

CT-navigation versus fluoroscopy-guided placement of pedicle screws at the thoracolumbar spine: single center experience of 4,500 screws

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Abstract

Purpose Single center evaluation of the placement accuracy of thoracolumbar pedicle screws implanted either with fluoroscopy or under CT-navigation using 3D-reconstruction and intraoperative computed tomography control of the screw position. There is in fact a huge variation in the reported placement accuracy of pedicle screws, especially concerning the screw placement under conventional fluoroscopy most notably due to the lack of the definition of screw misplacement, combined with a potpourri of postinstrumentation evaluation methods.

Methods The operation data of 1,006 patients operated on in our clinic between 1995 and 2005 is analyzed retrospectively. There were 2,422 screws placed with the help of CT-navigation compared to 2,002 screws placed under fluoroscopy. The postoperative computed tomography images were reviewed by a radiologist and an independent spine surgeon.

Results In the lumbar spine, the placement accuracy was 96.4 % for CT-navigated screws and 93.9 % for pedicle screws placed under fluoroscopy, respectively. This difference in accuracy was statistically significant (Fishers Exact Test, $p = 0.001$). The difference in accuracy became more impressing in the thoracic spine, with a placement accuracy of 95.5 % in the CT-navigation group, compared to 79.0 % accuracy in the fluoroscopy group ($p < 0.001$).

Conclusion This study underlines the relevance of CT-navigation-guided pedicle screw placement, especially

when instrumentation of the middle and upper thoracic spine is carried out.

Keywords Pedicle screws · Navigation · Placement accuracy · Computed tomography · Fluoroscopy

Introduction

Transpedicular screw fixation is widely used in spinal surgery and there are numerous studies concerning optimal and safe placement of pedicle screws [1–3].

Due to the lack of a generally accepted definition of “screw misplacement”, a potpourri of post-instrumentation evaluation methods is reported and placement accuracies vary extremely [4–6]. In this context, we present a single center evaluation of two different instrumentation methods for the thoracolumbar spine after placement of 4,500 pedicle screws either with conventional fluoroscopy or under CT-navigation.

Materials and methods

The present work is a retrospective analysis of 1,006 patients, operated in our clinic between 1995 and 2005, comprising 386 women and 620 men. All patients who underwent pedicle screw instrumentation in this period were included in the study. The surgical indications are specified in Table 1. There were 505 interventions carried out by means of CT-navigation (2,422 screws) in contrast to 501 cases operated under fluoroscopy (2,002 screws). At the end of the 1990s, due to a paradigm shift—that is changing from sole intraoperative fluoroscopy toward CT-navigation—comparable data with both implantation methods were available in the majority of cases.

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Table 1 Surgical indications

Indication	Number of patients operated with fluoroscopy		Number of patients operated with CT-navigation	
Tumors	48	9.6 %	46	9.1 %
Fractures	276	55.1 %	248	49.1 %
Infectious diseases	28	5.6 %	10	2 %
Degenerative disease	149	29.7 %	201	39.8 %
Total	501		505	

Surgery with the help of intraoperative computer tomography and three-dimensional neuronavigation and intraoperative control of pedicle screw positioning

For CT-neuronavigation-guided spinal instrumentation we used the mobile Tomoscan M-EG (Philips Medical Systems, Eindhoven, The Netherlands). This system contains a mobile CT gantry, a mobile CT examination table, which is fixed to the gantry during surgery, and a mobile workstation. All intraoperative imaging was performed with the patient being in prone position on the CT table throughout the whole surgical procedure without the need of repositioning. After skin incision and dorsal muscle preparation, multiple ($n > 5$) small titanium screws were temporarily implanted into the spinous processes and the vertebral laminae to serve as fiducial markers. An intraoperative CT volume image data set was obtained (120 kV, 30 mA, 0° gantry tilt, 2 mm increment, 2 mm slices, pitch = 1) under apnoea to obtain the utmost degree of picture quality. The whole volume data set was axially reconstructed by the CT computer and online transferred onto the neuronavigation system StealthStation® TREON Plus (Medtronic Navigation, Louisville, KY, USA). This was followed by a three-dimensional reconstruction on the neuronavigation workstation within the operating room. A passive open spine clamp with four reflecting signal points was tightly screwed onto one spinous process in the more caudal part of the surgical field. The fixed camera-spine system now enabled the image-to-patient registration of the implanted small titanium fiducials and the ongoing computer-guided three-dimensional neuronavigation during the whole neurosurgical procedure. The insertion of pedicle screws was performed by using this spinal navigation in all three dimensions.

