A Novel Landmark Based on Nutrient Foramen for Pedicle Screw Insertion in the Battlefield Emergency

Lantao Lu

Shanghai Changzheng Hospital

Jian Zhu

Shanghai Changzheng Hospital

Kaiqiang Sun

Shanghai Changzheng Hospital

Jingchuan Sun

Shanghai Changzheng Hospital

Jiangang Shi (✉ shijiangangspine@163.com)

Department of Orthopedic Surgery, Changzheng Hospital, Naval Medical University, No.415 Fengyang Road, Shanghai 200003, People's Republic of China <https://orcid.org/0000-0003-2133-0108>

Research

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Abstract

Background: Spinal injuries is with high frequency in the modern wars and some patients with severe spinal injures have to accept the emergency spinal surgery. Nutrient foramen is easy to identify intraoperatively. The purpose of this study was to investigate the feasibility and reliability of using the nutrient foramen to guide the pedicle screw placement.

Methods: Nine dried human vertebral bone were involved in this study. The anatomical association to the pedicles and bony landmarks were measured in the vertebrae for C6-T6. We also determined the frequency with which the nutrient foramina were present in 86 cadaveric vertebrae. We identified the pedicle location, base of the superior articular process, base of inferior articular process, base of transverse process, and the posterior median line with respect to the nutrient foramen

Results: The overall presence of the nutrient foramina was 63% in the specimens. The nutrient foramina located cranially and laterally on the lamina, and the nutrient foramen was located near to the pedicle.

Conclusion: The location of nutrient foramen can be used for identifying the entry point for pedicle screws in the cervicothoracic junction. The nutrient foramen is easy to identify during operation and with a high frequency of occurrence. Therefore, the nutrient foramen could be used as a reliable landmark to guide the entry point localization in emergency spinal surgeries in the battlefield.

Introduction

In the Iraq and Afghanistan wars, spinal injuries accounted for nearly 11.1% of all combat-related injuries [1–3]. The frequency of combat-related spinal injuries has shown an increasing trend [1, 3–5]. This change is probably attributed to the wide application of high energy weapons, especially the improvised explosive devices (IEDs) [4, 6–9]. Based on previous reports about the Iraq and Afghanistan wars, nearly 75%-80% of spinal injuries were caused by IEDs [4]. Moreover, the injuries caused by IEDs were the most severe form of trauma [9].

Among the spinal injuries caused by IEDs, thoracic and cervical spine are the segments most vulnerable to trauma, accounting for 28% and 15%, respectively [4, 10, 11]. And the prognosis of injuries in these two regions is significantly poor, with high mortality and disability rate [12–16]. Nearly 10% of spinal fractures were associated with spinal cord injuries (SCIs) [12–16]. In the SCIs recovery aspect, many factors would influence the neurological rehabilitation [12–16]. An earlier decompression surgery would predict a better neurological recovery outcome, especially in the first 72 h after the injury. [12–16]. However, in the complex environment of the battlefield, patients with severe spinal injuries could not be transported to base hospital timely in some cases [17]. Some severe patients even had to undergo emergency spinal decompression surgeries in the aid station [7, 8, 18]. Even in the normal hospital, with the involvement of auxiliary surgical techniques, the pedicle screw insertion is still challenging for spine surgeons, let alone in such a crude environment. Moreover, with the absence of auxiliary surgical techniques, the freehand technique would be the only choice, which further increases the difficulty of the surgical process. [19–22].

Moreover, few experienced spine surgeons are on the battlefield [23, 24]. Considering the purpose of emergency decompression surgery is just creating opportunities for sequential treatments, the pedicle screw placement procedure should be simplified; therefore, a surgeon could master the skill with just simple training.

In the pedicle screw placement process, the localization of the entry point is the most challenging step in the whole process [19–22]. Therefore, there is no doubt that if a suitable landmark is present, the difficulties would be significantly lowered. After reviewing previous articles, nutrient foramina on the lamina has been noticed [25]. This study aims to discover the relationship between the nutrient foramina and surrounding structures in the cervicothoracic junction, including C6 to T6, and then evaluate the feasibility and safety of pedicle screws insertion using this landmark.

