CT-Navigated Percutaneous Posterior Positioning of Pedicle Screws in The Cervical Spine

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Research Article

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Abstract

Background

To evaluate reliability, practicability and precision of a novel intraoperative computed tomography(iCT)-based (Airo mobile CT scanner, Brainlab, Munich, Germany) navigated procedure to minimally-invasive positioning of cervical pedicle screws.

Methods

Ten consecutive patients that suffered from a cervical traumatic instability needing posterior fixation were included in this retrospective analysis. Posterior pedicle screws were positioned iCT-navigated percutaneously. After positioning of the screws, a control scan was performed to assess screw placement and correction if needed. All CT scans were randomly evaluated by two investigators with experience in skeletal CT diagnostics.

In the iCT scans, positioning of the screws regarding affection of the medial pedicle cortex as well as the neuroforamina were measured. Additionally, image quality was evaluated with a subjective Likert-Scale (0-5) and a semi-objective Assessability score (0-4).

Results

44 screws were placed in an average duration of surgery of 139min [83-209]. The average subjective image quality was 3.9 [2-5], the average assessability score was 3.7 [2-4]. 27 screws (61%) were positioned exactly centered in the pedicle. 4 screws perforated the medial wall by more than 2mm [2.8-2.9]. 9 screws were positioned laterally by more than 2mm [2.5-4.9]. No postoperative neurological deficits were observed.

Conclusion

iCT-navigated percutaneous placement of pedicle screws is a rather safe and reliable method for posterior fixation of the cervical spine that allows fixation of traumatic cervical instabilities with minimal additional trauma. Even in shallow anatomic structures, visualization of instruments and implants allows for minimally invasive surgery.

Background

Injuries of the cervical spine are rare with an annual incidence of around 11.8/100.000 [1]. Nonetheless, due to the close relation between bony and neural structures they are potentially harmful with injuries to the spinal cord or nerve roots. Spinal cord injuries show a wide variety between 0.3-19/100.000 in annual incidence depending on the geographic region [2–4].

Unstable injury types should be fixed early to avoid neurological damage. Depending on the pattern and degree of instability, these injuries are fixed either by an anterior approach with discectomy or corpectomy and fusion depending on the extent of structural damage and/or a posterior approach with screw-and-rod systems.

In conventional cervical screw placement, rather short screws in the lateral articular process (lateral mass screws) are positioned via an open approach through a midline incision and dissection of soft tissue. These screws can be placed safely and without the need of special imaging or other dedicated equipment. The disadvantage is the decreased thread strength of the screws due to the short osseous course. Pedicle screws offer biomechanic advantages [5, 6]. There has been a number of papers discussing techniques to safely use this screws [7, 8], as well addressing navigated procedures but all of them were dealing with open approaches.

Percutaneous screw placement in the thoracolumbar spine has established as a suitable procedure for posterior fixation in spinal trauma treatment [9, 10]. These procedures need guidance by for example fluoroscopy to ensure proper positioning of the screws. This implies that it is mandatory to ensure sufficient visualization of the anatomic structures in fluoroscopy. This can be achieved in most cases in thoracolumbar fractures but due to the different anatomic configuration not in the cervical spine.

Thus, percutaneous approaches to the cervical spine are uncommon and the standard procedure is still an open approach. These bring the need for excessive dissection of the soft tissue that might cause complications like persisting pain, impaired function, wound healing issues and infections.

A possible approach to improve visualization without exposure of the complete surgical field is the use of 3D navigation systems. These systems use pre- or intraoperative 3D image sets in combination with infrared-based instrument tracking to visualize the position of instruments and implants in the anatomy. To achieve best results, the use of preferable high-quality intraoperative image data should be aimed as pre-operative image sets are usually acquired in a different patient positioning and thus different anatomy than intra-operatively.

