Welcome to another talk in André Boezaart’s “Must-Know Anatomy for Regional Anesthesia and Acute Pain Medicine” lecture series. This lecture is an outline of the microanatomy of the brachial plexus.
The series is authored by André Boezaart, who is a Professor of Anesthesiology and Orthopaedic Surgery at the University of Florida College of Medicine.
Introduction and brief historical overview
Our understanding of the microanatomy of the central and peripheral nerves has been advanced by the very recent work of Henning Andresen and his coworkers, …
Manoj Karmakar and his colleagues, …
… and most recently by the beautifully illustrated Atlas of Miguel Reina and a whole host of co-authors and collaborators.

You are encouraged to study these publications.
What is particularly interesting is that these newer works have basically confirmed and verified what has been written by giants such as Daniel Moore (left), Dag Selander (middle), and Gale Thompson (right) many years ago, to name a few, and perhaps forgotten by all of us that tried to follow in their footsteps. The newer authors have reminded us of these microanatomic facts, and with more modern techniques such as high-definition ultrasound, electron microscopy, etc., have better explained and defined, and basically verified what has been known for many years.
For example, Gale Thompson described the paraneural sheaths around the brachial plexus back in 1983 in *Anesthesiology* (pp. 117-22), although he did not name it such, …
… while Labat in 1923, Moore in 1952, and Dag Selander in 1983 wrote about the paraneural spaces and what they meant in terms of devastating outcomes of some regional anesthetic procedures around spinal roots. But these authors were years ahead of their colleagues who did not always understand the meaning and implications of these micro- and ultrastructural concepts.
These images from Gordinier’s 1899 textbook on the “Gross and minute anatomy of the nervous system”, for example, are remarkably similar to modern images.
See, for example, the remarkable similarity between the electron microscopic ultrastructure of the nerve root on the right-hand side with that on the left-hand side from Gordinier’s 1899 textbook showing the paraneural spaces.
Also note how accurate, even in modern terms, this depiction from the work of Keys and Retzius was in 1876.
Brachial plexus: MICROANATOMY
Reina and his colleagues have specifically stained oblique vertical microscopic sections of the lateral aspect of the neck with Masson’s tricolor stain to show the paraneural sheath. This sheath has more recently, perhaps more correctly in etymological terms, been named the circumneural sheath⁶. Reina, et al. clearly demonstrated this sheath in the more central spinal roots, although this circumneural sheath has been well known in peripheral nerves, as lately highlighted by Anderson and Karmakar among others. It was known for years as the “gliding apparatus” in neurosurgical literature. Not until the work of Reina did we fully understand this layer in the more central nerves.
Zooming in on the C5 and C6 roots of this figure, we can see the C5 and C6 roots and the C7 root or middle trunk of the brachial plexus. The circumneural sheath is marked with the white arrows here and the subcircumneural space with the red arrow. This subcircumneural space is widely believed to be the “sweet spot” of the nerve. Practitioners of yesteryear such as Moore and Thompson and others referred to this space as the “sweet spot” and coined the phrase “no paresthesia, no anesthesia” for needle placement outside this space. We now strongly believe that catheter placement outside this space may lead to satisfactory primary block where high doses of high-concentration local anesthetic agents are used, but it invariably leads to secondary block failure if catheters are not placed inside this “sweet spot”.
Please refer to the talks in this series on the basic anatomical principles and on the basic understanding of the brachial plexus where some of this is discussed in more detail. We also now strongly suspect that injections made via needles or catheters placed in the sub-epimyseal space, marked with the green arrows, will most probably, apart from a high incidence of secondary block failure, also lead to a high incidence of phrenic nerve block because the phrenic nerve is situated in that same space anterior on the belly of the anterior scalene muscle. The phrenic nerve is indicated with the blue arrow here.
