▽ Editorials

Finding Nerves Is Not Simple

It should be easy to get a needle next to a nerve. First, there are many books, articles, and now web sites that tell us where to find the target nerve. Second, a needle provokes a characteristic sensory event when it makes contact with the nerve. Finally, current injection through the searching needle makes proximity to the nerve evident by provoking distal motor activity. However, the clinical feat of driving a needle up to a nerve remains one of the most challenging aspects of anesthetic practice to master. Although books may provide handsome pictures, anatomy is variable and patients come in many different shapes. And now we learn that the 2 preferred methods used to gain clues to the needle tip location do not direct the needle to the same final resting site. In this issue of *Regional Anesthesia and Pain Medicine*, Karaca et al.[1] report that a carefully guided stimulating needle produces minimal sensory excitation despite activating efferent motor pathways. Reciprocally, Choyce et al.[2] and Urmey and Stanton[3] have shown that a needle that produces a paresthesia through contact only inconsistently produces motor activity when current is passed through it. At first glance, this appears paradoxical, but instead, I believe it is just unexpectedly complex.

As pointed out by Karaca et al.,[1] electrical stimulation produces preferential motor excitation probably because of the high inherent sensitivity of large myelinated Aα motor fibers to excitation by an electrical field, compared with the less excitable sensory fibers. There is well-known heterogeneity of membrane function among fibers serving different physiologic modalities, with nonmyelinated C fibers being most resistant to field stimulation. A differing mix of voltage-gated membrane channels for peripheral neurons with particular functions accounts for this diversity of response threshold, with a central role played by sodium channel subtypes that display distinct kinetics and respond at different voltage levels. This is fortunate because a motor response can usually be achieved using currents that, at most, arouse a nonpainful tactile sensation from activation of large myelinated sensory fibers. Therefore, the selective electrical stimulation of sensory fibers observed by Karaca et al.[1] rests on well-recognized electrophysiological mechanisms. There is also not much uncertainty why electrical stimulation usually occurs in the absence of mechanical paresthesia. Bollini et al.[4] report in this issue that further advancement of the needle beyond the depth that produces a motor response by current stimulation will cause a mechanical paresthesia by contact. Evidently, electrical nerve location works at a somewhat greater distance than mechanical paresthesia.

How a sensory event is produced by the contact of a needle against a nerve is somewhat less clear. Karaca et al.[1] offer the view that direct needle contact with the nervi nervorum on the epineural surface of the nerve trunk produces the expected sensation, but this explanation is unappealing to me for several reasons. These small nerves are found only at a low density,[5] so needle contact would be improbable, and they are unmyelinated afferents, which typically transmit a slow, toothache-type pain, not the immediate, electrical jolt characteristic of mechanical paresthesias. Also, similar to visceral afferents, they project to secondary dorsal horn neurons that show substantial convergence from receptive fields in various tissues,[6] making this pathway an unlikely electrophysiologic substrate for

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See Karaca et al. page 380 and Bollini et al. page 384

the exact somatotopic radiation experienced during needle stimulation. The nervi nervorum have been shown to secrete inflammatory mediators when stimulated.[7] The lack of evidence of nerve inflammation after needle paresthesia further indicates there is probably only minimal contribution of these afferents. An alternative explanation for mechanically induced paresthesia is needed.

Although it is not the job of an axon to generate signals other than at its terminus, mechanical stimulation of the central portion of axons may, under certain conditions, produce bouts of excitation. Actual transection of a nerve fiber reliably produces a burst of activity[8,9] because of the so-called demarcation potential that appears between the exposed cell interior and the outer environment. This mechanism is not a likely explanation of needle paresthesia because no such permanent damage is otherwise apparent. However, even distortion of a nerve will cause activity.[10] Somata of sensory neurons manufacture mechanosensitive membrane channels that admit a current carried by calcium or sodium ions when deformed.[11,12] These channels are transported peripherally[13] and can be assumed to reside in the membrane of the peripheral axon. Their opening by the encroachment of a needle tip would depolarize the nerve and generate a brief interval of afferent signals.

In a manner opposite to electrical stimulation, needle contact provokes an intense sensory experience but modest motor response. If sensory fibers can be mechanically stimulated by a needle, shouldn't motor ones do so as well? It is possible that mild motor events are triggered by mechanical contact (I can see small movements in my hand when rubbing my ulnar nerve in the ulnar groove) but are concealed by the reflexive movement that usually accompanies the startling sensation of a mechanical paresthesia. Alternatively, the number of motor fibers activated mechanically by a needle tip may be inadequate to generate an obvious movement. There is an additional molecular basis for expecting a selective sensory reaction to mechanical stimulation because the mechanosensitive ion channels may be restricted to primary sensory neurons.[13]

