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ORIGINAL ARTICLE

Impact of intraoperative imaging on decision-making during spine surgery: a survey among spine surgeons using simulated intraoperative images

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Abstract

Purpose To assess whether the intention to intraoperatively reposition pedicle screws differs when spine surgeons evaluate the same screws with 2D imaging or 3D imaging.

Methods In this online survey study, 21 spine surgeons evaluated eight pedicle screws from patients who had undergone posterior spinal fixation. In a simulated intraoperative setting, surgeons had to decide if they would reposition a marked pedicle screw based on its position in the provided radiologic imaging. The eight assessed pedicle screws varied in radiologic position, including two screws positioned within the pedicle, two breaching the pedicle cortex < 2 mm, two breaching the pedicle cortex 2–4 mm, and two positioned completely outside the pedicle. Surgeons assessed each pedicle screw twice without knowing and in random order: once with a scrollable three-dimensional (3D) image and once with two oblique fluoroscopic two-dimensional (2D) images.

Results Almost all surgeons (19/21) intended to reposition more pedicle screws based on 3D imaging than on 2D imaging, with a mean number of pedicle screws to be repositioned of, respectively, 4.1 (± 1.3) and 2.0 (± 1.3; $p < 0.001$). Surgeons intended to reposition two screws placed completely outside the pedicle, one breaching 2-4mm, and one breaching < 2 mm more often based on 3D imaging.

Conclusion When provided with 3D imaging, spine surgeons not only intend to intraoperatively reposition pedicle screws at risk of causing postoperative complications more often but also screws with acceptable positions. This study highlights the potential of intraoperative 3D imaging as well as the need for consensus on how to act on intraoperative 3D information.

Keywords Spine surgery · Pedicle screw · Accuracy · Three-dimensional imaging · Two-dimensional imaging

Introduction

For decades, pedicle screws have been the workhorse implants for spine surgeons as they allow for reliable mechanical fixation of vertebral segments in the treatment of many spine pathologies.

For safety, pedicle screws must be placed accurately through the pedicle into the vertebral body. Misplaced pedicle screws have reduced biomechanical strength and can cause (irreversible) damage to the spinal cord, nerve roots, and proximal vessels [1, 2]. During surgery, surgeons evaluate pedicle screw positions mainly on intraoperative fluoroscopic images and must promptly decide if the screw positions are acceptable. Pedicle screws with an unacceptable position need to be repositioned immediately.

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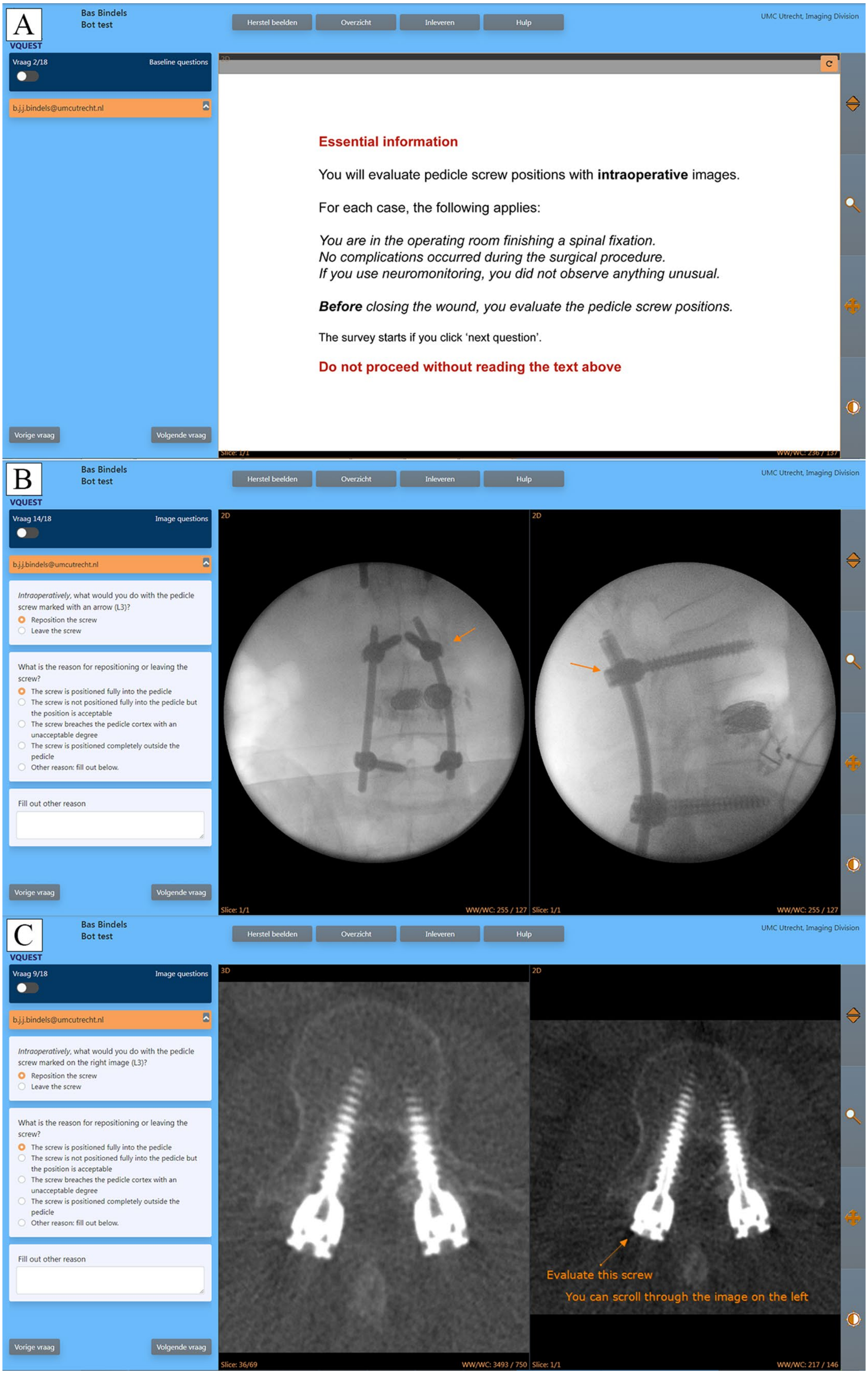