Materials And Method

Nine cadavers (five male and four female) were used in this study. All the specimens involved in this study were dried bone specimens. The age (mean $\pm$ SD) of the cadavers at the time of death was 70.2 ± 0.2 years. The cadavers were provided by the Department of Anatomy (Naval Medical University, China). In total, 144 pedicles and nutrient foramina between the C6 and T6 were measured,

The method of measurement was referred to Oshina et al. [25]. In brief, We manually examined each cadaver for the presence of nutrient foramina around the superior articular facet and transverse processes. The presence of a nutrient foramen was confirmed by identifying a circular depression with a lack of cortical continuity (Fig. 1).

If a nutrient foramen was present, the distance from the nutrient foramen to the base of the superior articular process (SAP), the base of the inferior articular process (IAP), the posterior median line (PML), and the base of the transverse process (TP) was measured (Fig. 1, Fig. 2).

The nutrient foramina were found to be usually caudal to the superior articular facet and medial to the base of the transverse process, and cranial to the inferior margin of the transverse process. If two nutrient foramina were present in this area, the larger one was evaluated. Nutrient foramina in other areas were excluded. (Fig. 2)

All measurements were made using an electronic digital caliper (precision 0.1 mm; Deli, Shanghai, China). We manually measured the distance between the nutrient foramina and various structures. The following parameters were assessed.

1. Percentage of occurrence of nutrient foramina. The total occurrence frequency of nutrient foramina on both sides, the occurrence frequency of nutrient foramina on the right side, and the occurrence frequency of nutrient foramina on the left side.
2. The mean distance from the base of SAP
3. The mean distance from the base of IAP

4. The mean distance from the base of TP
5. The mean distance from the base of PML

After assessing the previous parameters, the distance between the nutrient foramen and the bony landmark was compared between the left and right sides using Student's t-test. Differences with *P* values of < 0.05 were considered statistically significant. The statistical analysis was performed using SPSS (IBM SPSS 26.0 SPSS, Inc)

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Results

Nutrient foramina were present with the evaluation area in 65.28% (47/72) of the left side and 54.17% (39/72) of the right side. Overall, nutrient foramina were present in 59.72% (86/144) of the vertebrae in the cervicothoracic junction (Fig. 3 and Tables 1 and 2.). There were no significant differences bilaterally in the distance between the nutrient foramen and surrounding landmarks.

Table 1
Number of exposed nutrient foramina and mean distance from foramina to the bony landmark on the left side

	Exposure (/9)	Frequency (%)	SAP (mm)	IAP (mm)	PML (mm)	TP (mm)
C6	6	66.67	9.56 ± 2.50	7.88 ± 5.86	17.44 ± 5.87	8.54 ± 5.60
C7	6	66.67	8.68 ± 1.19	10.15 ± 6.26	20.00 ± 9.50	7.43 ± 4.73
T1	9	100.00	6.85 ± 2.89	13.22 ± 3.54	18.74 ± 5.67	6.44 ± 3.36
T2	7	77.78	6.74 ± 0.64	10.46 ± 1.50	14.92 ± 2.08	4.50 ± 0.97
T3	5	55.56	6.25 ± 0.20	15.55 ± 6.85	21.15 ± 5.25	5.10 ± 2.50
T4	5	55.56	9.33 ± 7.00	17.15 ± 0.55	19.30 ± 7.80	6.00 ± 2.70
T5	6	66.67	8.70 ± 2.75	13.00 ± 5.24	16.90 ± 4.60	5.87 ± 3.38
T6	3	33.33	8.50 ± 2.00	11.00 ± 2.60	11.35 ± 0.75	5.65 ± 1.85

Table 2

Number of exposed nutrient foramina and mean distance from foramina to the bony landmark on the right side

