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IDEAS AND INNOVATIONS

Hand/Peripheral Nerve

Vascularized, Denervated Muscle Targets: A Novel Approach to Treat and Prevent Symptomatic Neuromas

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Summary: There are many surgical approaches described to treat and prevent symptomatic neuromas, each of which has significant limitations. Here we describe the rationale and technical approach for a novel method that carries the promise of addressing some of these limitations. *(Plast Reconstr Surg Glob Open 2020;8:e2776; doi: 10.1097/GOX.0000000000002779; Published online 21 April 2020.)*

SYMPTOMATIC NEUROMAS: LIMITATIONS OF CONTEMPORARY SURGICAL APPROACHES

When a nerve is transected and not repaired, axons regenerating from the proximal stump will form an aggregate of disorganized neural growth called a neuroma. A subset of neuromas cause debilitating pain.[1] A number of surgical approaches have been employed in an attempt to treat symptomatic neuromas and prevent them before they occur. Although some have shown promise, all suffer from limitations.

Providing a target for the axons from the proximal stump of the injured nerve to reinnervate is the most effective approach to prevent and treat neuromas.[2,3] Restoring continuity to the injured nerve, via primary repair or nerve graft, offers a simple approach to achieve this aim. However, restoring continuity is not always possible or practical. In such cases, one of the earliest described and most widely employed alternative methods involves burying the proximal stump of the injured nerve into nearby muscle.[2] Although there is a pervasive misconception that the bury in muscle (BIM) approach prevents neuroma formation, this is not actually the case. A number of elegant animal studies have demonstrated that already innervated muscle is not receptive to new innervation via direct neurotization.[4–7]

Placement of a muscle graft, or regenerative peripheral nerve interface (RPNI), on the end of the injured proximal nerve stump is another more recently described method for preventing primary or recurrent neuromas. RPNIs were initially developed to amplify signals from the transected nerve stumps and thereby provide control of advanced prosthetics in the setting of limb amputation. In contrast to the BIM approach, RPNIs are denervated at the time of harvest and have therefore been shown to accept reinnervation via direct neurotization from the proximal nerve stump.[8] However, because RPNIs are nonvascularized muscle grafts, they must initially survive via diffusion of nutrients from the surrounding wound bed before revascularization. If too large to allow for sufficient diffusion of nutrients, necrosis will occur. Even when a small muscle graft is placed in an ideal wound bed, some degree of fibrosis and muscle resorption during the healing process is expected.[9] This raises concern about whether RPNIs provide sufficient receptors to accept all of the axons regenerating from the proximal nerve stump, particularly when larger caliber nerves are being treated.

Targeted muscle reinnervation (TMR) is another method, predating RPNIs, that was initially used in the setting of amputation to amplify signals for intuitive prosthetic control[10] and was later found to be an effective method to treat and prevent symptomatic neuromas.[11,12] TMR involves transferring the proximal nerve stump of an injured nerve into a nearby distal motor branch. Although early results are promising, this approach is not always practical, depending on the proximity of the injured nerve stump to a suitable motor branch and the amount of additional dissection that can be tolerated. Furthermore, the substantial size mismatch that tends to occur between the large caliber proximal nerve stumps and the diminutive terminal motor branches into which they are transferred raises additional concern for substantial axonal escape and neuroma formation at the coaptation site.[13]

VASCULARIZED, DENERVATED MUSCLE TARGETS

Here we describe the technique and rationale for a novel approach to treat and prevent symptomatic neuromas that attempts to address the limitations of the contemporary

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strategies described above. This method provides vascularized, denervated muscle targets (VDMTs) for the axons regenerating from the severed proximal nerve stump to reinnervate. This is accomplished by raising and fully islandizing a portion of muscle on a vascular leash in proximity to the transected proximal nerve stump to be treated. Any nerves traveling with the vascular leash are divided, and the vascular leash is electrically stimulated to ensure complete denervation of the muscle flap (Fig. 1). Following resection of the end-bulb neuroma, the nerve stump is then buried into or wrapped with the VDMT and secured with fibrin glue. Epineurial sutures can be used to secure the nerve stump to the surrounding VDMT if there is concern for tension with postoperative motion. We tend to place the VDMT back into the defect from which it was raised to avoid vascular kinking and contour irregularities; although this raises the potential concern of partial reinnervation from the adjacent cut muscle edge, we hypothesize that any collateralization is insignificant in comparison to the rapid, robust axonal ingrowth from the inset nerve stump. Alternatively, the VDMT can be transposed away from the site from which it was raised to avoid this concern, but care must be taken to confirm maintenance of vascularity if the leash is short and prone to kinking.