Intra-operative 3D image acquisition was usually performed by special C-arms that rotate around the patient and automatically take a large amount of 2D images. Volume datasets are created by methods as filtered back projection or iterative reconstruction. This is usually referred to as cone-beam CT (CBCT) or digital volume tomography (DVT). Compared to computed tomography (CT), these images have lower contrast resolution and suffer from metal artifacts that are caused by implants. Also, the possible size of the 3D volume is limited in CBCT. Due to these limitations, special designed CT scanners were constructed, optimized for the intra-operative use with large gantry openings and the possibility to be integrated into the operating room (iCT).

In this study, the feasibility of a setting that allows for iCT-navigated percutaneous placement of cervical pedicle screws should be evaluated in regard to reliability of the imaging and navigation as well as to the precision that the planned screw positions could be realized.

Methods

Percutaneous iCT-navigated placement of pedicle screws in the cervical spine was assessed in a series of 10 consecutive patients. The study protocol was assessed and approved by the local ethical committee (reference number 2022-16388).

Inclusion criteria were patients that suffered from fractures of the subaxial cervical spine that needed posterior fixation and had anatomical specifications, that allowed for positioning of pedicle screws in the cervical vertebrae. Depending on the fracture pattern, some patients already had anterior implants in place.

Exclusion criteria were patients that were sufficiently stabilized anteriorly and did not need additional posterior fixation, as well as patients that needed open reduction or decompression or showed a configuration of the cervical vertebrae that did not allow for proper placement of pedicle screws.

Procedure

All fractures were reduced by means of patient positioning. This was either achieved by retro- or anteflexion depending on the fracture type. In cases where 2-stage anterior fixation was performed initially, correct reduction was confirmed by a CT scan between the first and the second procedure. The correct anatomical alignment and reduction were controlled by fluoroscopy before draping.

The patient was positioned through the gantry of the CT scanner to facilitate the scanning procedure (see figure 1).

To be able to use the intraoperative CT data for navigation, the patient reference was fixed on a spinous process of one of the vertebrae, that were operated on (see figure 1a). An intraoperative CT scan (Airo, Brainlab, Munich, Germany) was then acquired and automatically transferred to the navigation platform (Curve navigation platform, Brainlab, Munich, Germany). Registration of the patient is not needed in this workflow as the system is pre-calibrated by the manufacturer.

Following the verification of the automatic registration, screws were planned intra-operatively in the navigation software. Then, according to the plan, percutaneous skin incisions of about 10mm were made in the course of the trajectory of the screw. The holes for the screws were drilled with the aid of a navigated drill guide. To ease percutaneous screw placement, a guide wire was placed into the drill hole, followed by positioning of the cannulated screws (Neon3, Ulrich Medical, Ulm, Germany).

The rod was delivered with the help of a clamp through the incision of the most caudal screw that was extended to about 15mm.

Assessment

After positioning of the screws, another iCT scan was performed to assess screw placement. In the clinical procedure, the assessment was performed immediately by the surgeon.

For this study, analysis of the data sets was performed retrospectively by an independent examiner, who was not involved in the surgical procedure. For this analysis, to allow for standardized conditions, precision of screw placement in the pedicle was assessed and rated as follows: If the screw position was not exactly centered, the highest value of the distance of the medial screw border to the medial pedicle cortex was measured in case of medial displacement. In lateral displacement, the largest distance of the lateral edge of the screw to the lateral border was measured. Although these measures do not necessarily represent a threat to neurovascular structures (especially regarding lateral displacement), they are reproductible and landmarks are clearly identifiable.

Degree of misplacement was graded according to Gertzbein classification. This classification describes the extent to which a screw breaches the medial pedicle wall [11].

Table 1: Gertzbein classification of screw positioning

Finding	**Grade**
No breach	**0**
Medial breach	
Less than 2mm	**1**
2 to 4mm	**2**
4 to 6mm	**3**
More than 6mm	**4**

The indication for immediate intraoperative screw revision was defined as a screw misplacement of Gertzbein Grade 3 or higher.

The main disadvantage of this classification is, that it only addresses medial breaches, while breaches to lateral or superior/inferior boundaries are not covered. Therefore, Heary classification was also applied. This classification covers breaches to the lateral pedicle wall as well as anterior or inferior breaches [12].

