Surgical Anatomy of the Supraclavicular Brachial Plexus

Sophia Leung, MD, Dan A. Zlotolow, MD, Scott H. Kozin, MD, and Joshua M. Abzug, MD

Investigation performed at the University of Maryland School of Medicine, Baltimore, Maryland

Background: Brachial plexus exploration is performed in infants when addressing birth palsies and in children and adults following trauma. The upper trunk is most often injured. Traditional drawings of the brachial plexus depict the suprascapular nerve as a branch of the midportion of the upper trunk, with the more lateral branch of the upper trunk as the anterior division. We have not found this orientation to be accurate in clinical practice. The purpose of this study was to determine the branching patterns of the upper trunk and to delineate nerve orientations at the level of the divisions.

Methods: Bilateral brachial plexus dissections were performed on eight adult cadavers. The length of the upper trunk and distance of the takeoff of the suprascapular nerve from the anterior and posterior divisions was measured. The native positions of the divisions and of the suprascapular nerve from lateral to medial were recorded across all trunks.

Results: In six (38%) of the sixteen specimens, a trifurcation was found at the level of the upper trunk. The suprascapular nerve was the most lateral structure at the clavicular level in all specimens, followed by the posterior division and then the anterior division. The mean distance of the takeoff of the suprascapular nerve was 4 mm proximal to the branch point of the divisions; however, in two specimens, the nerve was found to take off from the posterior division proper.

Conclusions: These findings differ from the standard illustrations and descriptions of the brachial plexus. A thorough understanding of the course of the upper trunk and its branches, such as the suprascapular nerve, is vital to performing nerve transfer surgery or neuroma excision and grafting.

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The brachial plexus is a complex network of nerves that conveys motor function and sensation to and from the upper extremity. The anatomy of the brachial plexus, as well as of the more common variants, has been described for decades[1,2]. The brachial plexus was first recognized as early as 400 B.C.E., and first studied in the medical literature in the context of birth injuries[3]. In 1918, Kerr performed dissections of 175 cadaveric specimens, and initially described what he termed the *true form* of the brachial plexus[3].

The brachial plexus is typically formed by the anterior rami of the fifth through eighth cervical spinal nerves and the first thoracic spinal nerve. The upper two roots, C5 and C6, unite to form the upper trunk, while C7 continues on as the middle trunk, and C8 joins with T1 to form the lower trunk[4]. The most commonly described variation is a prefixed plexus, with a contribution from C4, or a postfixed plexus, with a contribution from T2. The prevalence of a prefixed plexus ranges from 28% to 62%, and that of a postfixed plexus, from 16% to 73%[4,5]. At the level of the clavicle, the trunks are thought to give off two branches each, named the *anterior and posterior divisions.* Distal to the clavicle, the anterior divisions of the upper and middle trunks join to form the lateral cord, the anterior division of the lower trunk continues to form the medial cord, and the posterior divisions of all trunks join to form the posterior cord. The medial cord continues and ultimately forms the ulnar nerve. The lateral cord continues and eventually forms the musculocutaneous nerve. The medial and lateral cords provide branches that recombine to form the