A
Bas Bindels
Bot test
VQUEST
Herstel beelden
Overzicht
Inleveren
Hulp
UMC Utrecht, Imaging Division
Vraag 2/18
Baseline questions
b.j.j.bindels@umcutrecht.nl
Essential information
You will evaluate pedicle screw positions with intraoperative images.
For each case, the following applies:
You are in the operating room finishing a spinal fixation.
No complications occurred during the surgical procedure.
If you use neuromonitoring, you did not observe anything unusual.
Before closing the wound, you evaluate the pedicle screw positions.
The survey starts if you click 'next question'.
Do not proceed without reading the text above
Vorige vraag
Volgende vraag
B
Bas Bindels
Bot test
VQUEST
Herstel beelden
Overzicht
Inleveren
Hulp
UMC Utrecht, Imaging Division
Vraag 14/18
Image questions
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Intraoperatively, what would you do with the pedicle screw marked with an arrow (L3)?
Reposition the screw
Leave the screw
What is the reason for repositioning or leaving the screw?
The screw is positioned fully into the pedicle
The screw is not positioned fully into the pedicle but the position is acceptable
The screw breaches the pedicle cortex with an unacceptable degree
The screw is positioned completely outside the pedicle
Other reason: fill out below.
Fill out other reason
Vorige vraag
Volgende vraag
2D
2D
Slice: 1/1
WW/WC: 255 / 127
Slice: 1/1
WW/WC: 255 / 127
C
Bas Bindels
Bot test
VQUEST
Herstel beelden
Overzicht
Inleveren
Hulp
UMC Utrecht, Imaging Division
Vraag 9/18
Image questions
b.j.j.bindels@umcutrecht.nl
Intraoperatively, what would you do with the pedicle screw marked on the right image (L3)?
Reposition the screw
Leave the screw
What is the reason for repositioning or leaving the screw?
The screw is positioned fully into the pedicle
The screw is not positioned fully into the pedicle but the position is acceptable
The screw breaches the pedicle cortex with an unacceptable degree
The screw is positioned completely outside the pedicle
Other reason: fill out below.
Fill out other reason
Vorige vraag
Volgende vraag
3D
2D
Evaluate this screw
You can scroll through the image on the left
Slice: 36/69
WW/WC: 3493 / 750
Slice: 1/1
WW/WC: 217 / 146

◂**Fig. 1** Three screenshots from the online survey for case E-L3 with **A** general instructions to spine surgeons, **B** two 2D images, and **C** one 3D image. Spine surgeons could scroll through the 3D image in all three planes (axial, sagittal, and coronal)

Spine surgeons have become accustomed to evaluating intraoperative pedicle screw positions with two-dimensional (2D) fluoroscopic images. However, more advanced intraoperative fluoroscopic imaging methods, such as computed tomography (CT) and cone-beam computed tomography (CBCT), are gaining popularity [3]. Intraoperative CT and CBCT provide (reconstructed) three-dimensional (3D) images, which are more detailed than 2D fluoroscopic images, and add an axial view. Detailed 3D information may allow surgeons to identify misplaced pedicle screws more easily. However, the 3D information may also make surgeons reposition suboptimal placed pedicle screws more frequently even when it is uncertain whether these screws, if left in situ, would have caused any clinical symptoms postoperatively.

In this survey study, we assessed the hypothesis that the intention to intraoperatively reposition pedicle screws differs when spine surgeons evaluate the same screws with 2D or 3D imaging.

Methods

Study design

A web-based survey was conducted among spine surgeons from different institutions in North America, Europa, and Asia between October and December 2022. Spine surgeons within the network of the study authors were approached via e-mail to participate in the survey. A survey tool supporting 2D and 3D images was used (VQuest; www.vquest.eu). Survey questions were in English or Dutch. This study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [4].

Survey questions

The survey consisted of four baseline questions followed by questions about eight cases in which radiologic images from eight pedicle screws were shown.

The four baseline questions asked for the surgeon's background by including (1) years of clinical experience as a spine surgeon, (2) country of residency, (3) what type of intraoperative imaging the surgeon uses most often to evaluate pedicle screw positions intraoperatively, and (4) if the surgeon ever uses intraoperative navigation for pedicle screw insertion.

The eight cases assessed whether the surgeon would intraoperatively reposition an arrow-marked pedicle screw based on the provided radiologic image(s) and the reason for this decision. Surgeons provided the reason for their decision by writing a comment or answering a multiple choice question (Fig. 1). The same eight cases were presented twice: once with two 2D images (antero-posterior and lateral) and once with a 3D image scrollable in three planes (axial, coronal, and sagittal). All cases were presented in random order for each surgeon. Surgeons were blinded for the study objectives and were not informed that they assessed each pedicle screw twice.

Radiologic images

The radiologic images were selected from patients (≥ 18 years) who had undergone lumbar or thoracic spine surgery with pedicle screws at our institution between January 2017 and September 2022. Eligible patients had to have the following imaging available in their electronic health record: 2D fluoroscopic images obtained during surgery and a postoperative spinal radiograph and CT scan obtained within one year.

Two authors (BJJB and JJV) selected eight pedicle screws based on their radiologic position on the postoperative CT, representing a broad spectrum of the Gertzbein-Robbins classification [5]. After screening 305 patients, radiologic images originating from six patients were included in the survey (Fig. 2).

Two pedicle screws were positioned in the pedicle (grade A), two pedicle screws breached the pedicle cortex with < 2 mm (grade B), two pedicle screws breached the pedicle cortex with 2–4 mm (grade C), and two pedicle screws were positioned completely outside the pedicle (Grade E; Supplement 1). The two patients with the Grade E pedicle screws underwent revision surgery due to clinical symptoms related to the misplaced screw (case E-T1 after 91 days and case E-L3 after 403 days). Only radiologic images from the initial surgery were used (Table 1).

The selected 2D images for the survey had been obtained through intraoperative fluoroscopic imaging except for one case where we simulated a lateral fluoroscopic image by inverting a lateral postoperative radiograph acquired three days after surgery (Table 1). Intraoperatively acquired 3D images were not available for the included cases. Instead, we presented a postoperative CT scan as an intraoperative 3D image. None of the selected pedicle screws or attached rods had pulled out or showed signs of loosening on the postoperative CT scans, ensuring that the pedicle screw's postoperative position was representative of the position acquired intraoperatively. The CT scan's field of view was cropped so that only the vertebra of interest was visible in the three planes. Only the CT scans from the two grade A pedicle screws had no metal-artifact reduction algorithm applied (Table 1).

