Using Technique and Technology to Improve Safety and Outcomes in AIS

A Review of 12,795 Screws in Pediatric Spine Deformity

Vishal Sarwahi, MD,[a] Katherine Eigo, BA,[a] Effat Rahman, BS,[a] Sayyida Hasan, BS,[a] Keshin Visahan, BS,[a] Yungtai Lo, PhD,[b] Jon-Paul DiMauro, MD,[a] and Terry Amaral, MD[a]

Study Design. Retrospective cohort study.

Objective. This study aimed to compare outcomes in AIS patients who underwent PSF using either freehand with occasional fluoroscopic assistance (FOFA), computer-assisted surgery/navigation (CAS), or technique and technology (T&T).

Summary of Background Data. Pedicle screw insertion in scoliosis is challenging due to abnormal pedicle morphology. Fluoroscopic guidance was frequently utilized, until technological advancements led to the adaptation of computer-assisted screw insertion. Although improvement in screw accuracy has been documented, an increase in radiation exposure, surgical time, and blood loss can occur. This institution adopted a T&T, or technique and technology, approach that combines freehand technique with CT-based navigation technology for confirmation and navigation for challenging pedicles.

Methods. This was a two-part retrospective review of 573 AIS patients who underwent PSF. Part I: Three hundred four were operated in FOFA. Sixty-three patients were operated on with solely CT-based navigation technology (CAS Group). Two hundred six patients were in T&T. Perioperative outcomes were compared. Part II: Two hundred six T&T patients were compared with 326 AIS patients from the NSQIP database who were operated on using computer-assisted navigation (CAN). Operative time and 30-day complications were compared. All data are presented as medians, IQR, frequencies, and percents. Fisher exact, χ^2, Kruskal-Wallis, and Wilcoxon rank-sum tests were used.

Results. FOFA radiation dose was 2.3 mGy and radiation time was 20.4 seconds compared with 22.2 mGy and 21.6 seconds for CAS, and 15.0 mGy and 18.6 seconds for T&T ($P<0.001$, $P<0.001$). Operative time was shorter for the T&T patients when compared with FOFA and CAS ($P<0.001$). Part II: T&T had an operative time of 233.0 minutes compared with 323.0 minutes for CAN ($P<0.001$).

Conclusion. T&T optimizes screw accuracy while reducing the increased radiation burden and operative time associated with CAS. The T&T approach incorporates CT-based navigation technology as confirmation, while maintaining surgeon's skill.

Key Words: adolescent idiopathic scoliosis, technique and technology, intraoperative navigation, computed tomography, posterior spinal fusion

(*Spine* 2025;50:1523–1528)

Received for publication August 20, 2024; accepted December 10, 2024.

From the [a]Department of Pediatric Orthopaedics, Cohen Children's Medical Center, New Hyde Park, NY; and [b]Albert Einstein College of Medicine, Bronx, NY.

CCMC IRB: Approved

V.S. personal fees and royalties from Precision Spine, INC. outside the submitted work and not relevant to the study. The remaining authors report no conflicts of interest.

Address correspondence and reprint requests to Vishal Sarwahi, MD, Associate Surgeon-in-Chief, Chief, Spinal Deformity and Pediatric Orthopaedics, Billie and George Ross Center for Advanced Pediatric Orthopaedics and Minimally Invasive Spinal Surgery, Cohen Children's Medical Center, Northwell Hofstra School of Medicine, 7 Vermont Drive, New Hyde Park, NY 11042; E-mail: vsarwahi@northwell.edu

DOI: 10.1097/BRS.0000000000005262

Pedicle screws in scoliosis are a standard of care for deformity correction. Pedicle screw insertion, especially in a deformed spine where almost a third of the pedicles are abnormal, is challenging and has been shown to increase the risk of screw misplacement.[1] Common techniques utilized for placement of pedicle screws are freehand anatomic technique and fluoroscopy-assisted screw placement. With the freehand anatomic technique, surgeons insert screws based on the anatomic location of the entry point and prepare screw tracts depending on tactile feedback, and with the occasional use of fluoroscopy to localize entry points and for confirmation after the creation of the tract. In fluoroscopy-assisted screw insertion, pedicle screws are inserted under fluoroscopy guidance at each level. The surgeon relies largely on fluoroscopy imaging, which can increase the radiation exposure to both the patient and the team. However, in the freehand anatomic technique, the radiation burden may be lower, as fluoroscopy is utilized only when necessary and not for each screw.