Therefore, the processes of electrical and mechanical nerve stimulation can be explained on a neurophysiologic level. A bigger remaining question is how the finding of Karaca et al.[1] (that electrical nerve location creates no sensory event) can be reconciled with the observations of Urmey and Stanton,[3] as well as Choyce et al.[2] (that a needle placed by mechanical paresthesia need not activate motor pathways when attached to a current source). Together, these facts dictate that we accept a substantial degree of functional and anatomic heterogeneity within peripheral nerves. In fact, nerves are not homogeneous unitary structures filled with a well-shuffled mix of sensory and motor fibers. Rather, as detailed by Sunderland,[14] the axons are gathered up into fascicles that join and divide repeatedly to form a complicated network inside the bulk of the nerve (Fig 1). These fascicles may number in the dozens and occupy as little as a quarter of the cross-sectional area of a peripheral nerve, the rest taken up by the loose areolar tissue of the epineurium. The ratio of the area of fascicles to epineurial tissue is lowest where nerves cross joints, which are also common sites of neural blockade. It is therefore possible, and in many cases likely, for a needle to enter a nerve without contacting any sensitive neuronal tissue. The surplus path length and dispersion of fascicles inside nerves provides for increased tensile strength, flexibility, and movement of the internal components of the nerve, which incidentally equips a fascicle to slide away from an encroaching needle, and to allow the nerve to yield to compressive forces without damage to the fascicles.

Proximal to the departure of a nerve branch, the plexiform division and rejoining of fascicles within nerves disperses the fibers of the branch among many fascicles, which accounts for the relatively minimal functional loss that follows proximal partial nerve transections. Nonetheless, sensory and motor elements are largely segregated to different fascicles within a nerve. For instance, microelectrode stimulation of individual fascicles of the median nerve in the upper arm confirms that fibers bound

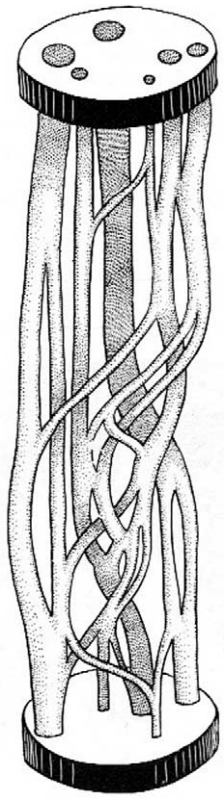

Fig 1. A drawing of a 3.5-cm length of musculocutaneous nerve, showing the multiple intertwined fascicles containing axonal fibers. Not shown, between the fascicles, are the nonneuronal connective tissue elements of the epineurium, which make up the preponderance of nerve volume. (Reprinted with permission.[14])

for cutaneous branches are largely grouped in separate fascicles from fibers destined for branches innervating muscles,[15] as must be the case if a block needle can produce a mechanical paresthesia yet no motor activity by electrical stimulation. Additionally, very proximal injections, including interscalene blockade, may encounter incompletely mixed motor elements from the anterior root and sensory elements from the posterior root.[16] At distal sites such as the median nerve at the wrist, fibers that constitute terminal branches group together within the nerve trunk[17] and, when stimulated, produce a purely sensory response for cutaneous fibers or a motor response for muscle fibers.

Still, there is a missing piece. If a needle advanced to the endpoint of a mechanical paresthesia is then used to emit current, why is a motor response not provoked by stimulation of neighboring motor fascicles? Such failure of motor stimulation evidently occurs less often in the middle of a nerve (8% of the axillary blocks of Choyce et al.[2] using stimulation up to 1mA) than proximally (70% in the data of Urmey and Stanton at 1mA,[3] 38% in the data of Bollini et al.[4] at 0.5mA), perhaps related to the greater segregation of modalities at the roots of the plexus. Two possible explanations may account for stimulation failure after paresthesia. First, the sphere of electrical stimulating current around the needle tip may be smaller than the distance between the relevant fascicles. Currently, there are no detailed investigations on the dimensions of the stimulating field. Second, very close proximity with a fascicle might shunt current away through the highly conductive neural tissue of the fascicle instead of through the poorly conductive epineurial tissue.[18] Consistent with this, Urmey and Stanton[3] noted both a greater probability of motor stimulation after mechanical paresthesia and a very low current requirement when stimulating with a noninsulated needle compared with an insulated needle that produces a current

distribution focused on the tip. The findings of Bollini et al.[4] are also relevant. After achieving a motor response by electrical stimulation, all of their cases in which this response is lost as the needle is advanced to produce a mechanical paresthesia nonetheless regain a motor response as the needle is withdrawn. This sequence is compatible with either of the hypotheses mentioned earlier.

A last, critical consideration is whether clinical care should be altered in light of these reports. The concern raised by the studies of Choyce et al.[2] and Urmey and Stanton[3] is that a lack of motor response to electrical stimulation does not indicate a lack of needle contact with the nerve. However, these needles were advanced to their final position with the stimulator off and the electrical current only applied thereafter, which does not duplicate the typical clinical practice. The new data from Karaca et al.[1] and Bollini et al.[4] provide substantial reassurance that the customary approach of continuous stimulation identifies nerve proximity without penetration of a fascicle. I would, nonetheless, need very persuasive indications to depend on this logic in an unconscious patient who could not say "ouch." For that matter, we must recognize that nerve damage is not absolutely avoidable even in an awake patient because we have no direct confirmation that the destructive events of a needle entering a fascicle or even injection into a fascicle are universally painful. Without data, it is not safe to assume that anything is simple.

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