Zooming in even more on the C5 and C6 roots, although we lose some focus now, shows the circumneural sheath (indicated with the white arrows) more clearly. The subcircumneural space is indicated with the red arrow, while the subepimyseal space is indicated with the green arrow. This is the same space in which the phrenic nerve, among others, lives.
Let us now look at a series of drawings by Mary Bryson made for the textbook *The Anatomical Foundations of Regional Anesthesia and Acute Pain Medicine* by the author of this lecture series.
The area above the clavicle of this model has been dissected…, and shows the muscles and nerves in three dimensions.
Zooming in on the supraclavicular area shows four of the five scalene muscles, the brachial plexus, and the subclavian artery and vein in relation to the clavicle and first rib.
Let us now make an oblique vertical cut similar to what was shown in the histological picture of Reina earlier, as indicated here,. . .
… and the picture we should see looks like this. Note the C5 (marked #8) and C6 (marked #9) spinal roots that are surrounded with yellow dura (marked #16). These two roots later join to form the superior or upper trunk.
The individual spinal roots are divided into an anterior motor root (marked #21) and posterior sensory root (marked #20). Deep to the dura (#16) is the arachnoid mater (marked #17). Both the arachnoid and dura mater follow the spinal root for a distance that varies from one person to the other distally outside of the neuroforamen. The root is also surrounded by pia mater, which is not depicted here, because at this level, the pia mater and arachnoid mater have usually already fused to form the perineurium. For more information on this, please refer to the lecture on the anatomy of the neuraxium. The fluid inside the spinal root is cerebrospinal fluid and an injection of local anesthetic agent deep to the dura and arachnoid will result in a subarachnoid block, which, depending on the volume injected, will lead to total spinal anesthesia.
Injection inside the parenchyma of the spinal root will cause the drug to spread via the perineural spaces to the spinal cord, as demonstrated by Dag Selander with fluorescent dye in 1983. Here, we can see the dye injected into a fascicle of the sciatic nerve of a dog …
… found in the subpial space of the spinal cord. The dye was also traced to as far as the cerebellum in some of his dogs.
The **perineural spaces** in the spinal roots have been beautifully demonstrated by Reina, and under electron microscopy with 2000× magnification, look like this.
In his famous and groundbreaking pioneering textbook *Regional Block* and his textbook on *Complications of Regional Anesthesia*, Daniel Moore wrote, “*Intraneural injections may be dangerous, not only on the basis that they may cause nerve damage, but, because solutions injected intraneurally may reach the subarachnoid space or the spinal cord via the perineural spaces of the nerves.*” He injected ink into the intercostal nerves of animals and the ink tracked to the spinal cord, as can be seen on the bottom picture here.
He also wrote, “The perineural spaces of the nerves are actual, not just theoretical avenues to the spinal cord when injections are injected intraneurally.” When he said “intraneurally” he of course meant deep to the dura at the spinal root level or inside the nerve fascicles at the peripheral nerve level. This is discussed in more detail in the talks on the microanatomy of the peripheral nerves.
This illustration, again by Mary Bryson made for the “The Anatomical Foundations of Regional Anesthesia and Acute Pain Medicine” textbook, depicts the six possible places where needles can be placed during paravertebral block. Paravertebral block refers to cervical, thoracic, lumbar, or sacral paravertebral block. All have dura and arachnoid around the spinal nerve roots. Please study this illustration carefully to note the yellow dura (marked #4), the magenta arachnoid (marked #5), and the pink pia mater (marked #6). The blue (#7) depicts the cerebrospinal fluid.
N1 (needle 1) demonstrates what can happen with needle placement for transforaminal injections when a sharp, thin needle is placed deep to the dura and arachnoid. Depending on the drug injected, this can lead to total spinal block and immediate respiratory arrest if local anesthetic agent is used or there can be no consequences if corticosteroids alone are injected.

