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OTHER ARTICLES

Preoperative Magnetic Resonance Elastography (MRE) of Skull Base Tumours: A Review

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Abstract

Conventional magnetic resonance imaging (MRI) can detect tumors consistency, but it can't predict tumor stiffness or adherence of the tumor to nearby structures. Magnetic resonance elastography (MRE) is a known non-invasive MRI based imaging technique used to assess the viscoelasticity of the tissues particularly liver fibrosis. This study discussed the importance of preoperative MRE in skull base tumors and the future implications of this new imaging modality. We did review of the English literature (by searching PubMed) regarding the use of MRE in preoperative assessment of skull base tumours stiffness and adherence to surrounding tissues. Recent research demonstrated that MRE can detect the stiffness and adherence of skull base tumors to surrounding structures by recording the spread of mechanical waves in the different tissues. In addition to non-radiation exposure, this technique is fast and can be incorporated into the conventional (MRI) study. MRE can palpate skull base tumours by imaging, allowing the stiffness of the tumour to be assessed. Preoperative assessment of brain tumours consistency, stiffness, and adherence to surrounding tissues is critical to avoid injury of important nearby structures and better preoperative patient counselling regarding surgical approach (endoscopic or open), operative time, and suspected surgical complications. However, the accuracy of MRE is less in small and highly vascular tumors. Also, MRE can't accurately detect tumour-brain adherence, but the new modality (slip-interface imaging) can. Hence, adding MRE to the conventional MRI study may help in preoperative diagnosis and treatment of skull base tumours.

Keywords Magnetic resonance elastography · Meningioma · Pituitary macroadenoma · Skull base tumours · Vestibular schwannoma · Slip interface imaging

Introduction

Recently, many new techniques for magnetic resonance imaging (MRI) of skull base lesions emerged. They include high resolution techniques, diffusion, and perfusion techniques (diffusion-weighted imaging (DWI) and perfusion-weighted imaging (PWI)), phase contrast, combined PET/MR scan, MR spectroscopy (MRS), three-dimensional (3D) visualization, and elastography. These new modalities can give more data about the characteristics of the lesion (vascularity, cellularity, calcifications, areas of necrosis, consistency, and stiffness). Conventional MRI and DWI can help in detecting tumour consistency, but they can't detect tumour stiffness or adherence to surrounding tissues [1–3]. With the evolution of less invasive endoscopic management of the anterior and central skull base lesions instead of open approaches, the need for an imaging technique that can determine tumor consistency and stiffness became very important to avoid injury of surrounding important structures [4].

Magnetic resonance elastography (MRE) is a non-invasive technique that was introduced in 1995 and is being used to assess stiffness of liver fibrosis (like manual palpation) instead of liver biopsy [5, 6]. It has been used to assess tumor stiffness of other organs (spleen, liver, pancreas, and breast) and proved to be very reliable and reproducible with very low failure rate [7, 8]. Also, recently Brain MRE showed promising results in the diagnosis of non-oncologic disorders like neurodegenerative disease of the brain (Alzheimer disease, parkinsonism, and dementia) [9–11]. Moreover, brain MRE showed valuable results in

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the diagnosis of demyelinating disease of the brain like multiple sclerosis [12].

MRE can detect changes in the viscoelastic properties of the tissues that occur with tumors development. So, recently, MRE is used to assess the stiffness, consistency, and adherence of brain tumors to surrounding structures, after being able to overcome difficulties of introducing shear waves through the curved skull contour [13–16].

Palpation by Imaging (The Three Processes Technique)

It is already possible to quantify intra-tumoral stiffness using imaging-based elastography, whether by ultrasound or by MR elastography (MRE). MRE, on the other hand, is uniquely capable of determining intratumoral consistency preoperatively, whereas ultrasound technology can only be used once the skull is opened intraoperatively [17].

The MRE technique uses a high-resolution dynamic 3 T MRI technique to measure non-invasively (palpation) tissue stiffness (stroma fibrosis), adherence to surrounding structures, and consistency. The tissue stiffness is calculated by measuring how mechanically induced shear waves propagate through the brain tissues (introduced intracranially via a soft pillow-like pneumatic driver placed under the patient's head within an 8-channel MRI head coil). These soft pneumatic pillows replaced the old wave generators that had been used to be applied directly to the skull, for better patient safety and comfort. Then, MRE is incorporated into the standard MRI with about extra four to seven minutes to be obtained. An echo planar imaging (EPI) MRE protocol is used for the fast acquisition of volumetric data, which is inverted with a 3D algorithm to measure tissue stiffness accurately. Then, a color map for intratumoral consistency grading (elastogram) is put. The unit of measurement is the kilopascal (kPa) with a range of (0–8 kPa). Tumors were considered hard if they had a stiffness value > 6 kPa. MRE is done in conjunction with the conventional MRI study (T1, T2, and T1 with contrast weighted images) and DWI [18–20].

