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Abstract: Intra-operative ultrasound (ioUS) is a very useful tool in surgery of spinal lesions. Here we focus on modern ioUS to analyze its use for localisation, visualisation and resection control in intramedullary cavernous malformations (IMCM). A series of 35 consecutive intradural lesions were operated in our hospital in a time period of 24 months using modern ioUS with a high frequency 7-15 MHz transducer and a true real time 3D transducer (both Phillips iU 22 ultrasound system). Six of those cases were treated with the admitting diagnosis of a deep IMCM (two cervical, four thoracic lesions). IoUS images were performed before and after the IMCM resection. Pre-operative and early postoperative MRI images were performed in all patients. In all six IMCM cases a complete removal of the lesion was achieved microsurgically resulting in an improved neurological status of all patients. High frequency ioUS emerged to be a very useful tool during surgery for localization and visualization. Excellent resection control by ultrasound was possible in three cases. Minor resolution of true real time 3D ioUS decreases the actual advantage of simultaneous reconstruction in two planes. High frequency ioUS is the best choice for intra-operative imaging in deep IMCM to localize and to visualize the lesion and to plan the perfect surgical approach. Additionally, high frequency ioUS is suitable for intra-operative resection control of the lesion in selected IMCM cases.

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Intra-operative high frequency ultrasound improves surgery of intramedullary cavernous malformations

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Abstract

Object: Intra-operative ultrasound (ioUS) is a very useful tool in surgery of spinal lesions. Here we focus on modern ioUS to analyze its use for localisation, visualisation and resection control in intramedullary cavernous malformations (IMCM).

Methods: A series of 35 consecutive intradural lesions were operated in our hospital in a time period of 24 months using modern ioUS with a high frequency 7-15 MHz transducer and a true real time 3D transducer (both Phillips iU 22 ultrasound system). Six of those cases were treated with the admitting diagnosis of a deep IMCM (two cervical, four thoracic lesions). IoUS images were performed before and after the IMCM resection. Pre- and early postoperative MRI images were performed in all patients.

Results: In all six IMCM cases a complete removal of the lesion was achieved microurgically resulting in an improved neurological status of all patients. High frequency ioUS emerged to be a very useful tool during surgery for localization and visualization. Excellent resection control by ultrasound was possible in 3 cases. Minor resolution of true real time 3D ioUS decreases the actual advantage of simultaneous reconstruction in 2 planes.

Conclusion: High frequency ioUS is the best choice for intra-operative imaging in deep IMCM to localize and to visualize the lesion and to plan the perfect surgical approach. Additionally, high frequency ioUS is suitable for intra-operative resection control of the lesion in non acute IMCM cases. Resection control in acute IMCM lesions is difficult to interpret since sometimes perifocal edema and/or perifocal hemosiderin can hinder the accurate differentiation of medullary to pathological tissue.

Keywords: Intra-operative ultrasound (ioUS), intramedullary cavernous malformation (IMCM), neurosurgery, resection control

Introduction

Intramedullary cavernous malformations (IMCM) are rare lesions and a meticulous review revealed only approximately 200 described cases in literature.[3, 5, 9, 10, 17, 20, 21, 23] Within the last decades surgical and imaging techniques for spinal lesions improved, especially since intra-operative ultrasound (ioUS) was introduced into clinical practice:[10, 13, 15] Reid et al. presented the first visualisation of a cervical spine astrocytoma with an arc scanner[19] and Regelsberger et al. presented successfully ioUS for the localization of spinal tumors in a large series of 78 patients.[18] Although a steady progress of novel ultrasound methods (phased-array probes, range of depth, improved resolution, 2D, 3D, Doppler Wave) could be obtained[4, 6, 7, 11-14, 17, 18] experiences in ioUS of IMCM are still rare. Furthermore, intra-operative imaging suggestions for intramedullary resection control needs more evidence. Since October 2008 we use in our department 2 new transducer types regularly for enhanced intra-operative ultrasound imaging in cranial and spinal cases. One transducer is a high frequency phased linear array probe with resolution in millimetre range. The other transducer is a true real time 3D probe displaying two full-resolution planes simultaneously or a live 3D image. 35 consecutive spinal cases with intra-dural lesions have been operated with the aid of ioUS until the October 2010. Most challenging regarding localisation are those lesions that are not directly visual on the dorsal surface of the medulla after opening the dura via a dorsal approach. Sometimes not even swelling of the medulla is recognisable.[3, 20] Here, we focus on 6 of our 35 cases with the diagnosis of IMCM to verify the value of these two modern intra-operative tools with regard to localisation, visualisation and resection control.

