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A Magnetic Resonance Imaging Technique to Evaluate Tumor–Brain Adhesion in Meningioma: Brain-Surface Motion Imaging

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Key words
- Adhesion
- Meningioma
- MRI
- Surgery

Abbreviations and Acronyms

BSMI: Brain surface motion image
CSF: Cerebrospinal fluid
CT: Computed tomography
MMP: Matrix metalloproteinase
MRI: Magnetic resonance images/imaging
TE: Echo time
TR: Repetition time
VEGF: Vascular endothelial growth factor
WHO: World Health Organization

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OBJECTIVE: **We examined the effectiveness of a newly developed magnetic resonance imaging (MRI) technique, brain surface motion imaging (BSMI), in the preoperative evaluation of tumor-brain adhesion in meningioma surgery.**

METHODS: **Cine phase-contrast MRI was used to measure cerebrospinal fluid (CSF) pulsations and heart rates at 2 different time points to create a subtraction image in meningioma patients who underwent BSMI. With no tumor-brain adhesion, a gap was observed in the tumor-brain movements, resulting in an outline of the tumor in BSMI. If adhesion was evident, no outline was observed. Cases were evaluated as exact if the presence or absence of edema in T2-weighted MRI, BSMI findings, and intraoperative findings all matched; as effected when only BSMI findings and intraoperative images matched; and as false when BSMI findings and intraoperative findings did not match.**

RESULTS: **BSMI judged 27 patients as adhesion (+) and 33 as adhesion (−), whereas surgical findings evaluated 22 as adhesion (+) and 38 as adhesion (−). The sensitivity and specificity were both high, at 95.5% and 84.2%, respectively. Forty-one of 60 patients were evaluated as exact, 12 as effected, and 7 as false. World Health Organization tumor grade assessment of effected subjects included 16.7% in grade 1 and 36.4% in grade 2.**

CONCLUSIONS: **BSMI was shown to be effective in evaluating adhesion between the meningioma and the brain, allowing safe and effective removal planning to be carried out preoperatively.**

INTRODUCTION

Meningiomas are representative, benign, extramedullary tumors that develop from the meninges surrounding the central nervous system (1, 5). Surgical resection is usually considered to be the first-line treatment of choice, although course observation and stereotactic radiotherapy are performed in elderly patients and those with serious concurrent disease or tumors with a small diameter (3, 10). Because successful treatment can be achieved by complete resection, this is recommended where practicable (4, 12).

The most straightforward and safe surgical approach to meningioma involves resecting the tumor from the surrounding brain during tumor decompression, and removing it either as a mass or in parts. The extent of adhesion between the tumor and the surrounding brain, however, is particularly relevant to the success of the surgical procedure. Strong adhesion is not common when an arachnoid space exists between the tumor and the brain; however, it is often observed when the arachnoid space collapses and the tumor infiltrates into the brain. This can also cause damage to the surrounding brain during surgical excision. Brain damage caused by surgical resection can lead to new postoperative neurological symptoms, so it is crucial to understand the degree of adhesion preoperatively and to evaluate the associated risks (1).

Traditional techniques to evaluate adhesion include computed tomography (CT) and T2-weighted magnetic resonance imaging (MRI), which can determine the presence of edema around the tumor, the regularity of the tumor form, the presence of a peritumoral band, and whether the feeding vessel includes branches of the internal carotid artery (2, 11, 19, 22, 23, 24).

We have developed a new MRI technique known as brain-surface motion imaging (BSMI) (23, 25). Here we present findings from the preoperative evaluation of the presence or absence of adhesion between a tumor and the surrounding brain using BSMI. We have studied additional patients since our previous report, and therefore examined the usefulness of the technique in the current study by introducing specific cases and comparing them against actual surgical findings.

METHODS

Of 86 patients with meningioma who received surgical treatment in our hospital between May 2008 and December 2011, BSMI could be performed in 60. Patients who received prior surgery were excluded. BSMI was preoperatively determined at the same time as MRI was performed.

The standard surgical procedure for tumor resection was craniotomy, with the navigation system used as required (Vector Vision Square: BRAINLAB, Feldkirchen, Germany). Written informed consent for the imaging study was obtained from all patients after the nature of the procedures had been fully explained.

MRI Technique

A Siemens Magnetom Avanto 1.5-T clinical imager (Siemens, Erlangen, Germany) was used to obtain the MRIs. Sagittal preliminary images were obtained by the phase-contrast cine technique with the following parameters: repetition time (TR) = 25 ms, echo time (TE) = 8.9 ms, flip angle = 15°, field of view = 230 mm, matrix = 256 × 256, slice thickness = 5 mm, velocity encode = 5 cm/s, pulse gated. The correlation between cerebrospinal fluid (CSF) flow and heartbeat was measured when the former was at its fastest and at its slowest. We therefore measured the temporal difference between the above 2 time points and the pulse trigger on the photoplethysmogram (Figure 1).

