Improved Understanding of Clinical Correlates with In-Situ Prosections

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Abstract

The correlation of anatomy with pathophysiology is not intuitive for many medical students. Despite detailed cadaver dissections and three-dimensional models, board-style clinical correlation questions can still be challenging for first-year students. To facilitate understanding in this regard, prosections were developed to illustrate the clinical correlations taught in the upper extremity, thorax, and head and neck. Brief, focused videos were introduced into lecture material leading to a 37% relative gain in performance on 30 exam items covering the related clinical correlations. https://doi.org/10.21692/haps.2023.008

Key words: In-situ dissection; clinical correlations; structure-function; cadaver tumescence; tumescent dissection

Introduction

Gross anatomy taught to first-year medical students lays the foundation for a lifetime of medical practice. As students learn to identify many different anatomical structures through the dissection of their cadaver donors, they are also introduced to clinical correlations. Initially, such correlations between anatomical structures and related medical scenarios serve to pique student interest and increase the retention of anatomical information. Later, they become the primary reason for their anatomy education. They underly board examination questions which in turn, mirror the ability of a physician to make a diagnosis. Clinical correlations require the higher order thinking that integrates the concrete with the abstract, structure with function.

While supplemental learning technology, such as 3-D models, interactive 3-D software, and virtual anatomy programs, have been shown to help students understand three-dimensional structure (Zilverschoon et al. 2021), there is still room for improvement with the integration of this structure with function. Along these lines, we began using special "in-situ" dissections to integrate structure with clinical correlations. In-situ dissections are thorough dissections that maintain the interrelationships between adjacent, deep, and overlying structures. These dissections allowed for a visual representation of structure as it relates to function and the graphic illustration of clinical correlations. We incorporated videos of these dissections into lecture material resulting in a marked improvement in student performance on related exam items.

Description

In-situ dissection videos were developed in the head and neck, thorax, root of the neck, and upper extremity. The use of tumescence, the infusion of wetting solution along tissue planes and fine structures, facilitated the mobilization of structures while maintaining their integrity (Loomis et al. 2022). No muscles were transected, fascial planes were preserved, and soft tissues uncovered and mobilized only to the extent needed to reveal multiple layers at once, demonstrating all pertinent structures without loss of their interrelationships. The video clip of each area usually began with a view of intact skin which was then reflected and underlying tissue planes and muscles retracted as needed to visualize pertinent anatomy.

To maintain in-situ relationships in the thoracic cavity, a median sternotomy was performed and the clavicles and ribs retracted. The heart and lungs were kept in place and the paths of vessels and nerves cleaned through the neck and chest, taking down the internal thoracic arteries from the sternum. Tumescence was again used to follow the phrenic nerve from the chest to the neck, infusing wetting solution just over the perineurium to mobilize the nerve's path without damaging its structure or adjacent anatomy. Areas of heart and lung auscultation and extents of pleural recesses relative to overlying ribs were demonstrated in the videos by opening and closing the rib cage over the structures. The cardiopulmonary relationships were highlighted at the hila of lungs, along with the spatial relationships of the vagus and phrenic nerves.

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The root of neck was exposed with reflection of the clavicles keeping the sternocleidomastoid muscles attached. To appreciate clinical scenarios of nerve compression in the upper extremity, nerves were visualized from the scalene muscles through the axilla, arm, and forearm into the hand.

Discussion

To better meet the need of medical students to understand clinical scenarios, curricula have undergone horizontal and vertical integration, increasing the focus on clinical correlations in anatomy instruction. The issue of how to most effectively and efficiently teach this expanded integration in the face of shrinking time and monetary resources has been at the center of much recent medical education research (Chang et al. 2022). Despite a plethora of supplemental resources available to students, cadaver dissection is still the gold standard, especially for focused individualized review, as when surgical residents need to refresh anatomical knowledge prior to assisting in surgery (Streith et al. 2022).