Despite the overall safety of these two techniques being quite high, Sarwahi *et al.*[2] reported a freehand accuracy rate of 87.96% for pedicle screw placement. Most of the displaced screws are "benign" misplacements, but screws have been reported adjacent to vital structures like the aorta.[2] Newer technologies like navigation have shown higher screw insertion accuracy, but carry the burden of increased radiation dosage, surgical time, and cost.[3–8] In most navigation, a preoperative computed tomography (CT) scan is utilized, which limits the ability to confirm the accuracy of screws intraoperatively. Utilizing an intraoperative CT-based navigation system overcomes this limitation; however, it means that at least two CT spins must be conducted if the surgeon wants confirmation of navigated screws.

Our experience has evolved from being primarily dependent on two intraoperative CT scan spins to combining freehand anatomic "technique" and CT-navigation "technology" to get the best of both. This "technique and technology", or "T&T" approach involves placing pedicle screws freehand and skipping challenging pedicles (usually 1–2) for later navigation. After screw insertion, a CT spin is carried out which allows confirmation of previously placed pedicle screws and navigation of the 1–2 remaining screws. This approach eliminates the need for a second spin, decreasing the radiation burden, while allowing for accuracy confirmation of all previously placed screws. This also reduces the surgical time associated with navigation and the problems associated with increased surgical time like increased blood loss.

The objective of this study was to compare surgical differences in adolescent idiopathic scoliosis (AIS) patients that had undergone posterior spinal fusion (PSF) using either freehand with occasional fluoroscopic assistance (FOFA), computer-assisted surgery/navigation (CAS), or technique and technology (T&T). It is hypothesized that surgeons utilizing T&T will have superior outcomes, such as screw accuracy, compared with both FOFA and CAS.

MATERIALS AND METHODS

Study Design

This was a two-part IRB-approved retrospective review of 573 AIS patients who underwent PSF between 2016 and 2023. All patients were younger than 18 years of age. Patient characteristics, including age, sex, and BMI were collected. Preoperative and postoperative radiographs were assessed for major Cobb angle, thoracic kyphosis (T5–T12), and fixation points. Perioperative parameters collected included estimated blood loss (EBL), operative time, radiation dose, radiation time, allogenic transfusions, screws malpositioned, 30-day complications, return to the operating room (OR), intraoperative screw revisions, and loss of neuromonitoring signals. Screw accuracy was assessed on postoperative CT scans utilizing Gertzbein-Robbins classification system, with Grades C-E defined as misplaced.[9] Grade A (entirely within the pedicle) and Grade B (<2 mm deviation from the pedicle) screws were used to estimate screw accuracy. Screws with a sagittal angulation that appeared significantly different than the neighboring screws on the radiograph were deemed "questionably" malpositioned, as per Suk's approach.[10] Radiographic screw misplacement was carried out in a double-blinded manner (by K.E. and E.R.).

Part I

The first part of this study consisted of a chart review of 573 AIS patients between 2016 and 2023. Before 2019, all pedicle screws were placed by surgeons utilizing freehand anatomic technique. Screws were placed based on anatomic landmarks, with ball-tipped probes used to palpate the screw tracts. Once all screws were placed, positioning was verified under fluoroscopy before rod placement.

In 2019, an intraoperative CT-based navigation system was acquired, which consists of a CT and image-guidance system that allows for real-time navigation. In 2020, surgeons modified surgical workflow and began utilizing the "technique and technology" approach. In this approach, surgeon places screws using the freehand anatomic technique, although pedicles that are challenging, usually one or two, are skipped. A reference clamp is attached to a spinous process and CT scan is done. Screw accuracy is evaluated, and any skipped screws are placed using navigation before rod placement, with no additional image guidance or navigation thereafter.

