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Oblique radiograph with methylene blue marking: A reliable technique for upper thoracic level localization

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A R T I C L E I N F O

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Upper thoracic spine
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A B S T R A C T

Purpose: Traditionally, plain radiographs are used in intraoperative spinal level localization (SLL), whereas counting vertebrae is often hampered by shoulders and scapulae in lateral views, thus increasing the potential for wrong-level surgery. To improve the localization accuracy, this study evaluated the safety and feasibility of oblique radiographs with methylene blue markings for SLL and explored the optimal angle and height of oblique radiographs.
Methods: The clinical data of 33 patients with upper thoracic spine lesions who were operated on in our hospital from January 2021 to April 2022 were retrospectively analyzed. Oblique radiographs with methylene blue markings were used for intraoperative SLL.
Results: A total of 33 patients were included in this study. The average BMI was 24.3 ± 0.7 kg/m^2. The ipsilateral lamina structures were clearly shown in all cases. The median radiographing times of all the patients was 3, and the median radiographing duration was 2 min and 25 s. The average angle of oblique radiographs was $55.1 \pm 3.8^\circ$, and the average distance from the skin to the root of the spinous process was 4.9 ± 1.2 cm.
Conclusions: Using oblique radiographs with methylene blue markings, not only the bone structure of an upper thoracic spine can be revealed clearly, but also the positioning deviation of traditional needle localization can be avoided. The lesion segment can be precisely located by this technology during surgery. Our angle of oblique radiographs and height determination method can be used to reduce the radiation exposure and shorten the operation time.

1. Introduction

Accurate preoperative or intraoperative spinal level localization (SLL) is critical for all spine surgery [1]. Finding no lesions after laminectomy is terrifying for spinal space-occupying lesions, especially for an intramedullary lesion, which usually needs a spinal cord incision to determine whether the segment is correct. Most wrong level localization can be found intraoperatively; however, findings after surgery always lead to medical disputes [2,3].

Stereotactic navigation for spinal surgery is limited compared to that for cranial surgery. The idea technique for SLL has easy availability and the lowest possible radiation exposure [4]. Various techniques exist, but there is little consensus on which one is the

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most effective [5]. Due to soft tissue displacement and skin folds, a significant deviation between the preoperative planned and actual positions often occurs, resulting in low accuracy of preoperative SLL.

Although external landmarks can be used to estimate general positions, radiographs are frequently used for intraoperative SLL by needle insertion and continuous counting to confirm spinal levels [5]. However, due to the overlap of the upper thoracic spine with the shoulders and scapulae, the spinous processes and laminae cannot be clearly shown in the lateral view, especially for patients with wide shoulders, short necks, and obesity [6,7]. Therefore, the lateral radiograph is not suitable for upper thoracic SLL. Oblique radiographs can be used to reduce the density of the shoulders and scapulae in the active field of view, thereby producing a cleaner image to count spinal levels in upper thoracic SLL [8].

In this study, we evaluated the safety and efficacy of oblique radiographs with methylene blue markings for SLL and explored the optimal angle and height of oblique radiographs.

2. Methods

The clinical data of 33 patients with upper thoracic spine lesions who were operated on in our hospital from January 2021 to April 2022 were retrospectively analyzed. Preoperative magnetic resonance imaging (MRI) was performed on all patients to assess the exact locations of the lesions. Oblique radiographs with methylene blue markings were used for intraoperative SLL, which counted spinal levels from C1 to the lesion segment. The demographics, the body mass index (BMI), the quality of oblique radiographs, and the angle and height of oblique radiographs were reviewed and analyzed. All patients signed the surgical consent form before surgery. Written informed consent was obtained from the patients for the publication of their cases and images.

The main risks of our technique are the possible muscle necrosis and nerve damage caused by methylene blue injection. To avoid the relevant complications, we measured the distance from the skin surface to the spinal canal before surgery and took great care not to inject methylene blue into the spinal canal, thus ensuring the safety of our technique. We also added the parameter MBI = methylene blue infiltrated into the spinal canal to Table 2. Due to the postoperative changes in the local muscles, the presence of muscle necrosis is difficult to assess with postoperative MRI. Considering the very small dose of injection (0.05–0.1 mL), the complication of muscle necrosis was not evaluated.

