Original Article

The articular surface technique for lumbar pedicle screw placement: a 3D feasibility study

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Background: Traditional pedicle screws (TPSs) and cortical based trajectory pedicle screws each apply stability with fusions of the lumbar spine and have shown good success. However, the technical considerations of each technique imply complications of loosening and failure that either technique is uniquely prone to having. The current study proposes a new pedicle screw technique through the articular surface of the vertebral superior facet. It is hypothesized that this path will allow utilization of a larger screw that rivals that of the TPS technique, while also maintaining the high-density bone encountered in the cortical based trajectory technique.

Methods: Retrospective review of 50 consecutive trauma patients that underwent lumbar computed tomography (CT) scans at a Level 1 Trauma Center in the age range 18–45. These scans were uploaded to Brainlab software for ideal starting point and trajectory mapping of pedicle screws coursing through each superior facet and pedicle of vertebral levels L1–S1 without cortical breach. Satisfactory pedicle screw variables consisted of a medial angle <10 degrees, screw length at least 30 mm, screw width at least 5.0 mm, and starting point measurements such as distance to the inferior articular surface and distance to the lateral articular surface.

Results: A total of 600 virtual pedicle screws were placed, in which 525 were satisfactory and measured with the above variables. The pedicle widths were shown to significantly widen with lower-level vertebra in the lumbar spine. Approximately 72% of unsuccessful pedicle screws were placed in levels L1 and L2 allowing wider pedicle screws to be placed more further down the vertebral column.

Conclusions: The articular surface technique (AST) for pedicle screw placement is a viable alternative in lumbar spinal fusions that offers decreased soft tissue dissection. However, the technique is likely better suited for lower lumbar fusions in L3 to S1.

Keywords: Fusion; spine; cortical; pedicle; screw

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Introduction

Posterior lumbar fusion is a procedure that limits the motion of a vertebral segment with the goal of reducing pain. Currently, the most common technique employed is pedicle screw fixation that uses a transpedicular path through the anatomical axis of the pedicle (1,2). While this approach provides dependable fusion rates and stability, it also has well documented downfalls. A significant drawback is its lateral to medial trajectory that: (I) increases the risk of neurovascular injury; and (II) subjects the patient to soft tissue dissection resulting in longer operation times and significant incision size (2-5). Another significant complication is the loosening of the pedicle screw in osteopenic vertebral body cancellous bone (2,6-8). Thus, there has been a push in recent years to increase safety and the screw-to-bone purchase while reducing soft tissue disruption.

This recent push has led to a popular alternative as the cortical screw system that introduces the cortical bone trajectory (CBT) which consists of a more midline entry point that projects in a medial-lateral as well as caudal-to-cephalad trajectory through the pars-interarticularis (5). This pathway allows the screw to be less dependent on the cancellous bone of the vertebral body; but more dependent on the high-density cortical bone in the dorsal, posteromedial and anterolateral sides of the pedicle, and marginal vertebral body (2,7). The results of this approach have been shown to increase pullout load over the pedicle screw approach by 30% (6). Furthermore, recent studies have shown that this technique reduces soft tissue dissection while either preserving or increasing fusion rates and strength (5,7,9,10).

Even with the numerous studies producing promising results, there are still questions surrounding the entry point and trajectory when performing the CBT (2). This is important in determining screw size which, along with the trajectory itself, contributes to the quantity of dense bone encountered that in turn dictates fixation performance. Increased screw size has typically been an advantage of the pedicle screw technique, while increased thread contact in high density bone has been a focus of the CBT (11). Thus, the aim of this study was to propose a new pedicle screw technique through the articular surface of the superior facet of the vertebrae. The hypothesis was that this path will allow surgeons to use a larger screw that rivals that of the pedicle screw technique, while also maintaining the high-density bone encountered in the CBT. We present this article in accordance with the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-23-30/rc).

Highlight box

Key findings

- The articular surface technique is a method of fixation that allows for longer pedicle screws to be used, compared to cortical screws.
- Allows for increased cortical purchase compared to traditional pedicle screws.
- Advantage of minimal incision and a decreased need for lateral retraction.