Patients operated utilizing freehand technique between 2016 and 2018 were included in the FOFA group, patients with intraoperative navigation in 2019 were in the CAS group, and patients between 2020 and 2023 were considered part of the T&T group.

Part II

In Part II, patients younger than or equal to 18 years who underwent posterior-only deformity surgery were identified using the 2012 to 2018 American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database. Procedural Terminology (CPT) codes 22800-22804. Patients were stratified into groups with and without navigation using CPT code 61873. Patients from the T&T group were compared with patients from the NSQIP database who underwent computer-assisted navigation (CAN) only. Patients who underwent revision or non-elective surgery or had incomplete charts were excluded.

The Shapiro-Wilks test was used to confirm distribution normality. Data were presented as medians and interquartile (25^{th}–75^{th} percentile) ranges for continuous variables and frequency and percentages for categorical variables. Continuous data was analyzed using Kruskal-Wallis or Wilcoxon rank-sum test, and categorical data were analyzed using χ^2 and Fisher exact test. Statistical analyses were performed by an independent biostatistician with SAS version 9.3 (SAS Institute, Cary NC). All *p*-values were two-tailed, with $P<0.05$ considered significant.

RESULTS

Part I: There were 573 AIS patients with a total of 12,795 screws; 304 in the FOFA group, 63 in the CAS group, and 206 in the T&T group. The median age was 15.0 years for the FOFA group, 15.6 years for the CAS group, and 15.4 years for the T&T group ($P=0.01$). Two

TABLE 1. Comparison of Demographic and Clinical Variables Between FOFA, CAS, and T&T Patients.

	FOFA (n = 304)	CAS (n = 63)	T&T (n = 206)	P
Age (yr)	15.0 (13.4–16.5)	15.6 (14.3–16.7)	15.4 (14.0–17.0)	**0.01**
BMI	21.0 (18.7–24.3)	21.7 (19.5–24.9)	21.3 (18.9–24.8)	0.59
Female, n (%)	220 (72.4)	42 (66.7)	145 (70.4)	0.43
Total radiation dose (mGy)	2.3 (1.4–4.0)	22.2 (15.0–37.2)	15.0 (12.5–17.6)	**< 0.001**
Total radiation time (s)	20.4 (13.9–30.9)	21.6 (16.2–34.0)	18.6 (11.9–20.5)	**< 0.001**
Preoperative Cobb (°)	54.0 (49.5–63.0)	52.0 (45.6–62.0)	53.1 (46.5–61.8)	0.15
Postoperative Cobb (°)	17.4 (13.4–23.0)	15.6 (11.8–20.9)	14.9 (9.1–22.8)	**0.04**
Preoperative kyphosis (°)	25.7 (17.0–36.0)	26.7 (13.6–37.0)	29.6 (20.1–39.1)	**0.02**
Postoperative kyphosis (°)	26.6 (21.9–32.0)	27.0 (21.8–34.4)	31.3 (24.2–37.4)	**0.001**
Operative time (min)	252.5 (225.0–319.0)	290.0 (248.0–360.0)	233.0 (202.0–265.0)	**< 0.001**
EBL (mL)	400.0 (300.0–600.0)	475.0 (300.0–700.0)	400.0 (250.0–500.0)	**0.01**
Allogenic transfusion, n (%)	47 (15.5)	19 (30.2)	41 (20.0)	**0.03**
30-day complications, n (%)	7 (2.3)	1 (1.6)	6 (2.9)	0.82
Return to OR, n (%)	15 (4.9)	2 (3.2)	2 (1.0)	**0.03**
Screws revised, n (%)	(n = 6533) 12 (0.18)	(n = 1210) 0	(n = 5052) 1 (0.02)	**0.01**
Loss of neuromonitoring signals, n (%)	27 (8.9)	4 (6.6)	6 (3.0)	**0.02**

Bold values are statistically significance ($P < 0.05$).
Data are presented as median and interquartile ranges and counts and percentages when applicable.
P-values were obtained from Kruskal-Wallis tests for continuous variables and χ^2 or Fisher exact tests for categorical variables.
EBL indicates estimated blood loss; OR, operating room.

hundred twenty (72.4%) of FOFA, 42 (66.7%) of CAS, and 145 (70.4%) of T&T patients were female ($P = 0.43$).

