Conduction anesthesia of the upper extremity —
A literature and technique review

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The author, who will be presenting a seminar on conduction anesthesia at the 44th AANA Annual Meeting in August, thoroughly reviews the history and clinical techniques of conduction anesthesia of the upper extremity. He draws both from the literature and his own experience. This article will serve as an introduction and reference for those who will be attending Mr. Reese’s sessions in August.

In 1600, Valverdi achieved a type of sensory loss by compressing the vessels and nerves of a region until sensation was lost. James Moore, in 1784, observed similar results by compressing the nerve trunks supplying the upper extremity. In 1843, Alexander Wood described the subdermic application of morphine sulfate in the vicinity of a painful area to relieve the symptoms. The year 1853 saw the introduction of the syringe and hollow metallic needle by Pravaz and Wood respectively.

Dr. William S. Halstead was probably the first person to produce chemical anesthesia of the entire upper extremity when, in 1884, under direct dissection of the neck, he exposed the individual nerve roots of the brachial plexus and topically applied a cocaine solution.

In 1887, J. Leonard Corning injected agents at the cutaneous antibrachial medialis nerve producing sensory loss along its distribution. A direct exposure technique, similar to Halstead’s, was utilized by Dr. George W. Crile in 1897, during which time he injected cocaine solution endoneurally to produce anesthesia for a shoulder disarticulation. August Bier, in 1908, demonstrated the intravenous injection of procaine to produce anesthesia of the entire upper extremity.

In 1911, Hirschel set the stage for modern percutaneous techniques with his description of a blind axillary approach in which he could selectively produce anesthesia of the upper extremity.

Shortly after Hirschel’s article, Kulenkampf described a blind percutaneous technique, which he practiced on himself until perfected, whereby the brachial plexus was approached supraclavicularly at the level of the first rib, making multiple injections on parasthesias until the extremity was anesthetized. In 1916, Kappis described a paravertebral approach utilizing the spinous and transverse processes of the cervical vertebrae.

A year later, Bazy introduced a percutaneous infraclavicular approach which was later modified by Babitzki and Balog. The infraclavicular technique apparently never gained a wide popularity, as it was not again mentioned in the anesthesia literature until 1973. At that time, Raj and associates described a modification utilizing an electronic nerve stimulator to locate the nerves of the plexus.
Technological advances of the 1920's allowed Pitkin to further develop Hirschel's axillary technique by utilizing 7-8 inch needles to place anesthetic agents high along the course of the plexus at or above the level of the first rib.

An uncomfortably high incidence of pneumothorax and undesirable chemical block of the stellate ganglion, vagus, or phrenic nerve; subarachnoid injection; an unreliable and low incidence of successful blocks; and a host of other complications associated with the supraclavicular, paravertebral, and infraclavicular techniques led Reading, in 1921, to reconsider the axillary approach.

From his observations of surgical dissections, Reading described and placed strong emphasis on the existence of a fascial "sheath" which surrounded the structures of the brachial plexus as they traversed the neck into the axilla. He also noted that the musculocutaneous nerve left the fascial sheath 2-3 cm above the level of the axilla and, therefore, required a separate injection to block. His descriptions, while precise and timely, went virtually unheeded for nearly two decades.

In 1927, Livingston and Wertheim, hoping to popularize brachial plexus anesthesia in the United States, modified Kulemkampf's supraclavicular approach making only one injection of medication in the deep cervical fascia without eliciting paresthesias. They, apparently unknowing, had utilized the fascial sheath, as they stated that "the solution rather than the needle will find the cords of the plexus"—an impossible task without such a structure.

During the next two decades, multiple authors described various techniques, apparently ignoring the "sheath" concept, but instead favoring to elaborately identify and inject the various nerves individually. One of these authors, Murphy, alluded to the importance of the fascial sheath by describing a supraclavicular single injection technique in which he noted "increased resistance to injection when higher volumes are reached." This resistance (which would not be perceived if the injection was made into muscle mass) was at the end point of his injection; and although he apparently enjoyed a high success rate, his work went unappreciated until 1958. At that time, Burnham again renewed interest in the sheath concept by describing a technique placing the anesthetic drug superiorly and inferiorly to the brachial artery at the level of the axilla. He described a characteristic "pop" when the needle entered the fascial sheath, upon which he injected the drug without any attempt to elicit paresthesias. Ether, working independently, developed a similar technique but reported subjectively more favorable results when large volumes of drug were utilized.