Heavily T2-weighted coronal images were obtained by the 3-dimensional electrocardiography synchronized spin-echo technique. The Sampling Perfection with Application optimized Contrasts using different flip angle Evaluation technique was used to perform imaging with the following parameters: TR = 2 R wave to R wave, TE = 49, echo train length = 143, echo train duration = 337 ms, generalized autocalibrating partially parallel acquisition acceleration factor = 2, field of view = 387 mm, matrix = 256 × 256, slice thickness = 1.9 mm, number of excitation = 1.4, and sampling time = 337 ms. The average imaging time was approximately 5 min. The actual images were obtained at the same 2 time points as the preliminary images.

A subtracted image was created using Image Fusion software (Siemens) to give the BSMI. Coronal images were used for all BSMI to maximize the visibility of areas where the tumor adhered from the brain surface to the bottom area. If there was no adhesion between the tumor and the surrounding brain, a motion gap was expected to cause a striped pattern along the rim of the tumor in BSMI. If the tumor adhered to the brain, the 2 were expected to move together with no gap in their motion, and so the boundary of the tumor was not expected to be visible in BSMI.

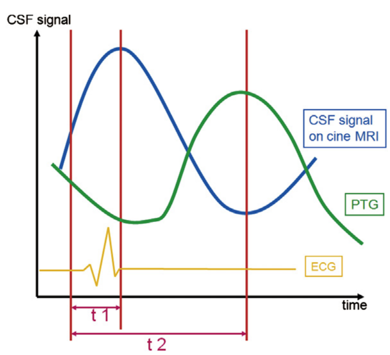

Figure 1. The principle of brain surface motion imaging. Method of measuring time delay between the photoplethysmogram wave and the highest and the lowest point of the cerebrospinal fluid signal on cine magnetic resonance imaging, shown as t1 and t2. *CSF*, cerebrospinal fluid; MRI, magnetic resonance image; *PTG*, photoplethysmogram; *ECG*, electrocardiogram. (Modified from: Yamada S, Nakase H, Hirabayashi H, Park YS, Taoka T, Kichikawa K: The novel MR imaging technique for meningiomas: brain surface motion image [in Japanese]. In: Haraoka J, ed. Brain tumor surgery science, art and technology. Tokyo: Narunia; 2010:203-208 [25].)

Evaluation

Three neurosurgeons comprehensively evaluated tumor—brain adhesion based on intraoperative findings using video recordings of microsurgeries and surgical records; 3 neuroradiologists comprehensively judged the findings of BSMI. Previous reports suggested that the level of edema in MRIs was correlated with the level of adhesion. We therefore hypothesized that adhesion would be present in patients who showed edema on T2-weighted MRIs. The effectiveness of BSMI was evaluated by comparing the presence of edema in T2-weighted MRIs, the prediction of adhesion in BSMI, and actual surgical findings. Cases were evaluated as exact when the findings of edema in T2-weighted MRIs, BSMI findings, and surgical findings all matched, as effected when only the BSMI findings and surgical findings matched, and as false when the BSMI findings and surgical findings did not match.

RESULTS

Of a total of 86 patients, 26 were excluded because surgery was performed at another institution or they were recurrent patients. BSMI was performed in the remaining 60 patients (24 male and 36 female patients; mean age 63.7 years). Table 1 shows patient clinical characteristics. No complications were associated with the examination.

Of the 60 patients, 27 (45.0%) were judged as adhesion (+) and 33 (55.0%) as adhesion (−) from BSMI, whereas surgical findings evaluated 22 (36.7%) as adhesion (+) and 38 (63.3%) as adhesion (−). The sensitivity and specificity were both high, at 95.5% and 84.2%, respectively (Table 2).

According to our classification, 41 (68.3%) cases were evaluated as exact, 12 (20.0%) as effected, and 7 (11.7%) as

Table 1. Patient Clinical Characteristics

Characteristics	Number (%)
Mean age in years (range)	63.7 (31—87)
Gender	
Male	24 (40)
Female	36 (60)
Side	
Right	26 (43.3)
Left	27 (45)
Bilateral	7 (11.7)
Location 1	
Frontal	33 (55)
Parietal	8 (13.3)
Occipital	5 (8.3)
Temporal	2 (3.3)
Skull base	9 (15)
Cerebellum	3 (5)
Location 2	
Convexity	29 (48.3)
Falx	11 (18.3)
Parasagittal	11 (18.3)
Sphenoid ridge	7 (11.7)
Clivus	1 (1.7)
Tuberculum sella	1 (1.7)
World Health Organization tumor grade	
Grade 1	48 (80)
Grade 2	11 (18.3)
Grade 3	1 (1.7)