Nerve sheath tumors (NSTs) may present with progressive neurological symptoms and loss of function requiring early operative management. However, operative management of NSTs remains challenging, given that 10%–55% of patients suffer postoperative deterioration of motor function. Intraoperative monitoring is of vital importance to minimize the risk of iatrogenic nerve injury during tumor resection. At present, there is not an established method to identify the location of normal nerve tissue within the tumor mass prior to surgery. Although preoperative MRI studies, including MR neurography and tractography, have proven useful in identifying the location of the tumor and its relationship to other anatomical structures, they often require proprietary MR sequences, image processing, and substantial cost. In the present study, we prospectively explored the capacity of preoperative high-resolution ultrasonography (HRUS) to predict the location of normal nerve fascicles and correlated the findings of HRUS with those of MR tractography and intraoperative electrophysiological mapping of NSTs.

**Methods**

Two patients with suspected upper limb NSTs were
evaluated with clinical examination, HRUS studies, and MR tractography prior to resection. Intraoperative electrophysiological mapping of the tumor was performed to confirm the location of functional nerve tissue. A common nomenclature specifying the position of nerve fascicles in relation to the tumor was agreed upon prior to the commencement of the study: Orientation was described along the anterior and posterior, medial and lateral, superior and inferior, and proximal and distal axes with the body in standard anatomical position.

High-Resolution Ultrasonography Studies. HRUS studies of the brachial plexus and proximal upper limb nerves were performed with a portable Mindray M7 ultrasonic imaging system using a 6–14 MHz linear transducer. The HRUS studies were performed in the preoperative suite immediately prior to surgery by an investigator (N.G.S.) who was blinded to the patients’ clinical information and results of MRI examinations. Tumors were systematically analyzed in the axial and longitudinal planes to assess for the presence of normal nerve fascicles associated with the tumor. Power Doppler imaging was performed when necessary to differentiate nerve structures from vessels. Representative images were exported in TIFF format.

MRI Studies. Diagnostic MRI studies of the relevant peripheral nerves were performed on a 3-T scanner (GE MR750, GE Healthcare). MRI sequences included T1-weighted imaging, T2-weighted imaging with fat saturation, and diffusion tensor imaging (DTI). Tractography was performed off-line. DTI was performed using single-shot echo-planar imaging (28 directions, TR 3000–3300 msec, TE 63–68, FOV 18–24 cm, 256 × 144, 3.0/4.0 mm, b-value 600 sec/mm²), from which apparent diffusion coefficient and fractional anisotropy (FA) values were calculated. Tractography was performed by placing seed points along the peripheral nerve element involved by the tumor, using an FA minimum threshold of 0.18 and a maximum turning angle threshold of 45°. MRI studies were reported by an investigator (C.C.) prior to surgery, including the location of nerve fascicles in relation to the tumor.

Intraoperative Electrophysiological Studies. Each patient was evaluated with electrophysiological studies during the surgical procedure. The stimulus threshold needed to obtain a motor response was recorded by direct stimulation of the nerve proper, either proximal or distal to the tumor, using a fine-tipped monopolar electrode. The tumor surface was then systematically mapped in a circumferential manner using a stimulus intensity at least 0.2 milliamps above threshold for eliciting a motor response. In general, white nerve fascicles could be seen clearly under the microscope (magnification of 3x to 5x) where electrical stimulation elicited muscle contraction. These white nerve fascicles differed in appearance from tumor tissue, which was usually gray and did not show a longitudinal fascicular pattern under magnification. The investigator interpreting the electrophysiological results from mapping the tumor surface (R.N.) was blinded to the results of the MRI and HRUS studies. Resection of the tumor mass was guided by a combination of intraoperative electrophysiological stimulation and recording techniques and microscopic visualization of nerve fascicles using standard peripheral nerve surgery techniques.

Correlation of Imaging and Electrophysiological Studies. Following each surgery, the results of the MRI, HRUS, and intraoperative electrophysiological studies were compared. The location of nerve fascicles using each modality was noted and the correlation between the techniques was evaluated.