VDMTs are in essence vascularized RPNIs. Because they are denervated, VDMTs, like RPNIs, are receptive to reinnervation from axons regenerating from the proximal nerve stump they are used to treat, thereby addressing the limitation of the BIM approach. By maintaining vascularity, VDMTs can be made larger than muscle grafts in size without undergoing necrosis and will heal without ischemia-induced fibrosis and resorption, thereby addressing the limitations of RPNIs. The size limit and dimensions of a given VDMT will depend on the orientation and amount of perfusion provided by the vascular pedicle it is raised on. As with all flaps, intraoperative assessment of perfusion is needed; after being raised, the margins of a VDMT may require further trimming until bright

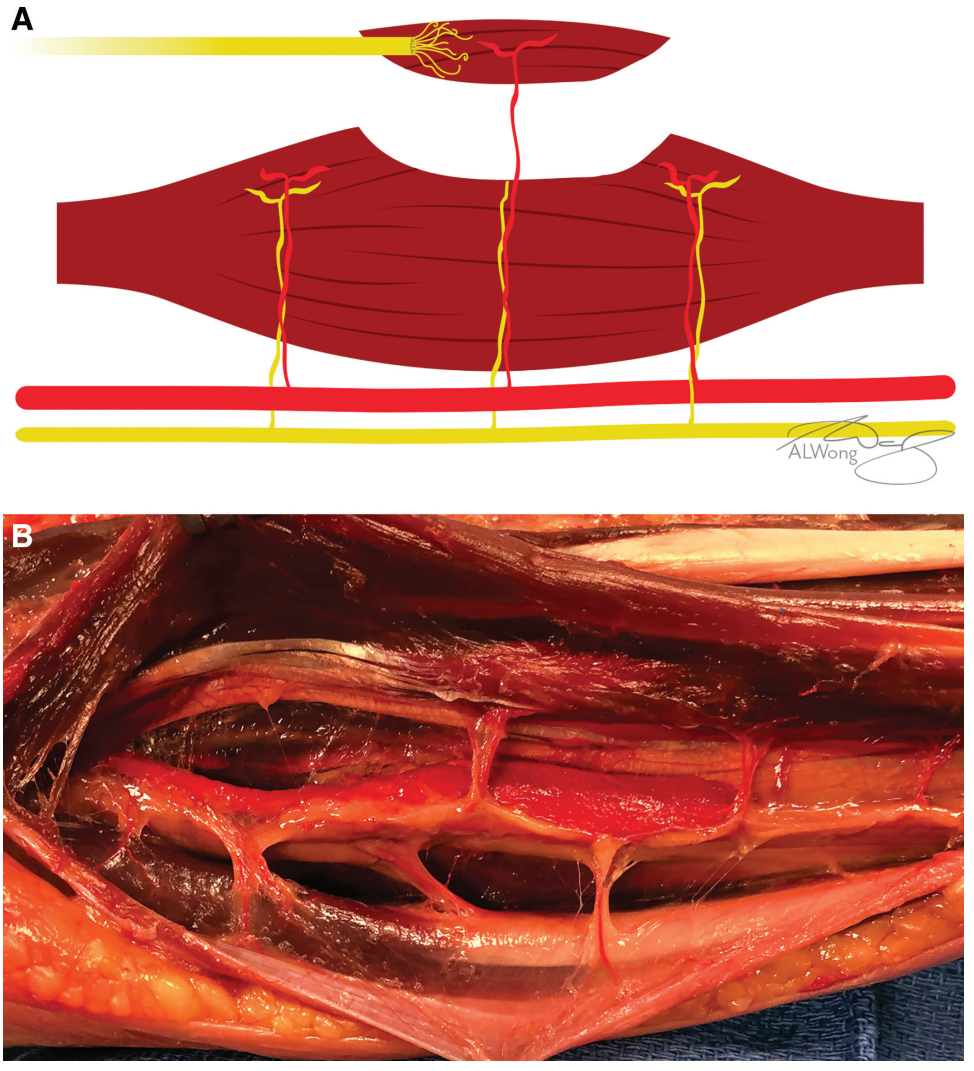

Fig. 1. Pertinent anatomic relationships. A, Schematic demonstrating VDMT islandized on a vascular leash without accompanying nerves and being reinnervated by axons from the proximal nerve stump being treated. B, Dye-injected cadaver forearm specimen demonstrating the abundance of vascular leashes arising from the ulnar vessels and perfusing adjacent muscles. Any of these vascular leashes can be used to design a VDMT.