Methods

Patients

A retrospective analysis of six consecutive patients (three women, three men) was performed. All patients were treated surgically at the Department of Neurosurgery, University Hospital Zurich from November 2008 to October 2010 by the authors (OB, NK, HB). The admission diagnosis for all patients was IMCM with preoperative MRI revealing a localization of the lesion in the cervical and thoracic spine with various neurological symptoms (Table 1). Diagnosis was verified postoperatively through histological investigation by the Department of Neuropathology at the University Hospital Zurich.

Intra-operative ultrasound (ioUS)

In this setting the iU22 Ultrasound System (Philips, Bothell, USA) with its high-resolution system and adjustable range for operating conditions (2D, 3D, Live 3D, Full Volume, xPlane, M-mode, Doppler and Color imaging) was used in this study.[4]

One probe was a 7-15 MHz extended frequency range intra-operative transducer (L15-7io, Philips) with a phased linear array with 128 elements, explora connector and eight degrees of trapezoidal imaging and 23 mm effective aperture length with high-resolution intra-operative imaging. The tip of the probe measures 11mm times 31mm.

Additionally the ultrasound probe X7-2 (Philips, 2-7 MHz frequency), which is predominantly designed for paediatric cardiologists or gynaecologists to acquire real-time 3D images, was used. The array probe enables live xPlane imaging to acquire two full-resolution planes simultaneously from the same heartbeat or region of interest. The system's multi-directional beam steering provides unlimited planes in all directions, and live volume imaging allows the acquisition and rendering of full volume data at true real-time frame rates with unparalleled isovoxel resolution. The tip of this ultrasound probe measures 29mm times 40mm. All ioUS images were analysed with regard to the postoperatively acquired MRI images by the authors.

Operative procedure

Patients were operated in prone position via hemilaminectomy or laminoplasty approaches (Table 1) as previously described.[2, 25] The spinal region of interest was localised and marked by the aid of x-ray before skin incision. Transdural ioUS was performed after hemilaminectomy or laminoplasty. After opening of the dura the surgical site was filled with saline solution as a transmitting medium for further ultrasound acquisition. The exact site of myelotomy was evaluated by ioUS re-scans and IMCM resection control was performed through open dura.

MR imaging (MRI)

Images were performed by a 1.5 Tesla MRI and analysed by the Department of Neuroradiology, University Hospital Zurich. Evaluation of the scans occurred independent and unrelated to this study by using a standardized software program (picture archiving and communication system, PACS).

Results

The preoperative symptoms of all patients improved after surgery with no new permanent neurological deficits (Table 1). The advanced electrophysiological monitoring during surgery was uneventful in all cases. Five patients (cases 2-6) improved 1 step in Frankel grade scale[8] after last follow-up. Patient number 1 improved from paraplegia to walking with assistance. All IMCM lesions could be removed totally and diagnoses were verified histopathologically.

Imaging

In all cases pre- and postoperative MRI and especially extensive ioUS were performed without any technical difficulties. Complete resection was defined by the surgeon macroscopically in all cases and confirmed by the independent neuroradiologist after postoperative MRI in all cases. In 4 out of 6 cases (patient 1-4) small remnants of hemosiderin were detected along the resection line.

The transdural localisation of the IMCM was possible with both probes, although some difficulties were seen with the size of the real time 3D probe through a hemilaminectomy approach. The smaller high frequency probe fits easily through basically any opening. The resolution of the 3D probe was not sufficient for resection control and this task was abandoned (Figure 1).

In 3 cases repeated imaging after initial small myelotomy was used to assure exact positioning above the cavernoma before further deeper incision. No corrections of myelotomy or false myelotomies were performed in all six cases because of exact anatomical localization by the high frequency ultrasound probe.

Resection control with the high frequency transducer was excellent in IMCM with mild perifocal edema and/or long period after first symptoms (cases 4, 5 and 6) (Figure 1 and 3), whereas resection control in IMCM with high edema (case 1-3) and/or short clinical time period to surgery was difficult to interpret (case 1) (Figure 2).

