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Clinical Study

Two-dimensional high-end ultrasound imaging compared to intraoperative MRI during resection of low-grade gliomas

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ABSTRACT

Ultrasound (US) is being used increasingly in intraoperative imaging. Its reliability in identifying low-grade gliomas (LGG), however, has not been shown definitively. We compared the quality and reliability of high-end two-dimensional (2D) ultrasound (US) and 1.5 Tesla intraoperative MRI (iopMRI) images in 11 patients with LGG. The parameters evaluated were: tumor border; internal structure; vascularity, location, and relation to landmarks and vessels; and accuracy in detecting remnants. Both methods allowed good visualization of internal characteristics of the tumor and its location. The tumor border was clear on 10 of 11 MRI and on 9 of 11 US. During surgery, however, the quality of US images diminished, leading to some difficulties in interpretation. One small superficial remnant was not identified and in one patient an artifact was falsely interpreted as a remnant. While iopMRI appeared superior for visualizing different stages of hemispheric LGG resection, 2D US still allows accurate initial tumor delineation and for almost real-time control of tumor resection.

1. Introduction

A number of imaging methods are used for intraoperative tumor visualization and resection control.[1] The most reliable and advanced method is intraoperative high-field strength MRI (iopMRI), which provides an objective estimate of the extent of surgery and allows more radical and safe tumor removal, regardless of the tumor type.[2–4] However, iopMRI is a logistically demanding, time-consuming and expensive device.

Ultrasound (US) imaging is a less expensive alternative to iopMRI. It provides almost real-time high-quality image information on tumor location, its features and relation to anatomical landmarks.[5–7] However, whether this method may help to further distinguish edematous brain from the tumor, and from the normal brain, remains unclear.[8] Recent studies show that US imaging aids in defining the extent of resection and visualizing tumor remnants, especially if they are confined or deeply located.[9] The reliability of this type of imaging for low-grade gliomas (LGG), however, remains controversial.[10] Some authors report that its application for such tumors is limited because the borders of LGG cannot be accurately defined.[11] Conversely, other studies show that US is reliable for both LGG and high-grade gliomas.[12,13]

The sensitivity and specificity of US has been compared with CT scans and MRI.[12,14,15] However, in these studies the CT scan or MRI were acquired either preoperatively or postoperatively. Therefore, they do not account for the changes that may occur during surgery such as brain deformation caused by patient positioning, loss of cerebrospinal fluid (CSF), and tumor debulking or tissue manipulation. We compared the quality and reliability of high-end US and high-field strength iopMRI data, acquired almost simultaneously before, during, and after the removal of hemispheric LGG.

2. Materials and methods

Eleven patients with supratentorial LGG were included in this prospective study. For seven patients 2D US images were acquired before the dura was opened, as well as during and after tumor removal, while for four patients US images were acquired prior to the dural incision. One patient had a pilocytic astrocytoma, five patients had astrocytomas, three patients had oligodendrogliomas and two had oligoastrocytomas. Four patients had undergone previous operations. The following parameters were evaluated on the preoperative images: tumor border; internal tumor structure (cystic or solid, homogeneous or heterogeneous); tumor vascularization; tumor location and relation to adjacent structures/landmarks; and tumor relation to major arteries/veins. The accuracy in detecting residual tumor tissue and the presence of artifacts during and after tumor removal was further assessed. These parameters were also evaluated on the corresponding MRIs, which were acquired immediately following US image acquisition. The specificity and sensitivity of US imaging was determined by at least two board-certified neurosurgeons, who compared the two datasets.

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The quality of the images was categorized as good, fair or poor, according to a previously published scheme.[9]

Surgeries were performed in an operating theater equipped with a high-field open-bore 1.5 Tesla MRI (MAGNETOM Espree, Siemens, Erlangen, Germany) and an integrated neuronavigation system (Vector Vision Sky Navigation System, BrainLAB, Heimstetten, Germany). Functional neuronavigation was used, integrating the functional MRI and fiber tracking data. The 2D B-mode US images were acquired using a SonoWand US high-end scanner (MISON AS, Trondheim, Norway). The US protocol of image acquisition followed the published recommendations.[6,7] For deep-seated or subcortical lesions, a 5 MHz phased-array probe with surface dimensions of 22 × 15 mm was selected that has an optimal image quality at depths of 2–7 cm; for superficial lesions, a 10 MHz linear array probe with optimal image quality at 2–4 cm was used. In order to improve the visualization of cortical tumors, a sterile gelatin plate was used as a ''standoff''. The entire operative field was scanned systematically in at least two perpendicular planes before and after tumor resection. The power Doppler option (US angiography) was applied in four instances, for which this information was regarded as important.