So MRE includes three stages.

- First stage includes generating the shear mechanical waves (by an external wave generator (active driver) using air pressure, sound, or piezoelectric waves). Active drivers produce waves at certain frequencies, then these waves are transferred via an external driver (passive driver) to the skull and brain tissues through the (soft pillow) [21].
- Second stage is the imaging and recording of the propagation of the induced shear waves in different tissues by an echo planar imaging.
- Third stage includes the creation of elastograms (coloured maps for the tissue consistency and stiffness) by a specific software [22].

MRE for Better Preoperative Planning and Patient Counselling

Surgery is the main line of treatment for skull base tumors. Preoperative detection of the tumour stiffness (fibrosis) and adherence to (brain, intracranial vessels, and cranial nerves) is very important to both the surgeon and patient counselling regarding possible complications and operative time. For example, if a firm tumour is encasing the carotid or adherent to the cavernous sinus, then we can expect a greater degree of difficulty and need for an open approach (craniotomy) or piecemeal removal with sharp dissection, which we must be well prepared for, unlike soft tumours that can be easily removed endoscopically by suction. Moreover, skull base lesions can have heterogenous intratumoral stiffness which the standard MRI can't detect, but the MRE can [23].

MRE plays a key role in preoperative planning, especially when determining whether open surgery or endoscopic surgery should be used. Hughes et al. demonstrated the importance of MRE in this regard. They divided intraoperative tumor stiffness into grades according to ability to remove the tumor with suction only or ultrasonic aspirator or sharp dissection with scissors and cautery. In addition, because calcification and necrosis look the same on MRI, MRE would be a means of distinguishing between them [20, 24]. It became evident that MRE can be used to assess stiffness of many types of intracranial tumors (pituitary adenoma, schwannoma, meningioma, glioma, and brain metastasis) [1].

MRE and Detection of Tumour Grade and Subtype

The main hypothesis for MRE studies in tumours assessment is that their mechanical properties change with the progress of the tumour and that these changes can be detected by MRE. Malignant tumors have higher cellularity, which results in lower apparent diffusion coefficient with resultant image contrast in (DWI). Also, malignant tumors are more rigid than the surrounding normal tissues as they have abundant extracellular matrix (collagen and fibrous tissues) and higher vascularity resulting in higher stiffness. Moreover, tumor stiffness was found to increase with the increase in tumor grade [25, 26].

Reiss-Zimmermann et al. showed the ability of MRE to delineate meningioma from other brain tumors by analysing their mechanical properties [27]. Another MRE study compared the shear stiffness of four intracranial tumors

(vestibular schwannoma, pituitary adenoma, meningioma, and glioma) and found increased stiffness of meningioma than pituitary adenoma. Moreover, MRE may have a role in detecting meningioma histopathologic subtype. It may differentiate firm meningiomas (fibrous and transitional) from soft meningiomas (meningothelial) [28].

MRE may have a role in detecting the grade of brain malignancy. Pepin et al. showed that MRE was able to detect the grade of glioma (grade IV was found to be softer than grade II). Stiffer gliomas were found to have different gene mutations than the softer. The ability of the MRE to distinguish mechanical alterations to detect genetic mutations is a new term called mechanogenomics [26].

Pituitary Macroadenomas (PMA)

Pituitary adenomas are very common benign intracranial benign masses. Although most of the pituitary macroadenomas are soft and can be sucked endoscopically through transsphenoidal approach, a small percent (about 5–10%) is firm and fibrous altering the surgical technique to open approach (craniotomy) with higher incidence of injury to surrounding neurovascular structures particularly in tumors with suprasellar and parasellar extension [29–31]. So, it is important to know the consistency of the adenoma before surgery to detect the surgical approach and avoid leaving a residual that mandates revision surgery or postoperative radiotherapy [32].

(MRI) based methods (conventional MRI, diffusion weighted MRI, and contrast enhanced 3D FIESTA at 3 T) have been studied for determining the consistency of PMA preoperatively and have shown promising results. However, none of these studies were able to determine tumor stiffness. These methods are based on static imaging characteristics and hence cannot directly measure tumor stiffness [33–36]. Moreover, diffusion weighted MRI is not suitable for imaging structures near air cavities or bone, which can result in artifacts during pituitary adenoma imaging [37]. Based on Hughes et al., a statistically significant difference in MRE values was found between soft and intermediate PMA cases (no hard PMA cases were examined) [38].

Virtual Magnetic Resonance Elastography (vMRE) in PMA

A recent study described this new technique which is based on 3 T MRI that can detect pituitary adenoma stiffness and consistency by using certain protocol of high-resolution DWI without the need for shear waves (static study) used in the conventional MRE. Advantages to this new technique is that it doesn't need hardware set-up with promising results. Limitation for this study was the small number of cases included (ten patients) [37].