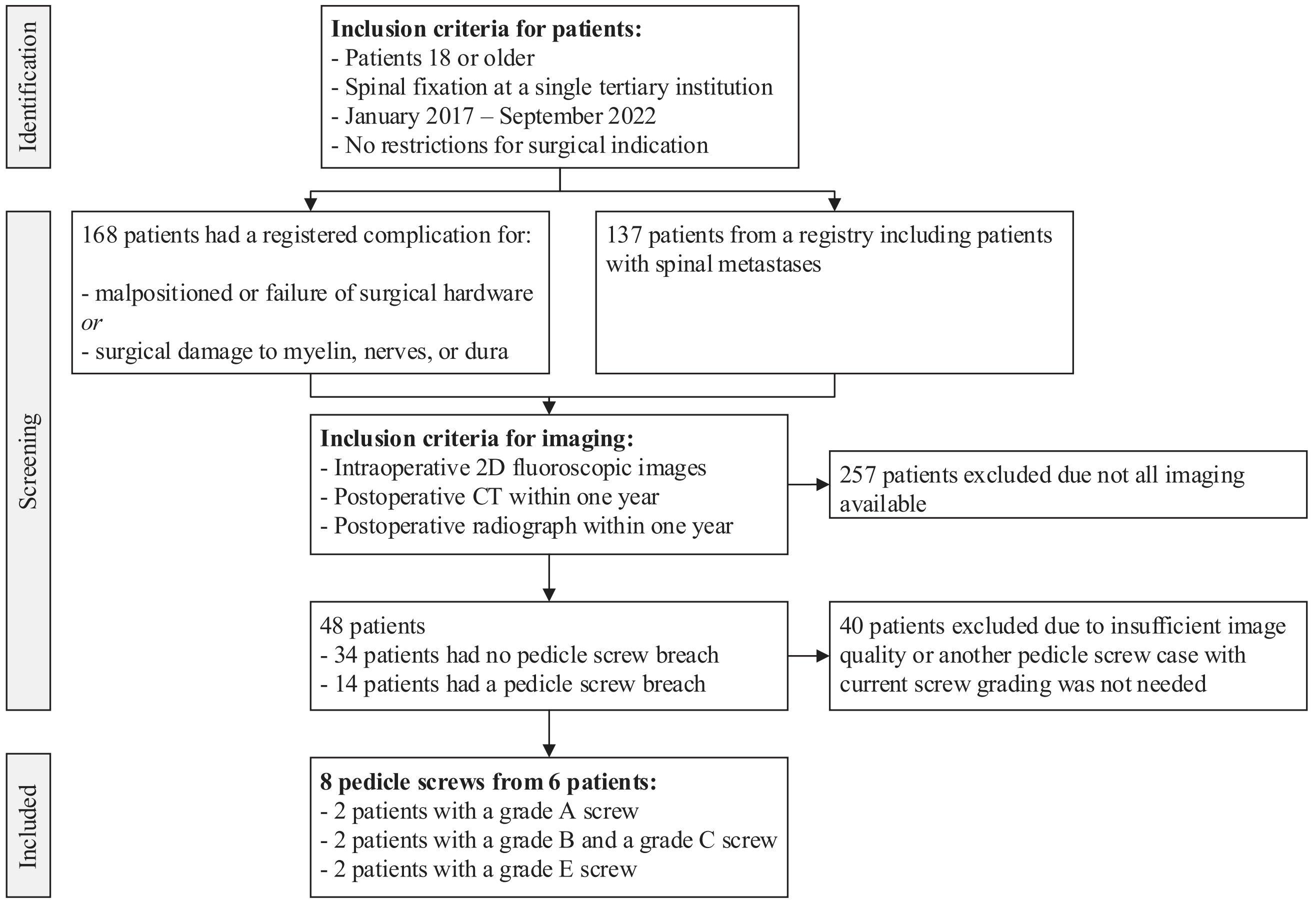


Fig. 2 Flowchart of the selection process for the eight (pedicle screw) cases

Study outcomes

The primary outcome was the reposition difference per spine surgeon. The reposition difference was expressed for each surgeon as the number of screws repositioned based on 2D imaging subtracted from the number of screws repositioned based on 3D imaging. Secondary outcomes were the number of repositioned screws per case and the reason for the decision per case. All outcome data were directly retrieved from the answers provided in the survey tool.

Power analysis

The number of spine surgeons needed to conduct the survey reliably was calculated using a two-sided paired *t* test. We hypothesized that surgeons would reposition a mean number of three screws based on 2D imaging (case E-T1, E-L3, and C-T7 or C-L1) and four screws based on 3D imaging (cases C-T7, C-L1, E-T1, and E-L3) [5, 6]. We estimated a standard deviation of 1.37 based on the probability of 0.375 for repositioning based on 2D imaging and a standard deviation of 1.40 based on the probability of 0.5 for 3D imaging. We assumed a correlation of 0.5 for assessing the same screws twice. To achieve 80% power and two-sided 5% significance, at least 18 surgeons evaluating 8 paired cases, thus 16 cases, were needed. The power analysis was conducted using G*Power v3.1 [7]. After inviting 39 spine surgeons, 21 surgeons (54%) from eight countries across three continents completed the survey.