In 1961, DeJong, using cadaver dissections to affirm these previous observations, described the anatomy of the fascial sheath. He noted that both the musculocutaneous and axillary nerves left the sheath above the level of the second portion of the axillary artery. He proposed that the sparing of these nerves was the most frequent reason for failure of the axillary block technique and that the only consistent method of assuring blockage of these nerves was by the injection of large volumes of drugs. By calculating the volume of a cylinder and assuming that liquid would spread equally in all directions, he determined that a volume of 42 ml would be necessary to force drug to the level of the plexus cords, thereby blocking the musculocutaneous and axillary nerves.

These figures were validated in vivo by Winnie and Collins in 1964, through the use of x-ray and radiopaque dye along with the anesthetic agents. They indicated that if indeed there was a continuous fascial sheath, then a single needle entry anywhere along its course should suffice to deposit drugs. This led to their introduction of the "single needle" axillary technique which would rapidly replace the then popular "above and below" (Burnham) technique. The single needle concept, along with tech-
nological advances of inert, flexible plastic catheters, enabled the introduction of a continuous axillary brachial plexus block.

Developing the volume concept further, Eriksson\textsuperscript{84} introduced the use of a rubber tourniquet which was applied to the upper arm just below the level of the axilla at a time prior to injection of any agents. This was done in an attempt to displace the fluid cephalad, thereby blocking the musculocutaneous nerve with a decreased volume. DeJong\textsuperscript{85}, Moore\textsuperscript{86}, and Winnie\textsuperscript{87} described similar results by holding digital pressure distal to the injection site.

In their 1964 paper, Winnie and Collins introduced their “subclavian perivascular technique”, continuing to place emphasis on the fascial sheath. They described a single needle injection which utilized the anatomical relationship of the brachial plexus and the subclavian artery; the sheath was entered at a point between the anterior and middle scalene muscles and superior to the clavicle. The result of such a technique was an increase in the ease and incidence of a successful block and a decrease in the occurrence of pneumothorax. They further enlarged on this by describing a continuous catheter technique and provided x-ray studies which demonstrated that a decreased volume (20-30 ml) was necessary to produce an anesthesia distribution similar to that of an axillary block using 40-50 ml. By using 40-50 ml with this approach, they were able to produce anesthesia adequate for surgical manipulation of the shoulder.

In the hope of increasing the utility of brachial plexus anesthesia, Winnie\textsuperscript{87} introduced yet a third technique. He suggested that a single needle entry be made between the anterior and middle scalene muscles at the level of the sixth cervical vertebrae. This would block the nerve roots, producing anesthesia of the entire upper extremity and shoulder with a smaller volume than described with previous techniques. Popularly called the “interscalene technique”, it has enjoyed wide acceptance and use.

In 1971, Balas\textsuperscript{88} reported on his experiences using the interscalene technique in combination with a paravertebral block of T2 for patients undergoing orthopedic procedures of the shoulder.

Generally speaking, these “sheath” techniques, or modifications of them, form the basis of current upper extremity conduction anesthesia.

The intravenous technique or “Bier block” enjoyed a resurgence of popularity in anesthesia literature during the late 1960’s and was reviewed by Colbern\textsuperscript{89} in 1972. With the recent advent of sophisticated equipment, the technique remains popular in many practices for surgery/manipulations of the distal arm or leg.

\textbf{Anatomy}

\textit{Brachial plexus.} The anterior rami of the lower four cervical and first thoracic spinal nerves emerge through the foramina formed by the anterior and posterior tubercles of the vertebral transverse processes, merging to form the nerves of the brachial plexus. This elaborate interlacement of nerves traverses the neck, follows the path of the subclavian artery passing below the clavicle, and enters the upper extremity through the apex of the axilla, so as to give rise to the three primary terminal nerves of the arm, the median, radial, and ulnar (Figure 1).

The musculotaneous nerve, which provides motor innervation to the flexors of the arm and sensory innervation to the distal arm, leaves the plexus at the lateral edge of the pectoralis major muscle and enters the substance of the coracobrachialis muscle—a fact that, until demonstrated and studied by DeJong\textsuperscript{82}, was destined to doom the axillary technique from widespread clinical practice. Cutaneous innervation of the nerves of the upper extremity are shown graphically in Figure 2.