An additional intraoperative CT scan (120 kV, 30 mA, gantry tilt parallel to the pedicle screws, 2 mm increment, 2 mm slices, pitch = 1) at the end of screw placement was obtained to confirm the accurate position of the implanted pedicle screws. The raw data were used to reconstruct transverse 2-mm-thick CT sections every 2 mm with a field of view adequate for visualization of the spine.

Surgery under fluoroscopy:

Insertion of pedicle screws was carried out with the help of biplanar fluoroscopy. Pedicles were cannulated using the “owl’s eye technique” [7] with the a.p.-radiation beam centred on the pedicle coaxial with its sagittal and transverse angle. A lateral beam served for control after having inserted the screw. Fluoroscopy times were not routinely recorded.

Postoperative control of screw positioning

If not done during surgery, all screws were evaluated by postoperative computer tomography with parameters similar to the intraoperative scan (120 kV, 30 mA, gantry tilt parallel to the pedicle screws, 2 mm increment, 2 mm slices, pitch = 1).

Evaluation of screw position

The intra- and perioperative CT-scans were reviewed by a spine surgeon and a radiologist, independently. According to the classification system by Leach et al. [4], screw placements were classified as follows:

Correctly placed screw completely inside the pedicle with no breach or perforation of the pedicle wall.

Minor perforation perforation of the pedicle wall less than 2 mm to either side.

Moderate displacement perforation of 2 mm to less than 4 mm to either side.

Severe displacement perforation of more than 4 mm to either side of the pedicle.

Measurements of the isthmus width of each instrumented pedicle were made on the base of the computed tomography images acquired for the CT-navigation. In the fluoroscopy group, the postoperative images were used to determine the pedicular diameter, in case of pedicle wall breach the diameter was estimated. The minimal diameter was measured in a plane perpendicular to the pedicle axis.

Statistical analysis

The screw perforation rate between the CT-navigation and the fluoroscopy group was compared by using Fisher’s exact probability test with a significance level set at $p = 0.05$.

Results

Computer tomographic controls of every screw were done in 98% of cases, either during the operation or in the early postoperative period. In the remaining cases, early

postoperative scans followed during the routine outpatient follow-up.

The number of all screw positions for both implantation methods is shown in Tables 2 and 3. In the CT-navigation group, a total number of 2,422 screws were placed, 774 in the thoracic and 1,648 in the lumbar spine, respectively. 74 out of the 774 thoracic and 59 out of 1,648 lumbar screws were misplaced (Table 2; Fig. 1). Correspondingly, 9.6 % of the thoracic screws and 3.6 % of the lumbar screws were misplaced when using CT-navigation.

In the fluoroscopy group, 2,002 screws were placed altogether with 608 thoracic and 1,394 lumbar screws, respectively. 232 out of 608 thoracic screws (38.2 %) were misplaced, whereas 85 out of 1,394 lumbar screws (6.1 %) showed a moderate or severe displacement (Table 3; Fig. 1). The difference between both implantation methods was statistically significant in the thoracic ($p < 0.001$) as well as in the lumbar group ($p = 0.001$).