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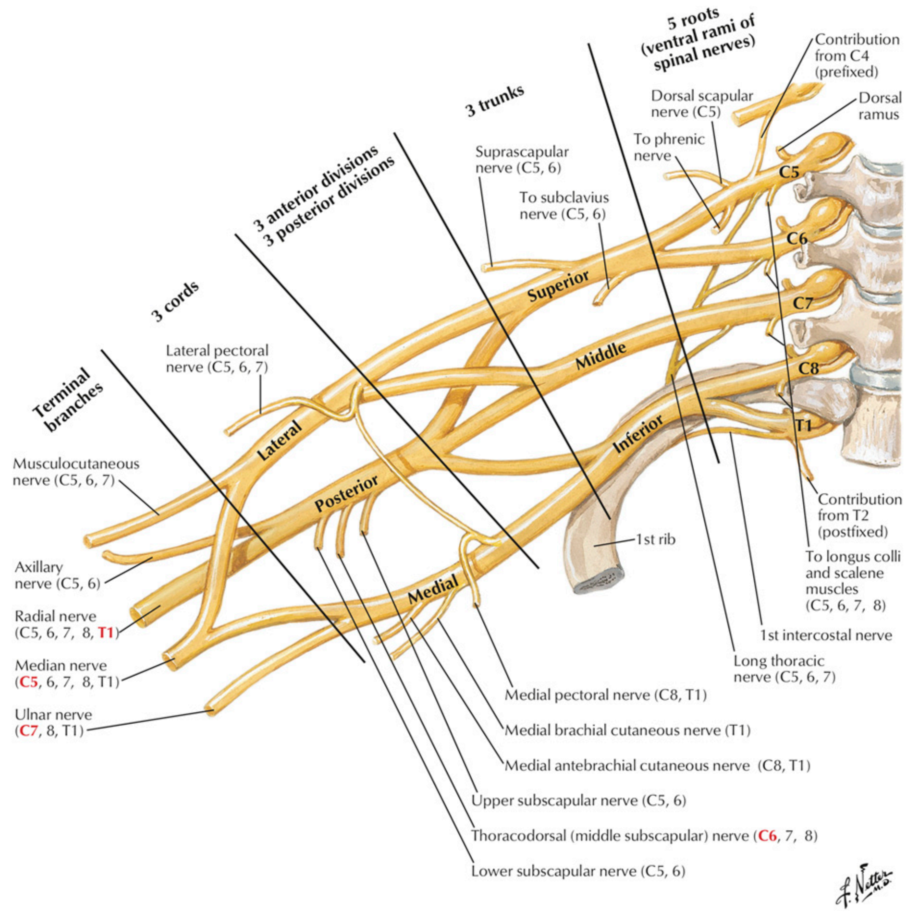

Fig. 1-A

Figs. 1-A and 1-B Traditional depictions of the brachial plexus. The suprascapular nerve is shown to take off proximal to the anterior and posterior divisions at the level of the upper trunk. The anterior division of each trunk is illustrated as being the more lateral structure, and the posterior division, the more medial. (Fig. 1-A reproduced, with modification, from: Netter F. Atlas of human anatomy. 3rd ed. Teterboro, NJ: Icon Learning Systems; 2003. Netter illustration used with permission of Elsevier, Inc. All rights reserved. www.netterimages.com. Fig. 1-B reproduced with permission of Elsevier. This illustration was published in: Standring S. Gray's anatomy: the anatomical basis of clinical practice. 39th ed. London: Elsevier; 2005. p 808. Copyright Elsevier [2005].)

median nerve. The posterior cord terminally bifurcates into the radial and axillary nerves. Along the way, branches emanate directly from the roots, trunks, and cords. The upper trunk of the brachial plexus is thought to directly give rise to three nerves: the dorsal scapular nerve off the C5 root, the suprascapular nerve off the midportion of the upper trunk, and the nerve to the subclavius muscle off the upper trunk[4,6,7]. Recent studies have noted variations in the locations of divisions, with inconsistent branch points and even absent structures[1,2,8-10].

In our clinical experience during surgical exposure of the brachial plexus in infants and young adults, the upper trunk consistently appears to trifurcate into the suprascapular nerve, the posterior division, and the anterior division. The suprascapular nerve is the most lateral structure, followed by the posterior division, and then the anterior division. Shin and Spinner previously described the upper-trunk branch point in adults as a "trifurcation" in a review article, but no related references or data were provided[5]. Clinically, we rely on the trifurcation as a landmark used to identify the suprascapular nerve as the recipient site for nerve grafting and transfer in cases of birth and traumatic brachial plexus palsies. The misidentification of the nerve branches can result in misconnection of nerve ends, making an accurate anatomic understanding of the brachial plexus critical for surgical reconstruction and to clinical outcome. No scientific publication, to our knowledge, has specifically described the trifurcation.

We hypothesized that the uninjured plexus may not have a trifurcation, and that what we see clinically is an aggregation of the branch points of the upper trunk following trauma. A secondary hypothesis was that the orientation of the branches from medial to lateral may also be affected by trauma. In standard depictions of the brachial plexus, the anterior divisions are consistently drawn as the lateral structures, with the posterior divisions positioned more medially[11,12] (Figs. 1-A and 1-B).