When students self-direct their dissections however, they may miss key features. Supplementing the traditional two-dimensional atlas with three-dimensional models and plastinated specimens has significantly expanded the appreciation of complex anatomical structures from multiple perspectives. With mixed-reality programs, students can walk around a virtual image that they perceive in their headset (Baratz et al. 2022). Despite differences between various types of three-dimensional models, most have provided significant improvement in overall student learning (Mogali et al. 2021; Radzi et al. 2022). The technology does not benefit all students, however. Spinning virtual structures can be disorienting and not helpful to students with decreased spatial ability (Labranche et al. 2021; Roach et al. 2021), and headsets can cause motion sickness and headaches, limiting the duration of their use (Kuehn 2018).

One way in which all approaches to anatomy can be limited is “not seeing the forest for the trees.” Appreciating the interrelationship between anatomical structures is key to understanding the cause and effect inherent in clinical correlations. As fine anatomical details are learned, whether it be by meticulous cadaver dissection, three-dimensional models and plastination specimens, or mixed reality, there is a risk of students learning structures in isolation.

The pectoralis minor muscle is reflected to fully visualize the subclavian artery whose sequential branches are seen and memorized, but the critical relationship between that muscle and the brachial plexus is lost. Forearm muscles are reflected in layers from superficial to intermediate to deep in order to see the muscles in their entirety and to follow arteries and nerves along their longitudinal paths, but the visual impact of seeing nerves tucked beneath muscle and fascial edges where they can be compressed is lost. Fascia is removed to better visualize muscle fibers, but the dynamic of compartment syndrome is more difficult to conceptualize. The heart and lungs are removed or virtual representations of them spun around on a screen to see their anatomy from all sides, but the interplay between heart and lung is less clearly appreciated. The concept of how a mediastinal shift would reduce venous return to the right atrium remains as abstract as before the dissection or mixed reality session.

Traditional dissections and three-dimensional models, while very helpful to learn the bulk of anatomical details, can leave students needing to make a mental jump to understand the more abstract clinical correlation. Having learned structures in isolation or as separated layers, this can be a very difficult task. Seasoned anatomists can look at the four layers of the plantar foot and intuitively reconstruct them in their minds, but to the students, they are often four distinct layers memorized as isolated entities. Medical students become very proficient at drawing the branches of the brachial plexus, however, integrating this structure into its environment to deduce the answer to clinical questions requires further development of critical thinking skills. These prosections were designed to provide a sequence of concrete visual steps to foster that abstract mental process of integration. Solving such clinical questions makes up much of medical students’ board examinations, as well as the bulk of the diagnostic skill they will require as physicians, so it is essential to help students transition to this higher order thinking whenever possible.

Since prosections have been shown to be equally effective at teaching anatomy as student dissections (Koh et al. 2023; Lackey et al. 2020), we designed our special prosections that focused on the clinical correlations with which the students had the most trouble. Concise, edited videos of prosections are effective teaching tools that are generally well-received by students (Dharamsi et al. 2022; Hadie et al. 2019; Natsis et al. 2022). Focusing on actual nerve compression sites such as the anterior interosseus nerve beneath the intact flexor digitorum superficialis (Figure 1) and the radial nerve at the proximal edge of the supinator (Figure 2), our brief videos integrated the concrete anatomical structures with the more abstract notions of dysfunction and levels of nerve compression.