Discussion

The use of ioUS is rarely described for spinal vascular lesions such as IMCM.[3, 22] In this study we analyzed our experiences with ioUS and focused on six selected cavernoma cases where the lesion was not visible on the surface after opening the dura from a dorsal approach. Intra-operative imaging for exact localization is highly recommended to keep the spinal cord incision as small and as precise as possible. There

is practically no alternative to ioUS to locate the lesion exactly after opening the spinal canal. Intra-operative MRI (ioMRI) for spinal intramedullary lesions has rarely been mentioned, despite its increasing use of for cranial lesions.[16, 22]

Recent advances in ultrasound technology, such as high frequency transducer and true real time 3D probes should be able to further improve surgical interventions.[4, 15] We evaluated those two new probes in six challenging cases for localization, visualization and possible resection control.

Localization

In all cases both ioUS transducer were suitable for surgical planning. No medullary pathological signs such as a hemosiderin ring or swelling were macroscopically found before opening of the dura. This was already described in other studies with other spinal pathologies.[3, 18] In our experiences the edges of the lesions were perfectly localized by high frequency ioUS and acceptable by real time 3D ioUS (Figure 1). Based on these findings an adjustment of the extent of the approach is possible and can be performed.[18] In our series we did not need to enhance our first approach by another hemilaminectomy or laminectomy/laminoplasty and saw no differences by localizing acute or non acute IMCM lesions intra-operatively. Furthermore no additional bone removal just for ultrasound imaging reason was necessary nor performed. However the real time 3D probe had sometimes difficulties to be placed for good imaging through the performed minimal invasive approach. After opening of the dura the ioUS helped us again to localize the exact site for the myelotomy and the resection of the IMCM (Figure 3) as well as reassurance of the myelotomy before seeing the cavernoma. Intra-operative functional monitoring may be used as a complementary tool to assure the best entry point in the myelon after positioning the trectorial line with ioUS.

Visualization

Visualization of the IMCM lesion is an important feature to adjust the surgical strategy individually and to prevent a postoperative morbidity in the patient by accessing the lesion incorrectly.[3, 20] To our knowledge no other intra-operative imaging technique (for example ioMRI) is used for IMCM resection.[22, 24] In our series these lesions could be displayed in sufficient quality by high frequency 2D and satisfactory by real time 3D imaging (Figure 1 and 2) with regard to the surrounded healthy tissue. It was useful to show the extent of the lesion as well as the three-dimensional expansion of the lesion. However significant resolution decrease was displayed in our cases with real time 3D imaging and reminded us of old ultrasound imaging quality.[22] With this transducer clear boarder alignments are not visible yet. Therefore current real time 3D imaging is not suitable to enhance visualisation of intramedullary lesions compared to the standard available 2D US imaging (Figure 1). It is not the size of the probe that hinders good spinal imaging, but the image quality by using just a matrix array with 2400 elements in the frequency range of 2-7MHz. Instead the high frequency lineary probe does elevate spinal imaging to a higher level in intra-operative real time imaging. The produced images show sharp differences of structures in millimeter range. Small anatomical structures such as arachnoidea and denticulate ligaments are now visible and help the surgeon with further intra-operative information of the surroundings. This is of significant value for orientation, if intramedullary lesions are not visible on the surface. Furthermore, after initial myelotomy and further possibly necessary reassurance to be on the right track, high frequency ultrasound can provide images in this small area of interest with excellent visualization.

Resection control

The main goal in IMCM surgery is to remove the lesion totally since this leads to a permanent elimination of the risk for further growth or hemorrhage.[3, 17, 20] A recurrence of symptoms after subtotal or supposedly total resection has also been reported. Complete surgical resection could improve the clinical symptoms caused by IMCM.[17] The resection of the active cavernoma tissue in spinal cases and critical sites is thought to be sufficient and excision of hemosiderin infiltration in the surrounded healthy tissue is not recommended.[1, 3] Our six IMCM cases were declared completely resected by the surgeon macroscopically. Our Department of Neuroradiology stated complete resection of the cavernoma tissue in all cases after early postoperative MRI and follow-up MRI after 3 months, with residual hemosiderin in 4 four cases. However clear visualisation of operated cavernomas in spinal MRI imaging is difficult.[24] The presented high frequency ioUS may have the potential to improve resection control intra-operatively since imaging of the lesion and surrounded tissue improved significantly. In our series the performed intra-operative resection control with ioUS showed different results: Resection control was dependant on the active state of the lesion in this series (Figure 1-3). High frequency ioUS is very well suitable for intra-operative resection control of IMCM lesions with little edema surroundings and non recent bleeding history (case 4 and 5). Resection control in our acute symptomatic IMCM lesions was difficult to interpret with any used ioUS transducer due to the perifocal edema or surrounding hemorrhage, which hinders to detect the accurate changeover from healthy to pathological tissue by image degradation (cases 1-3) (Figure 2). However, it needs to be noted that acute lesions do not go necessarily along with perifocal edema. Other circumstances such as venous thrombosis or congestion in acute as well as chronic cavernomas may be associated with perifocal edema. Overall the use of high frequency ioUS showed significantly higher definition compared to usual US probes (up to 9 MHz). Burr hole probes are very small in size, but their