The purpose of our study was to examine the uninjured brachial plexus in fresh and fresh-frozen cadavers to determine

TABLE I Comparison of Measurements by Side in Each Specimen

Specimen	Age *(yr)*/Sex	Side	Length of Upper Trunk* *(mm)*	Distance of Suprascapular Nerve Takeoff from Branch Point of Divisions* *(mm)*
1	78/M	Left	31.20	1.56
		Right	35.01	1.44
2	93/M	Left	39.53	0.00
		Right	34.31	1.06
3	84/M	Left	30.03	−7.06
		Right	18.16	5.54
4	89/F	Left	7.38	0.00
		Right	13.18	−5.20
5	84/M	Left	38.53	0.00
		Right	43.94	−5.42
6	79/F	Left	33.72	−3.80
		Right	20.22	−9.75
7	74/F	Left	21.93	−11.76
		Right	28.02	−10.80
8	82/F	Left	26.77	−11.63
		Right	24.03	−8.84

*Values are presented as the mean of three measurements. Positive values indicate a measurement distal to the branch point of the divisions, and negative values, proximal to the branch point of the divisions.

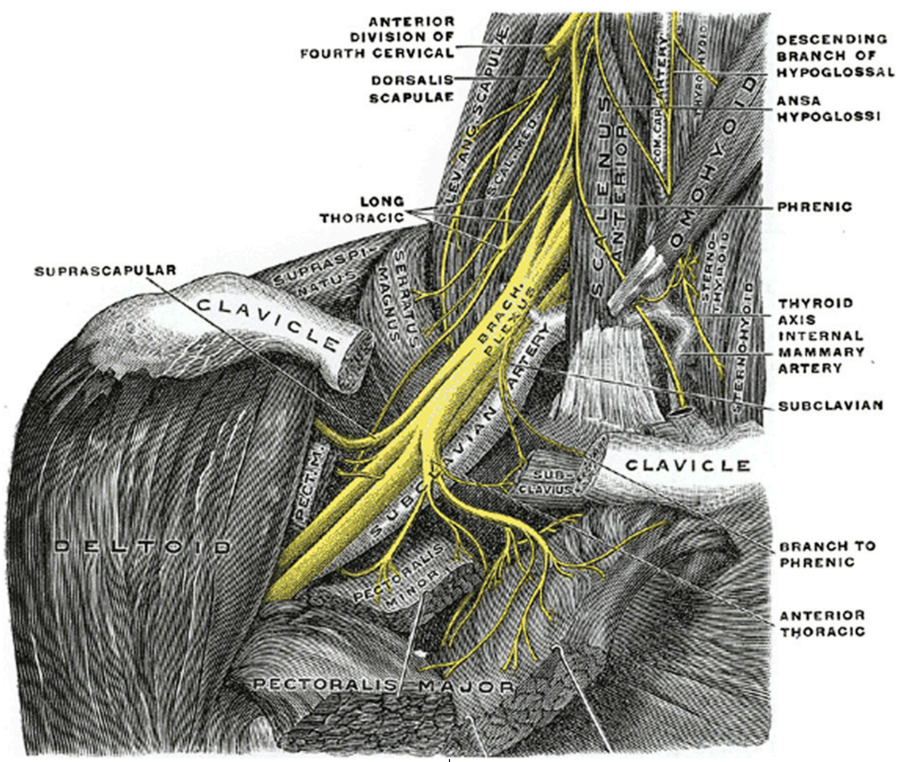

Fig. 1-B

TABLE II Takeoff Points of the Suprascapular Nerve from the Upper Brachial Plexus

Suprascapular Nerve Takeoff	No. of Specimens (N = 16)	Percentage
Upper trunk	9	56
Trifurcation	6	38
Posterior division	1	6

the presence or absence of a trifurcation and to delineate nerve orientations at the level of the trifurcation.

Materials and Methods

For this study, we used eight adult fresh and fresh-frozen cadavers with no anatomic or documented evidence of brachial plexus or other cervical injury. Bilateral brachial plexus dissections were performed via a transclavicular approach. A classic zigzag skin incision was made, starting adjacent to the mastoid process, with the supraclavicular incision along the posterior border of the sternocleidomastoid muscle extending distally to the midclavicular region. The infraclavicular portion of the incision was created by extending the incision toward the coracoid process, then extending further laterally along the deltopectoral groove. An osteotomy was made at the midshaft level of the clavicle to provide maximum exposure. Careful dissection was performed to expose the upper portion of the brachial plexus without disrupting its native anatomy.