Table 2: Heary classification of screw breach

Finding	Grade
No breach	**1**
Lateral breach with screw tip inside the vertebral body	**2**
Anterior or lateral breach of screw tip	**3**
Medial or inferior breach	**4**
Breach that requires immediate revision	**5**

To assess image quality, subjective impression was graded with a Likert scale (see figure 2). This grading should express the general impression of the imaging quality, artifact severity, impairment by the artifacts, spatial and contrast resolution. Likert scale rating was assigned for the complete scan while all other scores were assigned separately for each screw.

Objective quality was measured by a score that assesses the visibility of the medial pedicle border and the posterior vertebral wall (Assessability score, see table 3). The aim of the assessability score is to provide a semi-objective measurement to describe the capability of imaging modalities to visualize the most relevant structures in the imaging [13, 14]

Table 3: Assessability score for grading objective image quality

Finding	Points
Medial Pedicle wall	
visible in all slices	**2**
visible in more than 2/3 of all slices	**1**
visible in less than 2/3 of all slices	**0**
Posterior vertebral wall	
visible in all slices	**2**
visible in more than 2/3 of all slices	**1**
visible in less than 2/3 of all slices	**0**

Results

Patients’ baseline characteristics are given in table 4

Table 4: Baseline characteristics

Age	59.7
Gender	
Male	70%
Female	30%
Level of injury	
C3/4	20%
C4/5	0%
C5/6	20%
C6/7	60%
Preoperative neurological Status	
N0	40%
N1	0%
N2	20%
N3	30%
N4	10%

In all cases, image acquisition and assessment were flawless. Figure 3 shows an example of the imaging quality. There were no hard- or software impairments to the procedure. In total, 20 intraoperative CT scans were acquired (two in each patient). The intraoperative control scans from each patient were assessed according to the above-mentioned criteria.

44 screws were placed between C3 and Th3 in 22 vertebrae. In 7 cases (70%), an anterior fixation with titanium cages and additional locking plate was already in place. The average duration of surgery was 139min [83-209].

Gertzbein Classification of the screw positioning

Most screws (85%) were rated Gertzbein Grade 0, meaning they did not perforate the medial pedicle wall. Only 3 screws (7%) were rated Grade 2 with a breach more than 2mm. Also, as there was no screw rated Gertzbein 3 or 4, no intraoperative revision was needed. Details are shown in table 5.

Table 5: Gertzbein Classification of the screw positioning

Grade	Count
0	37
1	4
2	3
3	0
4	0

Heary Classification of the screw positioning

Most screws (61%) were rated Heary Grade 1 meaning there were placed exactly centered in the pedicle. Nine screws were rated Grade 2, meaning lateral displacement with the screw tip inside the vertebral body. The screws rated Grade 4 match the screws with Gertzbein Grade 1 or 2 as well as one additional inferior displacement. Details are shown in table 6.

Table 6: Heary Classification of the screw positioning

Grade	Count
1	27
2	9
3	0
4	8
5	0

Likert Scale of the image quality

Most scans (90%) were rated acceptable or better. The reason for the impairments in the remaining scan were heavy artifacts due to anterior implants in place. The average subjective image quality was 3.9 [2-5]. Details are shown in table 7.

Table 7: Likert Scale of the image quality

Grade	Count
1	0
2	1
3	2
4	4
5	3

Assessability score of the intraoperative CT scan

Most scans (81%) were assigned the best rating in the assessability score, the average score was 3.7 [2-4].

Table 8: Assessability score of the intraoperative CT scan

Points	Count
0	0
1	0
2	2
3	2
4	18

Discussion

To improve surgical management of patients with traumatic cervical spine injuries, a novel technique of percutaneous pedicle screw placement in the subaxial spine was evaluated in this study.

Standard of care of cervical spine injuries needing posterior stabilization is fixation by screw-and-rod systems based on lateral mass screws [6, 15]. Due to the biomechanical characteristics of these screws that show a rather short intraosseous course, fixation is usually performed at least two levels above to two levels below the injured segment. As the cervical spine shows a high degree of flexibility, this may cause a serious impairment of function. Using shorter constructs might decrease motion restriction. Cervical pedicle screws have been shown to offer biomechanic advantages [16–18].

