Predicting Meningioma Consistency on Preoperative Neuroimaging Studies

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KEYWORDS

• Meningioma • Consistency • Firmness • Texture • MRI • Prediction • Neurosurgical planning • Minimally invasive neurosurgery

KEY POINTS

- There are currently no validated neuroimaging techniques to predict preoperative meningioma consistency.
- T2-weighted imaging evaluation is relatively straightforward and may be useful. However, further validation is needed.
- Little is known about advanced MRI techniques, such as diffusion MRI, magnetic resonance (MR) elastography (MRE), and MR spectroscopy. Of these techniques, MRE and diffusion tensor imaging appear particularly promising.

INTRODUCTION

Meningioma is the most common primary brain tumor.[1] With surgery being a primary mode of therapy, minimally invasive alternatives to conventional open approaches to the resection of intracranial meningiomas, such as keyhole or endoscopic transnasal approaches, have recently become more commonplace in tumors of the skull base.[2–5] However, proper patient selection is critical to determine which neurosurgical operation is most appropriate for a given patient. Multiple factors, such as tumor location, invasiveness, encasement of vital structures, and vascularity, must be taken into consideration.[3,6–8] Tumor consistency, also referred to as firmness or texture, is another factor that has been increasingly recognized as an important criterion to consider before a meningioma operation. Multiple reports have described the significance of a meningioma's consistency to determine surgical planning and expectations regarding the extent of resection.[3,9–13] Furthermore, this information can be very helpful when patients are counseled regarding potential risks and length of operating time.[14] This is particularly true for tumors that demonstrate extremes of consistency (ie, extremely soft vs extremely firm). Although it appears that water and collagen content are important determinants

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of meningioma consistency, no definite association with histopathological subtype has been established.[2,5–7,15–17] This review summarizes the current neuroimaging literature as it relates to the preoperative evaluation of meningioma consistency.

REFERENCE STANDARDS OF MENINGIOMA CONSISTENCY

Before delving into the neuroimaging aspects of meningioma consistency determination, it is necessary to consider what reference standards are being used when a neuroimaging method is being evaluated for its discriminative ability. In 2013, Zada and colleagues[2] proposed a meningioma consistency grading system based on an ordinal scale rather than simply labeling meningiomas as either "soft" or "hard." The impetus for their approach was due to the common practice in neuroimaging studies of *retrospectively* using this binary approach based on neurosurgical operative reports, a method that also failed to recognize areas of mixed consistency within the tumor. Their 5-point scale was based on the surgeon's ability to internally debulk the meningioma as well as the ease with which the tumor capsule could be folded after debulking. A grade of 1 corresponded to an extremely soft tumor that required only suction for internal debulking and either had no capsule or the capsule was easily folded. At the other extreme, a 5 represented a calcified, extremely firm tumor with a density that was close to that of bone and whose rigid capsule did not allow for collapse or folding. Debulking of these tumors was difficult despite the use of ultrasonic aspiration, cautery loop, or sharp/mechanical dissection. Using this scale, 2 neurosurgeons independently evaluated 50 consecutive patients with meningioma who underwent surgical resection in a *prospective* fashion. The investigators found that this proposed grading system resulted in a high degree of user agreement between the 2 surgeons for overall tumor consistency. The investigators of a very recent neuroimaging study of meningioma consistency felt that the Zada classification resulted in less variability and subjectivity compared with a neurosurgeon's qualitative assessment of "hard" versus "soft."[5] Utilization of grading schemes such as those proposed by Zada and colleagues[2] may allow for more objective comparison of studies examining meningioma consistency.

NEUROIMAGING STUDIES OF MENINGIOMA CONSISTENCY

There have been a variety of neuroimaging approaches that have sought to predict meningioma consistency. However, there have been conflicting results and *no* universally accepted method has been established to date. These studies have used imaging approaches ranging from conventional imaging (MRI, computed tomography [CT]) to the application of advanced MRI techniques (**Box 1**).

Conventional MRI

Most of the literature concerned with imaging prediction of meningioma consistency has used conventional MRI techniques. **Table 1** provides on overview of these studies. To the best of our knowledge, the earliest of these was that by Chen and colleagues[16] from our institution. Their retrospective study of 54 patients found that hyperintensity on T2-weighted imaging (T2WI) relative to gray matter was associated with soft tumor consistency. On the other hand, T1-weighted imaging (T1WI) had no association with consistency. Indeed, multiple other studies have shown that there is an association between signal intensity on T2WI and meningioma consistency.[4,6–9,14,17–21] The hyperintensity on T2WI of soft tumors may be related to higher water content, whereas the lower signal on T2WI for hard tumors might be due to less water and more collagen and calcium content.[5,6,8,16,17,20,21] Increased cellularity is also thought to play a role in decreasing signal intensity on T2WI. Its interaction with fibrous content and interstitial fluid, which may increase signal intensity on T2WI, can affect signal intensity in a complex manner that could limit diagnostic accuracy of meningioma consistency prediction.[22]

Most conventional MRI studies have not found that there is an association between T1WI and meningioma consistency.[4,6–8,16] However, in one study, Hoover and colleagues[14] found that meningiomas that were hyperintense on T2WI and hypointense on T1WI were more likely soft, whereas

Box 1
Various neuroimaging techniques that have been examined to predict meningioma consistency

- Conventional MRI: mainly T2-weighted imaging
- Diffusion MRI: diffusion-weighted imaging and diffusion tensor imaging
- Magnetic resonance (MR) spectroscopy
- MR elastography
- Dynamic contrast-enhanced MRI
- Magnetization transfer MRI
- Conventional computed tomography