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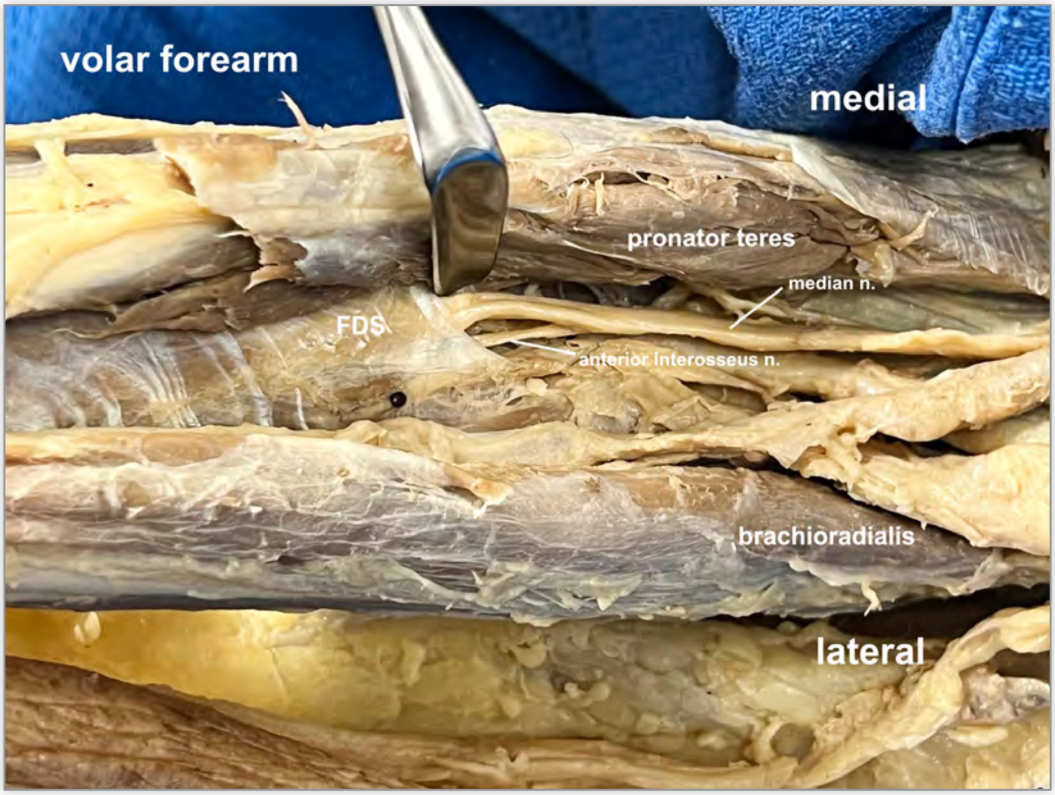

Figure 1. *The volar forearm was oriented with in-situ skin and soft tissue and the cubital fossa and thumb in view, then the video followed the median nerve from the arm, under the belly of the pronator teres, retracted with minimal mobilization, to the flexor digitorum superficialis which was kept intact. It was noted at what levels the median nerve innervated the pronator and other volar muscles, and at what levels it might be compressed. The scenario in which the anterior interosseus nerve was compressed but not the remainder of the median nerve could be appreciated by its position beneath the tight fibrous band of the flexor digitorum superficialis.*