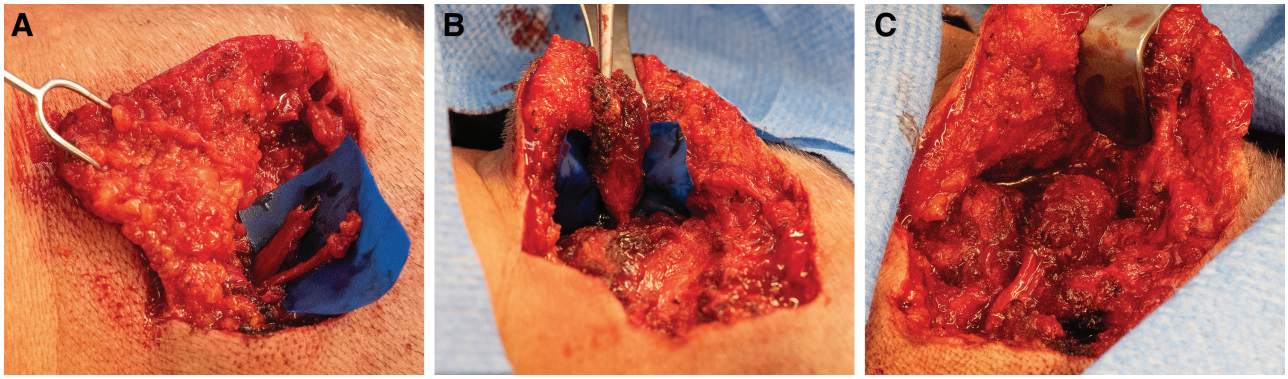

Fig. 2. Intraoperative photographs demonstrating proximal nerve stumps of greater and lesser occipital nerves that were transected during previous tumor resection, resulting in symptomatic end-bulb neuromas (A). A VDMT was raised on intramuscular vessels (B) that were identified with a hand-held Doppler ultrasound within the trapezius muscle adjacent to the neuroma stumps. The vascular pedicle was electrically stimulated to confirm the absence of accompanying nerve branches. Following excision of the end-bulb neuromas to healthy-appearing fascicles, the proximal nerve stumps were buried within the VDMT (C) and secured with epineurial sutures followed by fibrin glue (not shown).

red bleeding is observed. Relatedly, the optimal ratio of muscle volume to incoming axons to prevent neuroma formation is not known and should be a topic of further study. From a practical standpoint, vascular leashes arising from larger blood vessels that perfuse adjacent muscle can be found in abundance throughout the extremities with greater prevalence than motor branches suitable for TMR (Fig. 2). When a vascular leash entering a muscle is not accessible in proximity to the neuroma stump, VDMTs can be raised on terminal vessels within the muscle substance that can be readily located with a hand-held Doppler. That being said, there are some clinical scenarios in which raising a VDMT of sufficient size and proximity to a neuroma stump is either not possible or would compromise the function of the muscle from which it is raised (ie, in the hands and face). In such cases, when the caliber of the neuroma stump to be treated is small, the use of an RPNI may be optimal. This will depend on the yet unanswered questions of how much muscle bulk is needed to accept a given number of axons and how large an RPNI can be without undergoing necrosis or excessive resorption.

CONCLUSIONS

VDMTs offer a number of compelling, theoretic benefits that address some of the limitations of the contemporary surgical approaches used to treat and prevent symptomatic neuromas. Here we describe and demonstrate the feasibility of the technical approach, which can be readily applied to most sites in which neuromas occur. We have just recently begun employing this technique to treat patients, and reportable outcomes data are still lacking. Comparative studies with long-term outcomes are needed to confirm the hypothesized benefits of this novel approach.

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