FOFAVersus CASVersusT&T

The median preoperative Cobb angle was 54.0° for FOFA patients, 52.0° for CAS, and 53.1° for T&T ($P = 0.15$) (Table 1). T&T Group had a significantly lower postoperative median Cobb at 14.9° compared with FOFA (17.4°) and CAS (15.6°) ($P = 0.04$).

In the FOFA group, the median total radiation dose was 2.3 mGy and total radiation time was 20.4 seconds compared with 22.2 mGy and 21.6 seconds for CAS, and 15.0 mGy and 18.6 seconds for T&T ($P < 0.001$, $P < 0.001$). T&T patients had a significantly lower median operative time (233.0 min) compared with FOFA (252.5 min) and CAS patients (290.0 min) ($P < 0.001$). Similarly, T&T and FOFA patients had significantly lower median estimated blood loss (EBL) (400.0 mL) compared with CAS patients (475.0 mL) ($P = 0.01$). Allogenic transfusion rates were significantly higher for 19 (30.2%) CAS patients compared with 47 (15.5%) FOFA and 41 (20.0%) T&T ($P = 0.03$). Fifteen (4.9%) FOFA patients returned to the OR, compared with 2 (3.2%) CAS and 2 (1.0%) T&T ($P = 0.03$). Twelve screws (0.18%) had to be revised intraoperatively in FOFA, compared with 0 screws in CAS and only 1 (0.02%) screw in T&T ($P = 0.01$). Twenty-seven (8.9%) FOFA patients experienced the loss of neuromonitoring signals, compared with 4 (6.6%) CAS and 6 (3.0%) T&T ($P = 0.02$). Thirty-day complications were not significantly different across the three groups ($P = 0.82$). Thirty-day complications are listed in Table 2.

Screw Accuracy

In the CAS group, 4/1210 (0.3%) screws were malpositioned (grades C–E), therefore the accuracy rate is 99.7% (Table 3A and B). In the T&T group, 7/5052 (0.1%) screws were malpositioned, making the accuracy rate 99.9%. The lack of 3D imaging with the FOFA technique limits screw visibility, preventing a reliable determination of screw placement and accuracy. To address this, when assessing screw malposition and accuracy rates for FOFA, two approaches were utilized. FOFA's accuracy was estimated based on a subgroup of FOFA patients that had a postoperative CT scan done. In these 22 patients, 24/474 (5.1%) screws were malpositioned, therefore the accuracy rate is 94.9%. In approach #2, screw accuracy was based on 2D x-ray imaging. On x-rays, 473/6533 (7.2%) screws in the FOFA group were identified as "questionably" malpositioned. This makes the screw-based accuracy 92.8%. Therefore, FOFA was significantly less accurate than CAS and T&T ($P < 0.001$). Figures 1–3B demonstrate various malpositioned screw placements.

NSQIP CAN Versus T&T

Out of the 16,950 AIS patients that were queried, 326 patients underwent posterior-only operations with CAN (Table 4).

CAN patients were significantly younger than T&T patients with median 14.2 years compared with 15.4 years ($P < 0.001$). Median operative time was 323.0 minutes for CAN, which was significantly higher than 233.0 minutes for T&T ($P < 0.001$). T&T patients experienced significantly fewer 30-day complications than CAN patients (2.9% *vs*. 6.8%, $P = 0.05$).

DISCUSSION

In this large, retrospective analysis of different PSF approaches, there were two major findings: (1) patients operated on using only CAS had longer operative times and increased radiation exposure compared with FOFA and T&T (2) T&T is accurate, reduces operative time

TABLE 2. Comparison of Postoperative Complications Within 30 Days Between FOFA, CAS, and T&T Patients.