	Exposure (/9)	Frequency (%)	SAP (mm)	IAP (mm)	PML (mm)	TP (mm)
C6	2	22.22	6.35 ± 1.15	7.85 ± 0.05	16.20 ± 1.20	8.35 ± 1.45
C7	2	22.22	10.05 ± 2.75	7.85 ± 2.65	17.90 ± 1.30	6.10 ± 0.90
T1	8	88.89	6.36 ± 0.82	10.49 ± 1.64	16.91 ± 1.15	5.16 ± 0.87
T2	6	66.67	6.28 ± 1.24	10.63 ± 0.82	14.03 ± 1.74	5.03 ± 1.03
T3	5	55.56	5.88 ± 1.34	11.38 ± 2.15	11.82 ± 0.97	3.84 ± 1.29
T4	4	44.44	7.35 ± 1.88	9.90 ± 0.96	11.40 ± 3.21	5.25 ± 2.47
T5	6	66.67	7.53 ± 2.24	10.43 ± 2.72	12.25 ± 1.67	4.97 ± 2.23
T6	6	66.67	8.57 ± 1.68	10.85 ± 2.22	12.45 ± 1.73	4.77 ± 0.92

Association between the base of SAP and the nutrient foramen

When making calculations, we excluded the nutrient foramina located on SAP, IAP, and TP. The distance from the base of SAP to the nutrient foramen had a range of 3.3–12.8 mm. The distance from the base of the superior articular process to the nutrient was similar in the cervicothoracic segment.

Association between the base of IAP and the nutrient foramen

The distance from the base of IAP to the nutrient foramen was 2.6–17.7 mm. The distance from the base of IAP was 2.6–17.7 mm in the cervicothoracic segment. The distance tended to be similar in the cervicothoracic segment. In comparison with SAP, the nutrient foramen was further from IAP, which means the nutrient foramina were closer to SAP.

Association between the PML and the nutrient foramen

Similar to the previous parameters, the distance from PML to the nutrient foramen tended to be with no significant difference in the cervicothoracic segment. The value ranged from 7.2 to 20.6.

Association between the base of TP and the nutrient foramen

The distance from the lateral laminar border and base of the transverse process to the nutrient foramen was 2.3–10.5 mm in the cervicothoracic segment. The distance tended to be similar in the segment from C6 to T6. In the cervicothoracic junction, the internal border of the cervical transverse foramen and the

junction of the lateral laminar border and the transverse process was regarded as the base of the TP. Compared with the distance from PML to the nutrient foramen, the distance from the base of TP is smaller, which implied that the nutrient foramen were closer to the TP than the PML

Discussion

The war-related spinal injuries in the modern war

Based on the previous report, spinal injuries accounted for approximately 11.1% in the Iraq and Afghanistan wars [1]. Among the spinal injury victims, fractures were the most common injury; nearly 92% of these patients [26]. According to the American military data, the frequency of spinal injuries has shown an increasing trend in comparison with the data of previous wars, while the incidence was estimated only 1.2% in the Korea War, 1% in the Vietnam War and Gulf War, and 6% in the Panama War [1, 3–5].

One of the factors contributing to the increasing trend is the broad application of high energy weapons [4, 6–8]. The improvised explosive devices (IEDs) have been the most significant threat by terrorists worldwide and has been the leading cause of injury and death in Afghanistan and Iraq [24]. According to the US Department of Defense's definition, the IED is a "device placed or fabricated in an improvised manner incorporating destructive, lethal, noxious pyrotechnic, or incendiary chemicals, designed to destroy, disfigure, or harass ..." [27]. The term "IED" encompasses a broad spectrum of explosives or unused artillery rounds to sophisticated weapon systems and triggering devices containing high-grade explosives [27, 28]. Explosions produce intricate and astonishing injury patterns, with multisystem involvement contains pulmonary injury, traumatic injury, burns, crush syndromes, and blunt or penetrating injuries to the viscera, axial skeleton, and extremities [27, 28]. Blast injuries from IEDs are the most form of severe trauma [9].