Once the upper trunk and surrounding structures were identified, the following measurements were made three times with the use of a digital caliper: the length of the upper trunk from the confluence of C5 and C6 to the branch point of the anterior and posterior divisions, and the distance of the takeoff of the suprascapular nerve from the branch point of the divisions. Mean values were calculated from the three measurements. At the level of the upper trunk, the native positions of the divisions and of the suprascapular nerve from lateral to medial were recorded. Similarly, at the levels of the middle and lower trunks, the native positions of the divisions were recorded, and described as medial or lateral.

Source of Funding

All funding for the cadaveric specimens and materials involved in this study was provided by a University of Maryland School of Medicine, Department of Orthopaedics Intramural Orthopaedic and Musculoskeletal Research grant.

Results

Specimens from four male and four female cadavers were included in the dissections. The mean age at death was eighty-three years (range, seventy-four to ninety-three years) (Table I). In all sixteen specimens, the suprascapular nerve was found to be the most lateral structure at the clavicular level, followed by the posterior division and the anterior division, in that order (Figs. 2-A and 2-B). In all specimens, the three nerve branches were adjacent to each other, creating the impression of a trifurcation. The takeoff of the suprascapular nerve was found to be directly from the upper trunk in nine (56%) of the specimens. In these specimens, the takeoff was a mean of 8 mm proximal to the branch point of the anterior and posterior divisions of the upper trunk, or at 66% of the mean length of the upper trunk. In six (38%) of the specimens, the takeoff of

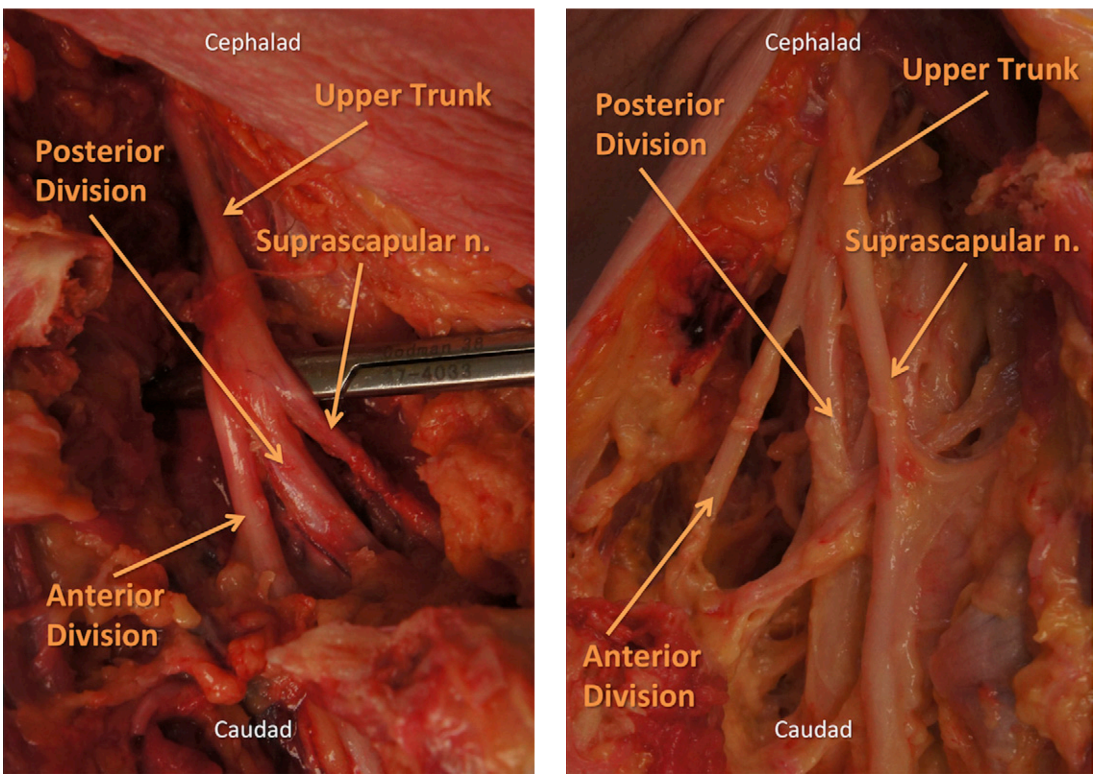

Fig. 2-A Fig. 2-B

Figs. 2-A and 2-B Adult cadaveric specimens of the left brachial plexus demonstrating trifurcation of the suprascapular nerve (n.), the posterior division, and the anterior division.