Statistical methods

The primary outcome was assessed for normality by a Shapiro–Wilk test and for statistical significance by a two-sided paired *t* test. McNemar's test with mid-p approach was applied to assess whether the number of repositions differed between the imaging methods per case [8]. Additionally, the primary outcome was stratified based on the years of experience as a spine surgeon and the continent of residency. No statistical subgroup analyses were conducted for the stratified groups, as the sample size of the study was not specifically calculated for this purpose. The number of repositioned screws

Table 1 Patient characteristics and details of radiologic imaging

Patient	Pedicle screw case	Type of surgery	Anatomic position of assessed pedicle screw	Diameter/length of pedicle screw	Gertzbein-Robbins grade	Amount of breach (direction)	2D imaging device	3D imaging device	Protocol for postoperative CT (3D), slice thickness
1	A-T7	Open fixation T7-T9, laminectomy and vertebroplasty T8	T7 right	4.0 mm /40 mm	A	No breach	Siemens Cios Spin	Philips, IQon Spectral CT	Abdomen, 0.9 mm,
2	A-T9	Percutaneous fixation T9-T11	T9 right	5.0 mm /45 mm	A	No breach	Philips Endura	Philips, Brilliance iCT 256	Abdomen, 0.9 mm
3	B-T8	Open fixation T4-T8	T8 left	4.5 mm /40 mm	B	1.8 mm (medial)	Philips Endura	Philips, Brilliance 64	Thorax O-MAR, 0.9 mm
4	B-T9	Percutaneous fixation T9-L2, vertebroplasty T11	T9 right	6.0 mm /45 mm	B	1.8 mm (medial)	Philips Pulsera	Philips, IQon Spectral	TL-spine O-MAR, 0.9 mm
3	C-T7	Open fixation T4-T8	T7 left	4.5 mm /40 mm	C	3.8 mm (medial)	Philips Endura	Philips, Brilliance 64	Thorax O-MAR, 0.9 mm
4	C-L1	Percutaneous fixation T9-L2, vertebroplasty T11	L1 left	6.0 mm /50 mm	C	2.7 mm (medial)	Philips Pulsera	Philips, IQon Spectral	TL-spine O-MAR, 0.9 mm
5	E-T1	Open fixation C4-T1, laminectomy C5-C6	T1 left	4.5 mm/28 mm	E	Whole screw 4.5 mm (medial + caudal)	Philips Endura (AP) + Postoperative radiograph (LAT)*	Philips, IQon Spectral	C-spine O-MAR, 0.9 mm
6	E-L3	Percutaneous fixation T11-L1 and L3-L5, vertebroplasty L4	L3 right	7.5 mm /55 mm	E	Whole screw 5.5 mm (medial)	Philips Endura	Siemens, SOMATOM Force	L-spine O-MAR, 1.0 mm

*No intraoperative lateral fluoroscopic 2D image was available. Abbreviations: 2D; two-dimensional, 3D; three-dimensional, A; grade A (screw in pedicle), AP; antero-posterior, B; grade B (breach < 2 mm), C; grade C (breach 2–4 mm), C-spine; cervical spine, CT; computed-tomography, E; grade E (screw completely outside pedicle), L; lumbar, L-spine; lumbar spine, LAT; lateral, mm; millimeters, O-MAR: metal artifact reduction for orthopedic implants, T; thoracic, TL-spine; thoracolumbar spine

was summarized using means and standard deviations. All statistical analyses were performed with R statistical software (version 4.0.3; packages 'Base-R' and 'Exact2 × 2'). A p value of < 0.05 was considered statistically significant.

Results

Baseline questions

Of all 21 participating spine surgeons, 9 out of 21 had more than ten years of experience as a spine surgeon. Eighteen surgeons use 2D fluoroscopy to intraoperatively confirm pedicle screw positions, and fifteen do not regularly use intraoperative navigation for pedicle screw insertion (Table 2).

Number of repositioned screws per spine surgeon

Nineteen spine surgeons intended to reposition more pedicle screws if assessed on a 3D image (Fig. 3). The Shapiro–Wilk test suggested a normal distribution ($p = 0.25$). The mean number of pedicle screws repositioned based on 2D imaging was 2.0 (± 1.3), and on 3D imaging, was 4.1 (± 1.3) with a mean reposition difference of 2.1 (± 1.5; $p < 0.001$) (Table 3). The stratified results for years of experience as a spine surgeon and continent of residency are presented in Table 3.

Number of repositioned screws and reason for repositioning per case

For the six pedicle screw cases presenting a breaching screw or a screw positioned completely outside the pedicle (B-T8, B-T9, C-T7, C-L1, E-T1, and E-L3), in 4% of the assessments (5/126 assessments) the pedicle screw was considered to be positioned fully into the pedicle based on 3D imaging and in 39% of the assessments (49/126 assessments) based on 2D imaging. For the remaining assessments, thus

Table 2 Professional characteristics of the 21 spine surgeons based on the four baseline questions

	Number of spine surgeons (%) ($N = 21$)
Years of clinical experience as a spine surgeon	
< 5 years	6 (29%)
5–10 years	6 (29%)
> 10 years	9 (43%)
Region/country of residency	
Europe	10 (48%)
Netherlands	7
Switzerland	3
North America	6 (29%)
USA	4
Canada	2
Asia	5 (24%)
China	2
Hong Kong	1
India	1
Taiwan	1
Intraoperative imaging modality used most to evaluate pedicle screw positions	
No intraoperative imaging	0 (0%)
Fluoroscopy (2D)	18 (86%)
Cone-beam CT (3D)	0 (0%)
Intraoperative CT (3D)	0 (0%)
Other*	1 (5%)
Not answered	2 (10%)
Use of intraoperative navigation for pedicle screw positioning	
Always	2 (10%)
Most times	2 (10%)
Usually not	12 (57%)
Never	3 (14%)
Not answered	2 (10%)

2D; Two-dimensional, 3D; Three-dimensional, CT; Computed-tomography. *Other was not specified