FOFA (n = 304)	CAS (n = 63)	T&T (n = 206)	P
7 (2.3%) 4 SSI 2 seromas requiring I&D 1 Postoperative Signal Loss requiring Revision	**1 (1.6%)** 1 rod dislodgement requiring revision	**6 (2.9%)** 2 SMA 3 SSI 1 perforated bowel	0.82

Bold values are statistically significance ($P < 0.05$).
P-values were obtained from χ^2 or Fisher exact tests.

compared with both FOFA and CAS, and reduces radiation exposure and blood loss compared with CAS.

CAS generates a virtual 3D model of the patient's spine, providing real-time feedback that can improve screw insertion accuracy in spinal surgery.[11,12] In contrast, FOFA relies on anatomical landmarks, tactile feedback, and 2D images to insert the screws. Rajasekaran *et al.*[13] compared 33 patients undergoing spinal deformity correction with or without navigation. The non-navigated group had pedicle screws inserted utilizing fluoroscopic guidance.[13] They found 54 (23.0%) pedicle breaches in the non-navigated group, compared with only 5 (2.0%) in the navigated group.[13] In this study, both CAS and T&T groups had similar accuracy rates of 99.7% and 99.9%, respectively. These rates were significantly higher than FOFA's accuracy rate, which was estimated to be between 92.8% and 94.9%. Molliqaj *et al.*[14] also found that robot-guided screw placement was significantly more accurate than freehand with fluoroscopic guidance. Notably, the freehand/fluoroscopic guidance group had an accuracy rate of 88.9%, and the robot-assisted group's accuracy rate was 93.4%.[14] In this study, FOFA's accuracy was higher, due to the use of 2D imaging to determine accuracy in FOFA, which may have led to an overestimation of accuracy. The CAS group also had superior accuracy reported, although, it was comparable to other studies, such as Hu *et al.*[15] who reported an overall malposition rate of 0.7%.

The T&T group had significantly shorter operative time, the median 57 minutes shorter than CAS, and 20 minutes shorter than FOFA. Increased operative time in CAS was also reported by Linden et al in 60 AIS patients compared with fluoroscopy.[4] In addition, total radiation time with the T&T approach was lowest compared

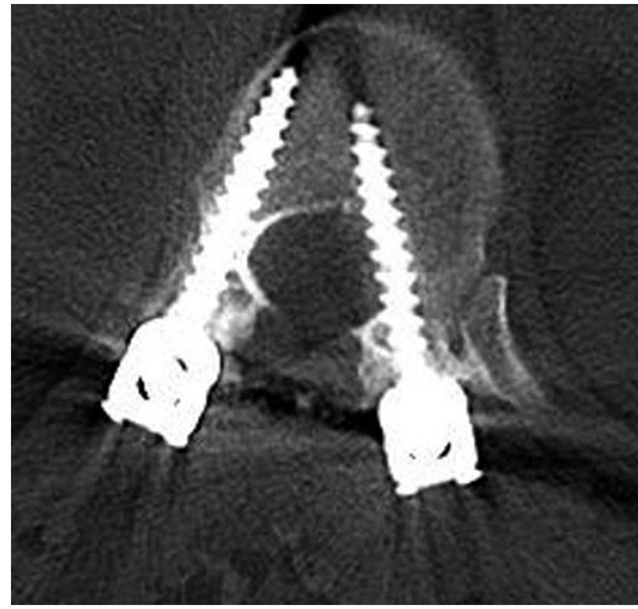

Figure 1. T12 left pedicle screw broaches the medial pedicle margin and involves the far-left lateral aspect of the spinal canal.

TABLE 3. Comparison of FOFA, CAS, T&T screws malpositioned utilizing approach # 1

	FOFA (n = 474)	CAS (n = 1210)	T&T (n = 5052)	P
Comparison of screws graded A-E across FOFA, CAS, T&T				
Grade, n (%)				**< 0.001**
A	427 (90.1)	1189 (98.3)	4987 (98.7)	
B	23 (4.9)	17 (1.4)	58 (1.14)	
C	9 (1.9)	4 (0.33)	6 (0.12)	
D	10 (2.1)	0	1 (0.02)	
E	5 (1.05)	0	0	
Comparison of acceptable screw placement (A and B) and screws misplaced (C-E) across FOFA, CAS, T&T				
Grade, n (%)				**< 0.001**
A	427 (90.1)	1189 (98.3)	4987 (98.7)	
B+C+D+E	47 (9.9)	21 (1.7)	65 (1.3)	
A + B	450 (94.9)	1206 (99.7)	5045 (99.9)	**< 0.001**
C + D + E	24 (5.1)	4 (0.3)	7 (0.1)	

Bold values are statistically significance ($P < 0.05$).
P-values were obtained from χ^2 or Fisher exact tests. $P < 0.05$ is considered significant.

