3 ± 2.3	34.9 ± 2.0	32.8 ± 1.8	32.7 ± 2.0	32.6 ± 2.1	33.2 ± 2.0
Female (mm)	36.0 ± 2.1	32.2 ± 2.3	30.5 ± 1.8	30.5 ± 1.8	31.0 ± 2.1	32.0 ± 2.0
All (mm)	37.7 ± 2.8†	33.5 ± 2.5‡	31.6 ± 2.1§	31.6 ± 2.2	31.8 ± 2.3	32.6 ± 2.1
Superior bilaminar screw (S)						
Male (mm)	35.0 ± 2.5	30.8 ± 2.2	28.3 ± 1.9	27.2 ± 1.9	26.6 ± 2.3	26.6 ± 2.4
Female (mm)	30.3 ± 2.2	26.5 ± 1.9	24.6 ± 1.6	24.0 ± 1.6	23.6 ± 1.7	23.5 ± 1.9
All (mm)	32.6 ± 3.3	28.7 ± 3.0	26.4 ± 2.6	25.6 ± 2.4	25.1 ± 2.5	25.0 ± 2.7
Pedicle screw (P)						
Male (mm)	33.7 ± 2.2	35.3 ± 1.9	37.0 ± 2.3	39.4 ± 1.9	41.1 ± 2.0	42.6 ± 2.2
Female (mm)	29.8 ± 1.8	31.5 ± 1.6	33.7 ± 1.8	36.1 ± 1.8	38.0 ± 1.9	39.7 ± 2.1
All (mm)	31.7 ± 2.8	33.4 ± 2.6‡	35.4 ± 2.6	37.7 ± 2.5	39.6 ± 2.5	41.2 ± 2.6
Post hoc comparison	U = I > S > P	I = P = U > S	P > I = U > S	P > I > U > S	P > I > U > S	P > I > U > S

*The values given are the mean ± standard deviation.

†, ‡, §, P > 0.05 in post hoc Tukey tests.

||Post hoc Tukey test after repeated measures 1-way analysis of variance test, for all patients including male and female; P < 0.05 in all comparisons except for those indicated as “ = ”.

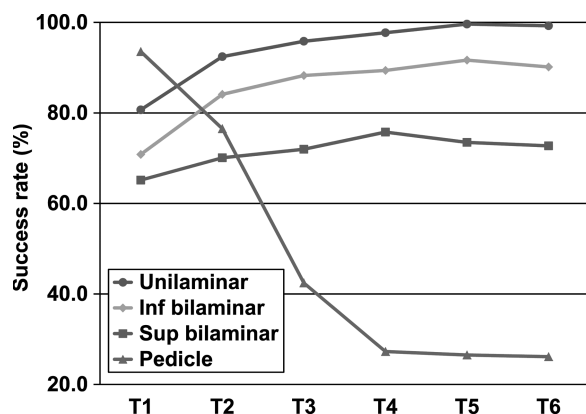


Figure 5. Success rates of the 4 types of screws with 4.5-mm diameter at each level are shown.

and lengths in the absence of any cortical breach of the pedicles and vertebral body anteriorly were measured.

Data Analyses

Three analyses were carried out. First, diameters and lengths of the 4 types of screws were compared at each thoracic level. Second, the success rate of each screw type was assessed and compared at each thoracic level. In this analysis, we assigned a 4.5-mm diameter screw, taking into account that most commercially available screws have 3.5- to 4.5-mm diameters for the cervical spine and 4.5 mm or more for the thoracic spine. Finally, laminar screw diameter and length with more than 90% success rate at each level were determined for reference. In the determination, the screw diameter and length were set at 0.5-mm and 1-mm intervals, respectively.

Statistical Analyses

Diameters and lengths of the 4 types of screws were compared using repeated measures 1-way analysis of variance test, followed by *post hoc* Tukey tests for individual comparisons. The success rates of the 4 types of screws were compared using Cochran *Q* test, followed by *post hoc* multiple McNemar tests with Bonferroni correction for individual comparisons. SPSS software package version 19.0 (SPSS, Chicago, IL) was used to perform the statistical analysis, and the level of significance was set at a 2-tailed $P < 0.05$.