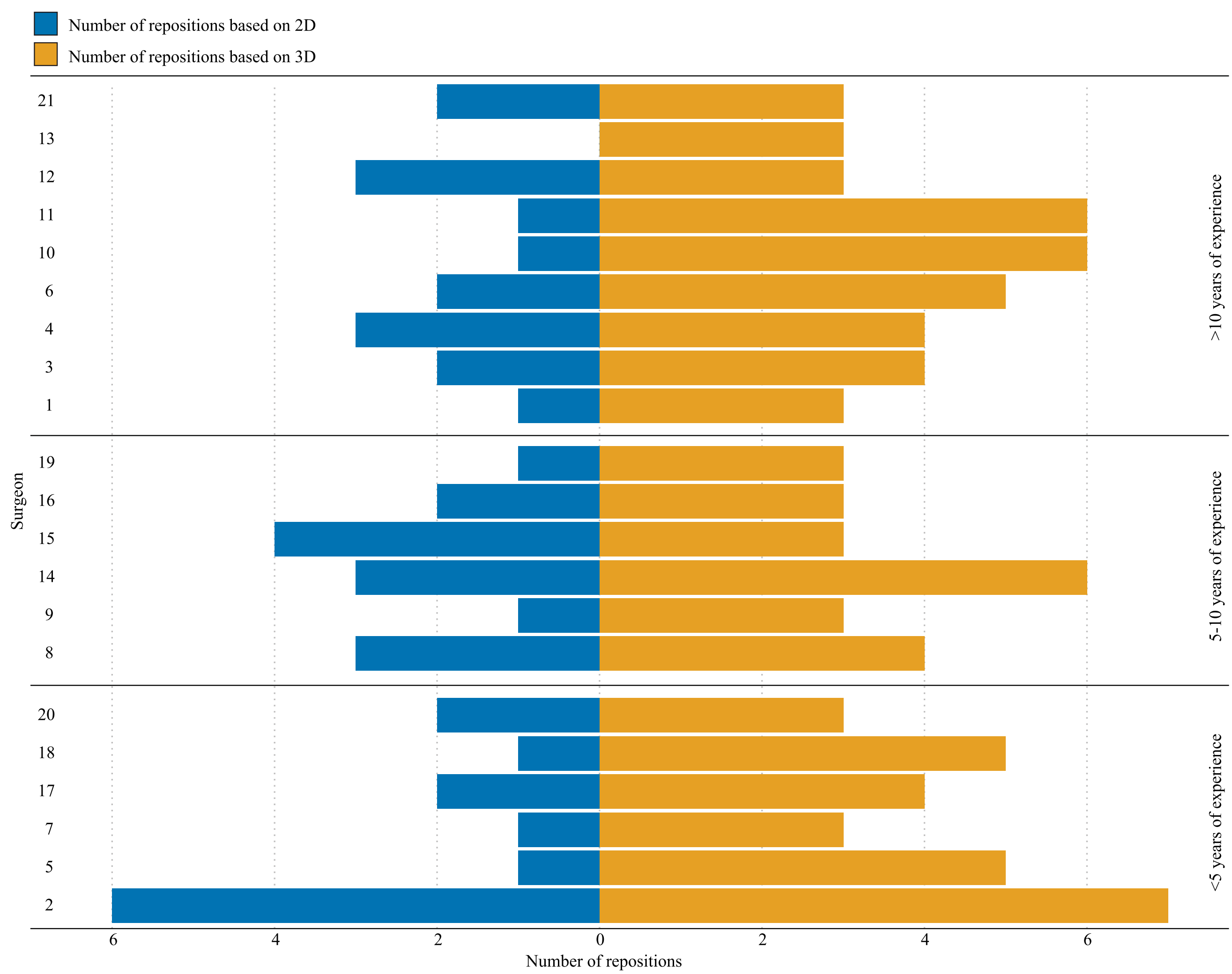


Fig. 3 The number of repositioned screws based on 2D and 3D assessment for each participating surgeon. Surgeons were ordered based on their years of experience as a spine surgeon

Table 3 Mean number of pedicle screw repositions per surgeon stratified for the years of experience as a spine surgeon and continent of residency

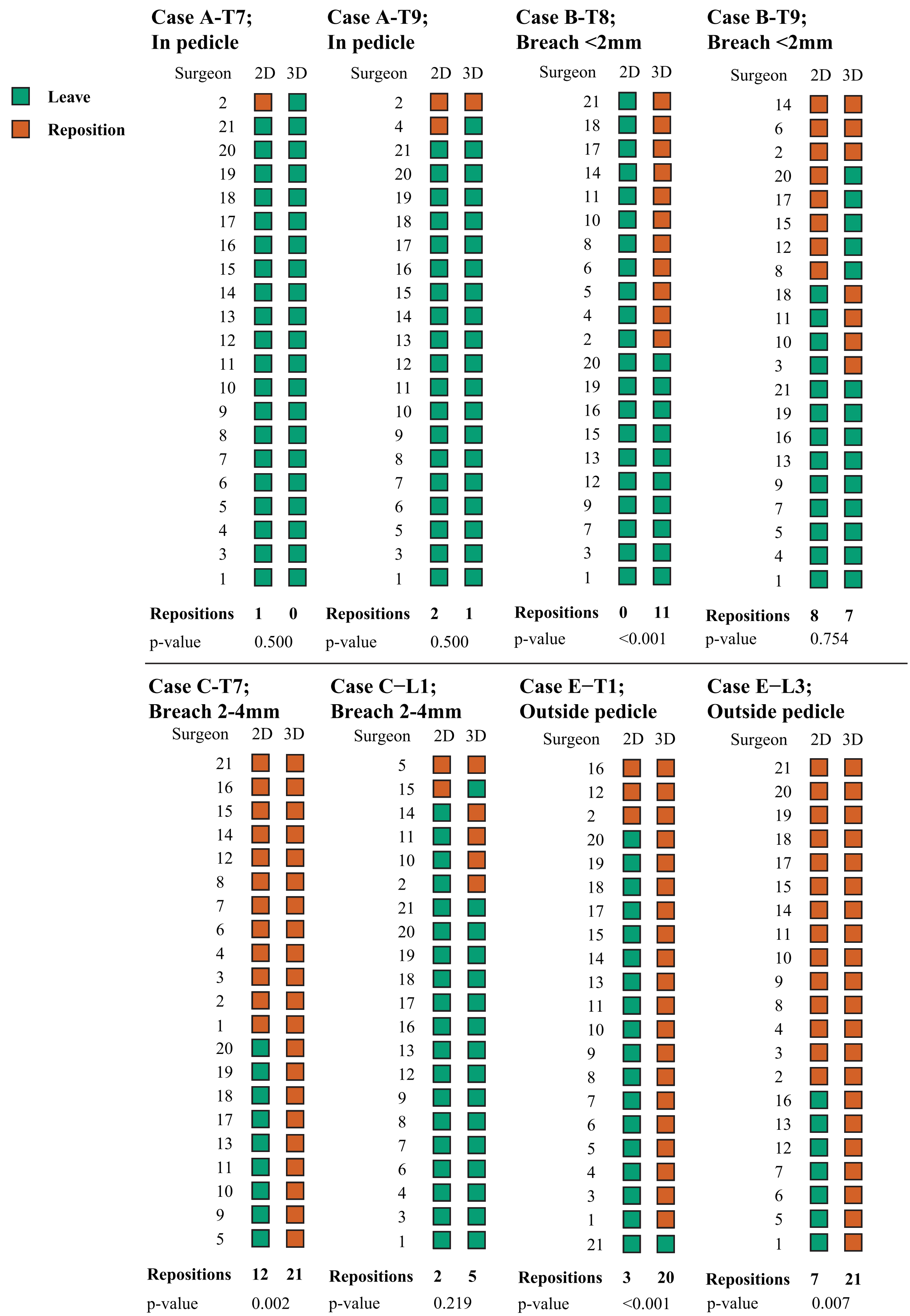
	Number of surgeons, n	Mean number of 2D repositions per surgeon, (± sd)	Mean number of 3D repositions per surgeon, mean (± sd)	Reposition difference per spine surgeon, mean (± sd)	*P*-value[a]
All surgeons	21	2.0 (± 1.3)	4.1 (± 1.3)	2.1 (± 1.5)	< 0.001
Years of clinical experience as a spine surgeon					
< 5 years of experience	6	2.2 (± 1.9)	4.5 (± 1.5)	2.3 (± 1.4)	–[b]
5–10 years of experience	6	2.3 (± 1.2)	3.7 (± 1.2)	1.3 (± 1.4)	–[b]
> 10 years of experience	9	1.7 (± 1.0)	4.1 (± 1.3)	2.4 (± 1.7)	–[b]
Continent of residency					
Asia	5	2.8 (± 1.9)	4.2 (± 1.6)	1.4 (± 0.5)	–[b]
Europe	10	1.5 (± 0.7)	4.1 (± 1.1)	2.6 (± 1.3)	–[b]
North America	6	2.2 (± 1.5)	4.0 (± 1.5)	1.8 (± 2.2)	–[b]