Figure 2. T9 right pedicle screw laterally breaches the pedicle.

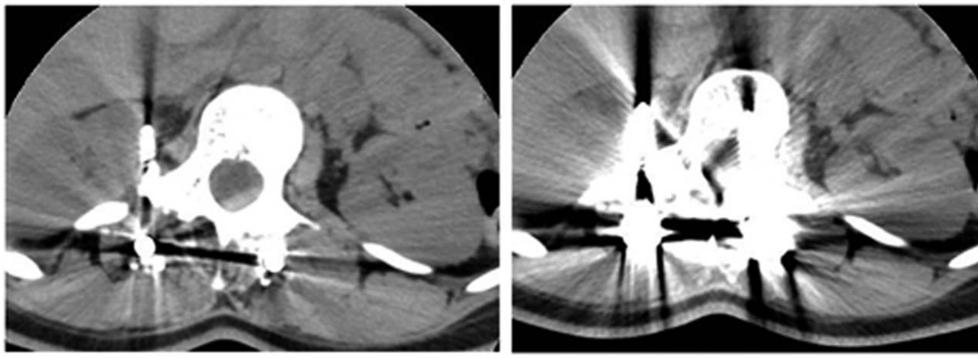

Figure 3. (A, B) The right L1 screw traverses the right costovertebral junction and terminates in the soft tissues just medial to the right kidney.

with CAS and FOFA. This was due to a single CT spin with T&T, compared with two spins in CAS, and multiple fluoroscopy image acquisition, which increased the radiation time. The radiation dose in T&T was lower than that of the CAS group, primarily due to the single CT spin. In contrast, FOFA's lowest radiation dose, in our study, is due to the sparing use of fluoroscopy with the freehand technique. The use of fluoroscopy, however, varies based on surgeon, center, and experience. Thus, may not reflect the ideal radiation dose with fluoroscopy in scoliosis surgery and is likely on the lower end of the range for fluoroscopy use.

Fares *et al.*[16] reviewing 148 AIS and NMS patients found that fluoroscopy times vary greatly. In their study, the average radiation dose for AIS patients was 23.8 ± 12.2 mGy.[16] Konieczny *et al.*[17] evaluated 293 pedicle screws using three different techniques: preoperative CT scan-based navigation, intraoperative 3D scan-based navigation, and fluoroscopy-guided screw placement. They found intraoperative 3D scan-navigation had a lower effective radiation dose per screw compared with fluoroscopy and preoperative CT-based navigation.[17] Their fluoroscopy technique involved a combination of freehand screw insertion with imaging for each pedicle at the time of insertion, followed by repeat imaging after screw insertion for 3 to 4 segments at a time.[17] This is different from our approach of using fluoroscopy after all screw insertion and/or only for difficult screws. This difference in approach can explain the lower radiation dose observed in the fluoroscopy (FOFA) group in our study. It also highlights the large variability in radiation exposure that exists with the fluoroscopy technique, which varies widely among surgeons; demonstrating that the true radiation burden seen with fluoroscopy is likely greater in general, and our FOFA dose is likely the lower end of the range.

TABLE 4. Comparison of Clinical Variables Between CAN and T&T Groups.

	NSQIP CAN (n = 326)	T&T (n = 206)	*P*
Age (yr)	14.2 (12.8–15.6)	15.4 (14.0–17.0)	**< 0.001**
Operative time (min)	323.0 (240.0–434.0)	233.0 (202.0–265.0)	**< 0.001**
30-day complications, n (%)	22 (6.8)	6 (2.9)	**0.05**

Bold values are statistically significance ($P < 0.05$).

