Intraoperative ultrasound assistance in treatment of intradural spinal tumours

Zhou, H; Miller, D; Schulte, D M; Benes, L; Bozinov, O; Sure, U; Bertalanffy, H
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Abstract

OBJECTIVE: Currently, the standard practice to treat intradural spinal tumours involves microsurgical resection of the lesions. It is essential to be able to locate the lesion precisely to reduce the risk of neurological morbidity. The purpose of this study was to evaluate intraoperative ultrasonography (IOUS) in visualizing intradural spinal tumours, and assess its potential to improve surgical precision and minimize surgical trauma.

METHODS: Between January 2006 and July 2007, 30 patients with suspected intradural spinal tumours underwent surgery with the aid of IOUS. There were 13 patients with intramedullary tumours (ependymoma=2, astrocytoma=5, hemangioblastoma=2 and metastasis=4); and 14 patients with extramedullary tumours (meningioma=6, neurinoma=6, filum terminale ependymoma=1 and lipoma=1). In 3 patients histopathology did not reveal any neoplasm despite an MRI suggesting tumour. Their sonographic features are analyzed and the advantages of IOUS are discussed.

RESULTS: The shape and expansion of intradural tumours could be visualized on IOUS. The sonographic visualization allowed adapting the approach to an appropriate location and size before dura opening. Certain sonographic features can be used for a differential diagnosis of different intradural tumours. In addition, IOUS can inform neurosurgeons about the location of the neoplastic tissue, its relation to the spinal cord and the size of residual tumour following excision.

CONCLUSIONS: IOUS is a sensitive intraoperative tool. When appropriately applied to assist surgical procedures, it offers additional intraoperative information that helps to improve surgical precision and therefore might reduce the procedure related morbidity.
Intraoperative ultrasound assistance in treatment of intradural spinal tumours

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ABSTRACT

Objective. Currently, the standard practice to treat intradural spinal tumours involves microsurgical resection of the lesions. It is essential to be able to locate the lesion precisely to reduce the risk of neurological morbidity. The purpose of this study was to evaluate intraoperative ultrasonography (IOUS) in visualizing intradural spinal tumours, and assess its potential to improve surgical precision and minimize surgical trauma.

Methods. Between January 2006 and July 2008, 30 patients with suspected intradural spinal tumours underwent surgery with the aid of IOUS. There were 13 patients with intramedullary tumours (ependymoma = 2, astrocytoma = 5, hemangioblastoma = 2 and metastasis = 4); and 14 patients with extramedullary tumours (meningioma = 6, neurinoma = 6, filum terminale ependymoma = 1 and lipoma =1). In 3 patients histopathology did not reveal any neoplasm despite an MRI suggesting tumour. Their sonographic features are analyzed and the advantages of IOUS are discussed.

Results. The shape and expansion of intradural tumours could be visualized on IOUS. The sonographic visualization allowed adapting the approach to an appropriate location and size before dura opening. Certain sonographic features can be used for a differential diagnosis of different intradural tumours. In addition, IOUS can inform neurosurgeons about the location of the neoplastic tissue, its relation to the spinal cord and the size of residual tumour following excision.

Conclusions. IOUS is a sensitive intraoperative tool. When appropriately applied to assist surgical procedures, it offers additional intraoperative information that helps to improve surgical precision and therefore might reduce the procedure related morbidity.
Key words: intraoperative ultrasonography; intradural spinal tumours; extramedullary tumour; intramedullary tumour
I. INTRODUCTION

Intradural spinal tumour is an important disorder that must be included in the differential diagnosis of patients with back pain, radicular pain, sensorimotor deficits, or sphincter dysfunction. These lesions are broadly divided into two categories based on their origin: extramedullary and intramedullary.

Currently, the standard practice to treat intradural spinal tumour involves surgical removal of lesions using microsurgical techniques after a careful evaluation. However, there is still a considerable risk of neurological morbidity. About 5% to 40% of patients who undergo surgical resection of an intradural tumour develop new neurological deficits. Outcome is determined by many factors including preoperative neurological condition, location and size of the tumour and success of surgical manipulation. The precise resection of the tumour is essential.

Using a low frequency sector scanner, Reid first applied intraoperative ultrasound to visualize and diagnose an intramedullary spinal cord tumour in 1978. However, poor image quality and difficulties in handling have limited its use. The introduction of phased-array probes, optimal focusing at a range of depths and the development of smaller probes that allow a less invasive approach reinvigorated the use of ultrasonography in neurosurgery. Despite these multiple reports, IOUS is still not used ubiquitously and routinely as a diagnostic tool in many countries. The interpretation of ultrasound images – especially in an intraoperative setting – depends very much on the
experience of the user. A correlation with MRI and a careful intraoperative analysis as well as a retrospective comparative description of ultrasound scans can help in the interpretation of ultrasound images.