Each surgeon evaluated eight pedicle screw positions twice, once with 2D imaging and once with 3D imaging

2D; Two-dimensional, 3D; Three-dimensional, sd; Standard deviation

[a]A two-sided paired *t* test was performed to assess whether the number of repositions differed between pedicle screws evaluated with 2D imaging and screws evaluated with 3D imaging

[b]The sample size did not allow for a subanalysis


Leave
Reposition
Case A-T7; In pedicle
Surgeon 2D 3D
2 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 1
Repositions 1 0
p-value 0.500
Case A-T9; In pedicle
Surgeon 2D 3D
2 4 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 3 1
Repositions 2 1
p-value 0.500
Case B-T8; Breach <2mm
Surgeon 2D 3D
21 18 17 14 11 10 8 6 5 4 2 20 19 16 15 13 12 9 7 3 1
Repositions 0 11
p-value <0.001
Case B-T9; Breach <2mm
Surgeon 2D 3D
14 6 2 20 17 15 12 8 18 11 10 3 21 19 16 13 9 7 5 4 1
Repositions 8 7
p-value 0.754
Case C-T7; Breach 2-4mm
Surgeon 2D 3D
21 16 15 14 12 8 7 6 4 3 2 1 20 19 18 17 13 11 10 9 5
Repositions 12 21
p-value 0.002
Case C−L1; Breach 2-4mm
Surgeon 2D 3D
5 15 14 11 10 2 21 20 19 18 17 16 13 12 9 8 7 6 4 3 1
Repositions 2 5
p-value 0.219
Case E−T1; Outside pedicle
Surgeon 2D 3D
16 12 2 20 19 18 17 15 14 13 11 10 9 8 7 6 5 4 3 1 21
Repositions 3 20
p-value <0.001
Case E−L3; Outside pedicle
Surgeon 2D 3D
21 20 19 18 17 15 14 11 10 9 8 4 3 2 16 13 12 7 6 5 1
Repositions 7 21
p-value 0.007

◂**Fig. 4** The number of intraoperatively repositioned pedicle screws for each (pedicle screw) case. Per case, the number of repositions between the imaging methods was compared with McNemar's test. Cases E-T1 and E-L3 underwent revision surgery due to clinical symptoms related to the misplaced screws. Table 4 shows the reason for repositioning for the statistically significant cases ($p < 0.05$)

considering the pedicle screw either to breach or to be positioned completely outside the pedicle, in 31% of the assessments (38/121 assessments) the breach was considered acceptable based on 3D imaging, and, based on 2D imaging, the breach was considered acceptable in 49% of the assessments (38/77 assessments) (Supplement 2 and 3). The number of repositioned screws was found to be significantly higher for 3D imaging than for 2D imaging in four cases: B-T8, C-T7, E-T1, and E-L3 (Fig. 4).

All 21 surgeons considered the pedicle screw of case B-T8 to breach the pedicle based on 3D imaging, of which 11 intended to reposition the screw. For the same case assessed with 2D images, none of the surgeons intended to reposition the pedicle screw of which 11 considered the screw to be fully in the pedicle (Table 4).

If assessed on 3D imaging, all 21 surgeons intended to reposition the pedicle screw from case C-T7. Based on 2D images, 11 surgeons intended to reposition the pedicle screw from case C-T7 (Table 4). Three surgeons noted that they first wanted to take the pedicle screw out to feel if a breach had occurred based on the provided 2D images (Supplement 2).

Twenty surgeons considered the pedicle screw position to be unacceptable in case E-T1 based on 3D imaging. Based on the 2D images provided for E-T1, 18 surgeons considered the screw position acceptable of which 13 considered the screw to be fully in the pedicle (Table 4).

None of the 21 spine surgeons would accept the position of the pedicle screw from case E-L3 based on 3D imaging. When surgeons assessed case E-L3 with 2D images, 15 surgeons would not accept the position of the pedicle screw and three considered the screw to be fully in the pedicle (Table 4).

Discussion

We performed a survey among 21 spine surgeons to assess the hypothesis that the intention to intraoperatively reposition pedicle screws differs when spine surgeons evaluate the same screws with 2D or 3D imaging. Radiologic images from eight pedicle screws were shown in a simulated intraoperative setting. Spine surgeons intended to intraoperatively reposition more pedicle screws based on 3D imaging than on 2D imaging.

Our finding that surgeons intend to reposition more pedicle screws based on intraoperative 3D imaging than 2D imaging has been reported previously. In one study among 189 patients, the number of spinal deformity surgeries where surgeons intraoperatively repositioned at least one pedicle screw increased from 13 to 45% [9]. In another study among 810 patients treated for various spinal pathologies, the intraoperative pedicle screw reposition rates almost tripled from 3 to 8% [6].