Data are presented as median and interquartile ranges and counts and percentages when applicable. $P < 0.05$ is considered significant.

P-values were obtained from Wilcoxon rank-sum tests for continuous variables and χ^2 tests for categorical variables.

With CAS, however, utilizing a preoperative or intraoperative CT scan, there is a relatively fixed radiation exposure, as it involves either one or two spins. These spins can be performed either at a standard or lower dose, further decreasing radiation. The downside of CAS is the lack of "confirmation" of pedicle screw accuracy. This requires another spin which is only feasible with an intraoperative CT scan. In a great majority of screw placements, the pedicle screws are accurately placed or are in "acceptable" positions. However, in an ideal situation, most surgeons would prefer to confirm accuracy before leaving the operating room. The T&T approach allows for a near ideal scenario-utilizing freehand anatomic technique for insertion of majority of screws, it allows for confirmation and re-direction of screws if needed. The T&T approach's accuracy is similar to CAS and the number of screws that needed to be revised.

The T&T approach incorporates technology for confirmation and assistance when needed, while maintaining surgeon's acquired skill. This combination allows for decreased surgical time with associated benefits like decreased blood loss, less pain from shorter muscle retraction duration, and possible lower infection rate as the wound is open for a shorter duration.[18] T&T approach decreased the surgical time by nearly 60 minutes compared with CAS, carrying potential cost benefits. The benefits of T&T continued: compared with the NSQIP CAN database, T&T had a significantly shorter median operative time by 90 minutes. Further, the T&T group had fewer 30-day complications compared with NSQIP CAN data.

T&T and CAS had significantly lower return to OR, screw revisions, and loss of neuromonitoring signal data (transient or otherwise), compared with FOFA. These findings highlight the limitations of screw insertion with FOFA. Loss of neuromonitoring signals can occur due to anesthesia, blood loss, or screw malpositioning. T&T and CAS offer the best technique of avoiding screw malpositioning and identifying a misplaced screw. In CAS, screw malposition is avoided as the screw placement is under navigation, whereas in T&T it can be avoided as surgeons can skip a difficult pedicle and insert the screw under navigation guidance. Both these techniques allow screw confirmation on intraoperative CT-imaging. This is also reflected in the number of screws that had to be revised intraoperatively; again, higher in FOFA. The return to the OR was also higher in FOFA and includes returns for screw revision. These surgical outcomes demonstrate the superiority of CAS and T&T over FOFA. The advantage of T&T over CAS is decreased radiation and shorter operative time, which makes it the best of both worlds.

Our study is not without limitations. First, the FOFA approach lacked CT scan confirmation. In addition, there was no CT spin done at the end to confirm the placement of the screws placed under navigation in the T&T group. Both instances may lead to false reporting of accuracy rates. Further, the observed operative times may be reflective of surgeon skills, curve magnitude, and rigidity. Therefore, patients with curves between 37.0° and 110.0° for AIS and 15.0° and 70.0° for kyphosis were selected. The large number of screws and patients reviewed likely decreases the effect of varied surgeon skills and may truly reflect the outcomes of most centers with mixed surgeon skillset.

The next question: considering high accuracy with freehand technique, as confirmed in the T&T group, do experienced surgeons require navigation in scoliosis surgery? The authors would prefer to answer that, although not essential, intraoperative CT is desirable, as even experienced surgeons prefer to confirm the accuracy of inserted screws. This confirmation is a great reassurance for the surgeon and for the patient.

➢ Key Points

- ❑ T&T combines freehand anatomic technique with confirmation of screw accuracy with one intraoperative CT spin.
- ❑ T&T is accurate, and reduces operative time compared with both FOFA and CAS.
- ❑ Patients operated on only using computer-assisted navigation (CAS) had longer operative times and increased radiation exposure.