Here, we report on our experience with intraoperative ultrasound (IOUS) as an integral aid for locating and determining the resection of intradural spinal tumours. We analyze the advantages of this technique and correlate images to preoperative MRI.

II. MATERIALS AND METHODS

PATIENTS

Between January 2006 and July 2008, 30 patients with suspected intradural spinal tumours underwent surgery with the aid of transdural IOUS. There were 18 males and 12 females, with a mean age of 52.9 years (16.6 SD) ranging from 27 to 87 years. The histopathological findings revealed intramedullary ependymoma (n=2), astrocytoma (n=5), hemangioblastoma (n=2), metastasis (n=4) and extramedullary meningioma (n=6), neurinoma (n=6), filum terminale ependymoma (n=1), lipoma (n=1). The remaining 3 patients underwent surgical biopsy on the basis of a positive MRI finding, without the diagnosis of a neoplasm. In these cases, histological test of tissue samples revealed chronic inflammatory lesions. The histological type of tumour and its location are presented in Table 1. Preoperative evaluation consisted of physical examination and radiological imaging, including MRI scans with dynamic contrast-enhanced imaging. All patients were determined to have imaging consistent with intradural lesions.
**SURGICAL PROCEDURE**

Assisted by knowledge of the regional anatomy and C-arm orientation, microsurgical procedures employed in this report were on par with current standards. A posterior approach using laminectomy or hemilaminectomy was used for all tumours. Bony structures were preserved as much as possible to prevent destabilization. In the 30 patients reported here, total laminectomy was performed in 17 patients, and unilateral hemilaminectomy in 13 patients. Somatosensory evoked potentials (SSEPs) were used to monitor the functional integrity of the spinal cord during spinal surgery in all patients.

**ULTRASOUND ASSISTANCE**

Transdural ultrasound (Toshiba, Apio, Typ SSA-770A, Japan) imaging was performed using multi-frequency probes. After exposure of the dura and before dural opening, ultrasound imaging was carried out to determine the location and size of dura incision. Provided that the paraspinal musculature and soft tissue were sufficiently mobilized, a single-level hemilaminectomy was, in general, sufficient to facilitate the insertion of a small (10×32 mm) linear probe (PLT-1202S, 7-14MHz frequency) in the sterile NaCl-solution filled entrance (Fig. 1). This probe can be routinely sterilized, and it does not need to be draped in a sterile protective plastic sheath with sterile gel, which could avoid leakage and infection. In more expanded surgical approaches, a sector probe (PST-65AT, 4.5-9MHz) was applied.

Throughout the procedure, ultrasonography was performed repeatedly to obtain detailed
images of tumours with increased precision. The sonographic findings were matched with the preoperative images. When the echographic examination failed to show salient features as expected from the MRI/CT images, the incision was expanded appropriately. As for the intramedullary tumours, repeated ultrasonic scanning was conducted following opening of the dura, and during tumour resection, to assess the extent of excision.

III. RESULTS

APPROACH

IOUS altered the surgical approach and laminotomy was extended in 5/30 patients to reach the tip of the lesion, in order to adapt the approach appropriately according to lesion size before dura opening.

INTRADURAL TUMOURS

With regard to removal of extramedullary lesions, IOUS helped us to precisely guide the complete excision in 11 patients, and significantly debulking in 3 patients, respectively. Intramedullary tumours were microscopically excised in 8 patients, and significantly debulked in 5 patients. Biopsies were performed on the remaining 3 patients.

In all 30 patients, a sonographic classification into intra- and extramedullary tumours was feasible (Table 2). Extramedullary tumours frequently displayed a homogenous signal intensity with well defined tumour margins without perifocal edema. Their origins from the dura, the nerve roots or the filum terminale were sonographically identified. (Fig. 2,
Fig. 3). Intramedullary tumours characteristically presented themselves with a heterogeneous morphology, sometimes carrying intrasional or perilesional cysts. The tumour margins were usually poorly defined with a perifocal edema or syringomyelia (Fig. 4).