What is known and what is new?

- There are several methods of obtaining fixation and fusion in the spine.
- The current study describes a novel technique for screw placement in the spine that has significant advantages to traditional modalities.

What is the implication, and what should change now?

- Traditional screws require significant soft tissue retraction.
- Cortical based screws are shorter and smaller therefore they often do not pass anterior to the instantaneous axis of rotation of the vertebra limiting their ability to achieve true, 3-column fixation.
- Utilizing articular surface technique (AST) screws allows for less soft tissue dissection, provides 3-column stability, and secures strong cortical purchase.

Methods

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Approval of this study was obtained from Institutional Review Board (IRB) of Baylor Scott & White (No. 160223) and individual consent for this retrospective analysis was waived. A retrospective review was conducted on trauma patients that underwent computed tomography (CT) of the lumbar spine. Fifty consecutive patients were selected from the 18–45 age bracket that underwent the necessary lumbar CT scan. A preliminary screen was performed by the senior radiologist ensuring no injury. A second screen was performed by the senior spine surgeon confirming no trauma or fracture to the pedicles. Patients not within 18–45 years of age or those that did not attain a lumbar CT scan were excluded. The patient's trauma CT scans were then uploaded to Brainlab Elements DICOM software (Munich, Germany). Once reconstructed on Brainlab, a single individual assessed the ideal starting point and trajectory according to a modified version of the Chin *et al.* technique that was utilized for C2 pedicle screw trajectory instrumentation (12). In this technique, the ideal trajectories and starting points for C2 pedicle screws were measured with axial and sagittal CT scan images. We extrapolated the method utilized for charting the C2 pedicle screw trajectories for pedicle screws in our study at levels L1–S1 bilaterally. The goal was to insert a satisfactory screw through the superior facet without pedicle breach that was 30–40 mm long; at least 5 mm in width; that had a trajectory optimized across the pedicle, ideally within 10 degrees parallel to the cephalad endplate in the cephalocaudal direction and the midline in the mediolateral direction. If these parameters could not be met, the screw was

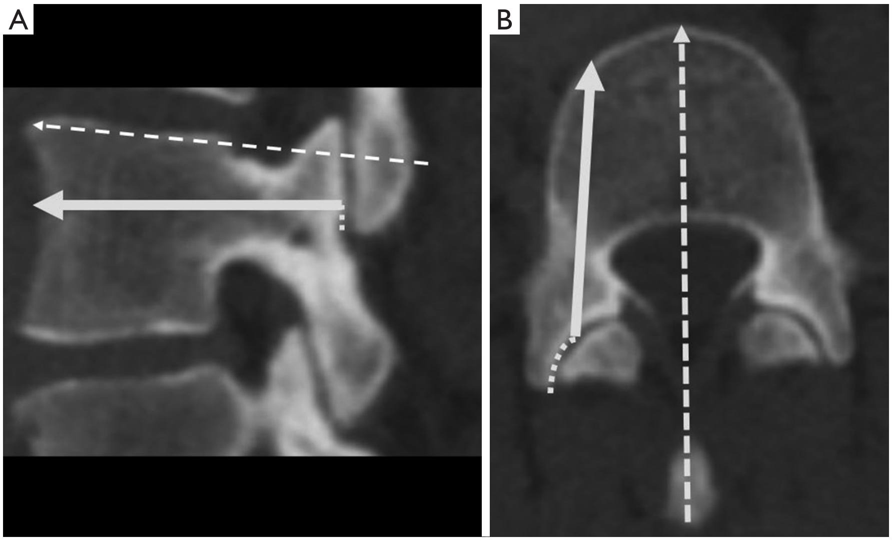

Figure 1 Sagittal and axial CT cuts demonstrating proposed screw trajectory. (A) The large dotted arrow represents a line that is parallel to the superior endplate. The large solid arrow represents the pedicle screw trajectory. The small dotted line represents the DIAS. (B) The large solid arrow represents the screw trajectory coursing through the facet articular surface. The large dotted arrow represents the midline plane. The small curved dotted line coursing along the superior surface of the articular surface represents the DLAS. CT, computed tomography; DIAS, distance to the inferior articular surface; DLAS, distance for the lateral articular surface.

considered 'unsatisfactory'. Brainlab helped to determine if a pedicle wall was breached by using Hounsfield units (HU) identified by the software. If the virtual screw placement traversed an area of bone that was found to be <500 HU, the authors considered the bone to have insufficient density for intact bone, and a cortical breach was unable to be ruled out and was thus considered a 'breach' (13,14).