\textit{Muscle.} The middle scalene muscle arises from the posterior tubercles of the transverse processes of the lower six cervical vertebrae, travels posterior to the nerve plexus, and inserts on the first
rib posterior to the subclavian artery (Figure 1).

The anterior scalene muscle arises from the anterior tubercle of the transverse processes of C3-6, travels anterior to the plexus and subclavian artery, and inserts on the scalene tubercle of the first rib. The subclavian vein is thus separated from the subclavian artery by the belly of the anterior scalene muscle (Figure 1).

The scalene muscles act as accessory muscles of respiration and, during a slow deep inspiration, can be palpated to contract prior to contraction of the sternocleidomastoid muscle. This serves as an additional aid in proper identification of the “interscalene groove”, which is especially important in the supraclavicular approaches.

Electropectoral sheath. Of particular significance to the anesthetist is the concept and anatomical reality of a continuous fascial “sheath” extending from the transverse processes of the cervical vertebrae which surrounds the brachial plexus and subclavian artery to form a neurovascular bundle. This sheath envelops the plexus throughout its course to the arm and fuses distally with the intermuscular septum of the upper arm (Figure 1).

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Figure 1.
Anatomical relationships of the brachial plexus and classic sites of injection for conduction anesthesia. (1) “Interscalene,” Winnie; (2) “Subclavian perivascular,” Winnie; (3) “Supraclavicular,” Kulenkampff; (4) “Infraclavicular,” Bazy; and (5) “Axillary,” Hirschel.

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Figure 2.
Cutaneous innervation of major nerves of the brachial plexus.
Conceptually, this sheath and neurovascular space may be compared to the epidural space. Theoretically, the anesthetist should be able to enter the sheath at any level along its course and, provided a sufficient quantity of the appropriate drug is deposited, be able to produce conduction anesthesia of all areas innervated by the brachial plexus, namely the shoulder and upper extremity.

DeJong and Winnie using dissection, mathematical calculation, and radiographic techniques indicate that the liquid volume needed to fill this sheath in the average adult is 40-50 ml.

Techniques

In addition to maintaining an active schedule of elective surgical procedures involving the shoulder and upper extremity, we are often asked to provide our services for a number of patients who need surgical or orthopedic manipulative and casting procedures as a result of trauma. This trauma occasionally causes moderate to severe blood loss and seldom occurs in a patient with an empty stomach. The hazards of general anesthesia for such patients is well documented and deserves no further comment here.

For both classifications of patients described, regional anesthesia, and in particular, brachial plexus anesthesia, offers an acceptable alternative to general anesthesia techniques. Regional anesthesia provides these essential requirements: (1) analgesia of the affected area; (2) profound skeletal relaxation, which affords an immobile surgical field, as well as eases the task of manipulation and reduction of fractures; and (3) chemical sympathectomy, which reduces vasospasm and edema. Furthermore, all of these are obtainable without significant systemic physiological trespass for the patient.

Depending upon the specific needs of the situation, we utilize one of two fundamental plexus "sheath" techniques or a combination of the two. As indicated earlier, a myriad of techniques have been proposed by various authors, each having its own merits and failings. The techniques presented are those taught and utilized at the Naval Regional Medical Center in San Diego, California and combine what we feel are the most favorable features of the various techniques heretofore described.

Axillary approach

The axillary block is utilized primarily for patients with surgical needs "below the elbow." The patient is asked to lie in the supine position with the affected arm abducted 90 degrees from the body, with the forearm flexed and externally rotated so that the dorsum of the hand is lying on the table or pillow aside his head—resembling a military salute. When patient discomfort or trauma prevents this position or if infection is noted in the vicinity of the axilla, the technique is abandoned in favor of a supraclavicular approach.

Pulsation of the axillary artery is digitally palpated as far proximal as the border of the pectoralis major muscle. An intradermal wheal is made with .5% Xylocaine® or .1% procaine, using a 26-gauge needle. A 1 1/4-inch, 22-gauge needle (with a fluid-filled, intravenous-extension tubing attached) is placed through the skin wheal and directed superiortly and medially to the pulse, forming an acute (10-20°) angle with the artery until a distinct "click" or "pop" (indicating penetration of the fascial sheath) is perceived. The needle is then advanced parallel to the artery 1-2 cm.