The predilection sites of the war-related spinal injuries

According to previous statistics, nearly 75%-80% of spinal injuries were caused by IEDs in Iraq War [4]. Among them, the thoracic spine was most vulnerable to trauma, nearly 28% [1, 4, 10, 11]. The most involved thoracic segments were T4, T5, and T6 [29]. The high fracture incidence mechanism in these levels is probably that this section is the midpoint of the thoracic curve, where the spine is furthest from the center of gravity of the torso, and the line of action of an axial load through the pelvis [29]. The patterns at this level suggested a mix of flexion and compression or compressive failure of the anterior spinal column with distraction failure of the posterior spine [29]. Ragel et al. recognized that IEDs' explosive pattern was similar to the mechanism of flexion-distraction thoracolumbar fractures (Chance fractures) [11]. Bernstock et al also reported that extremes of the mobile spine segments were also at particular risk for fracture in IED blast injuries [26]. Perhaps it was the reason why the cervicothoracic junction was one of the most commonly involved bursts caused by IEDs [26, 30].

The complications, prognosis, and treatments of the war-related spinal injuries

The spinal injuries were commonly associated with spinal cord injuries (SCIs), which is associated with a high risk of mortality and disability [3, 5, 9]. Approximately 10% of spinal fractures are associated with spinal cord injury [5, 9]. The thoracic SCIs were also the most common with a frequency range from 23.6–64.8%, followed by the frequency of cervical SCI ranged from 1.9–52.4% [26]. According to previous research, decompression surgery's timing would influence neurological recovery [12–16]. An earlier decompression surgery would acquire a better neurological recovery rate in comparison with the one delayed [16]. As Ruddell et al reported in their studies, decompression surgery in 72 h could achieve maximum benefits with the lowest odds of in-hospital cardiac and respiratory complications. A 7-day delay would lead to the greatest odds of hemorrhage and respiratory complications [16]. However, in the cases that the patients with severe spinal injuries and the timely transportation cannot realize, the emergency decompression surgery has to be practiced in the aid station [24, 32 [31]. Based on the recommendation of American Department of Defense, in the case of progressive neurological deficits, open cerebrospinal fluid leaks, expected delay in transport (> 5 days), or concern for neurological deterioration with transfer should be practiced with surgical stabilization of major spine trauma before the patients transported to the base hospital. So, these patients have to accept the emergency surgeries in the aid station, thus creating opportunities for follow-up treatment.

The entry points of pedicle screw insertion technique

A suitable landmark is necessary to localize the entry point rapidly, thus shortening the operation time. In the study of the entry point for pedicle screw insertion, according to the previous articles, many authors have proposed a series of landmarks aiming at simplifying the location of the entry point in the process of pedicle screw placement. However, most of them should be located based on the surrounding bony landmarks. Abumi et al firstly reported the localization method for cervical pedicle screw insertion by using the SAP as the landmark to localize the entry point [32]. After that, several studies have been conducted to modify the localization method. For example, Avila et al [33] have proposed using the junction of TP and SAP as the landmark to locate the entry point. Based on their study, the entry point was caudally and medially 3 mm to the landmark [33]. One of the disadvantages of the previous localization methods is that surgeons' subjective influence would influence the localization procedure. Moreover, most of the previous localization method also requires laminectomy [34]. Even a small laminectomy would increase the complexity of the operation procedure, blood loss, and operation time [35]. Moreover, a universal landmark would be more suitable.

Nutrient foramen as the landmark to locate the entry point

After reviewing the previous articles, we noticed a novel location strategy that the entry point can be localized using the nutrient foramen as the landmark [25, 36] (Fig. 4). The nutrient foramina were originated from the dorsal branches of the segmental arteries supplied the vertebral bodies in their proximal portions [25]. Using the nutrient foramen as the landmark had the following advantages. Firstly,

the exposure of the nutrient foramen was easy to practice without the laminectomy of the surrounding structures. The nutrient foramina were found to be usually located just caudal to the SAP and medial to the base of the TP on the border of the laminae and cranial to the inferior margin of the TP [25]. Secondly, the nutrient foramina were easy to identify during operation. After the paraspinal muscles have been distracted to both sides, the blood would flow out from the lamina. To the best of our knowledge, the attempt to apply the nutrient foramen to the pedicle screw is in 2018. Tawfik first reported the use of nutrient foramina in C2 pedicle screw insertion[36]. In the same year, Oshina et al reported the supplantation of nutrient foramina to C3-T12 pedicle screw insertion [37].