We evaluated the feasibility of our technique from three aspects. 1) Whether the bone structures of the spine (lamina, spinous process, and pedicle) are shown in oblique radiographs to facilitate counting (parameters “Lamia”, “SP”, and “Pedicle” in Table 2). 2) The times and duration of intraoperative oblique radiographing for the assessment of radiation exposure levels and the consumption of

Table 1
Clinical Features, imaging findings, and surgical methods in the present study.

No.	Age	Sex	Weight (kg)	Height(m)	BMI (kg/m2)	Diagnosis	Verebral Level	Surgical Methods
1	52	M	78	1.76	25.2	Schwannoma	T3-4	Hemilaminectomy
2	28	M	75	1.72	25.4	Cavernous angioma	T2-3	Laminoplasty
3	37	M	74	1.73	24.7	Ependymoma	T1-3	Laminectomy
4	79	F	70	1.52	30.3	Meningioma	T3	Laminectomy
5	58	F	55	1.55	22.9	Angioma	T4-5	Laminectomy
6	66	F	57.5	1.56	23.6	Ependymoma	T3-4	Laminectomy
7	63	M	70	1.71	23.9	Schwannoma	T5-6	Hemilaminectomy
8	57	F	66	1.53	28.2	Meningioma	T3	Hemilaminectomy
9	58	F	67	1.62	25.5	Schwannoma	T1-2	Hemilaminectomy
10	58	F	49	1.65	18.0	Meningioma	T4-5	Hemilaminectomy
11	62	F	65	1.58	26.0	Cavernous angioma	T2-3	Laminoplasty
12	57	M	70	1.62	26.7	Schwannoma	T1-2	Hemilaminectomy
13	66	F	49	1.56	20.1	Meningioma	T4-5	Hemilaminectomy
14	33	M	67	1.72	22.6	Schwannoma	C7-T1	Hemilaminectomy
15	60	M	92	1.7	31.8	Glioma	T1-2	Laminectomy
16	30	F	61	1.55	25.4	Schwannoma	T5	Hemilaminectomy
17	46	M	85	1.72	28.7	Schwannoma	T5-6	Hemilaminectomy
18	81	F	53	1.57	21.5	Meningioma	T3-4	Laminectomy
19	36	M	69	1.68	24.4	Schwannoma	T4-5	Transmuscular
20	54	F	50	1.62	19.1	Cavernous angioma	T3-4	Laminoplasty
21	28	F	37	1.5	16.4	Meningioma	T4-5	Laminectomy
22	47	M	78	1.75	25.5	Schwannoma	C7-T1	Hemilaminectomy
23	6	M	22	1.21	15.0	Glioma	T3-5	Laminectomy
24	59	F	75	1.5	33.3	Meningioma	T5	Laminectomy
25	32	M	64	1.7	22.1	Cavernous angioma	T4/T6	Laminoplasty
26	61	M	81	1.73	27.1	Arteriovenous fistula	T5-6	Laminoplasty
27	33	M	66	1.63	24.8	Glioma	T4-5	Laminoplasty
28	40	M	65	1.68	23.0	Schwannoma	T1-2	Hemilaminectomy
29	68	F	57	1.56	23.4	Meningioma	T2	Laminectomy
30	74	F	61	1.57	24.7	Schwannoma	T1-2	Hemilaminectomy
31	63	F	65	1.62	24.8	Meningioma	T3	Hemilaminectomy
32	40	M	75	1.7	26.0	Ependymoma	T2-6	Laminectomy
33	39	F	57	1.6	22.3	Solitary fibrous tumor	T2-3	Laminoplasty

Table 2
Criteria of oblique radiography and surgical findings included in the present study.