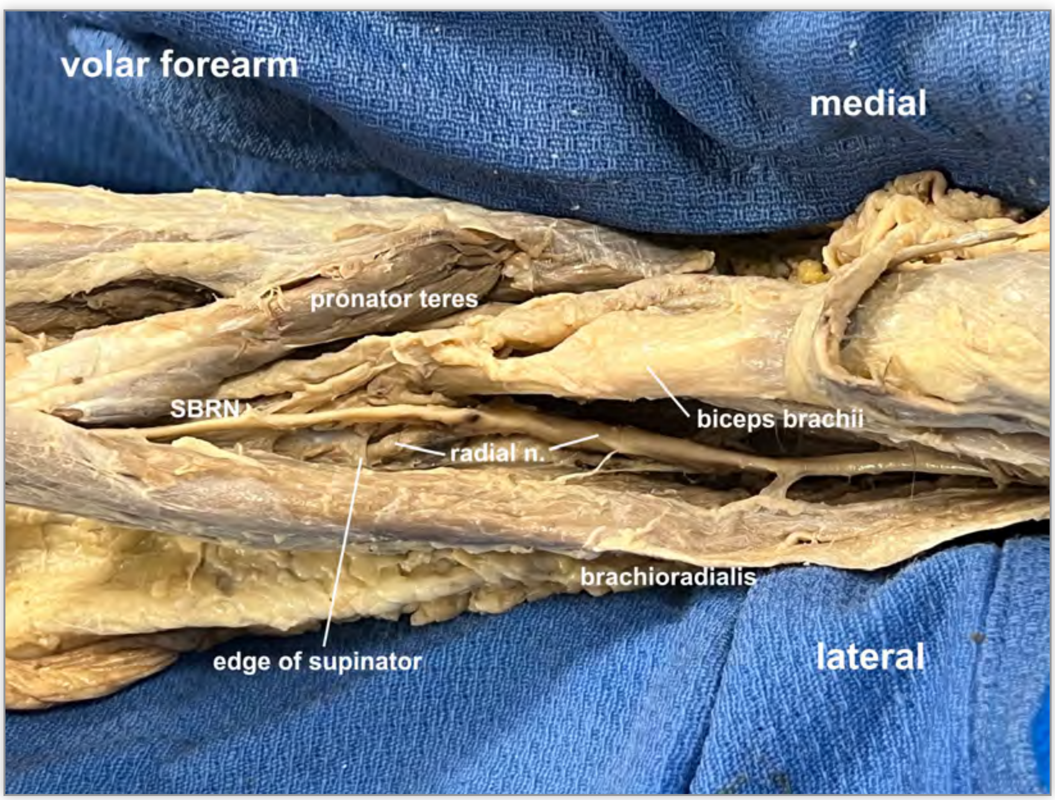

Figure 2. *With the pronator teres muscle returned to its in-situ position, the brachioradialis muscle was retracted to demonstrate the radial nerve which was followed from its emergence from the spiral groove of the humerus across the elbow. Radial nerve innervation of the brachioradialis and the extensor carpi radialis longus and brevis muscles was noted proximal to the site of compression of the deep radial nerve branch beneath the fibrous band of the supinator muscle. Also noted was the superficial branch above the supinator. Both can help students understand why radial nerve compression in the proximal forearm does not cause wrist drop nor loss of sensation, unlike a mid-shaft humeral fracture which causes both.*

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With visceral organs still in place, predicting the extents of visceral/parietal spaces and their relationships to the overlying ribs became more intuitive. The abstract concepts of cardiac pathophysiology were visibly integrated with the concrete anatomy of the heart and lungs in the chest. The right atrium and superior and inferior vena cava were portrayed not as isolated structures, but as dynamic sources of preload affected by heart position and the changing pressures of the intrathoracic cavity. The visual impact of such a demonstration can help students make the jump from the concrete to the abstract, assimilating the two. In addition to directly visualizing the site of the ribs over the apex of the heart, viewing the in-situ heart in a mirror helped explain the orientation of an ultrasound image at this site (Figure 3). Intact lungs were inflated and deflated correlating function with clinical scenarios. In the CNS, the meninges, vascular territories, and cranial nerve pathways were also appreciated in videos.

Multiple brief videos focused on the interrelationships of key anatomical structures in-situ were introduced into lectures covering upper extremity, cardiopulmonary, and neuroanatomy clinical correlations. These videos were also available to students individually online allowing for quick review and orientation when studying practice questions.

To determine if and to what extent these short in-situ dissection videos helped students answer higher order questions, student performance on related exam items in the Fall semester of 2022 (n=154) was compared to that of students from the Fall semester of 2021 (n=114) in which the in-situ videos were not available (Appendix 1). The sessions were taught by the same professor, over the same amount of time, using the same material, except for the inclusion of the in-situ videos. Thirty higher order exam items covering clinical correlations in the upper extremity, cardiovascular, and nervous system were compared.

The average percentage of the class which answered the questions correctly increased from 60% without the in-situ dissection videos to 82% with the videos, a gain of 22 percentage points, or a 37% relative gain. To test the hypothesis that the difference in score from 2021 to 2022 was significantly greater for items which benefited from the videos a one-sided t-test for two dependent means was performed. The results from 2021 (M=59.5, SD=18.6) compared