RESULTS

Patient Demographics

CT scans of 132 patients were included in this study. There were 66 males and 66 females. The mean age was 55 ± 17 years (range, 20–82). We simulated insertion of 264 USs, IBSs, SBSs, and PSs for each level from T1 to T6, performing a total of 6336 screw insertion simulations.

Screw Dimensions

The maximum allowable screw diameters are summarized in Table 1 and Figure 3. Overall, the diameter of each type of laminar screw was at its minimum at T1 (US, 5.4 mm; IBS, 4.9 mm; and SBS, 4.4 mm) and gradually increased to T6 (US, 6.7 mm; IBS, 5.5 mm; and SBS, 4.8 mm). This was in stark contrast to the diameter of PS, which had a steep decline from T1 to T4 and leveled off from T4 to T6. Among the 3 types of laminar screws, SBS had the smallest diameter followed by IBS and then by US at all levels ($P < 0.05$ in all pairs of *post hoc* comparisons). PS had the largest diameter among the 4 types of screws at T1 ($P < 0.05$ in all pairs of *post hoc* comparisons), similar diameter with IBS at T2 ($P = 0.70$), and smaller diameter than any other screws at T3 to T6 ($P < 0.05$ in all pairs of *post hoc* comparisons).

The maximum allowable screw lengths are summarized in Table 2 and Figure 4. The length of each type of laminar screw was maximum at T1 (US and IBS, 37.7 mm; SBS, 32.6 mm), sequentially decreased to T3, and tended to plateau at either T3 or T4. In contrast, PS lengths steadily increased from 31.7 mm at T1 to 41.2 mm at T6. Among the 3 types of laminar screws, SBS had the shortest length at all levels ($P < 0.05$ in all pairs of *post hoc* comparisons), measuring 32.6 mm at T1 and 25.0 mm at T6. PS had the shortest length among the 4 types of screws at T1 ($P < 0.05$ in all pairs of *post hoc* comparisons), similar length with US and IBS at T2 ($P = 1.000$ and 0.858, respectively), and greater length than any other screws at T3 to T6 ($P < 0.05$ in all pairs of *post hoc* comparisons).

Feasibility of Placing Laminar Screws Compared With PSs

The success rates for the 4 types of screws with a 4.5-mm diameter are summarized in Table 3 and Figure 5. Success

TABLE 3. Success Rates for 4.5-mm Diameter Screws*

	T1	T2	T3	T4	T5	T6
Unilaminar screw (U)	80.7	92.4	95.8	97.7	99.6	99.2
Inferior bilaminar screw (I)	70.8	84.1	88.3	89.4	91.7	90.2
Superior bilaminar screw (S)	65.2	70.1†	72.0	75.8	73.5	72.7
Pedicle screw (P)	93.6	76.5†	42.4	27.3	26.5	26.1
<i>Post hoc</i> comparison‡	$P > U > I > S$	$U > I > P = S$	$U > I > S > P$	$U > I > S > P$	$U > I > S > P$	$U > I > S > P$

*All given values are in percent.

† $P = 0.060$ in *post hoc* multiple McNemar tests.

‡*Post hoc* multiple McNemar tests after Cochran *Q* test; $P < 0.05$ in all comparisons except for one indicated as “ = ”.

TABLE 4. Diameters and Lengths of Laminar Screws Having More Than 90% Success Rate

	T1	T2	T3	T4	T5	T6
Unilaminar screw						
Diameter (mm)	4.0	4.5	4.5	5.0	5.0	5.0
Length (mm)	34	30	28	28	28	29
Inferior bilaminar screw						
Diameter (mm)	3.5*	4.0	4.0	4.0	4.5	4.5
Length (mm)	34	30	29	29	29	30
Superior bilaminar screw						
Diameter (mm)†	3.0‡	3.5	3.5	3.5	3.5	3.5
Length (mm)	28	25	23	28	22	22

*Success rate using a 4.0-mm screw: 89.1%.