No.	Oblique Radiograph Exposure			DSS (cm)	LA (°)	RT (times)	RD (h:m:s)	MBI	Accuracy*
	Lamina	SP	Pedicle						
1	yes	no	no	6.5	52.5	3	0:03:28	no	yes
2	yes	no	yes	6.8	56.2	3	0:03:49	no	yes
3	yes	yes	yes	4.9	53.2	2	0:03:22	no	yes
4	yes	no	no	4.8	55.7	4	0:02:01	no	yes
5	yes	yes	yes	4.3	56.5	4	0:01:45	no	yes
6	yes	yes	yes	3.4	58.5	3	0:04:03	no	yes
7	yes	no	no	3.9	57.8	3	0:10:50	no	yes
8	yes	no	no	5.8	52.3	3	0:03:38	no	yes
9	yes	yes	no	6.3	54.8	2	0:01:05	no	yes
10	yes	no	yes	3.5	57.2	4	0:03:10	no	yes
11	yes	no	yes	5.2	53.9	3	0:02:46	no	yes
12	yes	yes	yes	5.3	49.3	2	0:00:52	no	yes
13	yes	no	no	3.4	57.2	3	0:00:51	no	yes
14	yes	yes	yes	5.9	51.2	3	0:00:49	no	yes
15	yes	yes	no	6.5	57.6	2	0:12:01	no	yes
16	yes	no	yes	4.5	61.3	4	0:02:07	no	yes
17	yes	no	yes	6.2	59.6	5	0:09:25	no	yes
18	yes	no	no	4.8	54.8	3	0:01:51	no	yes
19	yes	no	no	5.5	57.3	4	0:01:16	no	yes
20	yes	no	no	5.1	61.1	3	0:01:37	no	yes
21	yes	no	no	2.9	59.3	4	0:03:15	no	yes
22	yes	yes	yes	7.3	51.3	2	0:00:58	no	yes
23	yes	no	yes	2.3	52.8	4	0:01:34	no	yes
24	yes	no	no	4.3	59.1	4	0:03:41	no	yes
25	yes	no	no	3.5	59.1	3	0:02:29	no	yes
26	yes	yes	no	4.5	58.2	4	0:05:25	no	yes
27	yes	no	no	6.1	52.8	3	0:03:15	no	yes
28	yes	yes	yes	4.5	50.0	2	0:02:14	no	yes
29	yes	yes	yes	4.8	48.2	2	0:01:35	no	yes
30	yes	yes	yes	4.9	47.7	2	0:02:25	no	yes
31	yes	no	yes	5.6	56.7	4	0:01:45	no	yes
32	yes	no	no	5.3	49.0	4	0:03:09	no	yes
33	yes	no	yes	4.3	57.8	3	0:02:03	no	yes

Abbreviation: SP=Spinous Process; **DSS** = Distance from the Skin Surface to the Root of the Spinous Process; **LA** = Lamina Angle; **RT** = Radiographing Times; **RD** = Radiographing Duration; **MBI** = Methylene Blue Infiltrated into Spinal Canal.
* Whether the preoperative localization of the lesion segment is consistent with the actual lesion segment after exposure

operative time (parameters "RT" and "RD" in Table 2). 3) Whether the preoperative localization of the lesion segment is consistent with the actual lesion segment after exposure (parameter "Accuracy" in Table 2).

2.1. *Workflow of the technology*

After a patient was placed in the prone position, the spinal level was estimated by palpation, and syringe needles were inserted periodically from the cervical spine to the caudal side (Fig. 1A). A 5-mL syringe needle combined with a 1-mL syringe was used to facilitate the injection of methylene blue in the target segment (Fig. 2A, C). We found that a 0.05 mL of methylene blue injection was relatively suitable for showing the position of the needle tip without diffusing the dye too much. The operation was performed immediately after the methylene blue injection with a short time for the dye to infiltrate into the surrounding tissue (Fig. 2B). Moreover, we measured the depth from the skin to the spinal canal before surgery to avoid methylene blue being injected into the spinal canal. Then we took oblique radiographs and counted the spinal levels from C1 downwards in oblique views (Fig. 1B–E).