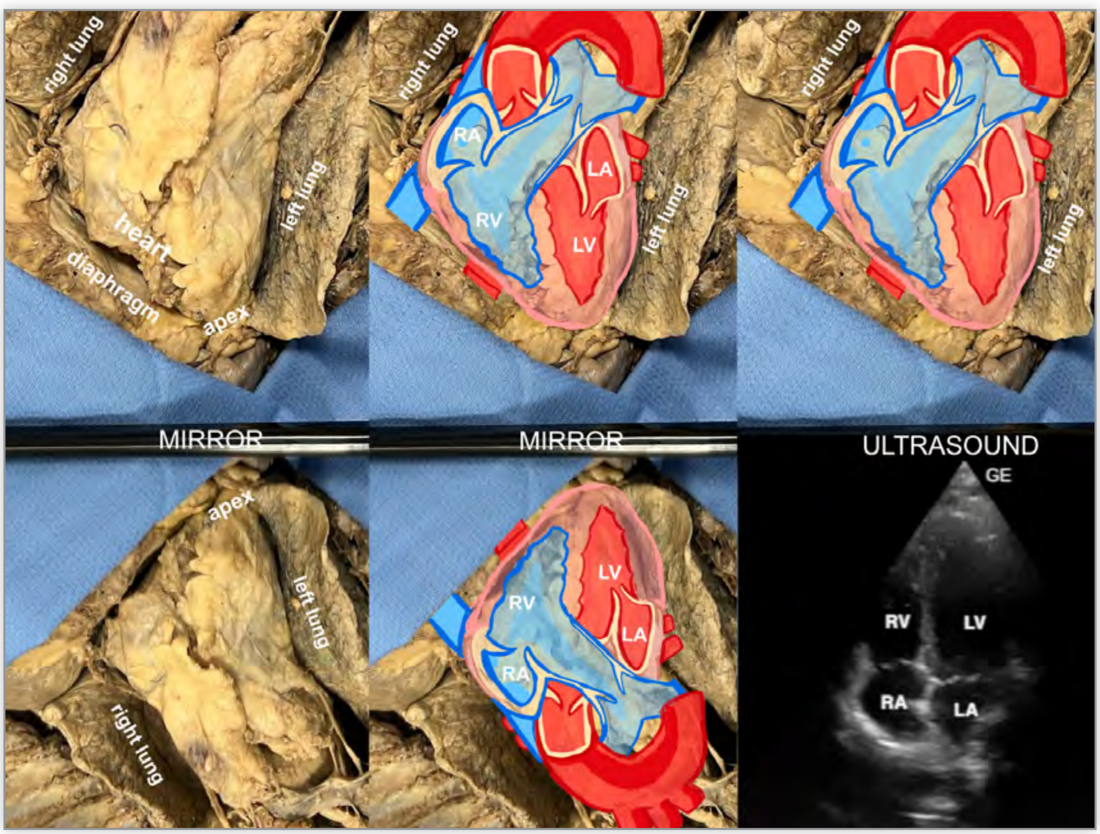

Figure 3. *This video began by orienting the in-situ heart and lungs. A mirror was then held up to the apex of the heart to demonstrate its reflection. Schematics of the heart's chambers were then overlaid on both the direct view of the heart and its reflection. This reflected schematic correlated nicely with a juxtaposed apex ultrasound image.*

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to 2022 (M=81.8, SD=12.7) indicated that the 2022 scores were significantly greater, $t(29)=7.8$, $p<.00001$.

Of note was a scheduling change from an eighteen-week course running concomitantly with a cellular biology course, to a nine-week course without the concomitant cellular biology course. While this block scheduling could have affected the change in exam performance, there was no significant improvement in the performance on the eleven other items which covered gross anatomy between 2021 (M=83.8, SD=12.6) and 2022 (M=84.9, SD=8.2), $t(10)=0.27$, $p=.39$ (Figure 4, Table 1). The performance on those items was already in the range of 84% for both years however, so there was not as much room for improvement compared to items covered by the in-situ videos, which had a 2021 average of 59.5%.