†Success rates using a 4.0-mm screw: T1, 74.7%; T2, 86.0%; T3, 86.0%; T4, 87.5%; T5, 86.8%; and T6, 87.6%.

‡Success rate using a 3.5-mm screw: 84.6%.

rates at each level followed a similar trend for screw diameters described previously. Using this assigned diameter, the success rate of US increased from 80.7% at T1 to 99.2% at T6, IBS from 70.8% to 90.2%, and SBS from 65.2% to 72.7%. On the contrary, success rate of PS decreased from 93.6% at T1 to 26.1% at T6.

At T1, PS had the highest success rate, followed by US, IBS, and SBS sequentially ($P < 0.05$ in all pairs of *post hoc* comparisons). At T2, US had the highest success rate followed by IBS, PS, and SBS ($P < 0.05$ in all pairs of *post hoc* comparisons except the one between PS and SBS, where $P = 0.060$). At T3 to T6, US had the highest success rate, followed by IBS, SBS, and PS sequentially ($P < 0.05$ in all pairs of *post hoc* comparisons).

Laminar Screw Sizes Having More Than 90% Success Rate

Table 4 summarizes laminar screw sizes having more than 90% success rate. USs have larger diameter (4.0–5.0 mm) than bilaminar screws (3.0–4.5 mm), as expected. For bilaminar screws at T1, 3.5-mm screws can be used for the IBS and 3.0-mm screws can be used for the SBS. A 3.0-mm screw may not be available and may be replaced with a 3.5-mm screw for T1 SBS, having a success rate of 84.6%. At T2 to T6, 4.0- to 4.5-mm screws have more than 90% success rate for IBS and 3.5-mm screws for SBS: a 4.0-mm SBS has 86.0% to 87.5% success rate at these levels, as shown in Table 4.

DISCUSSION

Although laminar screws have been introduced as a viable alternative to or augmentation of PSs in the upper thoracic area, previous studies regarding their anatomic feasibility have some limitations. The goal of this study was to evaluate the anatomic feasibility of laminar screws in the upper thoracic spine and to compare them with PSs.

Trajectory of the Laminar Screw

We decided to place the screws following the slope of the lamina rather than using a predetermined angle, considering that the lamina is completely exposed during real surgery. This method has been used for cervical laminar screws^{18,22} and in a previous report on thoracic laminar screw placement.¹⁰ In addition, we set the screw trajectory aimed at the proximal third of the junction of the contralateral transverse process and lamina. This was to increase the screw length, which was achieved by (1) the cranially angulated trajectory and (2) the additional space provided by the transverse process without breaching the facet joints above and below. This also gives an option of bicortical screw fixation depending on the surgeon's discretion, when he or she would prefer to have a longer screw inserted. Using this landmark, the screw trajectory can be guided by the cancellous tactile feedback of the probe followed by screw insertion without intraoperative radiographical imaging. We think that this suggested trajectory may serve as an easier and more practical intraoperative guide for safe screw placement than using an angle determined by preoperative CT scan.^{15–17}

Screw Dimensions and Feasibility

In this study, screw dimensions showed the following trends from T1 to T6: (1) gradually increasing laminar screw diameter from T1 to T6, in stark contrast with PS diameter that steeply declined from T1 to T4 and leveled off from T4 to T6 (Figure 3) and (2) laminar screw length being maximum at T1 and sequentially decreasing to T3, and tending to plateau at either T3 or T4, in contrast to PS length linearly increasing from T1 to T6 (Figure 4). At T3 to T6 both unilaminar and bilaminar screw diameters were significantly larger than PS diameters ($P < 0.001$, respectively), whereas their lengths were significantly smaller than PS lengths ($P < 0.001$, respectively). The diameter of SBS was smaller than that of IBS and