In cases of instrumentation of pedicles with an isthmus of less than 5 mm (predominantly in the thoracic spine) the in-out-in-technique is an approved tool to achieve a sufficient anchoring of the screw with an acceptable lateral breach (≤ 3 mm). Looking at our results, especially the

rather high displacement rate in the upper thoracic levels is most notably due to the rigid definition of misplacement. In the fluoroscopy group, there were 115 lateral breaches of less than 4 mm among all thoracic screws (Table 3). Out of these, there were 103 pedicles with an isthmus width of 5 mm or less, resulting in 103 wrongly categorized screws in the misplacement group. Considering this, the misplacement rate of all thoracic screws placed with fluoroscopy decreases to still 21 %. In contrast, 39 out of the 50 thoracic screws with a lateral breach of less than 4 mm in the CT-navigation group would have been categorized as “correctly placed” leading to a misplacement rate of 4.5 %. The mean pedicle diameters measured at the isthmus perpendicular to the axis are shown in Fig. 2.

Revisions of malpositioned screws were done either based on intraoperative judgement by the surgeon or less frequently because of the compromise of neural structures by the screw. Considering the retrospective character of our study, the reproduction of circumstances and specific reasons for screw revisions was not always easy. Traceable revisions of malpositioned screws have been carried out in 22 fluoroscopy cases (4.4 %) and in 6 navigation cases (1.2 %), respectively.

Table 2 Distribution of screw positions in the CT-navigation group

Level	Total screws	Correctly placed	Minor perforation <2 mm	Displaced			
				2–<4 mm lateral	2–<4 mm medial	≥4 mm lateral	≥4 mm medial
Th1	8	2	4	2	0	0	0
Th2	11	8	3	0	0	0	0
Th3	17	12	3	0	0	2	0
Th4	38	19	10	5	2	1	1
Th5	42	31	1	5	3	1	1
Th6	51	30	13	6	2	0	0
Th7	66	44	12	8	0	1	1
Th8	55	36	6	10	2	0	1
Th9	54	42	10	2	0	0	0
Th10	56	48	4	2	0	2	0
Th11	158	138	14	6	0	0	0
Th12	218	177	33	4	1	3	0
Total thoracic screws	774	587	113	50	10	10	4
		700		74			
L1	207	174	23	6	4	0	0
L2	280	230	41	4	1	2	2
L3	259	238	12	8	1	0	0
L4	363	312	36	10	1	4	0
L5	424	370	41	8	2	3	0
S1	115	106	6	0	3	0	0
Total lumbosacral screws	1,648	1,430	159	36	12	9	2
		1,589		59			
Total screws	2,422	2,289		133			

Table 3 Distribution of screw positions in the fluoroscopy group

Level	Total screws	Correctly placed	Minor perforation <2 mm	Displaced			
				2–<4 mm lateral	2–<4 mm medial	≥4 mm lateral	≥4 mm medial
Th1	4	2	0	1	0	1	0
Th2	6	1	2	1	2	0	0
Th3	11	0	4	4	2	1	0
Th4	14	4	0	5	4	0	1
Th5	60	16	12	18	12	2	0
Th6	46	14	8	12	10	1	1
Th7	84	34	16	14	16	3	1
Th8	71	22	7	22	14	4	2
Th9	85	24	11	23	21	5	1
Th10	72	35	19	12	3	2	1
Th11	75	60	11	2	1	1	0
Th12	80	65	9	1	2	2	1
Total thoracic screws	608	277	99	115	87	22	8
		376		232			
L1	199	170	25	2	1	1	0
L2	208	151	52	1	2	2	0
L3	240	198	33	3	2	2	2
L4	268	204	52	4	6	1	1
L5	287	162	89	12	13	8	3
S1	192	98	75	2	12	3	2
Total lumbosacral screws	1,394	983	326	24	36	17	8
		1,309		85			
Total screws	2,002	1,685		317			

There were nine nerve root lesions with paresis of the dependent muscles due to screw perforation (four cases L5, two cases L4 and S1, respectively, one case L3) in the fluoroscopy group. Furthermore, we saw two cases of incomplete myelopathy due to medial perforation in the thoracic region, which partly resolved after revision.

In the navigation group two nerve root lesions (L5 and L4) appeared.