Results

Case 1. This 14-year-old girl presented with a 2-month history of worsening pain and intermittent numbness of digits 1–3 of the right hand. Seven years previously she had a schwannoma resected from the median nerve near the axilla following the identification of a mass. There was no family history of neurofibromatosis or peripheral NSTs. Physical examination demonstrated a small, round, firm, tender, superficial mass under the prior surgical scar on the medial aspect of her right upper arm. Muscle strength and sensation in the limb were normal.

HRUS studies identified a hypoechoic mass measuring 1.5 cm × 1.5 cm in the axial plane and 5 cm in the longitudinal plane. The median nerve was identified proximal and distal to the tumor and demonstrated a fascicular pattern characteristic of the sonographic features of normal peripheral nerve. At the region of the tumor, the median nerve fascicles were noted to fan out and curve around the posterior surface of the lesion (Fig. 1B and D). There was no fascicular pattern apparent over the anterior and lateral surfaces of the tumor. Power Doppler studies did not identify blood flow in the nerve fascicles associated with the tumor.

MR tractography was reported to show posteromedial deviation of the nerve fibers by the mass, consistent with the findings noted on ultrasound (Fig. 1A and C), and FA values suggested intact axons in the same regions where HRUS identified a fascicular pattern. Diffusion sequences demonstrated an apparent diffusion coefficient of 1.8 mm²/sec, suggestive of a benign tumor.

At surgery (Fig. 2 left), an incision in the medial aspect of the proximal arm was performed to expose the median nerve tumor. There were several superficial sensory nerves that were scarred and were isolated away from the underlying tumor. Direct electrical stimulation demonstrated the presence of intact motor fascicles over the medial and posterior aspects of the tumor but not along its anterior and lateral surfaces. Under the microscope, a longitudinal incision was performed along the anterolateral surface of the tumor where there were no motor responses, and a gross-total resection was achieved. Postoperatively, sensation was intact and muscle strength was normal in the upper limb. Histopathological evaluation demonstrated features consistent with a schwannoma.

Case 2. This 40-year-old woman presented with a 2-year history of increasing right supraclavicular neck swelling. She reported that the mass was tender to palpation, which elicited a sharp electrical-like pain down her arm terminating in her fourth and fifth digits. She also ex-
experienced tingling in her palm if she agitated the mass or raised the right arm above her head. There was no family history of neurofibromatosis or peripheral NSTs. Physical examination demonstrated a tender mass over the right neck above the medial clavicle. Percussion of the mass precipitated dysesthesias radiating distally in a C-8 spinal nerve distribution. Muscle strength and sensation in the limb were normal, and deep tendon reflexes were present and symmetrical with those elicited from the contralateral upper limb.

HRUS studies identified a mixed-echogenicity tumor associated with the lower trunk of the brachial plexus and measuring 3 cm × 2 cm in the axial plane and 5 cm in the longitudinal plane. The spinal nerves and trunks of the brachial plexus proximal to the tumor and the brachial plexus elements distal to the tumor appeared of normal caliber and were hypoechoic, characteristic of the sono- graphic findings of the normal brachial plexus. Distinct nerve fascicles were identified over the posterior, inferior, and anterolateral aspects of the tumor (Fig. 3B and D). There was no fascicular pattern identified over the anteromedial quadrant of the tumor. Power Doppler studies did not identify blood flow in the nerve fascicles associated with the tumor.

The results of MR tractography were reported as showing fiber tracts coursing over the posterior, inferior, and anterior aspects of the tumor (Fig. 3A and C). The apparent diffusion coefficient of the tumor was 2.0 mm²/sec, consistent with a benign pathology.²

At surgery (Fig. 2 right), a curvilinear incision was made over the tumor mass above the clavicle. Direct electrical stimulation of the tumor identified functioning nerve tissue over the posterior, anterior, lateral, and anterolateral aspects of the tumor. There was no response to stimulation of the medial and anteromedial aspects of the tumor. Subsequently, the tumor capsule was entered along the medial aspect and the tumor was dissected away from the functioning nerve tissue. Postoperatively the patient experienced numbness along her right upper medial arm and normal muscle strength in the limb. Postoperative MR neurography demonstrated no residual tumor. Histopathological evaluation demonstrated features consistent with a schwannoma.