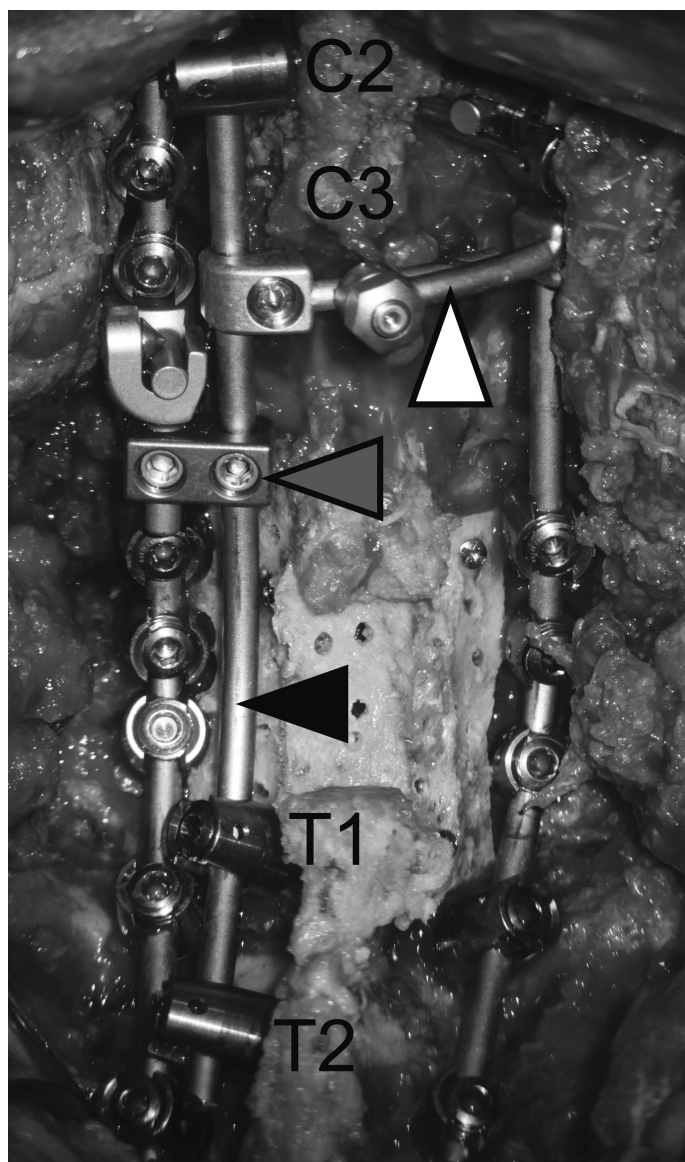


Figure 6. An intraoperative photograph shows augmentation of 2 screw-rod constructs by a third rod (black arrowhead) on the left medial side and laminar screws inserted at C2, T1, and T2. The third rod is connected with the 2 other rods using a transverse connector (white arrowhead) and a domino (gray arrowhead).

US at all levels (Figure 3) because of the unique shape of the thoracic lamina, which is thinner cranially than caudally. The length of SBS was smaller than that of IBS and US at all levels (Figure 4) because its trajectory was more horizontal (Figures 1A and 2A).

In comparing the feasibility of placing laminar screws *versus* PS, success rates at each level followed a similar trend as the screw diameters. At T1, PS had greater success rate than laminar screws (US > IBS > SBS); at T2, US had greater success rate than IBS, followed by PS and SBS, and at T3 to T6, laminar screws (US > IBS > SBS) had greater success rate than PS (Figure 5). The reverse pattern of success rates of laminar screw *versus* PS (Figure 5) demonstrates that laminar screws can be a viable alternative to PS, particularly at T3 to

T6, where the pedicle width is inherently small and the success rate of laminar screws is significantly higher than PS.

Laminar screw dimensions having more than 90% success rates in the absence of any cortical breach were determined at each level for reference. US dimensions were significantly larger than bilaminar screws (Table 4). Except for SBS at T1, 3.5- to 5.0-mm screws had more than 90% success rate for all screw types at all levels. This implies that in a salvage or augmentation procedures, standard cervical or thoracic screw systems may safely be used as laminar screws depending on the thoracic level in most cases.

Although laminar screws may be inserted with ease, assembling them to PS-rod constructs may be difficult because of their different orientation and location. In our experience, use of lateral extenders facilitates the assembly, especially under conditions in which the laminar screw is placed somewhere in the middle of the construct. When laminar screws are used for augmentation of the PS-rod constructs, we prefer to add additional rod(s) attached to laminar screws and to connect the rod(s) with the primary rods using domino(s) and/or transverse connector(s) (Figure 6).