N2 (needle #2) demonstrates needle placement inside of the parenchyma of the nerve root. Depending on the drug used, the volume and concentration and injection pressure, there can be devastating consequences that may vary from late respiratory arrest (because the drug has to diffuse through the pink pia mater (#6) before it can reach the cerebrospinal fluid and the respiratory centers), to monoplegia, paraplegia, or quadriplegia, depending on the size and position of the syrinx that usually follows such an intra spinal root injection.
Needle #3 (N3) is a large bore Tuohy needle that has been specifically designed for peri- or epidural injection so that it can push the spinal root and dura out of the way. As will be seen in the lecture on the microanatomy of the neuraxium, the spinal root dura is much thinner than the spinal dura, and therefore easier to penetrate. Needle #4 (N4) represents a subdural and subarachnoid (or intrathecal) injection with the same consequences as those of needle #1.
Needle #5 illustrates needle placement into an arachnoid villus, which is basically also intrathecal. The arachnoid villi are discussed in more detail in the talk on the macro- and microanatomy of the neuraxium. For this lecture, it is sufficient to understand that these villi are normal in all people, and degenerative perineural cysts are well recognized and formed by degeneration and distention of root sheath arachnoid granulations. They are more prevalent in older people and in cervical regions. Nine to eighteen percent of asymptomatic patients have these saccular diverticula. In the lumbar or sacral areas, they are known as Tarlov cysts, and 30% of normal elderly people have saccular diverticula of the lower cervical spinal nerve roots.
Needle #6 depicts a needle placed deep to the dura but outside the arachnoid. Subdural but extra-arachnoid injections have been well described for epidural block. If a relatively large volume of local anesthetic agent is injected into this potential space at the root level, it will likewise lead to the so-called “massive epidural” with a wide spread of a patchy block and significant sympathectomy.
The C8 spinal root, before the T1 spinal root joins it to form the lower or inferior trunk, has basically the same microanatomical structure as the C5 and C6 roots.
Note the relative positions of the anterior scalene muscle (marked #2) …
… the ventral and dorsal middle scalene muscles (marked #3 and #4) …
… with the dorsal scapular nerve (#23) and long thoracic nerve (#24) emerging between them.
The posterior scalene muscle (marked #6) is more tendonous at this level as its slips of origin implant on the posterior tubercles of the transverse processes of the 5th, 6th, and 7th cervical vertebrae.
The phrenic nerve can again be seen on the belly of the anterior scalene muscle. It may be important to note that it is in the epimyseal layer (#12) and even in the same sub-epimyseal space (marked #13) as the spinal roots.
The prevertebral layer of the deep fascia (#1), which may continue distally as the epineurium that is surrounding the middle trunk (marked #19) as indicated here. This forms the epineurium of the peripheral nerves further distally. Please refer the talk on the microanatomy of the peripheral nerves for more detail on this.
It already contains fascicles that are surrounded by yellow perineurium that is a continuation of the dura that first moves from around the roots to into the trunk to form septae before closing to form fascicles more distally, as can be seen on this enlargement of the middle trunk. The fluid inside these fascicles, similar to the fluid inside the spinal roots, is cerebrospinal fluid. On this illustration, the sub-circumneural space (marked #15), the circumneural sheath (marked #14), the sub-epimyseal space (#13), and the epimysium or fascia (#12) can again be seen. This sub-circumneural space (#15) will in most instances join that of the upper and lower trunks.
Keep in mind that when we look at the neck with normal ultrasound, we cannot distinguish all the layers outlined in this talk. Please refer to the movies on the dynamic sonoanatomy and static sonoanatomy pdf’s of the various areas on the www.raeducation.com website. We may be able to see these layers with high-definition ultrasound, but this technology and know-how is not yet readily available. When we look at the neck with ultrasound, we look at the structures more horizontally, as illustrated here. The so-called “donut” that we see when we inject fluid (or hydro-dissect) around a spinal root is most likely the fluid accumulating in the sub-epimyseal layer. This may be sufficient for single-injection or primary blocks, but sub-epimyseal catheter placement will most likely result in secondary block failure in case of continuous nerve blocks.
What is more important, however, is to differentiate the ultrasound appearances of the different nerves on the basis of their microanatomical structures as we now understand them. Spinal roots such as the C6 root, …
… which emerges between the large anterior (or Chassaignac) tubercle …
… and posterior tubercle of the transverse process of the 6th cervical vertebra illustrated here, are hypoechoic (or black) …
… because it is basically a fluid-filled structure.
Spinal root hypoechoic ultrasound appearance.
The trunks, ...
… on the other hand, have septae or fascicles and look different …
… in that they have a more hyperechoic (or white) appearance, as can be seen in this middle trunk.
Peripheral nerves, finally, have a so-called honeycomb appearance because of the fascicles that they contain.
Peripheral nerves contain fascicles, which have a typical ...
… so-called honeycomb appearance because of the fascicles that they contains.
Honeycomb appearance of peripheral nerves.
Thank you for your attention and I look forward to seeing you again soon in another talk in this series on the minimum anatomical knowledge a practitioner should have for regional anesthesia and acute pain medicine procedures.
REFERENCES


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This lecture series was adapted from:

“The Anatomical Foundations of Regional Anesthesia and Acute Pain Medicine: Macro-, Micro-, Sono, and Functional anatomy”.

By André P. Boezaart
Illustrated by Mary K. Bryson

Published by: Bentham Science (eBooks)
(http://ebooks.benthamscience.com/index.php)
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