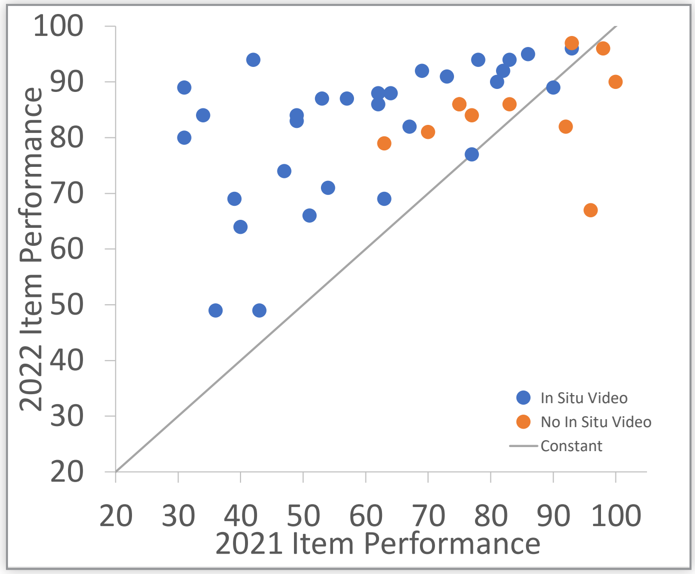

Figure 4. *Exam item performance with in-situ dissection videos and without.*

Learning objective	Clinical correlation covered	Methods previously utilized	In-situ video added	Point change (%)
Correlate the dural blood supply with intracranial bleeding.	Middle meningeal artery injury and presentation	Atlas drawings, CTs, polling questions	No new videos added	- 10
Outline the cerebral ventricles and correlate with sites of obstruction	HA, pineal tumor, site of obstruction	Atlas, CT, MRI, donor images, polling questions	No new videos added	+ 3
Outline the bones and sutures of the skull and the names of their points of intersection	Skull fracture crossing lambdoid suture	Atlas, CT, bone models	none	- 10
Correlate the vessels supplying cortical and brainstem regions with the function of those regions.	Stroke with loss of sensation and motor function to lower extremities	Atlas, drawings, imaging, gross brain photos and videos tracing regions	No new videos added	+ 16
Predict nerve lesions and symptoms resulting from cerebral aneurysms.	Posterior communicating artery aneurysm	Atlas, drawings, imaging, gross brain photos and videos tracing regions	No new videos added	+ 11
Map out coronary artery and vein locations.	Vein traveling with anterior interventricular artery (LAD)	Atlas, drawings, angiograms	none	- 2
Correlate structures in the thorax with their function.	Identifying structures on CT crossing diaphragm	Atlas, diagrams, imaging	none	- 29
Outline the normal and abnormal vertebral curves.	Description of scoliosis	Atlas, charts, imaging, bone models	none	+ 7
Correlate the segmental and continuous ligaments of the spine with their function	Spinal tap needle piercing ligamentum flavum	Atlas, diagrams, bone models	none	+ 11
Correlate the segmental and continuous ligaments of the spine with their function.	Cervical spine fracture with injury to long ligament	Atlas, diagrams, bone models, imaging	none	+ 11
Correlate the attachments, blood supply and innervation of the superficial and deep back muscles with their function.	Injury to trapezius in motor vehicle accident, weakness of shoulder elevation	Atlas, diagrams, clinical pearls, polling questions	none	+ 4
			Average	**+1**

Table 1. *Learning objectives of sessions that had no videos added in 2022 shown with their associated clinical correlations, the methods used, and the difference in the percentage of the class answering the exam item correctly. Overall, there was not a significant difference between 2021 and 2022, although the performance was already quite high on these items.*

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Conclusion

For medical students to become sound, safe physicians, the concrete anatomy that will someday be palpated beneath the examining hand or perceived through the stethoscope must be integrated with abstract concepts such as pressure gradients, vascular territories, and levels of neurological injury. In-situ dissection videos presenting focused, impactful representations of clinical correlations facilitated this integration in our anatomy course in which a 37% relative gain in performance on exam items related to upper extremity, cardiovascular, and neuroanatomy clinical correlations was observed.

About the Authors

Mario Loomis, MD is an associate professor and Chair of the Department of Anatomy at Sam Houston State University College of Osteopathic Medicine in Conroe, Texas. His research interest is to use his background as a Plastic and Reconstructive surgeon to optimize clinical integration into the teaching of gross anatomy. Shawn Staudaher, PhD is a data scientist in the Educational Affairs Department at Sam Houston State University College of Osteopathic Medicine in Conroe, Texas. Teresa Loomis is a sophomore at Benedictine College in Atchison, Kansas. She is pursuing a nursing degree and uses her artistic and media skills to draw, animate, photograph, and video human anatomy to supplement medical education.