Skull Base Meningioma

Skull base meningioma are highly vascular tumors that can arise from olfactory groove, suprasellar area, petroclival region, cerebellopontine angle (CPA) and sphenoid wing [39]. Depending on their consistency, meningiomas range from soft masses that can be suctioned out to hard masses that must be removed piecemeal and aspirated by ultrasound [4]. About 50% of brain meningiomas has heterogenous consistency [17]. A study on brain meningiomas compared MRE results with intraoperative stiffness assessment by the surgeons and postoperative histopathology analysis of the tumors. It found that MRE results correlated well with intratumoral heterogeneity during resection and with fibrous and cellular content of the tumor [40].

Murphy et al. divided intraoperative stiffness of menigioma into five grades (soft, mostly soft, intermediate, mostly firm, and hard). They demonstrated that preoperative MRE can accurately determine meningiomas stiffness particularly in firm fibrous tumors and meningioma with intermediate stiffness, thus we can avoid injury to important nearby structures like internal carotid artery, cavernous sinus, and optic nerve [41].

Firm skull base meningioma is treated through an external approach, meanwhile meningioma with softer consistency can be managed endoscopically. If the elastogram showed stiffness more than 5.1 kPa (cut-off point) in a portion of skull base meningioma, then open approach may be needed [40, 42]. Diffusion tensor MRI is a recent technique and it showed good results for predicting the consistency of intracranial meningiomas [43].

Skull Base Schwannomas

Huston et al. demonstrated a good correlation between MRE measurements and stiffness detected at surgery [44]. As for vestibular schwannomas, MRE can determine tumour stiffness and consistency which differs according to the histologic subtype (Antoni type A, more cellular) and (Antoni type B, less cellular). Hence, MRE can aid in preoperative planning for subcapsular tumour dissection and predicting areas of adherence to brain or surrounding structures [28].

Limitations of MRE

- MRE doesn't correlate well with small tumors (less than 3.5 cm) or highly vascular tumors or heterogenous tumors. Highly vascular tumors appear softer in MRE, but they aren't suckable and difficult to resect. These

problems can be fixed in the future by introducing higher spacial resolution techniques [20].

- MRE can't accurately detect tumour- brain adherence in meningiomas and schwannomas of brain and skull base. A new modality of MRE, slip-interface imaging (SII), using the same principles as MRE (but the unit here is octahedral shear strain (OSS) instead of kilopascals), can assess tumor adherence to brain to detect if the tumour is easily dissectable or adherent to brain tissue, allowing for lower surgical risk and better preoperative planning. Tumors that are free of adhesion will move freely at a tumor-brain boundary when shear force is applied, unlike tumors that are fixed to the surrounding brain. This technique showed good results in predicting tumor-brain adherence in both vestibular schwannoma and meningioma [45–47]. Unlike SII MRE which is a dynamic study, standard MRI is a static study that predicts the tumour-brain adhesion by showing the peritumoral CSF cleft and peritumoral edema which are usually not accurate in detecting presence of adhesion and its degree [1, 48].
- Assessment of intraoperative stiffness degree and comparing it with the results of the MRE elastogram in the studies, was done by a surgeon which can vary from one person to another (subjective and not objective assessment) [41].
- Small number of cases included in the studies that assessed value of MRE in assessment of stiffness in PMA and meningioma.
- Studies have not addressed skull base tumors within the bone like intraosseous meningioma or infiltrating pituitary macroadenomas.

Future of MRE in Skull Base Tumours Management

Due to the use of EPI (faster image acquisition but with poor image quality due to noise, distortion, and low-resolution images), MRE images are typically less detailed than conventional MRIs. Future improvements in imaging acquisition techniques for MREs will resolve this issue [49].

Conclusions

MRE is a short time study that allows preoperative radiologic palpation of brain and skull base tumors, enabling assessment of tumours consistency and stiffness. This in turn results in proper preoperative surgical planning and determine the surgical approach (endoscopic or open) with less injury to important nearby vessels, nerves, and brain tissue. However, the accuracy of this imaging technique is less in small and highly vascular tumors. Also, MRE can't accurately detect tumour- brain adherence, but the new modality (slip-interface imaging) can. Adding MRE to conventional magnetic resonance imaging study (T1 and T2 weighted imaging, DWI, and contrast enhanced MRI), may help in the preoperative diagnosis, differential diagnosis, and treatment of skull base tumours.

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Declarations

Conflict of interest There is no conflict of interest regarding the publication of this paper.

Ethical Approval This research was in accordance with the ethical standards of the institutional and the national research committee of Egypt and with the 1964 Helsinki declaration and its later amendments.

Informed Consent Not applicable.

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