Pedicle screws entirely positioned through the spinal canal often cause clinical symptoms, and immediate repositioning can prevent irreversible (neurologic) damage [5, 10, 11]. The pedicle screws from cases E-L3 and E-T1 were positioned medial to the pedicle (entirely in the spinal canal), and both patients underwent secondary revision surgery due to clinical symptoms related to the misplaced pedicle screws. Based on 2D imaging, 20 of the 21 surgeons accepted the position of at least one of the two pedicle screws. If an intraoperative 3D image had been obtained, then almost all surgeons (20/21) would have repositioned the two pedicle screws immediately, possibly preventing a reoperation and/or irreversible neurological damage. The literature presents different results on whether the number of reoperations for misplaced pedicle screws decreases when an intraoperative 3D image of every placed pedicle screw is obtained compared to a 2D fluoroscopic workflow. One study among 198 patients treated for spinal deformity reported that reoperations due to misplaced pedicle screws decreased from 4.9% to no reoperations in five years [9]. However, another study among 810 patients with various spinal pathologies reported that reoperations due to misplaced pedicle screws did not (yet) decrease in 2.5 years; 0.99% with intraoperative CT available versus 0.99% without intraoperative CT available [6].

Spine surgeons repositioned the pedicle screws from cases B-T8 and C-T7 more often based on 3D imaging. In actual clinics, these two cases did not develop any clinical symptoms related to the breaching pedicle screws. Moreover, based on postoperative CTs and the postoperative clinical status of the patients, the treating spine surgeons did not consider revision surgery necessary. Breaches up to two millimeters are generally considered safe [5, 11–13] and breaches of up to four millimeters, when assessed on a postoperative CT, do not, as a rule, lead to clinical symptoms [5, 12, 13]. Therefore, repositioning the pedicle screws from cases B-T8 and C-T7 may be unnecessary.

Our study findings suggest that the additional intraoperative 3D information could increase redundant repositioning of pedicle screws with an acceptable position, a development that has been reported previously [6]. Future studies should specify how to interpret and act on intraoperative 3D information for evaluating pedicle screw positions as its use in spinal practice will only increase. Additionally, future

Table 4 The reason for repositioning or leaving screws for the four pedicle screw cases that differed statistically significantly regarding the number of repositions

Case B-T8							
		Total for 2D (%)	3D				
			In, accept	Breach, accept	Breach, reposition	Out, reposition	Other
Total for 3D (%)			0 (0%)	11 (52%)	10 (48%)	0 (0%)	0 (0%)
2D	In, accept	11 (52%)	0	4	7	0	0
	Breach, accept	9 (43%)	0	7	2	0	0
	Breach, reposition	0 (0%)	0	0	0	0	0
	Out, reposition	0 (0%)	0	0	0	0	0
	Other	1 (5%)	0	0	1	0	0
Case C-T7							
Total for 3D (%)			0 (0%)	0 (0%)	14 (67%)	7 (33%)	0 (0%)
2D	In, accept	2 (10%)	0	0	2	0	0
	Breach, accept	5 (24%)	0	0	2	3	0
	Breach, reposition	10 (48%)	0	0	7	3	0
	Out, reposition	1 (5%)	0	0	0	1	0
	Other	3 (14%)	0	0	3	0	0
Case E-T1							
Total for 3D (%)			1 (5%)	0 (0%)	12 (57%)	8 (38%)	0 (0%)
2D	In, accept	13 (62%)	0	0	10	3	0
	Breach, accept	5 (24%)	1	0	1	3	0
	Breach, reposition	3 (14%)	0	0	1	2	0
	Out, reposition	0 (0%)	0	0	0	0	0
	Other	0 (0%)	0	0	0	0	0
Case E-L3							
Total for 3D (%)			0 (0%)	0 (0%)	6 (29%)	15 (71%)	0 (0%)
2D	In, accept	3 (14%)	0	0	1	2	0
	Breach, accept	3 (14%)	0	0	0	3	0
	Breach, reposition	11 (52%)	0	0	5	6	0
	Out, reposition	4 (19%)	0	0	0	4	0
	Other	0 (0%)	0	0	0	0	0

The written answers to 'Other' are added as a supplement (Supplement 2)

Survey answers: In, accept; *The screw is positioned fully into the pedicle*, Breach, accept; *The screw is not positioned fully into the pedicle but the position is acceptable*, Breach, reposition; *The screw breaches the pedicle cortex with an unacceptable degree*, Out, reposition; *The screw is positioned completely outside the pedicle*, Other; *Other reason*

2D; Two-dimensional, 3D; Three-dimensional

studies should assess when 2D fluoroscopy may become less reliable for intraoperatively evaluating pedicle screw positions due to anatomical factors, such as spine deformity, high body mass index, or overlaying structures such as the pelvis or scapulae [5, 11–13].

This study has several limitations. First, the survey cases do not represent a real situation in the operating room. During spine surgery, surgeons work with other team members and receive tactile feedback during screw insertion, and if an intraoperative fluoroscopic image is considered insufficient, a new image can be obtained. However, we consider it unlikely that this limitation affected the study findings. Six surgeons made a total of seven comments concerning five of the eight 2D cases, suggesting that, in an actual situation, they would have obtained additional 2D images or would have felt the pedicle walls with an awl first (Supplement 2). Of those five 2D cases, three presented screws without a breach or a breach of < 2 mm. More importantly, regarding the two cases that developed clinical symptoms postoperatively (E-L3 and E-T1), none of the surgeons made a comment on the provided 2D or 3D images, and almost all considered the screws positioned well (enough) based on the 2D images, as did the actual surgical team at that time. Second, spine surgeons assessed pedicle screw positions without knowing the indication for surgery, the function of the screw within the spinal construct, the planned screw trajectory, and the dimensions of the screw or pedicle. For example, spine surgeons can intentionally place thoracic pedicle screws with a lateral breach through the in-out-in technique, limiting the risk of a more critical medial breach. [14] To minimize the impact of specific patient considerations on decision-making, we did not include anatomically deformed pedicles and only included screws with a medial pedicle breach. Third, the survey did not capture individual surgeon thresholds for accepting pedicle screw positions, and our results indicate that those thresholds differ among surgeons. However, almost all spine surgeons intended to reposition more pedicle screws based on the provided 3D imaging than on the provided 2D images. Additionally, the results stratified for years of experience as a spine surgeon and the continent of residency appeared to be similar among the groups, though the number of participants did not allow for a reliable subanalysis. Fourth, we presented postoperative CT scans as intraoperative 3D images. A postoperative CT scan is superior for evaluating soft tissue to intraoperative 3D imaging, such as CBCT. However, for evaluating pedicle screw positions, multiple studies have shown that spine surgeons assess pedicle screw positions with equal accuracy on CT as on CBCT [15–17]. Also, some CTs were acquired well after the initial surgery, which, theoretically, may have resulted in late-onset loosening and movement of the pedicle screws. However, none of the selected pedicle screws or attached rods had pulled out or loosened on the used postoperative CTs. In addition, none of the patients had a history of osteoporosis or osteopenia. Therefore, we considered using postoperative CTs justified for our study objectives and unlikely to affect our findings.