Oshina et al have investigated four parameters in seven cadavers, including occurrence percentage of the nutrient foramina, distance from the bottom of the SAP, distance from the lateral border of the lamina, and the relationship between the pedicle and the nutrient foramen [25]. Similar to our study, they have reported that the nutrient foramina were present 63% from C3 to T12 [25]. However, the distances between the bony structures and the nutrient foramen in our study is larger than the value of their study. The difference could be attributed to population difference. Although the value of distance is different from the previous study, the association with the bony landmarks was consistent. The location of the nutrient foramen is closer to the base of SAP and the base of TP.

Compared with Oshina et al's study, we have measured another two parameters, including the distance to the PML and the distance to the base of the IAP. To the best of our knowledge, four parameters could achieve more precise localization of the nutrient foramen.

Limitations

There are several limitations in our study. For example, the number of cadavers included was still small, making it difficult to compare the location of the nutrient foramen at each level through statistical analysis. Enlarging the sample size would increase the accuracy of the assessments. In the choice of the specimens, dried bone specimens were involved in our study. The dried bone specimens have the advantages in exposing the nutrient foramina in comparison with the formalin-fixed specimens. However, such kind of specimens cannot display the relationship between the surrounding soft tissues and the bony landmarks, especially the vessels and the nerve roots. To the best of our knowledge, this study is the pilot study for identifying nutrient foramina in the cervicothoracic segment in Chinese population, we believe that our data demonstrating the association between the nutrient foramina and pedicles is adequate. Another limitation is that there is no cadaveric pedicle insertion experiment in our study, the feasibility and safety are both evaluated based on the measured data and the CT images. Therefore, the further study should involve the cadaveric study to determine the safety of insertion using this landmark.

Conclusion

Our study indicates that the nutrient foramen is identifiable in the majority of the cervicothoracic segments with the relatively consistent location and high occurrence frequency. The nutrient foramen

could be seemed as a reliable landmark to guide the pedicle screw insertion. Therefore, the nutrient foramina are enough to satisfy the specific treatment of rapid pedicle screw insertion in the battlefield. We believe that the nutrient foramen would be widely used in the future emergent spinal surgeries.

Abbreviations

SAP

superior articular process; IAP:inferior articular process; PML:posterior median line; TP:transverse process; CT:computed tomography

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Yes

Availability of data and materials

Yes

Competing interests

The authors disclose that they have no competing interest

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Authors' contribution

SJG is Chief Investigator and guarantor. LLT and ZJ were responsible for the conception of the study. LLT led protocol development, supported by all authors. ZJ and SKQ were the two reviewers at each stage. SKQ and LLT lead on data analyses. All authors have contributed to data interpretation, conclusions, and dissemination. LLT drafted the initial manuscript. Subsequent drafts were developed with SJC and SJG. All authors have read, contributed to, and agreed upon the final manuscript.

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Figures

Figure 1

Schematic figure of the parameter measured in the subaxial cervical vertebrae. This figure illustrates the four surrounding landmarks: the base of SAP, the internal border of TF (the base of TP), the base of IAP, and PML. The arrow points the nutrient foramen on the lamina.

Figure 2

Schematic figure of the parameter measured in the thoracic vertebrae. This figure illustrates the four surrounding landmarks: the base of SAP, the internal border of TF (the base of TP), the base of IAP, and PML. The arrow points the nutrient foramen on the lamina.

Figure 3

The nutrient foramina in the cervicothoracic junction. The nutrient foramina are circled in the red circles.

Figure 4

Schematic figures of the nutrient foramen as the landmark to localize the entry point. A illustrates the lateral view of the localization process and B illustrates the posterior view of the localization process.