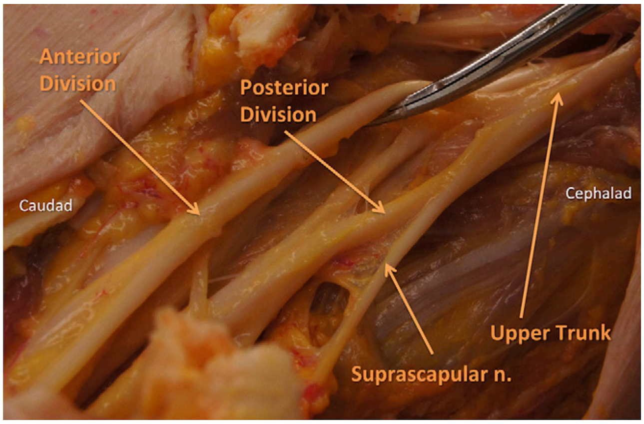

Fig. 3

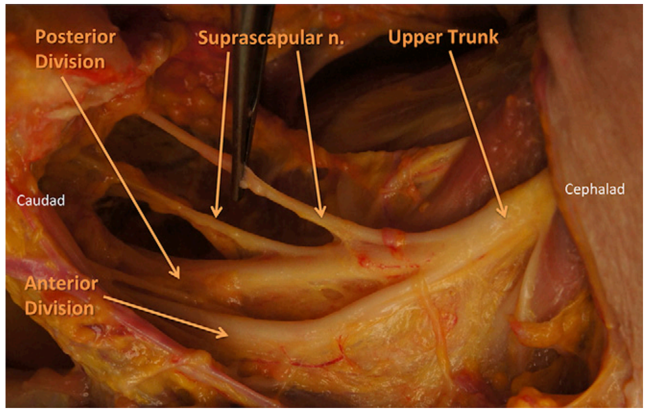

Fig. 4

Fig. 3 In two specimens, the suprascapular nerve (n.) was found to take off from the posterior division proper, as seen here. **Fig. 4** In one specimen, two branches of the suprascapular nerve (n.) were seen: one taking off from the posterior division proper, and the other, "trifurcating" at the level of the upper trunk.

the suprascapular nerve was within 2 mm (0 mm in three specimens) of the branch point of the divisions, and was considered to be a true trifurcation (Table II). This includes direct takeoff from the posterior division proper in two specimens (Fig. 3). In one specimen, two suprascapular nerve branches were seen; one taking off from the posterior division proper, and the other, trifurcating at the level of the upper trunk (Fig. 4). The mean length of the upper trunk was 28 mm (Table I).

The native position of each division at the levels of the upper, middle, and lower trunks was recorded as being more medial or lateral. The posterior divisions were the more lateral structures, and the anterior divisions, the more medial in all sixteen upper and lower-trunk specimens. This was also the case in fourteen of sixteen middle-trunk specimens.

Discussion

The brachial plexus is a complex network of nerves that originates in the neck and axilla, and begins to form during week 5 of embryologic development. Each of the embryonic somites migrates to form extremities, initially in the form of upper-limb buds, and each brings its own nerve supply. Therefore, each myotome and dermatome retains its original segmental innervation. Through the migration process, some of the nerves come into proximity and fuse in a particular pattern, which forms a plexus early in fetal maturation[1,9,13]. With growth of the fetus, there is relative elongation of the neck, as well as alterations of the ribs, which can change the inclination of the neurovascular bundles.

The location of the brachial plexus, along with its relationships to nearby osseous structures, makes it quite vulnerable to injury by traction, penetrating wounds, and compression from cervical rib fractures[1]. Upper-trunk injuries are the most common[14,15]. Brachial plexus injuries occur in patients of all ages, from infancy to adulthood. The plexus is also susceptible to iatrogenic injury during surgical approaches, such as radical neck dissections and procedures involving exposure of the shoulder, clavicle, and axilla[5]. A detailed understanding of the anatomy of the brachial plexus is necessary for accurate diagnosis and effective treatment of these injuries.