When mapping out the placement of the articular surface technique (AST) pedicle screws, the virtual screw was first provided with a position that optimized its trajectory through the pedicle while maintaining as much parallelism with the midline and superior endplate as possible. The virtual screw was then positioned over the articular surface of the superior facet at this trajectory without breaching any of the walls. At this point, using HU, it was determined if at any point the virtual screw traversed an area of bone <500 HU in this alignment. If breach occurred, the screw was subsequently decreased in width until either a breach was no longer recorded, or the width of the pedicle screw reached the 5 mm minimum threshold. At this juncture, if a breach was still being read, a minimal amount of angulation laterally or caudally was attempted to mitigate the breach. Typically, the screws needed a certain amount of caudal and medial angulation for ideal trajectory through the pedicle without breaching. Once the posterior-anterior and the cephalo-caudal trajectories were established, the authors then ensured the screw met the 30 mm minimum length. Following the placement of a satisfactory screw, we recorded the measurements of the medial angle in comparison to the midline, the length of the screw, the width of the screw, and the measurements analyzed in reference to the starting point [distance from the inferior articular surface (DIAS), distance from the lateral articular surface (DLAS)] in regards to the inferior facet as shown in *Figure 1*. The length and width of the screw was automatically measured by the Brainlab software. The DLAS measurement also used HU to determine the end of the lateral surface of the facet. Once the HU level fell below 500, a measurement was conducted at that exact point to the screw insertion point. Similarly, HU were also used to find the end of the inferior facet of the superior vertebrae in order to evaluate the DIAS. The point at which the inferior facet dropped below 500 HU was marked as a point of reference on the superior facet (*Figure 1*) and the distance between screw insertion and this point was used to determine DIAS (13,14). The outline of the AST screw is demonstrated in *Figure 2*.