As shown in Fig. 3, intraoperative localization requires adjustment of the patient's height (HP) so that the patient's spine is centered in the fluoroscopic field of the *C*-arm. To prevent prolonging operative time and avoid increasing radiation exposure due to intraoperative adjustment of HP, we preoperatively measured the distance from the skin surface to the root of the spinous process (parameter "DSS" in Table 2 and Fig. 3). DSS plus the height of the center point of the *C*-arm (HCP) is the actual height (HP) that needs to be adjusted after the patient is positioned, thus ensuring that the target spine segment is in the center of the fluoroscopic field. The distance from the skin surface to the spinous process (DSS) was measured from the preoperative MRI or CT axial radiograph (specific measurements are shown in Fig. 3).

Since oblique radiographs often require localization based on the lamina (the spinous process and pedicle are not fully shown), the fluoroscopic rays need to be directed along the lamina to effectively show it. By measuring the lamina angle (parameter "LA" in Table 2 and Fig. 3) from preoperative MRI or CT axial radiographs to help determine the intraoperative fluoroscopic angle of oblique radiography, we reduced the times of fluoroscopies and saved operative time. LA is obtained by measuring the angle between the median axis of the lamina and the spinous process in preoperative MRI or CT axial radiographs. The lamina angles from T1 to the lowest

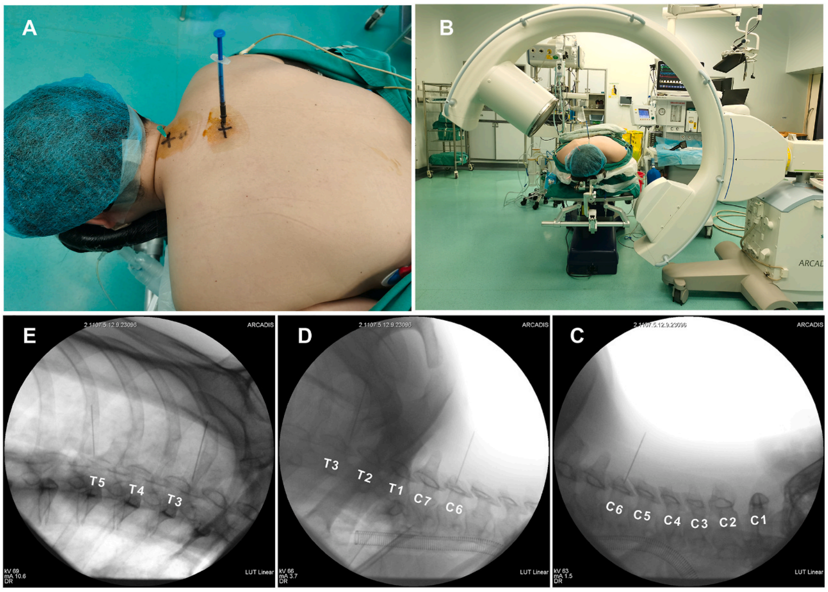

Fig. 1. The workflow of using methylene blue to mark oblique radiographs. Place the syringe needle periodically **(A)**. Perform oblique radiograph **(B)**. Count the spinal levels from C1 downwards in oblique views (another patient) **(*C*–E)**. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article).