**EXTRAMEDULLARY TUMOURS**

There were some identifiable differences on IOUS between meningioma and neurinoma on the surface, echogenicity, internal structure, and movement of the respective lesions. Obvious cysts, small or large, were observed in many neurinomas concurrent with low echoes. In addition, neurinomas had a relatively rounded and smooth surface, and exhibited ‘floating’ movements synchronized with cardiac pulsations because of minimal adherence to the dura mater. Of the 6 neurinomas, 3/6 tumours had cysts, 4/6 showed low echoes, and 2/6 isoechogenicity. 5/6 of the neurinomas were rounded and smooth, only one had an irregular surface, and 3 showed movements (Fig. 2). In contrast in meningiomas, cysts were not seen and echogenicity was high. Meningiomas displayed a more irregular surface, and adhered tightly to the dura mater. Of the 6 meningiomas, 5/6 had an irregular surface. None had a cyst or demonstrated pulsatile movements. Most were adherent to the ventral or dorsal dura mater. They were much more echogenic than neurinomas but were not uniform, showing hyper- and hypo-echogenic spots (Fig. 3)

Filum terminale ependymomas are classified as a distinct entity. They displayed different sonographic characteristics, as opposed to cervical and thoracic ependymomas and were characterized by a homogeneous signal intensity which was distinctly higher than that of
the myelin. Also, there was a clear demarcation of the tumour from the surrounding nerve tracts.

**INTRAMEDULLARY TUMOURS**

In cases of intramedullary tumours, cavities filled with aqueous fluid as in cystic low-grade astrocytomas were shown as regions of low echo intensity on IOUS. Other pathological features were usually manifested on ultrasonography by their hyperechogenic characteristics, and perifocal edema had an increased reflexion compared to normal spinal tissue. IOUS frequently showed syrinx formations in the cases of ependymomas. It was difficult to differentiate between intramedullary ependymoma and astrocytoma sonographically. The border between intact cord and tumour was rarely sonographically evident (Fig. 4), but the image allowed better preliminary evaluation of these tumours.

Haemangioblastomas turned out to be a specific sonographic entity among intramedullary tumours, as they most often contained only a homogeneous and less echogenic cystic part with a small tumour nodule, sometimes associated with cephalad and caudad syrinxes, a pattern not seen in ependymoma. There were many anechoic areas in B-Mode, corresponding to vascular processes within the tumour, which could be well defined by perfusion characteristics in color-mode.

In addition, metastatic tumours were seen as well-defined rounder solitary tumours within the spinal cord.
In some rare cases, clinical and radiological manifestations may suggest a presence of a spinal cord tumour, and a biopsy is routinely performed for establishing a definite diagnosis. Even in these rare cases, IOUS could give the precise location of the lesion inside the spinal cord.

IV. DISCUSSION

GENERAL CONSIDERATION

About 30% of spinal cord tumours are intradural tumours. The majority of intradural tumours are extramedullary, with the most common subtypes of nerve sheath tumour (neurinoma and neurofibroma) and meningioma. Intramedullary tumours account for 2% of all central nervous system tumours, and the most frequent diagnoses are ependymoma, astrocytoma and hemangioblastoma. Slin'ko EI, et al. reported 360 cases of intradural extramedullary tumours, of which 33 were ventral, and 107 were ventrolateral located. Without sufficient visualization which is often not easily obtained, the surgical removal of ventral or ventrolateral extramedullary tumours and most of the intramedullary tumours is difficult.

The surgical trauma secondary to the approach is likely to cause long-term disabilities. In addition, the untoward damages during exploration to locate intramedullary tumours and of the surgical trauma of the spinal cord may result in new neurological deficits. The
major challenge of these surgical procedures on intradural spinal tumours was how to establish clear anatomical landmarks to guide the resection.\textsuperscript{16}

Over the last few years, intraoperative imaging aids such as MRI and CT have been considered for neurological surgery.\textsuperscript{17-20} In spite of higher resolution, these costly technologies require cumbersome procedures, are rigid and difficult to adopt for continuous real-time imaging during surgery. In comparison, IOUS is of low cost and flexible, different ultrasound probes can be applied relatively easily to adapt to various sizes and shapes to address various applications in surgery.\textsuperscript{8-10,21}

**BENEFIT OF IOUS**

IOUS helps with surgical planning. Its capability of continuous and real-time visualization of intradural spinal tumours provides a valuable precision-guided tool to define the exact location and size, the degree of displacement of the spinal cord, and differential diagnosis of intradural spinal tumours during the procedure. Equipped with the continuously refining knowledge about the tumour, surgeons can rationally plan and adapt an image-guided optimal removal of lesions. For example, differential diagnosis of neurinoma versus meningioma might lead to a different approach of the procedure. A neurinoma is soft, and its removal is easier. While meningiomas are hard, and should be removed piecemeal so as to not cause spinal cord trauma, preservation of the arachnoid mater and complete resection of the adherent part are also essential to prevent recurrence.\textsuperscript{22}
GUIDANCE OF DURA OPENING