Statistical analysis

For statistical analysis, categorical data is reported

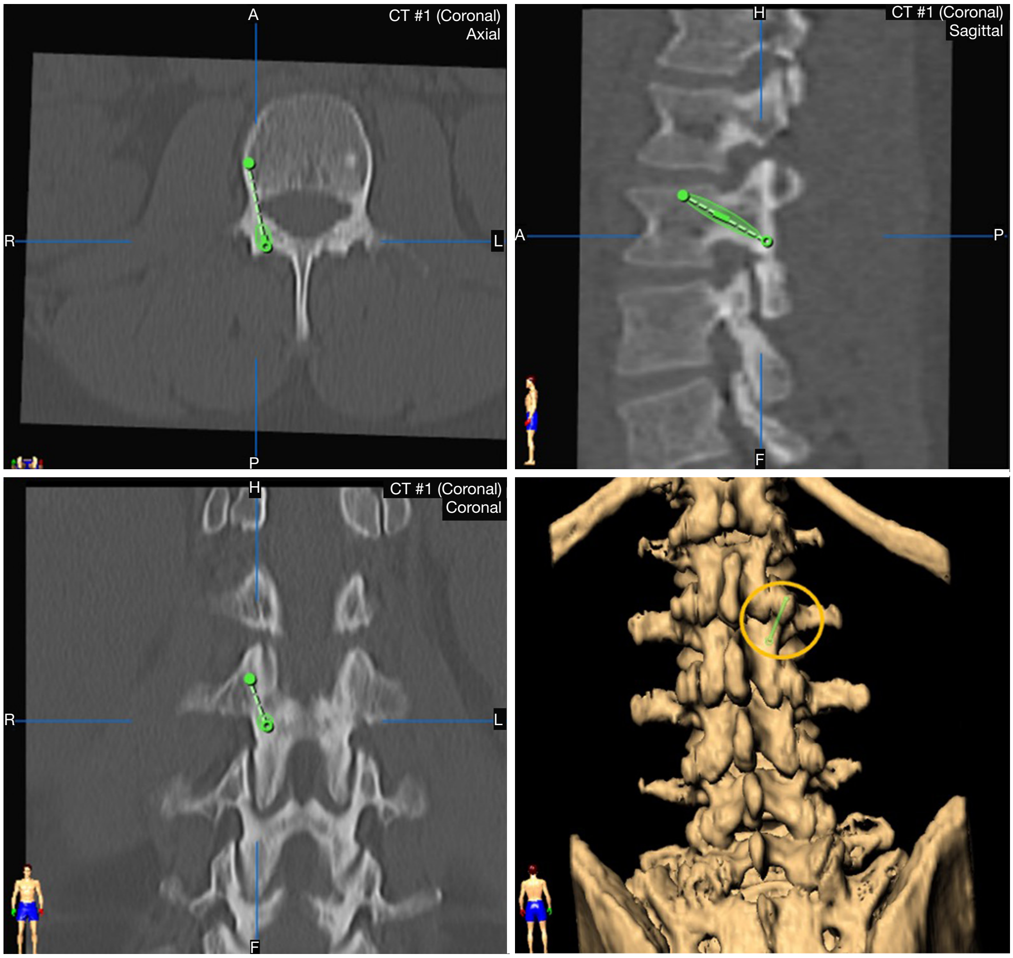

Figure 2 Outline of proposed articular surface technique screw. The virtual screw can be appreciated on the 3D reconstruction. The green dashed lines represent the trajectory of the screw; the small green circles represent the starting point of proposed screw; the yellow circle represents the footprint of screw on the 3D reconstruction; the green solid line represents the trajectory of screw on 3D reconstruction. CT, computed tomography; A, anterior; P, posterior; R, right; L, left; H, head; F, feet; 3D, 3-dimensional.

as counts (%). Numerical data is presented as mean [standard deviation (SD)] or median (range) according to its normality. To assess association between categorical variables a Chi-square test or Fisher's exact test were used. Comparison of normal variables by group was performed with a two-sample *t*-test. A generalized estimating equation (GEE) model was used to assess if side or vertebrae are associated factors for breach. Mixed effects models were used to assess if breach, side, and vertebrae level are factors of pedicle width. Type III tests for factor effects were used due to the different sample size in each breach group. Marginal means were calculated. The statistical analysis was performed with SAS 9.4 software (Cary, NC, USA).

Results

In our study there were a total of 39 (78.0%) males to 11 (22.0%) females with an average age of 28.12 (SD 6.6) years old. Out of 50 total patients analyzed, there were 24 (48.0%) patients that had all satisfactory screw criteria and 26 (52.0%) patients that had at least 1 unsatisfactory screw. Out of the females analyzed in the study, 9 out of 11 females showed to have at least 1 unsatisfactory screw (81.82%) while 17 out of 39 males demonstrated at least 1 unsatisfactory screw (43.6%). A Fisher's exact test found an association between at least one unsatisfactory screw and gender (P=0.039). The rate of unsatisfactory pedicle screws was remarkably at its highest at L1, and progressively

Table 1 Rate of lumbar screw satisfaction by lumbar level

Lumbar level	Rate of satisfactory screws by vertebral level			
	Satisfactory screw	Unsatisfactory screw	Rate of unsatisfactory screws at level (%)	Rate of unsatisfactory screws of total (%)
L1	67	33	33	5.50
L2	79	21	21	3.50
L3	94	6	6	1.00
L4	99	1	1	0.17
L5	96	4	4	0.67
S1	90	10	8	1.67
Total	525	75		

Table 2 Estimated pedicle width means by vertebral level

Vertebral level	Satisfactory screws, mean (mm)
L1	5.02
L2	5.02
L3	6.15
L4	7.44
L5	9.64
S1	12.68

decreased at more distal vertebral levels (as illustrated in *Table 1*). A mixed effects model was used to model the pedicle width and demonstrated significance regarding satisfactory screw placement, laterality and vertebral level (P values of <0.001, 0.004 and <0.001, respectively) as seen in *Table 2* with pedicle widths getting bigger with inferior progression of levels and satisfactory screws.