When the needle is properly placed, the anesthetist can demonstrate a visual pulsation of the needle hub (Figure 3), responding simultaneously to the arterial pulse next to which it lies. Failure to demonstrate this needle pulsation may be taken as indication to reposition the needle. Paresthesias, while not specifically sought in this approach, are useful and can indicate when the needle is approaching correct placement. We tend to emphasize "good needle bounce" more so than paresthesias.
Occasionally, the needle will penetrate the axillary artery or vein. Moore\(^8\) suggests slowly withdrawing the needle until blood cannot be aspirated, and then injecting the desired volume. We suggest totally withdrawing the needle, holding digital pressure at the puncture site for 2-3 minutes so as to prevent hematoma formation in the sheath, and then continue with the technique as before. Vascular puncture is of no significant consequence unless a hematoma forms or the blood return goes unnoticed and a drug is injected.

Arterial injection of epinephrine-containing solution may result in sequelae related to severe vasoconstriction in the distal arm, while intravenous injection may result in systemic central nervous symptoms of agent overdose which could include seizure activity. Careful attention to detail will prevent such complications, but should they occur, some authors have advocated intravenous doses of muscle relaxants\(^6\), barbiturates, or diazepam\(^3\) to attenuate the symptoms. We must condemn the use of relaxants for this purpose, as their use may make an unfortunate situation potentially life threatening. We have found that when central nervous system stimulation does occur as a result of intravascular injection, patients generally require only moderate systemic cardiovascular and respiratory support until the activity subsides. This is because the manifestations are usually short lived.

The predetermined volume of drug(s) (based on patient weight, height, and physical status) is injected with frequent aspiration of the syringe to obviate intravascular injection. When the desired volume is injected, the syringe is removed from the extension tubing, and the tubing connector is observed for fluid return. As the fascial sheath is only a partially distensible space, a drop or two of fluid will generally be noted to flow from the tubing if the volume is correctly placed within the sheath. A failure to note such fluid return should alert the anesthetist to the possibility of intramuscular injection, with predictably poor results.

Air is then aspirated into the syringe, and the syringe is replaced on the extension tubing. As the needle is slowly withdrawn from the sheath, the syringe plunger is advanced, forcing any remaining medication in the extension tubing (approximately 3 ml) into the subcutaneous tissue. Thus, the intercostobrachial nerve is anesthetized as it runs superficial to the sheath.\(^4\) The intercostobrachial nerve (“T2”) supplies cutaneous sensation to the upper-inner aspect of the upper arm (Figure 2) and must be anesthetized if an upper arm tourniquet is to be used for even a short time. This nerve does not exist in the fascial sheath and, therefore, must always be blocked separately. Failure to recognize and individually block this nerve has resulted in numerous reports of brachial plexus block “failures” and conversions to general anesthesia.

As with any anesthetic technique, the axillary approach to the brachial plexus has distinct disadvantages as well as advantages. The predominate disadvantage to this approach is the occasional failure to adequately anesthetize the lateral antebrachial cutaneous (musculocutaneous) nerve as it branches.
from the lateral cord of the plexus and leaves the fascial sheath at the level of the neck of the humerus, or approximately 3 cm proximal to the injection site described earlier. This nerve carries sensory fibers from the radial aspect of the palmar and dorsal sides of the forearm (Figure 2). This is, unfortunately, a common incisional site, as well as the frequent site of forearm fractures requiring reduction and casting.

Several methods to anesthetize this nerve separately\textsuperscript{10, 35, 45} have been described, but a lack of well-defined landmarks have made blockage of this nerve elusive and reproducible success unreliable.

DeJong\textsuperscript{82} and Winnie\textsuperscript{88} have advanced the idea of injection of large volumes (40-50 ml) into the sheath at the axillary level, while others\textsuperscript{34-37} have advocated the use of a tourniquet or digital pressure distal to the injection site. In theory, each of these methods is supposed to force the fluid in a cephalad direction, thus bathing the nerve as it branches and leaves the sheath. We have found the tourniquet and digital pressure of little clinical use, and the high volume method of only limited reliability.