The goal of brachial plexus repair, nerve grafting, and nerve transfer is to restore as much function as possible to the upper limb. In upper-trunk palsies, priorities for neural reconstruction include elbow flexion, shoulder movement, and shoulder stability. For the restoration of dynamic shoulder function, the suprascapular nerve is frequently a target for nerve transfer[16]. Reconstructing the posterior division of the upper trunk is also critical for shoulder function, as it provides the primary innervation to the deltoid. The anterior division of the upper trunk conveys the motor axons for the musculocutaneous nerve and sensory axons from the radial side of the forearm and the thumb. When there are insufficient intraplexal donors for nerve grafting directly from the roots to the divisions, a common strategy is to use the single available root to power the deltoid via the posterior division of the upper trunk, and to rely on downstream nerve transfers for restoration of elbow flexion. Intercostal nerves and fascicles of the ulnar and/or median nerves can be transferred to the musculocutaneous nerve or directly to the biceps and/or brachialis motor nerves, bypassing the anterior division of the upper trunk[17-19]. Incorrect placement of nerve grafts from the single available root to the anterior division of the upper trunk along with distal nerve transfers for elbow flexion places the few available intraplexal axons into a dead end and provides no axons for reinnervation of the deltoid. Such errors are particularly possible when only exposing the brachial plexus through a supraclavicular approach, when the divisions cannot be traced distally for identification. Therefore, knowledge of the existence and relative orientation of the supraclavicular trifurcation of nerve branches is critical to reconstructing the upper trunk and to optimizing patient outcomes.

Despite our initial hypothesis that the trifurcation may only be present in the injured plexus, we found the trifurcation in over one-third of the uninjured adult specimens. The

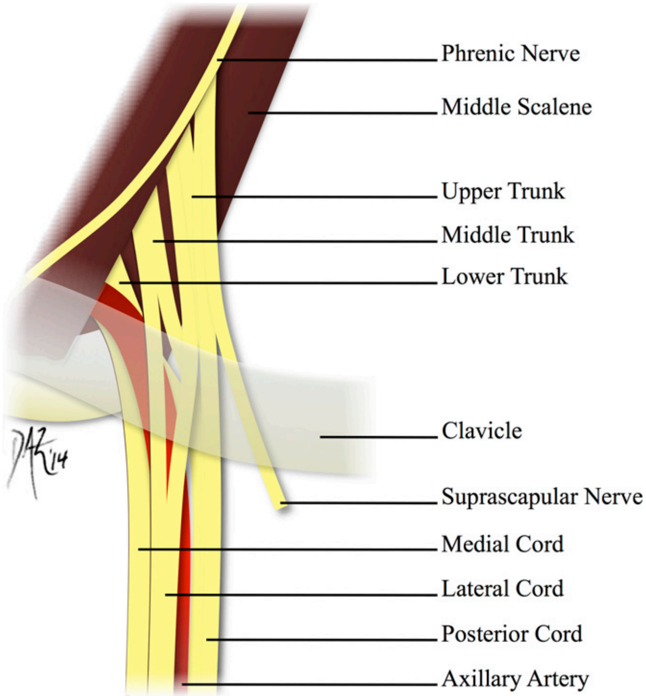

Fig. 5
A schematic representation of the left brachial plexus showing the most common orientation of the divisions seen in the specimens. Note that the orientation of the cords has also been adjusted to correlate with our findings. The upper trunk is shown resembling a trifurcation.

trifurcation of the upper trunk may therefore be a common anatomic variant in the uninjured plexus. In the specimens in which the takeoff of the suprascapular nerve was directly from the upper trunk, as has classically been described[1-3,8-10], the branch point was in the distal half of the trunk in all but one specimen. In another specimen, one branch of the suprascapular nerve was found to take off distal to the branch point of the divisions.