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Appendix 1: Learning objectives of sessions with their associated clinical correlations, the previous methods used, and the in-situ dissection videos that were added with the subsequent point-change in the percentage of the class who answered the associated exam item correctly.

The average increase of twenty-two percentage points was from 60% to 82%, a 37% relative gain.

Learning objective	Clinical correlation covered	Methods previously utilized	In-situ donor video added	Point Change (%)
Correlate clinical signs with cranial nerve somatic and visceral function to localize sites of injury.	Brainstem stroke, ventral caudal pons: CN VI presentation	Atlas images, diagrams, charts, clinical pearl highlights polling questions	Video of gross brain tracing cranial nerves and correlating with clinical scenarios	+ 24
Correlate the brain's venous drainage with common types of intracranial bleeding.	Subdural hematoma, origin of bleed: bridging veins	Atlas images, diagrams, charts, imaging, clinical pearl highlights	Video of calvarium, dura, bridging veins entering sup sag sinus	+ 30
Predict underlying cardiac structures based on surface chest anatomy	Heart sound auscultation at sites on chest wall	Atlas images, diagrams, charts, imaging, clinical pearl highlights	Video of chest opening directly over heart, demonstrating intercostal spaces	+ 3
Discern the azygous venous system and its relationship to the thoracic duct, esophagus, and superior vena cava.	Thoracic duct injury in posterior mediastinum	Atlas images, diagrams, charts, clinical pearl highlights polling questions	Videos exploring chest, heart and lungs in place, retracting heart and esophagus to see thoracic duct	+ 15
Deduce clinical scenarios as they relate to the anatomy of the vertebral column, spinal cord, and meninges.	Injury vertebral artery transverse process	Imaging, atlas, diagrams, charts, clinical pearl highlights	Video following vertebral artery from subclavian in chest, overlay pics of cervical vertebrae	+ 27
Deduce where the vagus nerves are located in the mediastinum and their relationship to the thoracic viscera.	Relationships of vagus and phrenic nerves in mediastinum	Atlas diagrams, clinical pearl highlights polling questions	Video tracing vagus nerves from neck through chest	+ 6
Correlate patient presentations with the locations of bone, nerve, or tendon disorders of the shoulder.	Rotator cuff injuries, relationship with subdeltoid bursa	Imaging, atlas diagrams, bone models, charts, clinical pearls, polling	Video exposing rotator cuff by retracting deltoid anterior and posterior, and rotating humerus	+ 35
Discern the peripheral nerves affected by injuries to the upper, lower, medial, lateral, or posterior aspects of the brachial plexus.	Posterior cord crutch injury presentation	Atlas diagrams, charts, drawing brachial plexus, clinical pearl highlights polling questions	Video tracing brachial plexus from scalenes in neck through axilla and to endpoints in upper extremity	+ 18
Discern the venous supply of the upper extremity, pectoral musculature and the breast.	Upper extremity venous drainage, cephalic, basilic	Atlas diagrams, charts, clinical pearl highlights	Video reflecting skin, retracting muscles, following veins from hand to chest/axilla	+ 34
Discern the peripheral nerves affected by injuries to the upper, lower, medial, lateral, or posterior aspects of the brachial plexus.	Lower brachial plexus injury presentation	Atlas diagrams, charts, drawing brachial plexus, clinical pearl highlights, polling questions	Video tracing brachial plexus from scalenes in neck through axilla and to endpoints in upper extremity	+ 24