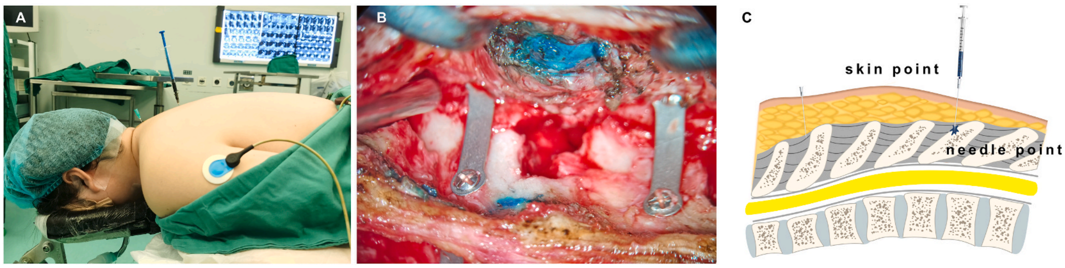

Fig. 2. Injection of methylene blue in the target segment. A 5-mL syringe needle combined with a 1-mL syringe is used to facilitate the injection of methylene blue in the target segment **(A)**. The needle tip is closer to the lamina than the skin puncture point **(B)**. A 0.05 mL of methylene blue injection is more suitable for showing the position of the needle tip without diffusing the dye too much **(C)**. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article).

thoracic segment of the lesion were measured, and then, the average value was taken as the ideal angle for oblique radiographs (specific measurements are shown in Fig. 3).

2.2. *Statistical analysis*

Data are expressed as mean ± standard deviation, or median (25th-75th percentile). The normality of variables was assessed. All statistical analyses were performed with IBM SPSS Statistics 25.

3. Results

A total of 33 patients were included in this study. The most common tumors were schwannoma (11 cases), meningioma (9 cases), and cavernous angioma (4 cases). The patients included 16 males and 17 females, aged from 6 to 81 years, with an average age of 50.6 years. The average BMI was 24.3 ± 0.7 kg/m^2, and 42.4% of the individuals had a BMI of ≥25. Furthermore, 14 patients underwent hemilaminectomy, 11 underwent laminectomy, 7 underwent laminoplasty, and 1 underwent transmuscular approach (Table 1). The ipsilateral lamina structures were clearly shown in all cases, and the spinous processes and ipsilateral pedicles were only clearly shown in some cases (36.4%, 51.5%). The median radiographing times of all the patients was 3, and the median radiographing duration was 2 min and 25 s. The average angle of oblique radiographs was 55.1 ± 3.8°, and the average distance from the skin to the root of the spinous process was 4.9 ± 1.2 cm (Tables 2 and 3).

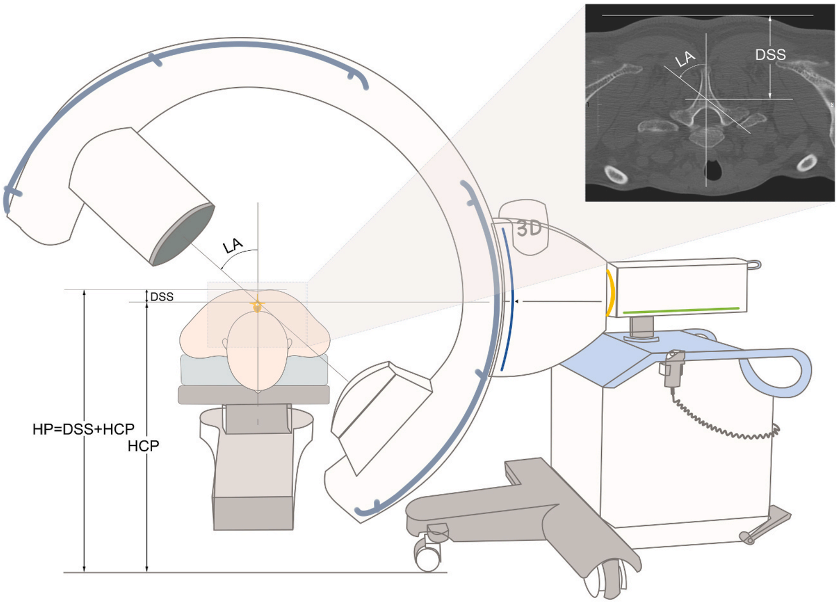

Fig. 3. The optimal angle and height of oblique radiographs. "LA" represents the average lamina angle. "HP" represents the height of the patient. "HCP" represents the height of the center point of the *C*-arm fluoroscopy. "DSS" represents the height from the skin to the root of the spinous process.