References

1. Sarwahi V, Sugarman EP, Wollowick AL, Amaral TD, Lo Y, Thornhill B. Prevalence, distribution, and surgical relevance of abnormal pedicles in spines with adolescent idiopathic scoliosis vs. no deformity: a CT-based study. *J Bone Jt Surg*. 2014;96:e92.
2. Sarwahi V, Wendolowski SF, Gecelter RC, et al. Are we underestimating the significance of pedicle screw misplacement? *Spine (Phila Pa 1976)*. 2016;41:E548–E555.
3. Dea N, Fisher CG, Batke J, et al. Economic evaluation comparing intraoperative cone beam CT-based navigation and conventional fluoroscopy for the placement of spinal pedicle screws: a patient-level data cost-effectiveness analysis. *Spine J*. 2016;16:23–31.
4. Linden GS, Ghessese S, Cook D, Hedequist DJ. Pedicle screw placement in adolescent idiopathic scoliosis: a comparison between robotics coupled with navigation versus the freehand technique. *Sensors*. 2022;22:5204.
5. Shin MH, Ryu KS, Park CK. Accuracy and safety in pedicle screw placement in the thoracic and lumbar spines: comparison study between conventional C-arm fluoroscopy and navigation coupled with O-arm® guided methods. *J Korean Neurosurg Soc*. 2012;52: 204–209.
6. Urbanski W, Jurasz W, Wolanczyk M, et al. Increased radiation but no benefits in pedicle screw accuracy with navigation versus a freehand technique in scoliosis surgery. *Clin Orthop Relat Res*. 2018; 476:1020–1027.
7. Berlin C, Quante M, Thomsen B, et al. Intraoperative radiation exposure to patients in idiopathic scoliosis surgery with freehand insertion technique of pedicle screws and comparison to navigation techniques. *Eur Spine J*. 2020;29:2036–2045.
8. Meng XT, Guan XF, Zhang HL, He SS. Computer navigation versus fluoroscopy-guided navigation for thoracic pedicle screw placement: a meta-analysis. *Neurosurg Rev*. 2016;39:385–391.
9. Gertzbein S, Robbins S. Accuracy of pedicular screw placement in vivo. *Spine (Phila Pa 1976)*. 1990;15:11–14.
10. Suk SI, Kim WJ, Lee SM, Kim JH, Chung ER. Thoracic pedicle screw fixation in spinal deformities: are they really safe? *Spine (Phila Pa 1976)*. 2001;26:2049–2057.
11. Debnath UK, Hossein Mehdian SM, Webb JK. Spinal deformity correction in duchenne muscular dystrophy (DMD): comparing the outcome of two instrumentation techniques. *Asian Spine J*. 2011;5: 43–50.
12. Jutte PC, Castelein RM. Complications of pedicle screws in lumbar and lumbosacral fusions in 105 consecutive primary operations. *Eur Spine J*. 2002;11:594–598.
13. Rajasekaran S, Vidyadhara S, Ramesh P, Shetty AP. Randomized clinical study to compare the accuracy of navigated and non-navigated thoracic pedicle screws in deformity correction surgeries. *Spine (Phila Pa 1976)*. 2007;32:E56–E64.
14. Molliqaj G, Schatlo B, Alaid A, et al. Accuracy of robot-guided versus freehand fluoroscopy-assisted pedicle screw insertion in thoracolumbar spinal surgery. *Neurosurg Focus*. 2017;42:E14.
15. Hu X, Lieberman IH. What is the learning curve for robotic-assisted pedicle screw placement in spine surgery? *In: Clinical Orthopaedics and Related Research*; 2014;472:1839–44
16. Fares N, Levey ST, Ashy C, et al. Intraoperative radiation exposure in adolescent idiopathic and neuromuscular scoliosis. *J Pediatr Orthop*. 2024;44:e40–e45.
17. Konieczny MR, Boos J, Steuwe A, Schleich C, Prost M, Krauspe R. Effective dose of radiation per screw in surgery of adolescent idiopathic scoliosis: matched pair analysis of 293 pedicle screws inserted using three different techniques. *J Child Orthop*. 2020;14: 554–561.
18. El-Kadi M, Donovan E, Kerr L, et al. Risk factors for postoperative spinal infection: a retrospective analysis of 5065 cases. *Surg Neurol Int*. 2019;10:121.