Discussion

Accuracy of placement: lumbar spine

For the lumbar region the accuracy rate of screw placement in our series is 96.4 % when using CT-navigation and 93.9 % when using fluoroscopy, respectively, with a statistically significant difference ($p = 0.001$) between both implantation methods. These rates seem to be acceptable, when comparing them with accuracy rates reported in literature [8–12]. In a meta-analysis of a total of 7,533 pedicle screws, Tian and Xu [8] reported a mean accuracy rate of 90.21 % out of 6,063 in vivo placed thoracolumbar

pedicle screws, independent of the method of implantation. Other reports communicate misplacement rates of up to 30 % in the lumbar spine when using conventional implantation methods for pedicle screw placement [13, 14].

In a recently published meta-analysis, Kosmopoulos and Schizas [2] report a median placement accuracy for in vivo placed navigated screws of 93.7 % (2,778 thoracolumbar screws) and 86.6 % (10,107 thoracolumbar screws) for unnavigated screws, respectively. Looking specifically onto the lumbar level, the reported median accuracy of navigated screws in this study is 96.1 %; however, on the base of only 864 screws. In comparison, without the use of navigation techniques, the median accuracy decreases to only 79.0 % (1,674 screws).

Considering our data, we can point out that the correct screw placement is safer when using CT-navigation rather than fluoroscopy, with a marginal but statistical significant difference. With both methods, we achieved an acceptable safety concerning the correct screw placement within the pedicle. However, a prolonged operating time and the requirement of technical adjuncts with a corresponding high demand on handling skills have to be kept in mind.

It seems justifiable that either method—CT-navigation and fluoroscopy-guided implantation of pedicle screws—is applied in one institution provided that the handling of both methods is routinely ensured.

Accuracy of placement: thoracic spine

Compared to the lumbar region, the placement of thoracic pedicle screws remains a challenge, despite of modern technology and computer assistance especially in the upper thoracic spine, where misplacement rates of up to 40 %

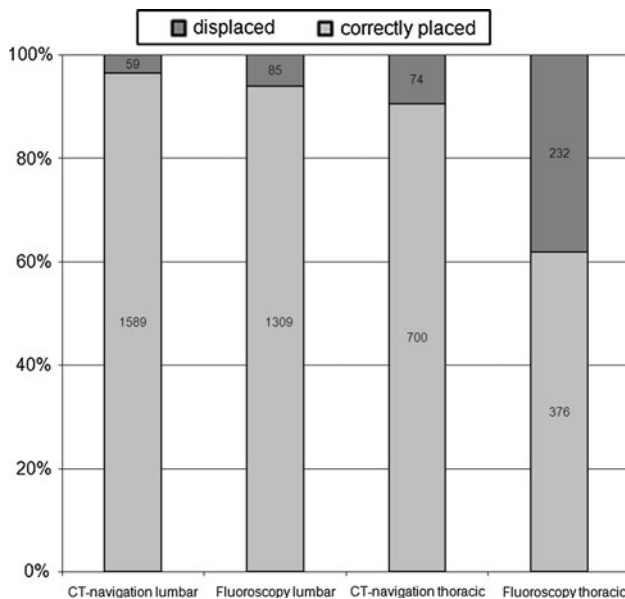
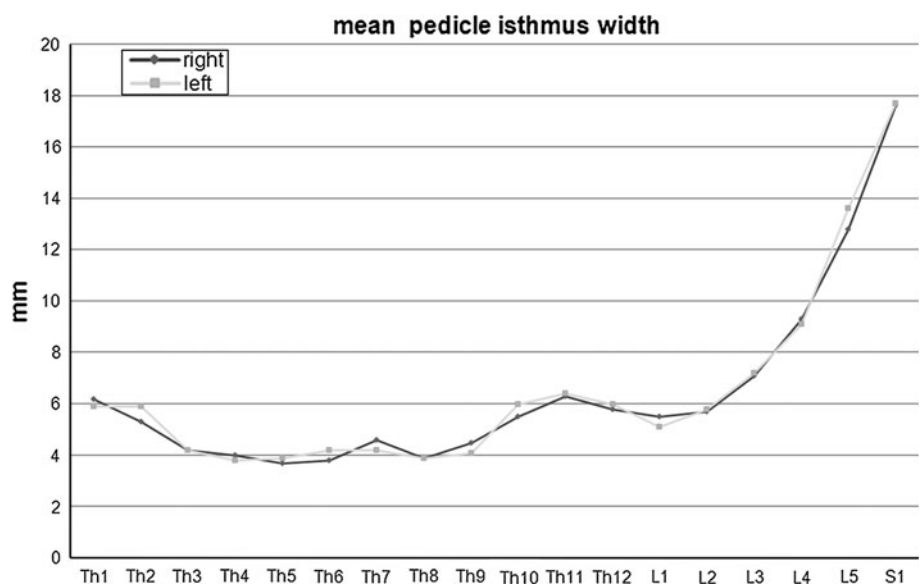