Discussion

In the present study, patients undergoing resection...
of a peripheral nerve schwannoma were evaluated with HRUS, MR tractography, and intraoperative electrophysiological mapping to determine the location of normal nerve tissue. The study demonstrated that HRUS was able to delineate normal nerve tissue from tumor. More importantly, it correctly distinguished the regions of the tumor adjacent to functioning fascicles (as identified by intraoperative electrophysiology) from those without overlying functioning motor nerve fibers. These findings suggest that HRUS examination of patients with peripheral NSTs prior to surgery may provide critical information for planning the surgical procedure and surgical approach. It may also prove useful to identify patients most at risk for iatrogenic neurological injury.

Avoiding injury to motor nerve fascicles is a paramount objective of benign NST resection. Presently, this is achieved using careful surgical technique, including operative microscopy, in combination with intraoperative electrophysiological monitoring. Additional techniques, such as diffusion weighted MRI and DTI, have been explored as methods to characterize lesions prior to surgery, although the application of MRI techniques to identify normal nerve tissue and hence aid surgical planning has not as yet been described.

With improvements in technology and resolution, HRUS has been increasingly employed in the evaluation of peripheral nerve disorders. HRUS has some advantages over other imaging modalities. HRUS studies are relatively quick to perform and may be performed using portable units in clinic, periaoperative, and operative suite settings, thus facilitating expeditious and contemporaneous assessments at the time of clinical decision making. HRUS assessments are also able to characterize the nature of tissues surrounding nerve structures, such as adjacent blood vessels, as well as characterize the vascularity and consistency of the tumor. There are considerable cost savings when comparing HRUS with other imaging modalities such as MRI.

Previous studies using HRUS to study peripheral NSTs have focused on distinguishing between schwannomas and neurofibromas. Typically, it has been challenging to distinguish between peripheral NST types using ultrasound alone. However, the position of the tumor relative to the nerve may provide supportive evidence. In particular, schwannomas characteristically appear as elongated spindle-shaped masses oriented longitudinally and eccentrically in relation to the nerve, displacing normal nerve tissue. Conversely, the nerve and tumor tend to be more intermixed and may be indistinguishable in neurofibromas, particularly of the plexiform type. Recent studies have demonstrated the usefulness of ultrasound-guided nerve mapping in facilitating surgical access to a targeted nerve. It is noted that the present study is the first to address the use of HRUS to delineate the location of nerve fascicles relative to tumor tissue in schwannomas.

On the basis of the findings of the present study, HRUS may be considered a potentially valuable investigation in the preoperative work-up of patients with suspected NSTs, to identify the location of normal nerve tissue in relation to the tumor. HRUS may also be useful to help avoid neurovascular structures in percutaneous biopsies of suspected NSTs, especially in deep or surgically difficult locations. Further studies may be valuable to determine the sensitivity of HRUS for the detection of nerve fascicles in schwannomas at other locations, and the ultrasound characteristics of nerve fascicles within neurofibromas and malignant NSTs.

Conclusions

The present study provided illustrative examples of the capacity of HRUS to identify the location of normal nerve tissue in association with schwannomas. The findings suggest that HRUS may be considered as a valuable supplementary investigation in the preoperative work-up of NSTs. Identifying the location of normal nerve tissue prior to surgery may more fully inform the surgeon about the likelihood of iatrogenic nerve injury during percutaneous biopsy or open resection of the tumor, and may help guide the choice of surgical technique.

Disclosure

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Mapping of nerve fascicles before schwannoma resection


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