The first image was acquired at the beginning of surgery: for the iopMRI this occurred under general anaesthesia, prior to the skin incision and for the US imaging it occurred prior to the dural opening. Thereafter, US scans and MRIs were performed to control the tumor resection and also postoperatively for verification of the extent of tumor removal.

3. Results

Gross total tumor removal was achieved in six patients. In the remaining five patients an incomplete resection was planned because their tumors extended into highly eloquent cortical and subcortical areas or critical anatomical structures. The preoperatively planned extent of resection was achieved for all patients. Intraoperative imaging revealed unexpected residual tumors in five patients, all of whom underwent additional resection.

3.1. Initial imaging

The USs and MRIs of all patients acquired at the outset were of high quality and allowed adequate evaluation of the tumors. Comparison of the two imaging methods showed that they both allowed good visualization of the relevant anatomical landmarks, such as the falx, tentorium, skull base, or ventricles (Figs. 1 and 2). The tumor location could therefore be accurately assessed in all patients with both imaging methods. The tumor border delineation was well visualized on 10 of 11 (90.9%) MRI and in 9 of 11 (81.8%) of the US studies (Fig. 3). US imaging provided detailed information on the internal structure of the tumor in all patients, while for two iopMRI this was not possible; on MRI the tumors appeared homogeneous. No significant differences were found regarding tumor pathological type or size. In two patients, large vessels within the tumor were clear on images obtained with the power Doppler US but not with the iopMRI (Fig. 2B).

3.2. Tumor resection control

The quality of the iopMRIs acquired during tumor removal was superior to the corresponding US images and allowed for good detection in all patients with residual tumors, regardless of the tumor size. There were no major artifacts that would influence the evaluation of the findings. The US images provided a reliable, almost real-time, image control of the progress during surgery. The mean duration of image acquisition was less than 2 minutes and did not result in a major interruption of workflow. During surgery, however, the quality of the images diminished, leading to some interpretation difficulties, especially in patients with small or superficially located remnants. One small superficial remnant was not identified on an US image because of the poor image quality at the border between the resection cavity and the remaining tumor. In another patient, an artifact was falsely interpreted as a remnant (Fig. 4). Resection and pathological examination of this artifact showed that it did not contain tumor cells.

4. Discussion

Although the optimal management of patients with LGG remains controversial and challenging, there is growing evidence that the extent of resection correlates with survival; it may prolong the time to recurrence and decrease the rate of malignant degeneration.[16–19] According to the results of a meta-analysis of all major clinical publications on this topic since 1990, extensive surgical resection is associated with a longer life expectancy for patients with both LGG and high-grade gliomas.[20] The beneficial effect of radical surgery is related to the volume of residual tumor, as demonstrated by several volumetric analyses.[4,21] Therefore, maximal tumor removal is currently regarded as a mainstay of LGG management. This, however, may be difficult to achieve for tumors that have infiltrated eloquent or critical brain structures. Further, LGG may be difficult to differentiate from normal brain tissue under the operating microscope.

The safety and radicality of such surgeries has been substantially enhanced by the introduction of functional navigation and intraoperative imaging techniques such as US, CT scan, and MRI.[3,4,22] High-field MRI with an integrated functional neuronavigation system is one of the most advanced intraoperative imaging methods. It provides the anatomical and functional data required for safely planning and performing the surgery. Further, it allows for an objective control of the extent of resection and for an immediate update of the neuronavigation data. The intraoperatively obtained anatomical and functional data enable the surgeon to decide

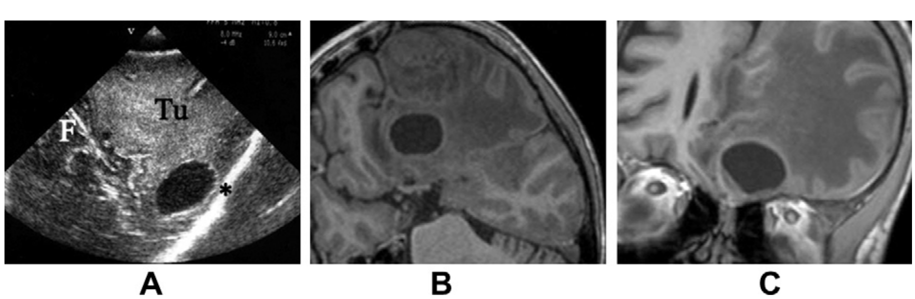

Fig. 1. (A) Coronal ultrasound showing clear visualization of the tumor, the falx and the skull base compared to (B) axial and (C) coronal T1-weighted intraoperative MRI. F = falx, Tu = tumour, ∗ = skull base.