IOUS could help to pinpoint the appropriate location beneath the dura and optimize the localization and dimension of the incision of the dura. IOUS made it possible to identify the entire expansion of the tumour, so that the preparation of soft tissue and osseous structures can be carried out before dura opening. And if necessary, the laminectomy or laminotomy may be extended according to the refined tumour size obtained through repeated assessments at various vantage points. Following this lead, cerebrospinal fluid is released appropriately early during surgery in order to decrease the intraspinal pressure and reduce the chance of subsequent bone work in cases of edematous spinal cord protruding through the dural opening. Accordingly, a haemorrhage into the opened intradural cavity with a subsequent meningeal irritation secondary to an enlargement of the approach can be avoided.15,23

GUIDANCE OF MYELOTOMY

IOUS is capable of precisely locating tumours inside the spinal cord and invisible on the surface of the spinal cord, and provide immediate visual reference on the surface of the spinal cord for effective removal of tumours. The success of radical surgical resection of parenchymal tumours inside the spinal cord is largely determined by the surgeon’s ability to precisely locate tumours not visible on the surface, and to differentiate residual tumour from normal myelin. IOUS imaging in this situation will pinpoint the precise location of tumours and suggests efficient path to reach the tumour. Also it provides clear and objective differentiation between the lesion and healthy tissues based on distinct ultrasonographic features. Without a real-time imaging aid of IOUS, surgeons have to
relly on MRI images of parenchymal tumours with some external markers that may be lost during surgery, rising unnecessary exploration that may cause damage to the spinal cord. Prior to myelotomy, it is of crucial importance to evaluate and determine whether the tumour can be totally resected or can only be debulked with different entailed procedures. If the tumour lacks demarcation and is isoechogenic with the spinal cord, it can represent a highly infiltrative lesion that may not be totally resected. In the later case, even IOUS may only offer limited help, as the margin between healthy and tumour infiltrated spinal tissue may be unclear.

**VASCULAR IMAGING**

The visualization of vasculature is essential to preserve function of healthy tissues and might prevent damage. Moreover visualization of abnormal vasculature around lesions will suggest optimal approach to effectively resect hypervascular tumours and minimize bleeding (Fig. 4).9,12

**INTRAOPERATIVE IMAGING**

High image quality and resolution are crucial for successful image-guided surgery. Higher frequency in ultrasonography produced improved resolution but reduced tissue penetration. Early procedures employed ultrasound probes with a frequency of 7.5MHz and, more recently, 10.0MHz.15,24-27 Because the 10MHz probe has an optimal image quality at a closer range (0.5- 4cm), it is better suited for spinal cord tumour surgery. In our procedures, we employed multi-frequency probes, usually at a frequency of 9-12MHz for an increased resolution. With small and exquisite designs, these special probes could
provide much desired real-time images showing the minute details in intradural tumours.

**LIMITATIONS**

The advantages of IOUS examination in spinal surgery must be individually assessed and its diagnostic potential in intradural pathologies will be proven in larger series studies. Furthermore, image quality may decrease with ongoing resection because of blood and air bubbles in the surgical field during resection of tumours. One needs to bear in mind that current imaging techniques may not fully reflect the biological extent of the tumour. That is, the detection of microscopic tumour cell migration into the surrounding parenchyma may not be feasible and hence the aim of intraoperative image guidance would be to achieve the optimal extent of resection.

**V. CONCLUSIONS**

In this paper, the use of intraoperative ultrasonography as an aid in surgical removal of intradural spinal tumours is reported. IOUS provides real-time information about the precise location of the neoplastic tissue, its relation to the spinal cord, the size of residual tumour following excision, and differential diagnosis of tumours, with manifestations on selection and adaptation of surgical approach for specific tumours. It is our experience that, when appropriately applied to assist surgical procedures, IOUS is a sensitive intraoperative tool that helps to improve surgical precision and might reduce the procedure related morbidity.
REFERENCES


Table 1. Histopathology and location of intradural tumours operated on with IOUS

<table>
<thead>
<tr>
<th>Type of tumours</th>
<th>n</th>
<th>cervical</th>
<th>cervical-thoracic</th>
<th>thoracic</th>
<th>lumbar-sacral</th>
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<tbody>
<tr>
<td>Intramedullary tumours</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ependymoma</td>
<td>2</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Astrocytoma</td>
<td>5</td>
<td>2</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Hemangioblastoma</td>
<td>2</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Metastasis</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Extramedullary tumours</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meningioma</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Neurinoma</td>
<td>6</td>
<td>2</td>
<td></td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Filum terminale ependymoma</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Lipoma</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Biopsy</td>
<td>3</td>
<td>2</td>
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Table 2. Sonographic characteristics of intra- and extramedullary tumours