The optimal position for the starting point and angulation for the articular surface trajectory pedicle screws was optimized for the DIAS, DLAS, screw length, screw size, and medial angle for the 525 satisfactory screws placed. The values that are reported are specifically for the satisfactory screws, as the unsatisfactory screws were nullified in the statistical analysis. The average values of the variables above are listed specific to each vertebral level in *Table 3*. The caudal angle for the specific trajectories were not included in the parameters studied, as this angle will likely be visualized under C-arm during placement of these screws.

Screw size, measured in millimeters in diameter was broken down in 5, 5.5, 6, 6.5 mm, etc., in 0.5 mm increment increases all the way to 10 mm. There were 525 total measurements for the screw sizes. The screw sized tended to show a direct correlation with the descending level of lumbar vertebra. For example, 71.64% of the screws for L1 consisted of 5 mm screws. This trend gradually decreased to using only 7.61% of the S1 screws as 5 mm screws. On the other side, the highest percentage of the S1 screws came from 8 mm screws with 100% of the 10 mm screws being used only on the S1 vertebra. These results illustrated in *Figure 3*.

Discussion

This study introduces the AST, a novel technique for placing pedicle screws that has not been previously described. The AST utilizes a unique starting point through the subchondral bone of the superior facet and attempts to combine the strengths of the previous traditional pedicle screws (TPSs) with the CBT screws while minimizing the limitations inherent to each technique. TPS fixation involves the placement of screws through the pedicle with the starting point just lateral to the articulation of the zygapophyseal joint of the corresponding vertebrae, approximately at the junction with the midpoint of the transverse process (15). This technique utilizes the ability to obtain 3-column fixation of the lumbar spine with larger screws, and is the gold standard for spinal fixation. However, there are disadvantages to TPS, in which much of the screw is placed in the vertebral body cancellous bone rather than cortical bone, which can limit screw purchase and fixation, particularly in osteopenic bone (6,15,16). In contrast to minimally invasive techniques under navigation,

Table 3 Average parameter measurements of DIAS, DLAS, screw length, medial angle, and screw width at respective vertebral levels and laterality

Vertebral level	DIAS (mm)	DLAS (mm)	Screw length (mm)	Medial angle (°)	Screw width (mm)
L1	0.17	6.08	39.79	3.64	5.35
L2	0.36	6.57	40.63	4.62	5.75
L3	0.86	6.53	40.57	5.44	6.09
L4	1.33	6.27	39.08	6.42	6.35
L5	2.23	6.79	34.86	9.32	6.88
S1	2.18	5.04	32.02	17.85	7.83

DIAS, distance from the inferior articular surface; DLAS, distance from the lateral articular surface.