Conclusions

Spine surgeons intend to intraoperatively reposition pedicle screws more frequently based on 3D imaging than 2D imaging. When provided with 3D imaging, spine surgeons not only intended to reposition pedicle screws at risk of causing postoperative clinical symptoms more often but also screws with acceptable positions. This study highlights the potential of intraoperative 3D imaging for evaluating pedicle screw positions as well as the need for consensus on how to interpret and act on intraoperative 3D information.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00586-024-08222-9.

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Data availability Available upon reasonable request with the corresponding author.

Declarations

Conflict of interest JJV is co-founder and stock owner of SentryX. BJJB, MLJS, and JJV collaborate with Philips Medical Systems, and JJR is employed by Philips Medical Systems.

Ethics approval Ethics committee approval was granted under No. 22-961.

Informed consent From patients alive at the start of the study, informed consent was obtained; for deceased patients, a waiver of informed consent was granted.

References

1. Gautschi OP, Schatlo B, Schaller K, Tessitore E (2011) Clinically relevant complications related to pedicle screw placement in thoracolumbar surgery and their management: a literature review of 35,630 pedicle screws. Neurosurg Focus FOC 31(4):E8. https://doi.org/10.3171/2011.7.FOCUS11168
2. Ye Y-X, Huang D-G, Hao D-J, Liu J-Y, Ji J-J, Guo J-N (2022) Screw pull-out strength after pedicle screw reposition: a finite element analysis. Spine (Phila Pa 1976). https://doi.org/10.1097/BRS.0000000000004553
3. Malham GM, Wells-Quinn T (2019) What should my hospital buy next?-Guidelines for the acquisition and application of imaging, navigation, and robotics for spine surgery. J Spine Surg 5(1):155–165. https://doi.org/10.21037/jss.2019.02.04
4. Vandenbroucke JP et al (2007) Strengthening the reporting of observational studies in epidemiology (STROBE): explanation and elaboration. PLoS Med 4(10):e297. https://doi.org/10.1371/journal.pmed.0040297
5. Gertzbein SD, Robbins SE (1990) Accuracy of pedicular screw placement in vivo. Spine (Phila Pa 1976) 15(1):11–14. https://doi.org/10.1097/00007632-199001000-00004
6. Bydon M et al (2014) Safety and efficacy of pedicle screw placement using intraoperative computed tomography: consecutive series of 1148 pedicle screws. J Neurosurg Spine 21(3):320–328. https://doi.org/10.3171/2014.5.SPINE13567

7. Faul F, Erdfelder E, Lang A-G, Buchner A (2007) G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 39(2):175–191. https://doi.org/10.3758/bf03193146
8. Fagerland MW, Lydersen S, Laake P (2013) The McNemar test for binary matched-pairs data: mid-p and asymptotic are better than exact conditional. BMC Med Res Methodol 13:91. https://doi.org/10.1186/1471-2288-13-91
9. Saarinen AJ, Suominen EN, Helenius L, Syvänen J, Raitio A, Helenius I (2022) Intraoperative 3D imaging reduces pedicle screw related complications and reoperations in adolescents undergoing posterior spinal fusion for idiopathic scoliosis: a retrospective study. Children (Basel). https://doi.org/10.3390/children9081129
10. Mac-Thiong J-M, Parent S, Poitras B, Joncas J, Hubert L (2013) Neurological outcome and management of pedicle screws misplaced totally within the spinal canal. Spine (Phila Pa 1976) 38(3):229–237. https://doi.org/10.1097/BRS.0b013e31826980a9
11. Sugawara R, Tsuji T, Saito T, Nohara A, Kawakami K, Kawakami N (2015) Medially misplaced pedicle screws in patients without neurological deficits following scoliosis surgery: to observe or to remove? Eur Spine J 24(7):1450–1456. https://doi.org/10.1007/s00586-015-3860-y
12. Kim YJ, Lenke LG, Bridwell KH, Cho YS, Riew KD (2004) Free hand pedicle screw placement in the thoracic spine: is it safe. Spine (Phila Pa 1976) 29(3):333–342. https://doi.org/10.1097/01.BRS.0000109983.12113.9B
13. Raley DA, Mobbs RJ (2012) Retrospective computed tomography scan analysis of percutaneously inserted pedicle screws for posterior transpedicular stabilization of the thoracic and lumbar spine. Spine (Phila Pa 1976) 37(12):1092–1100. https://doi.org/10.1097/BRS.0b013e31823c80d8
14. Belmont PJ, Klemme WR, Dhawan A, Polly DW (2001) In vivo accuracy of thoracic pedicle screws. Spine (Phila Pa 1976) 26(21):2340–2346. https://doi.org/10.1097/00007632-200111010-00010
15. Burström G et al (2021) Intraoperative cone beam computed tomography is as reliable as conventional computed tomography for identification of pedicle screw breach in thoracolumbar spine surgery. Eur Radiol 31(4):2349–2356. https://doi.org/10.1007/s00330-020-07315-5
16. Fujimori T et al (2017) Reliability and usefulness of intraoperative 3-dimensional imaging by mobile c-arm with flat-panel detector. Clin Spine Surg: A Spine Publ 30(1):E64–E75. https://doi.org/10.1097/BSD.0b013e3182a357ad
17. Beck M et al (2012) Reliability and consequences of intraoperative 3D imaging to control positions of thoracic pedicle screws. Arch Orthop Trauma Surg 132(10):1371–1377. https://doi.org/10.1007/s00402-012-1555-y