Another reason for an inadequate block is the anesthetist's failure to recognize that the plexus and sheath are superficial structures within the axilla. Deep intramuscular injection may be the result of overzealous needle exploration while the anesthetist is trying to elicit a paresthesia. Marked pulsation or "bounce" of the needle (even if placed immediately next to the axillary artery) will not be noted if the needle tip has penetrated the posterior wall of the sheath. Slow withdrawal of the needle until the "bounce" is noted will generally ensure success.

The much feared complication of pneumothorax, as well as chemical block of the phrenic, vagus, stellate ganglion, cervical plexus, epidural, or subarachnoid structures is virtually impossible. This feature makes bilateral axillary block a viable consideration when so indicated.

When postoperative analgesia and/or sympathectomy is desired, a continuous application\textsuperscript{38, 46} may be gained by inserting a "catheter-over-needle" (20-22-gauge) appliance, taping it in place, and connecting intravenous extension tubing and a syringe. Maintenance is similar to that of an epidural catheter.

Once the technique is completed, we observe for signs of block onset by asking the patient to "touch his nose" with his thumb. As the extensors of the forearm (radial nerve) are the first muscle group affected, the patient will be able to lift his arm from the bed, but when the forearm approaches the vertical position over his chest, the hand will fall flaccidly to his chest. Guard the patient's face when asking him to try this maneuver, especially when the hand is in a cast or heavy appliance.

The ulnar nerve provides motor innervation to the flexors of the forearm and last three fingers of the hand. Consequently, blockage of this nerve can be predicted by observing for attenuation of the patient's ability to "make a fist". In contrast, the patient's inability to utilize the extensors of the fingers to "open a fist" against resistance forewarns of impending radial nerve blockage.

The musculocutaneous nerve supplies the motor fibers of the biceps. Thus, onset of the patient's inability to lift his arm from the bed will indicate blockage of this important nerve, and will generally be the last motor function attenuated with this technique.

When such movement of the extremity is severely limited by dressings or appliances, one can discriminate the onset of blockage by stimulating the "autonomous sensory zones" of the major nerves (Figures 4 and 5) with an alcohol sponge or needle point. (The sponge is actually preferred, as it decreases the possible additional contamination. These autonomous sensory zones are areas of skin supplied by only one
major nerve without overlap from others. These observations, when positive within 5-10 minutes from injection (depending on specific characteristics of the agents injected), will generally assure adequate blockage if allowed to "soak" for an additional 10-15 minutes—the usual turnover and "prep" time in a busy operating room.

Supraclavicular approach

On occasion, the anesthetist is asked to provide anesthesia for surgery of the upper arm and/or shoulder, which is by no means an impossible task with regional anesthesia. Again, both an interest in and understanding of the anatomy of the brachial plexus and an appreciation of the fascial sheath is paramount if one is to be successful with this technique.

The patient is asked to lie in the dorsal recumbent position with his arms at his side. The head is flexed opposite the side being injected, with the face remaining forward so as not to distort the anatomy of the neck—a common problem when the head is turned to the side. The patient is asked to "reach for his toes" with the arm of the side to be injected, thereby causing flexion of the neck muscles and depressing the clavicle and shoulder.

The muscular anatomy of the neck is then palpated, beginning with the lateral border of the clavicular head of the sternocleidomastoid muscle. Lateral to this, one can feel the anterior and middle scalene muscles. The scalene muscles are accessory muscles of respiration; and on slow deep inspiration, they can be palpated to contract a short time prior to contraction of the sternocleidomastoid muscle.
This maneuver will assist the anesthetist in properly locating the muscles and subsequently the "interscalene groove" which is so important to this technique. The index finger is placed inferiorly in this groove until the pulsation of the subclavian artery is noted. Identification of this structure, which runs between the anterior and middle scalene muscles (Figure 1), will ensure proper location of the injection site.

Keeping the index finger on the pulse, the anesthetist then makes a skin wheal of 0.5% Xylocaine® solution at a point approximately 1 cm above the finger along the interscalene groove. A 1½ inch 22-gauge hypodermic needle attached to fluid-filled intravenous extension tubing and syringe is advanced at right angles to the skin of the neck through the skin wheal until a "pop" (the fascial sheath) is perceived. The needle is then slowly advanced until a paraesthesia radiating to the distal arm (below the elbow) is noted by the patient. This paraesthesia is essential and confirms the needle's presence within the fascial sheath. Upon identification of this paraesthesia, the anesthetist turns the needle caudad and advances it to the hub. This ensures placement of the needle tip as far distal in the sheath as possible.