Fig. 1 Distribution of screw positions related to either method of implantation and anatomical region

Fig. 2 The isthmus width of each pedicle was determined perpendicular to the axis at the most narrow site



have been reported [9, 15]. In a study of Rampersaud et al. [9], pedicle breaches occurred in 31.6 % (25 out of 79 screws) of all 2D navigated thoracic screws with 72 % of pedicle breaches being lateral. Using intraoperative multiplanar imaging, Bledsoe et al. [10] found 93.3 % out of 150 thoracic screws to be contained solely in the desired pedicle and all 10 pedicle violations were Grade 1. Other studies report on a comparable number of misplaced screws in the thoracic spine [16–18].

When dealing with conventional, namely fluoroscopic, support for pedicle screw insertion into the thoracic spine, the reported misplacement rates are considerably higher in comparison to screws placed under navigation, especially 3D-navigation techniques like O-arm [19–21]. Only a few publications are available regarding placement accuracy of non-navigated pedicle screws in upper thoracic levels. In a study of Guzey et al. [16], the rate of misplacement was 20.3 % for 113 upper and middle thoracic screws placed under uniplanar or biplanar fluoroscopy. An in vivo study of non-deformed spines reported on 27 and 109 screws placed at T1–T2 and between T3 and T9, respectively, from a total of 209 screws placed between T1 and T12 [22]. With fluoroscopy support, the placement accuracy was 88 % for the T1–T2 screws (15 screws solely contained in the pedicle and 9 lateral perforations less than 4 mm), and 66 % for the T3–T9 screws (15 screws completely intrapedicular, 55 lateral perforations less than 4 mm).

In a randomized controlled trial comparing navigated and non-navigated pedicle screw insertion into thoracic spine, there was a rate of 23 % of pedicle breaches in the non-navigation group compared to only 2 % in the navigation group [23].

Our results impressively underline the significance of navigation support mainly in the middle and upper thoracic area. A misplacement rate of more than 20 % (129 misplaced screws out of 608) seems to be unacceptable compared to only 4.5 % misplacements when using CT-navigation leading to the conclusion that pedicle screw instrumentation in the middle and upper thoracic area should be carried out with the help of navigation only.

The availability of an intraoperative CT seems to be of particular importance. An accurate assessment of screw positions becomes hereby possible without any significant time delay and with utmost accuracy. In terms of the assessment of pedicle screw position the accuracy of computed tomography significantly surpasses any other imaging modality [24, 25]. If necessary, a prompt revision of misplaced screws is possible as well [11]. The revision rates of lumbar as well as thoracic pedicle screws are markedly lower when using CT-navigation compared with fluoroscopy-assisted implantation.

Conclusion

Reviewing the literature, our study is the largest single center series comparing the placement accuracy of thoracolumbar pedicle screws placed either with CT-navigation or fluoroscopy. Although retrospective in nature, this work underlines the significance of CT-navigation, especially when instrumentation of the middle and upper thoracic spine is carried out. As an alternative to other modern 3D navigation techniques, the computed tomography based navigation is an indispensable tool in these cases. In the lumbar and lower thoracic spine, both methods seem comparable.

A post-instrumentation CT scan seems to be of particular importance, allowing the surgeon to evaluate the accuracy of instrumentation before wound closure and to replace it when necessary.

Conflict of interest None.

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