Due to the special anatomy of the cervical vertebrae, fluoroscopy-based placement of pedicle screws is hardly achievable and was considered too risky for neurovascular structures [19]. Figure 4 illustrates the proximity of the screw course to the vertebral artery. Additionally, cervical pedicle screw placement was described using an open approach with exposure of the anatomical structures of the surgical field so far. Reliable control of placement of cervical pedicle screws using open approaches has been reported [20]. As mentioned above, open approaches imply possible disadvantages regarding soft tissue damage and infection [21]. In fixation of thoracolumbar fractures, percutaneous procedures have established to reduce the surgical impact [9, 10, 22].

The technique used in this study was based on the experience that was acquired using fluoroscopy-based as well as 3D-navigated percutaneous screw placement in the thoracolumbar spine. As soft tissue coverage in the neck is comparably thicker than in the lower sections of the spine, possible deterioration of instruments and guide wires is a challenge to placement precision. As the data of this study show a certain degree of not exactly centered screws (although without clinical relevance) despite initial screw planning was centered, impairment of instruments and guide wires due to soft tissue tension needs to be considered. Improvements of positioning tools might help to reduce this issue in the future. Overall, screw placement precision was comparable to previously reported results [19, 23].

3D navigation significantly facilitates placement and helps to ensure proper screw course [20, 24, 25]. The value of this technique highly depends on the quality of the imaging, so the aim is to use as high-quality imaging as possible. Generally, it is possible to use pre- or intraoperative 3D data in navigated procedures. Usually, the precision is better when using intraoperative data as positioning of the patient is completed and there are no alterations in positioning between image acquisition and the procedure. So long, intraoperative 3D imaging, acquired by 3D C-arms was the standard to use as from navigation. As seen in other studies, the image quality of 3D C-arms suffers from artifacts when there are implants in place what can cause so heavily reduced image quality, that navigation is not impossible with these images [13, 14]. Regarding the lower cervical spine, C-arm based 3D imaging has limitations due to the presence of thoracic and shoulder structures, limiting visibility of the spine. CT imaging generally offers higher image quality with less artifact generation, especially with implants in place [14, 26]. Thus, the use of intraoperative CT data additionally increases visualization and safety of screw positioning [25]. Although some impairment in image quality was observed, especially when anterior fixation was in place, assessment of relevant anatomy and implant course was possible in all cases, showing a high reliability of the imaging modality.

In this study, some malpositioning could be observed. None of the patients had any neurological deficits due to implant irritation. Most of the divergent screw courses were to the lateral side. Besides the above-mentioned anatomical reasons, this might be due to the fact, that the initial wire itself is not navigated, only the guide is. Depending on bone density, the course of the wire might differ from the planning. By improving implantation procedures this could be avoided in the future.

Conclusion

Injuries to the cervical spine are a challenging entity due to the demanding anatomy and stabilization techniques. To reduce soft tissue damage and motion impairment to the patient, percutaneous pedicle screw placement, assisted by intraoperative CT-based navigation, is a reliable and safe procedure. Further improvements to implant positioning procedures may even increase positioning precision.

Abbreviations

CT Computed tomography

iCT Intraoperative computed tomography

CBCT Cone beam computed tomography

DVT Digital volume tomography

Declarations

Ethics approval and consent to participate: the study protocol was assessed and approved by the local ethics committee (Regional Medical Board of Rhineland-Palatinae, reference number 2022-16388)

Consent for publication: Not applicable

Availability of data and materials: Data available on request from the authors

Competing interests: the authors declare, that they do not have competing interests

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Authors' contributions: HK designed the study and wrote the manuscript, MK and PAG assisted with data analysis and writing the manuscript, SV did the procedures, wrote parts of the manuscript and provided supervision

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Figures

Figure 1

Intraoperative view with guide wires and reference base (a), view of the visualization of the instruments during navigation (b)

Figure 2

Likert scale for grading subjective image quality

Figure 3

Intraoperative CT slice demonstrating the image quality with clear discrimination of implant, bone and spinal canal