4. Discussion

Accurate localization of the correct level of the thoracic spine remains a challenge despite the advances in spinal surgery techniques [3,5]. Many reports have been published on using various instruments and techniques to prevent wrong-level spine surgery [9]. Rosahl et al. [10] placed radiographic skin markers to localize thoracic spine lesions with preoperative MRI but limited to severe spinal deformities, obesity, skin folds, and thoracic hypermobility of the chest. Paolini et al. [11] described a simple and reliable localizing method in which the vertebra was marked preoperatively with methylene blue in an anteroposterior radiograph view. However, due to preoperative marking, the dye always spreads to the adjacent spinous process.

Some scholars have adopted more invasive preoperative positioning techniques. Hsu et al. [12] localized thoracic spine levels by preoperatively placing intravertebral polymethylmethacrylate percutaneously. However, complications, such as radiculopathy, lung fat embolism, infection, and intracanal extrusion with spinal cord compression, were confirmed by complete spinal axis CT after the procedure. Preoperatively placing radio-opaque fiducials, such as screws, gold, and coils percutaneously under CT guidance has also been proven to be an accurate and safe preoperative SLL method [13–18]. These localization strategies do save intraoperative time, but we believe that the time saved is of little clinical significance. In addition, CT-guided puncturing requires more radiation exposure, which is associated with more medical resources and high medical costs.

Needle localization, in which a needle is inserted, and continuous counting is performed to confirm spinal levels by plain radiographs, is a traditional method in thoracic spine surgery. In lateral views, counting always starts from C1 down in the upper thoracic spine. However, counting is often hampered by the shadowing of the shoulders and scapulae that obscure the anatomical features of the vertebrae, especially in patients with obesity, osteoporosis, and short necks (Fig. 4A and B). In addition, the spinous processes and laminae of the thoracic vertebrae are not at the same level, also affecting the precise localization of spine levels [19].

To obtain unobstructed visualization for lateral radiographs, Witiw et al. [20] used a device to displace the shoulders caudally. The increase in visualization level by this method is limited. In addition, damage may be caused to the brachial plexus with this method. Singh et al. [8] employed the modified oblique fluoroscopic technique for intraoperative localization of cervicothoracic levels. The image provided in oblique view is clearer than that provided in lateral view, which allows accurate operative localization. However, in this technique, the *C*-arm needs to be rotated under fluoroscopy to obtain an optimal angle, meaning more radiation exposure. In our study, by measuring the lamina angle preoperatively, the radiation exposure was reduced, and the positioning time was shortened.

Oblique radiographs have high requirements for the position selection of the *C*-arm, and it is not easy to find the appropriate height and angle. Inexperienced physicians need multiple attempts, which increases the radiation exposure and prolongs the positioning time. When the trajectory of a beam is parallel to the plane of the ipsilateral lamina, the rays passing through the lamina can be made overlapped for easy visualization and counting of the lamina. The average lamina angle of patients was 55° in our study.

In addition to angle, height is an important parameter of the oblique view. To ensure the lamina is in the center of the field of view, it needs to be placed at the center of the *C*-arm. In this study, the distance from the skin to the root of the spinous process was measured

Table 3
The quality and radiographic parameters of our spinal level localization technique (n = 33).

BMI (kg/m2)	Oblique Radiograph Exposure			DSS (cm)	LA (°)	RT (times)	RD (h:m:s)	MBI (%)	Accuracy* (%)
	Lamina (%)	SP (%)	Pedicle (%)						
24.3 ± 3.9	33 (100%)	12 (36.4%)	17 (51.5%)	4.9 ± 1.2	55.1 ± 3.8	3 (2.5–4)	0:02:25 (0:01:36–0:03:28)	0 (0%)	33 (100%)

Abbreviation: SP=Spinous Process; **DSS** = Distance from the Skin Surface to the Root of the Spinous Process; **LA** = Lamina Angle; **RT** = Radiographing Times; **RD** = Radiographing Duration; **MBI** = Methylene Blue Infiltrated into Spinal Canal.
* Whether the preoperative localization of the lesion segment is consistent with the actual lesion segment after exposure.