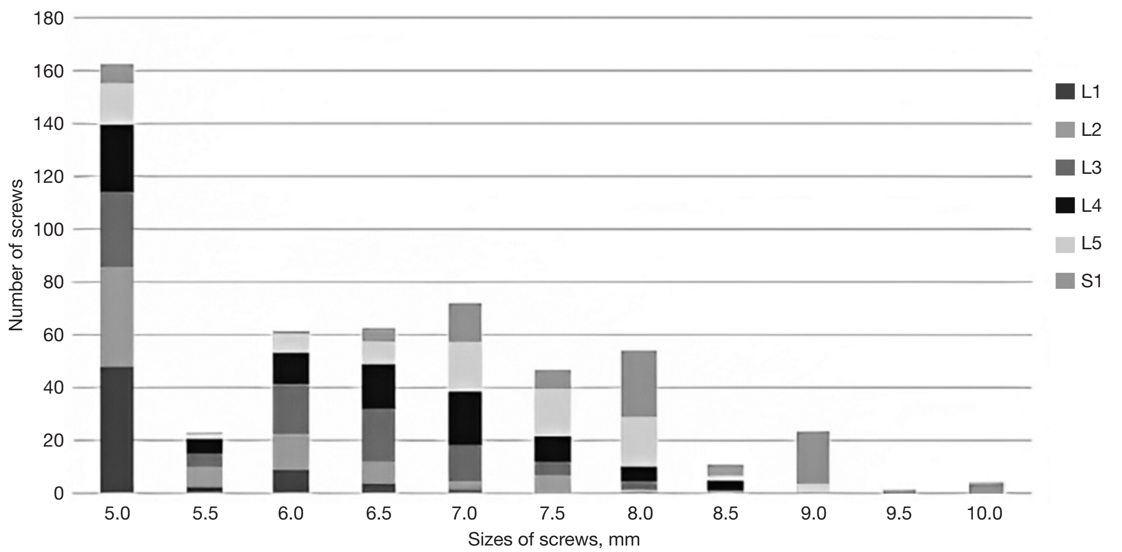

Figure 3 Distributions of the screw width sizes within the levels of the lumbar vertebra. The larger screws appear to be used more frequently in the lower lumbar vertebra.

where only a small stab incision with minimal soft tissue retraction is required; TPS requires a larger exposure in order to initiate the pedicle screws lateral to the facet joint with immense retraction of the tissues which can be a significant source of morbidity due to blood loss and pain following the procedure (6,15,16). In response to these disadvantages, Santoni *et al.* described the CBT where the starting point and the screw trajectory were altered in order to obtain better cortical bone purchase (6). This technique uses a starting point on the hard, cortical bone of the pars interarticularis, just below the facet joint, and follows a medial to lateral and cephalad trajectory into the pedicle (16). The trajectory of these techniques can be illustrated in *Figure 4*.

The reported advantages of the CBT are the higher amount of cortical bone purchased and smaller exposure, as the starting points are closer to midline. However, a disadvantage to consider is the screws only reside in the posterior column of the spine. Therefore, they are shorter in length and smaller in diameter than TPS to avoid fracturing the pars or breaching the cortical margin of the pedicle and lateral vertebral body (17). Because of this, cortical screws often do not pass anterior the instantaneous axis of rotation of the vertebra and their ability to achieve true, 3-column fixation is compromised leading to concern for adequate stability in a lumbar fusion (17,18).

We introduce the AST as a technique designed to limit lateral dissection and increase cortical purchase while

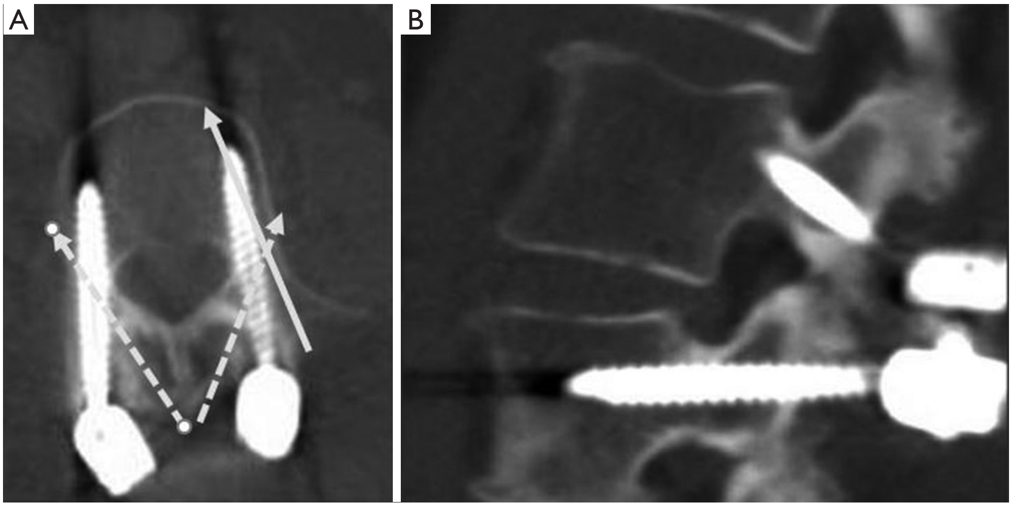

Figure 4 CT scan representing of the AST screws *in vivo*. (A) Axial slice with comparisons to the CBT technique (dotted arrows) and the traditional pedicle screw technique (solid arrow). (B) Sagittal cut demonstrating difference in angulation with CBT screws (top screw) and AST screws (bottom screw). CT, computed tomography; AST, articular surface technique; CBT, cortical based trajectory.