frequency rate is mostly even smaller than standard probes and therefore definition is rather inferior. We do not see any advantage in these probes or the use of color coded mode in spinal imaging. Currently the best intra-operative resection control of intramedullary IMCM lesions still remains the experienced view through the microscope (Figure 3). However with further improvements in the resolution of ioUS within the next years, this intra-operative technique might be part of relevant changes in the definition of resection control.

Conclusions

High frequency ioUS is the best choice for intra-operative imaging to localize and to visualize IMCM and to plan the perfect surgical approach before and after opening the dura, or even after initial myelotomy. Additionally, high frequency ioUS is suitable for intra-operative resection control of the lesion in mild IMCM cases without edema or acute hemorrhage. Resection control in acute symptomatic IMCM lesions might be difficult to interpret since perifocal edema hindered the accurate differentiation of medullary to pathological tissue in our cases.

Disclosure

The true real-time 3D transducer (X7-2) has been provided by the company (Philips) for research proposes. This is not the case for the US system (IU22) or the high frequency 2D transducer (L15-7io), which were bought by the department. No financial collaborations, consulting contracts or other conflicts of interest exist for all authors.

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Figure Legend

Figure 1: Comparison of the two transducer types (high frequency transducer vs. real time 3D probe) in patient 4: (I-III) show 2D images with the high frequency probe and (IV-VI) show the images produced by the real time 3D probe. (IV) is the corresponding anatomical alignment image to (I) and (V) to (II). (I) and (IV) display coronal and (II), (III) and (V) sagittal planes. Image (VI) indicates a cone picture from the use of the “live 3D” full volume mode. The resolution decrease from high frequency ioUS (I-III) to real time 3D ioUS (IV-VI) was so significant that resection control with real time 3D ioUS was dropped.

D indicates dura, OD open dura, C cavernoma, DL denticulate ligaments, R resection cavity.

Figure 2: Resection control (sagittal spinal image) with high frequency 2D ioUS of an acute IMCM (patient 1): (I) shows the cavernoma (C) before dura opening (D). (II) displays the resection cavity (R) with open dura (OD). Perifocal edema hinders the accurate differentiation of medullary to possible residual pathological tissue.

Figure 3: Sagittal image of the spinal cord for resection control with the high frequency transducer and illustration of corresponding intra-operative pictures to the right (patient 5): (I) shows the cavernoma (C) with closed dura (D). (II) indicates an intra-operative view after dura opening: No significant sign of the complete intramedullary located lesion on the surface or swelling of the spinal cord is visible. (III) displays the resection cavity after IMCM resection before closure of the dura (OD). (IV) shows microscopic images of the myelotomy and resection cavity. IoUS and microscopical views confirm complete resection.

Figure 1:

Figure 2:

Figure 3:

Patient no.	Sex	Age	Spinal level	Deficits on admission (time from clinical onset to surgery)	surgical approach	F (F)
1	F	19	T 9-11	Acute paraplegic, bladder dysfunction (5 days)	Hemilaminectomy T 9	A
2	M	26	T 2	Fast increasing sensory deficits (2 weeks)	Hemilaminectomy T 2	D
3	M	28	T 1-2	Slowly progressive sensorimotoric deficit lower extremities (3 months)	Hemilaminectomy T 2	C
4	F	46	C 2-3	Slowly progressive sensorimotoric deficit right upper extremity (8 months)	Hemilaminectomy C 3	D
5	F	20	T 2-3	Slowly progressive paresis left leg (3 months)	Laminoplastie T 2-3	D
6	M	26	C 4	Progressive dysesthesia right arm	Hemilaminectomy C4	D

Table 1: List of the six patients with intramedullary cavernous malformation included in this study

F indicates female; M, male; T, thoracic; C, cervical.