Given our clinical experience, coupled with those of researchers at the Mayo Clinic[5] and many others with whom we have discussed our results, the consistent finding of a trifurcation during surgical dissection may, in part, be an artifact of the injury. Consolidation of the neuroma of the upper trunk may create the appearance of a trifurcation, even in patients in whom a trifurcation was not present prior to the nerve injury. Because of the proximity of these nerves, it is certainly plausible that scarring coalesces all three nerve branches into a trifurcation.

An equally important, and perhaps clinically more relevant, finding is the relative orientation of the nerve branches at the level of the divisions. Unlike in the depictions in major references[11,12], the posterior division of the upper trunk was uniformly more lateral than the anterior division. The clinical implications of this misrepresentation are noteworthy and could lead to improper plexus reconstruction (as described above). Furthermore, in all specimens, the posterior division of the lower trunk was also more lateral than the anterior division. Only in the middle trunk did we find the anterior division arising from the lateral aspect, and only in two (13%) of the sixteen specimens.

The orientation of the divisions in this study does not correlate with the course of the medial, lateral, and posterior cords as has been depicted[11,12] (Figs. 1-A and 1-B). In the common illustration of the plexus, the medial and lateral cords are shown anterior to the axillary artery, and the posterior cord directly posterior. However, in our clinical experience, the posterior cord is more a posterolateral structure, the medial cord is posteromedial, and the lateral cord is anterior (Fig. 5). Our clinical impression is consistent with the results of this study, namely that the posterior divisions are consistently more lateral. Since the posterior divisions are the more lateral structures, this places the posterior cord as the most lateral structure. This orientation also matches the positions of the terminal branches of the brachial plexus. The medial cord terminates as the ulnar nerve, a structure that is posterior to the brachial artery. The radial nerve, as the terminal branch of the posterior cord, is also posterior to the brachial artery, but lateral to the ulnar nerve. The only anterior terminal branches are the median nerve and the musculocutaneous nerve, both of which receive contributions from the lateral cord.

There are many possible explanations as to why we found that the orientations of the divisions differed from those which typically have been described. One possibility is that the illustrations may have been drawn to correlate with the nomenclature, rather than with the observed anatomy. The posterior cord is pictured posterior because it is the confluence of all of the posterior divisions, allowing for a simplification of the anatomy. Because the anterior divisions contribute to the medial and lateral cords, these have been drawn as anterior structures. The true orientation may be more complex. It is also possible that the position of the arm and shoulder during dissection may have rotated the brachial plexus into appearing as it has been drawn. The plexus is often pictured with the shoulder in 90° of abduction (Figs. 1-A and 1-B). In this position, external rotation of the shoulder can potentially rotate the infraclavicular plexus so that the medial and lateral cords both become seemingly anterior structures.

On the basis of the results of this study, surgeons operating on the upper trunk of the brachial plexus should recognize that the divisions and the suprascapular nerve are in proximity and often form or resemble a trifurcation. The most lateral structure is the suprascapular nerve, followed by the posterior division, and then the anterior division. The medial-to-lateral orientation remains true for the lower trunk, but there may be variability in the middle trunk. Surgeons operating on the middle trunk should be aware that the relative positions of the anterior and posterior divisions may be less well defined.

This study had several limitations. As in any cadaveric study, dissection may disrupt the normal anatomy and lead to inaccurate results. In vivo imaging studies are required to confirm our results with more certainty. We were also unable to examine specimens at different stages of development to determine if the anatomy of the brachial plexus changes with age and growth. A clinical study of patients with brachial plexus injuries would also be required to determine if the appearance of a trifurcation is more common after injury. ■

Sophia Leung, MD
Department of Orthopaedics,
University of Maryland School of Medicine,
110 South Paca Street,
6th Floor, Suite 300,
Baltimore, MD 21201.
E-mail address: leungss@upmc.edu

Dan A. Zlotolow, MD
Scott H. Kozin, MD
Shriners Hospitals for Children,
3551 North Broad Street,
Philadelphia, PA 19140.
E-mail address for D.A. Zlotolow: dzlotolow@yahoo.com.
E-mail address for S.H. Kozin: skozin@shrinenet.org

Joshua M. Abzug, MD
Department of Orthopaedics,
University of Maryland School of Medicine,
1 Texas Station Court, Suite 300,
Timonium, MD 21093.
E-mail address: jabzug@umoa.umm.edu

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