allowing for placement of pedicle screws that approximate the same diameter and length as TPS. This technique places the starting point directly through the dense subchondral bone of the superior articular facet and project in a posterior to anterior direction along the long axis of the pedicle. The first step, and perhaps the most important, is defining a favorable starting point. The AST surgical technique initially involves the resection of the inferior half of the cephalad vertebrae's inferior facet in order to expose the articular surface on the superior facet, as is typically performed in a transforaminal lumbar interbody fusion (TLIF). Using 3-dimensional CT-reconstructions in combination with software that allows for placement of virtual screws, we were able to effectively map the ideal coordinates along the superior articular facet of the same-level vertebrae as well as the trajectories allowed for safe placement of a pedicle screw utilizing the AST. These parameters are summarized for each vertebral level in *Table 3*. The goal for this technique is to place the screws in a straight posterior to anterior direction parallel to the superior endplate without any superior/inferior and medial/lateral deviation and without having any breach medially or inferiorly on the pedicle. This maximizes efficiency with pedicle screw placement with minimal lateral soft tissue dissection and easier technical placement of the screws with less lateral hand translation causing abutment against the soft tissues. According to the dimensions listed in *Table 3*, an angle of <10 degrees can place a satisfactory pedicle screw using the AST without breach. The incision and soft tissue dissection for the AST is considerably less than that for CBT and TPS techniques. For instance, shown in *Figure 5*, when being used in a standard TLIF procedure, the superior vertebrae can hold CBT screws and the caudal vertebrae can hold the AST screws as the inferior facet will already be resected and allow exposure to the intervertebral disk. Therefore, with the CBT screws' trajectories in an 'up and out' position would allow the screw placement site to be near the AST screws on the ipsilateral side, allowing for much less dissection and incision for exposure. Less soft tissue dissection and exposure is thought to lead to less blood loss, shorter surgical time, similar rates of bony union, and better patient reported outcomes (19-21).

A major advantage for the utilization of the AST is the stability afforded with a screw size comparable to the TPS and the cortical purchase provided by the articular facet's subchondral bone. The superior facet provides a thick subchondral bone that is able to provide stable purchase of pedicle screws comparable to purchase demonstrated in the CBT screws. CBT screws have been shown to maintain 30% increase in uniaxial pullout strength in comparison to TPS (2,6,22). The AST pedicle screw is then allowed to span to the anterior aspect of the vertebral body, providing 3-columnn stability along with cortical fixation at the entry point. Once the starting point is located, a burr can be used to penetrate the facet subchondral bone, and then a probe/hand-drill is used to create a path for the screw to

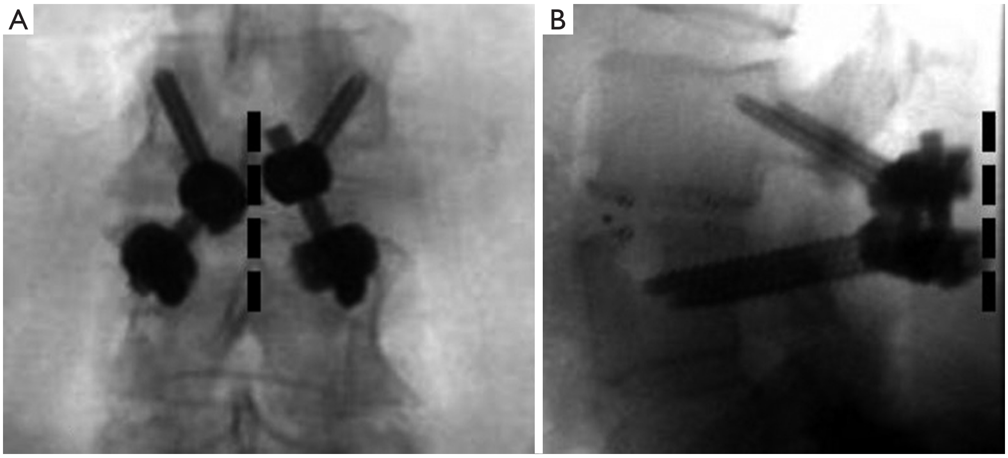

Figure 5 Fluoroscopic trajectories. (A,B) Intraoperative fluoroscopy illustrating hybrid fixation techniques of AST and CBT with the overlying incision of 4–5 cm by the dotted lines. The pedicle screws of the different techniques results in offset due to the different trajectories. AST, articular surface technique; CBT, cortical based trajectory.

