

Limb Loss as Salvage: Reinventing Amputation for the 21st Century

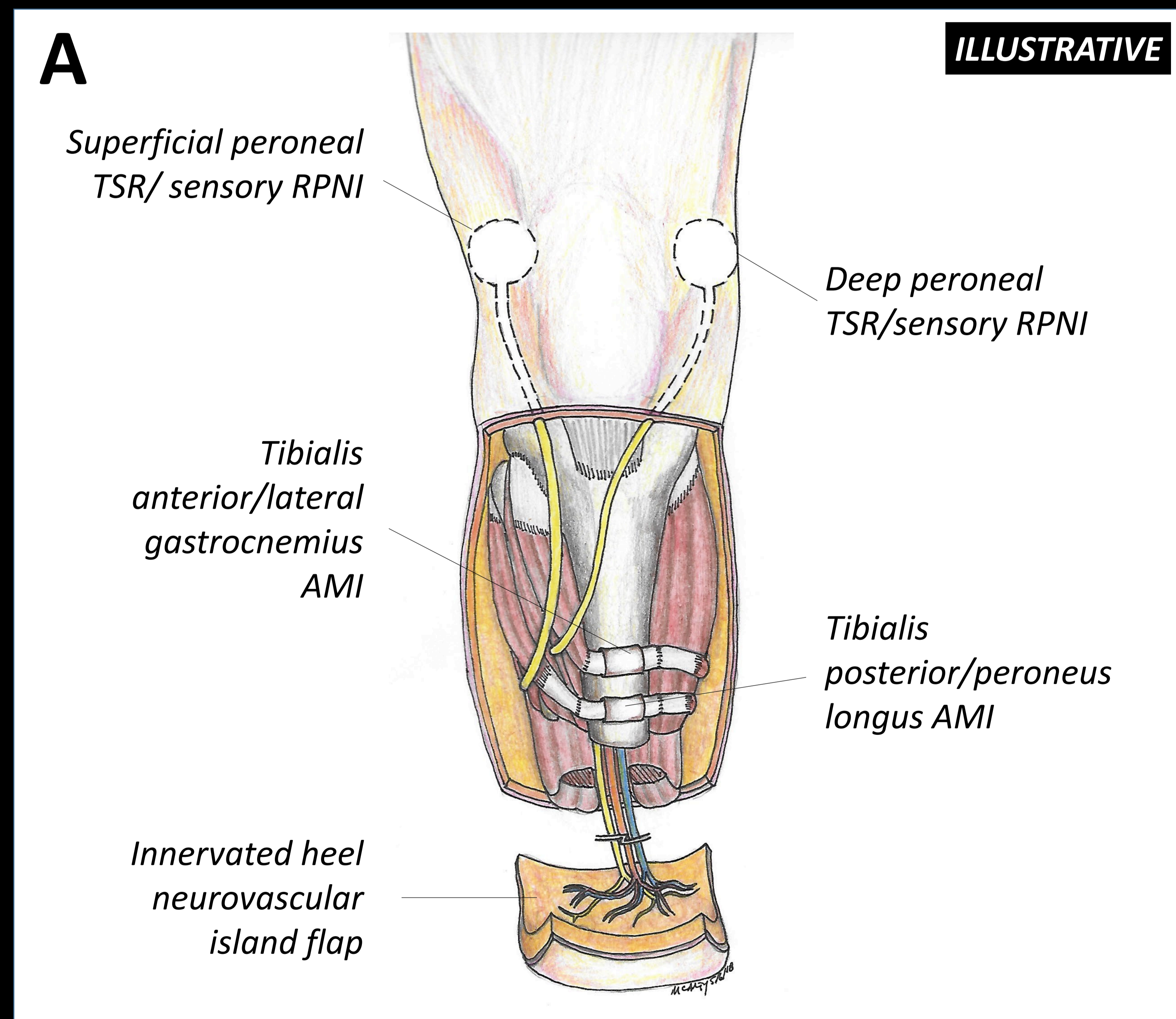
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In light of dramatic advancements in external prosthetic limb technology and limb transplantation, the standard surgical paradigm for amputation no longer represents the best the field has to offer. We propose a reinvention of the manner in which limb amputation is performed, framed in the context of time-tested reconstructive techniques, as well as novel surgical procedures including targeted muscle/sensory reinnervation (TMR/TSR), regenerative peripheral nerve interfaces (RPNI) and agonist-antagonist myoneural interfaces (AMIs). Implementation of the proposed techniques in the acute setting has the potential to elevate advanced limb replacement strategies to a clinical solution with outcomes on par with, or perhaps exceeding, what is possible through traditional surgical approaches to limb salvage. We therefore argue that amputation, performed with the intent of optimizing the residuum for interaction with either a bionic or a transplanted limb, should be viewed not as a surgical failure, but as an alternative form of limb reconstruction.