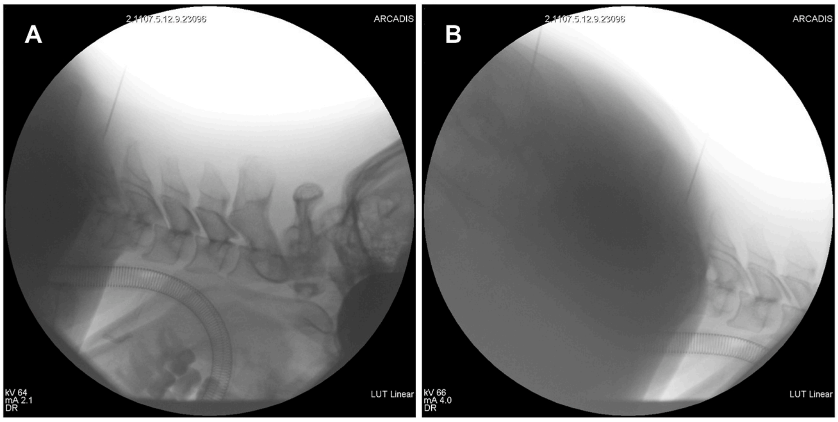

Fig. 4. The visualization of lateral view in intraoperative needle localization. Counting from C1 down in the upper thoracic spine in lateral views is often hampered by the shadowing of the shoulders and scapulae that obscure the anatomical features of the vertebrae.

preoperatively to quantify the height of the intraoperative oblique radiograph.

Because the needle tip is closer to the lamina than the skin puncture point, visualizing the needle tip may contribute to reducing positioning errors (Fig. 2C). Chin et al. [21] docked the spinal needle on the transverse process to identify the thoracic levels even after the spine was exposed. We visualized the needle tip by injecting methylene blue to improve the positioning accuracy.

Considering that obesity could affect the implementation of the proposed technique, we statistically analyzed the BMI of all patients. The average BMI of the patients in the studied group was 24.3 ± 0.7 kg/m2, and 42.4% of them had a BMI ≥25. Therefore, the proposed technique is applicable to patients with different BMIs, i.e., applicable to obese patients. In the meantime, the proposed technique could achieve accurate localization for different surgical procedures, including Laminectomy, Hemilaminectomy, and Laminoplasty. Spine segment localization is mainly based on the bone structures such as the vertebral body, lamina, spinous process, and pedicle. We statistically analyzed the visualization of the lamina, spinous process, and pedicle in oblique radiographs and found that only the lamina could be visualized 100% of the time. Therefore, we believe that the lamina is more suitable for spine segment localization in oblique radiographs. The median fluoroscopy times of all the patients was 3, and the median fluoroscopy duration was 2 min and 25 s, indicating that the proposed technique has a low fluoroscopy frequency and a low cost of operation time. Since no methylene blue infiltration into the spinal canal was detected intraoperatively, methylene blue injection was safe if controlling the depth of injection.

4.1. Limitation

Our study also has some limitations. Firstly, the patient should have lamina structures for easy identification and localization. Poor imaging may still occur in patients with severe osteoporosis. Secondly, our research sample size was small. Thirdly, Different body habitus may affect the angle of the oblique radiograph. The new technique is limited only for upper thoracic SLL.

5. Conclusions

Using the oblique radiographs with methylene blue markings, not only the bone structure of the upper thoracic spine can be clearly revealed, but also the positioning deviation of traditional needle localization can be avoided. The lesion segment can be precisely located by this technology during surgery. Our angle of oblique radiographs and height determination method can be used to reduce the radiation exposure and shorten the operation time.

Author contribution statement

He Huang: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.
Min Wei: Performed the experiments; Analyzed and interpreted the data.
Jianfeng Fan: Contributed reagents, materials, analysis tools or data.
Renjun Peng: Analyzed and interpreted the data.
Xiping Ding: Performed the experiments.
Jian Xi: Conceived and designed the experiments; Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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