Limitations of This Study

As with any study, there are a number of limitations with ours. Computer simulation with a CT-based 3-dimensional model that is used is not as realistic as a cadaveric or clinical study and subsequently leads to several limitations. First, although entry points and trajectories can be changed several times to determine the ideal ones during computer simulation, they may be more difficult to locate during actual surgery. This may have overestimated the actual success rates of both laminar and pedicle screws. However, it enables evaluation of anatomic feasibility more accurately than cadaver studies because multiple trials are allowed. In addition, it allows assessing the feasibility of both unilateral and bilateral screw placement using different trajectories at exactly the same levels on the same patient. Second, we defined cortical breach as violation of the interior cortical margin. We chose the interior cortex considering that decortication would be required in most instances and some clearance would be required for safe screw insertion during real surgery. Third, our simulation using CT scan-based models cannot evaluate the influence of bone quality on the stability of screw fixation. A formal biomechanical investigation is required if laminar screws may be recommended in cases with low bone mineral density. Fourth, we did not take into account deformed anatomy, which is common in patients with thoracic deformity such as scoliosis. In this study, we have focused only on patients with normal thoracic spine morphology. Fifth, our CT simulation does not take into account the viscoelasticity of bone during screw insertion. Pedicle expansion has been reported to occur in 85% of the patients in whom screw diameter exceeded 65% of the pedicles' outer diameter.²³ In a similar manner, there exists the possibility of laminar expansion, which may allow for a higher success rate with laminar screws. Nevertheless, we have no way of accounting for such bony expansion in our simulation model. Therefore, to keep the test consistent, we

did not account for bone expansion in our simulation. In any case, our definition of the “success rate” of screw placement based on a simulation may have underestimated the actual success rates. Bone expansion during laminar or PS insertion should be considered in their clinical use. Finally, race, age, height, and the original diagnosis of our subjects were not considered.

Despite these limitations, we think that this study has unique strengths. We used 3-dimensional simulation, which enables more accurate assessment of the anatomical feasibility than using simple 2-dimensional images. We used a large number of CT scans. We analyzed the feasibility of bilateral laminar fixation and of unilateral screw placement.

CONCLUSION

To the best of our knowledge, this is the largest series to evaluate the feasibility of upper thoracic laminar screw placement and the first to assess the feasibility of bilateral as well as unilateral screw placement using 3-dimensional analysis. We found a reverse pattern of maximum allowable screw dimensions between laminar and pedicle screws: (1) laminar screw diameter gradually increased from T1 to T6, in contrast with PS diameter that steeply declined from T1 to T4 and leveled off from T4 to T6 and (2) laminar screw length decreased from T1 to T3 and tended to plateau at either T3 or T4, in contrast to PS length that linearly increased from T1 to T6. This reverse pattern between laminar and pedicle screws demonstrates that laminar screw placement can be a viable alternative to PS when PS placement is not easy. Particularly at T3 to T6 where the pedicle width is inherently small, the success rates of laminar screw placement without cortical breach, either unilaminar or bilaminar, were significantly and consistently higher than PS placement, despite compromised screw lengths. Except for SBS at T1, all laminar screws (US, SBS, IBS) at all levels having more than 90% success rates ranged from 3.5 to 5.0 mm.

➤ Key Points

- Laminar screw diameter gradually increased from T1 to T6, whereas PS diameter steeply declined from T1 to T4 and leveled off from T4 to T6.
- Laminar screw length decreased from T1 to T3 and tended to plateau at either T3 or T4, whereas PS length linearly increased from T1 to T6.
- From T3 to T6, the success rates of both unilaminar and bilaminar screw placement were significantly and consistently higher than those of PS placement, despite compromised screw lengths.
- Except for SBS at T1, all laminar screws (US, SBS, IBS) at all levels having more than 90% success rates ranged from 3.5 to 5.0 mm.
- In view of their anatomic feasibility, laminar screws may be a viable alternative to PSs in the upper thoracic spine.

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