Proposed Approach

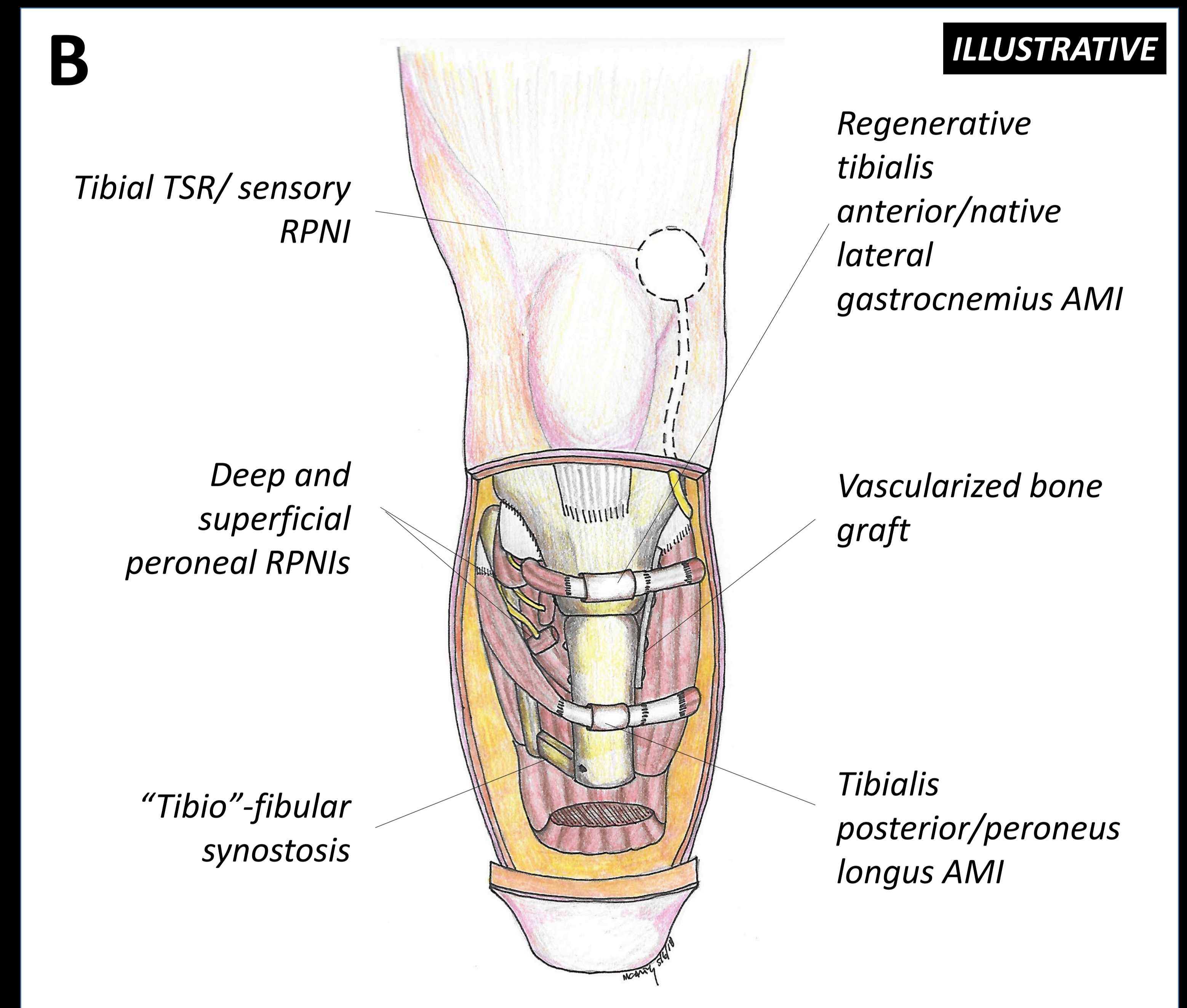
The specific clinical approach we advocate depends upon the amount of intact distal tissues available at the time of amputation. The intents of this approach are to maximize eventual motor control, establish sensory feedback pathways, prevent neuroma development and, when feasible, enable optimal downstream biological restoration.

A. Full Availability of Distal Tissues: The ideal circumstance is one in which the patient demonstrates fully intact distal soft tissues but requires amputation due to chronic pain or joint instability. In this scenario, we advocate the utilization of natively innervated and vascularized muscles that once controlled joints contained in the amputated segment to construct AMIs in the residual limb. Near-anatomic length may also be preserved for both distal muscle organs and sensory nerves through the fabrication of regenerative constructs (either TMR, RPNI or AMI), with coiling or wrapping of the excess nerve length within the confines of the residual limb soft tissue envelope. When possible, the distal residual limb envelope may be augmented by incorporating neurovascular island flaps derived from the palmar or plantar skin to maintain fine sensory perception in these receptor-dense tissues.



B. Incomplete Availability of Distal Tissues: A less ideal but arguably more common scenario is one in which some, but not all, distal tissues are intact at the time of limb amputation (e.g., motor vehicle accident, thermal injury, ballistic injury, oncologic condition). In this circumstance, we advocate the utilization of natively innervated and vascularized muscles to construct AMIs where possible, followed by the utilization of regenerative approaches to establish relays for large joint control and to achieve nerve length preservation for distal sensory and motor nerves.

Consideration may also be given to the utilization of distal neurovascular island flaps for residual limb resurfacing, or vascularized or non-vascularized bone grafting from the amputation segment in order to augment bony length and establish distal tibiofibular or radioulnar synostoses. In this scenario, temporary coverage through means such as skin grafting and/or local tissue rearrangement may also be warranted as a bridge to optimal amputation.



C. Minimal or No Availability of Distal Tissues: The third clinical scenario is one in which no distal tissues remain intact for recruitment at the time of amputation (e.g., traumatic amputation). In this circumstance, we advocate the construction of native models where possible, followed by regenerative models (i.e., TMR/TSR, RPNI, and regenerative AMI), with the primary intent of establishing large-joint sensorimotor control and preventing neuroma formation. Grafting of nerves from the amputated limb may also be considered as a means to restore and preserve the distal nerve tree, assuming that the limb is available and the nerves demonstrate appropriate integrity. This scenario may also warrant consideration of free tissue transfer resurfacing of the distal residual limb in order to preserve residual limb length, assure stable padding and protect innervated constructs created at the time of amputation.