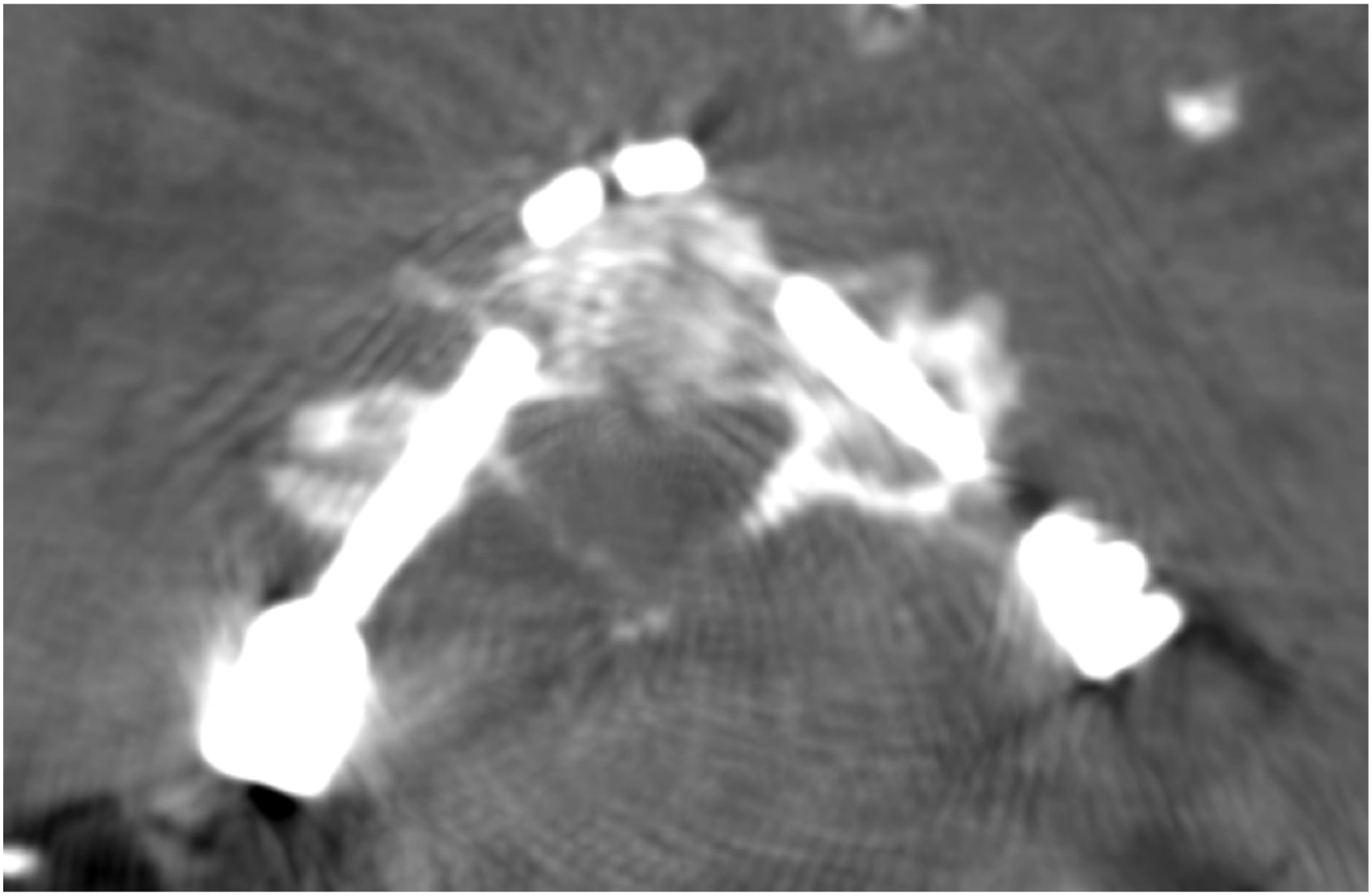

Figure 4

Intraoperative CT slice showing the proximity of screw course to vertebral artery