The syringe is then aspirated to ensure that a vascular structure has not been violated. Finally, the medication is injected.

A variation of this includes the use of an indwelling plastic catheter to provide continuous analgesia or sympathectomy.38, 46

Depending on the choice of drug(s) and their concentration, the onset of the block will be noted in 3-15 minutes, with the flexor and abductor muscle groups being the first affected. The patient's inability to elevate his arm from his bed is an early sign of a successful block.

Combined technique

As mentioned previously, it has been our experience that the axillary technique will frequently spare a complete block of the musculocutaneous or radial nerve, while the supraclavicular technique may spare the ulnar distribution. These "failures" require corrective and time-consuming measures, including a repeat of the technique or alternative sheath approaches, individual nerve "touch-up" injection, local infiltration by the surgeon, large systemic doses of analgesic or tranquilizer medications, or induction of general anesthesia.

We have found that simply increasing the total volume injected during either the axillary or supraclavicular techniques, as described by some authors, does not provide a clinically significant increase in successful results and often places the total dosage in excess of established toxic ranges. Repeat of the technique is often difficult or impossible because of distortion of the anatomy and attenuation of paresthesias from the previously injected agents. Furthermore, when the technique is utilized again, it often places the total dosage in unacceptable ranges. Isolation and injection of individual nerve branches requiring paresthesias are again difficult, since there is partial loss of sensation from previously injected agents and surgeons are often unwilling to infiltrate at the operative site.

We hold the practice of "covering" inadequate regional anesthesia with systemic analgesics or tranquilizers as unacceptable and cannot condone their use for this purpose. Brachial plexus conduction anesthesia is often utilized for patients who are not properly prepared physiologically for general anesthesia (those cases involving hypovolemia or full stomach). As such, these patients must be considered at additional risk should the regional technique fail to prove adequate for surgical needs. Whenever possible, surgery should be postponed 6-8 hours, the physiological parameters treated, and the regional technique repeated.

When a delay is impossible, time
must be taken to ensure a properly conducted rapid-sequence induction, intubation of the trachea, and maintenance of systemic anesthesia. Furthermore, the anesthetist must bear in mind the possible presence of exogenous catecholamines in the agents used for the regional technique, prior to the commencement of surgical intervention.

All of the aforementioned alternatives are felt to be incompatible with our large-volume acute care practice; therefore, we frequently combine the axillary and supraclavicular techniques previously described, utilizing a calculated total volume based on 1 ml/2-inch patient height, of a .4% or .8% Xylocaine® solution with epinephrine 1:200,000 to which we add .2% Pontocaine®. This allows for rapid onset (3-10 minutes), moderately long duration (120-180 minutes), and a total agent dose that remains well below established toxic levels.

One-half of the predetermined volume is injected via the axillary route and is followed immediately by the second half via the supraclavicular approach. This combined technique with separate blockage of T2 has provided us with the ability to provide reliable results of both early onset and complete anesthesia of the upper extremity —using the same or lesser volume than one would normally use in a single technique.

Discussion

The use of brachial plexus conduction anesthesia is but one of many ways in which to prepare patients for surgical/orthopedic manipulation procedures. In the training program at our institution, conduction anesthesia is considered a fundamental application of anesthesia knowledge and, as such, deserves the same attention and consideration as any other anesthetic technique.

The values as well as deficiencies must be considered in light of the patient's condition, surgical needs, and the anesthetist's preference and abilities, just as with any anesthetic technique. All students must demonstrate a thorough knowledge of anatomy, physiology, pre- and post-operative care, as well as the fundamentals of sterility and technique prior to clinical application. This fundamental premise, along with strong motivation on the part of students, reveals no significant differences in skill mastery between physician and nursing students.

It seems indeed unfortunate that some would advocate legislation which would deny some providers the ability to provide patients with this efficacious form of anesthesia care.

REFERENCES


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The author wishes to state that the opinions or assertions contained in his article are his private views and are not to be construed as official and or reflecting the views of the Department of Anesthesiology, Naval Regional Medical Center, San Diego; the Navy Nurse Corps; the Department of the Navy; or Department of Defense.

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