be placed, similar to the TPS technique. This is contrary to the CBT technique, where a power-drill must be used for the screw creating an opportunity for violation of the pedicle wall. Santoni *et al.* demonstrated that 20% of the CBT screws placed had violated the medial pedicle wall (6). The median screw length for this study was 40.0 mm screws and the average screw size was shown to be 6.44 mm, attaining the length and size of TPS techniques, and significantly more than the CBT screws. CBT screws are limited by the confines of its up and out trajectory through the pars interarticularis and ending abruptly at the superior endplate (6). Thus, the thick subchondral bone beneath the superior facet and the length of screw fixation allow maximization of screw working length and can confer an increased screw pullout force in comparison to a TPS while maintaining the 3-column stability even in the face of osteoporotic bone (23).

The limitations of this article include its lack of biomechanical testing for the AST screws regarding pullout strength and stability under cyclical load. Theoretically, the cortical screw purchase of the subchondral bone of the zygapophyseal joint's superior facet coupled with the longer screw length creates an increased screw working length that logically creates higher purchase (6,23,24). Another limitation to this study is that 52% of patients in this study demonstrated unsatisfactory screw placement. Although this percentage seems high, it can be first explained by our conservative criteria of <10° angulation medially, >30 mm of screw length, and >5 mm screw size and all having to stay within the confines of the pedicle without any breach. Any screw that had to be angled more than 10° medially was beyond our criteria of satisfactory screws, even though the screw could be placed without violating pedicle walls and still maintain significant purchase for stability. Therefore, the percentages of unsatisfactory screws were seen to be increased. However, in real practice if the surgeon deems it necessary to project the screws outside the 10° boundary in order to prevent a pedicle breach, they would only have to tolerate soft tissue interference for a further translated hand without compromising stability. Secondly, *Table 1* demonstrates that 72% of the breached pedicles took place at the L1 and L2 vertebral levels, which can be seen in *Table 2* to be the smallest pedicle widths of the lumbar spine. TPSs or CBT screws might be more appropriate for the upper lumbar vertebrae when the pedicle width is less than 5 mm and coupling them with AST screws on the bottom of the construct. Since AST screws are most often used at the bottom of a one- or two-level fusion, the most common vertebra instrumented with this technique are L4 and L5, which almost always have pedicle widths that allow for safe placement with the AST as illustrated in *Table 2* and have the lowest breach rates of all the levels. Screw width to pedicle width mismatch is another reason for the high percentage of unsatisfactory screws. It is common for surgeons to put slightly larger pedicle screws at levels with very small pedicles, particularly in pediatric patients with more viscoelastic bone. However, there is a risk of fracturing the pedicle when oversized screws are used (25).

All to say, a superior breach is better tolerated than an inferior breach as the nerve root is typically hugging the underside of the pedicles as it is exiting the intervertebral notches (26).

Conclusions

The AST is a novel method of fixation that has yet to formally be employed in the realm of spine surgery. This technique allows for longer, more TPSs to be used, compared to cortical screws, but still allows for increased cortical purchase compared to TPSs. When used at the distal aspect of a construct that uses CBT screws at the cranial vertebra, it has a significant advantage of minimal incision and a decreased need for lateral retraction and exposure in order to accomplish an adequate fusion.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-23-30/rc

Data Sharing Statement: Available at https://jss.amegroups.com/article/view/10.21037/jss-23-30/dss

Peer Review File: Available at https://jss.amegroups.com/article/view/10.21037/jss-23-30/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-23-30/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board (IRB) of Baylor Scott & White (No. 160223) and individual consent for this retrospective analysis was waived.

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