<table>
<thead>
<tr>
<th></th>
<th>morphologic characters</th>
<th>echogenicity of solid tumour part</th>
<th>cystic part</th>
<th>perifocal edema</th>
<th>syrinx</th>
</tr>
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<tbody>
<tr>
<td><strong>Intramedullary tumour</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ependymoma</td>
<td>margins frequently poorly defined</td>
<td>comparable with myelin heterogenous</td>
<td>frequently, intralesional or perilesional cyst</td>
<td>frequently</td>
<td>frequently</td>
</tr>
<tr>
<td>Astrocytoma</td>
<td>margins frequently poorly defined</td>
<td>comparable with myelin heterogenous</td>
<td>often, intralesional or perilesional cyst</td>
<td>frequently</td>
<td>sometimes, less than ependymoma</td>
</tr>
<tr>
<td>Hemangioblastoma</td>
<td>a cyst with a small tumour nodule</td>
<td>hyperechogenic tumour nodule</td>
<td>perilesional cyst, macrocystic appearance with homogeneous CSF-like echogenicity</td>
<td>sometimes</td>
<td>sometimes, with cephalad and caudal syringes</td>
</tr>
<tr>
<td><strong>Extramedullary tumour</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meningioma</td>
<td>irregular surfaces</td>
<td>higher than myelin and higher than neurinoma</td>
<td>rarely, microcystic appearance</td>
<td>never</td>
<td>never</td>
</tr>
<tr>
<td>Neurinoma</td>
<td>rounded and smooth surfaces, movement</td>
<td>often with low echoes or isoechogeticity</td>
<td>sometimes, microcystic or macrocystic appearance with low echogenicity</td>
<td>never</td>
<td>never</td>
</tr>
<tr>
<td>Filum terminale ependymoma</td>
<td>clear demarcation from the surrounding nerve tracts</td>
<td>homogeneous signal intensity, higher than myelin</td>
<td>sometimes, with low echogenicity</td>
<td>never</td>
<td>never</td>
</tr>
</tbody>
</table>
FIGURE LEGENDS

Figure 1. A, the ultrasound panel (Toshiba, Aplio, Typ SSA-770A, Japan); B, sector probe (PST-65AT, 4.5-9MHz); C, linear probe (PLT-1202S, 7-14MHz); D and E, a single-level hemilaminectomy is, in general, sufficient to facilitate the insertion of the smaller probe (PLT-1202S, 7-14MHz).

Figure 2. A, B, MRI (sagittal and transverse) of a neurinoma at L3-4; C, IOUS showed a rounded and smooth surface, which was of low echogenicity and contained a macrocystic appearance inside. During surgery a movement synchronized with cardiac pulsations was observed; D, the intraoperative view, black arrow showed the tumour.

Figure 3. A, B, MRI (sagittal and transverse) of a meningioma at Th5-6; C, IOUS showed a considerable increase of echogenicity compared to neurinoma case. Echogenicity was not uniform and displayed irregularities, but no cysts. The tumour was adherent to the dura mater without pulsatile movement during surgery. Note that the underlying disk space was also exhibited clearly (white arrow); D, the intraoperative view, black arrow showed the tumour.

Figure 4. (A-C) Intramedullary ependymoma at Th 5-6. (A) MRI, (B) IOUS before dural opening showing inhomogeneous echogenicity, accompanied by a syrinx caudal of the tumour (arrow); (C) IOUS imaging during resection. Note that the diameter of the spinal cord was shrinking during resection due to the tumour removal and the opening of the syrinx. (D-G) Intramedullary astrocytoma at C3. (D) MRI, (E) IOUS before dural opening showing isoechochogenity of the spinal cord, tumour margins were not clear, with an increased reflexion of perifocal edema; note: some vessels (white solid arrow) were
visualized on the lateral side of the lesion with the color-mode, which were confirmed in the procedure as enlarged veins (arrow in Fig. 5G). Astrocytomas are highly infiltrative and sometimes hypervascular tumours that are usually only debulked as in the present case; (F) during resection, the image quality decreased slightly because of blood and air bubbles in the surgical field. The open arrow showed perifocal edema; (G) the intraoperative view.

**Abbreviations:**

C, cervical; CT, computed tomography; IOUS, intraoperative ultrasonography; L, lumbar; MRI, magnetic resonance imaging; SSEPs, somatosensory evoked potentials; Th, thoracic.