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Correlate the structure and function of the intrinsic muscles of the hand with normal and abnormal function of the median and ulnar nerves.	Presentation median nerve injury at wrist specific muscle weakness: opponens pollicis	Imaging, atlas, diagrams, charts, clinical pearl highlights polling questions	Videos exploring hand by retracting overlying layers, following nerves, correlating with clinical scenarios	+ 9
Given a loss of function, predict the nerve involved and the site of injury.	Ulnar nerve injury, distinction between cubital tunnel, Guyon's canal, and brachial plexus	Imaging, atlas diagrams, charts, clinical pearl highlights polling questions	Videos tracing nerves from brachial plexus, to elbow, forearm, wrist, and hand	+ 6
Distinguish between the layers of the thoracic wall from the skin to the parietal pleura, subdivisions of the parietal pleura, the pleural space, and the visceral pleura.	Site of pleural tap below lung in mid-axillary line	Imaging, atlas diagrams, charts, clinical pearl highlights polling questions	Video of chest wall opening with median sternotomy, demonstration of pleural recesses, overlying intercostal spaces	+ 52
Predict locations of upper extremity injuries based on physical findings	Serratus anterior denervation: loss of abduction over 100˚	Atlas diagrams, charts, clinical pearl highlights polling	Video of axillary dissection, long thoracic and thoracodorsal nerves highlighted, muscles in place	+ 10
Correlate the structure and function of the intrinsic muscles of the hand with normal and abnormal function of the median and ulnar nerves.	Physical exam testing of deep ulnar nerve: abduction fingers	Atlas diagrams, charts, clinical pearl highlights polling questions	Video following ulnar nerve from forearm, through wrist, superficial and deep branches, with their endpoints	+ 34
Correlate the structure and function of the intrinsic muscles of the hand with normal and abnormal function of the median and ulnar nerves.	Cubital tunnel syndrome, specific muscle weakness, adductor pollicis	Atlas diagrams, charts, clinical pearl highlights polling questions	Videos tracing nerves from brachial plexus, to elbow, forearm, wrist, and hand	+ 50
Discern the superficial and deep palmar arterial arches, their branches, and collateral connections.	Allen test: communication between superior and deep palmar arches	Atlas diagrams, charts, clinical pearl highlights polling questions	Video following radial and ulnar arteries at wrist into hand, superficial arch with deep arch image overlay. Correlated with ultrasound videos	+ 9
Discern the bony and fascial structures of the hand as well as the spaces and bursa.	osteoarthritis of saddle joint with first metacarpal: trapezium	Atlas diagrams, charts, clinical pearl highlights polling questions, bone models in lecture	Videos of wrist dissection, correlation with ultrasound videos	+ 30
Discern the structure and function of, and clinical implications of injury to the flexor and extensor tendons in the wrist and hand.	Laceration over prox phal of thumb, involving which tendon? EPL	Atlas diagrams, charts, clinical pearl highlights polling questions, bone models in lecture	Video tracing extensors through dorsal compartments to endpoints	+ 15
Discern the peripheral nerves affected by injuries to the upper, lower, medial, lateral, or posterior aspects of the brachial plexus.	Injury upper brachial plexus, describe arm position	atlas diagrams, Charts, drawing brachial plexus, clinical pearl highlights, polling questions	Video tracing brachial plexus from scalenes in neck through axilla and to endpoints in upper extremity	+ 58

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Discern the boundaries, contents, nearby structures, and clinical significance of the anatomical snuffbox and dorsal wrist compartments.	Lac over snuff box into 1,2,3 dorsal compartments, also lac-SBRN	Atlas diagrams, charts, clinical pearl highlights polling questions	Video tracing extensors through dorsal compartments, highlighting snuffbox with contents	+ 17
Predict locations of upper extremity injuries based on physical findings	Injury along lateral chest wall: injury to long thoracic n.	Atlas diagrams, charts, clinical pearl highlights polling questions	Video of axillary boundaries with serratus & latissimus in place, followed from origins to insertions, correlated with function	+ 26
Correlate the attachments, blood supply and innervation of the superficial and deep back muscles with their function.	Injury to latissimus dorsi, vessel injury causing hematoma-thoracodorsal	Atlas diagrams, charts, clinical pearl highlights polling questions	Video of axillary boundaries with serratus & latissimus in place, followed from origins to insertions, correlated with function	+ 16
Describe the boundaries, contents, nearby structures, and clinical significance of the carpal tunnel and Guyon's canal.	Numbness 1,2,3, intact palmar sensation: carpal tunnel syndrome	Atlas diagrams, charts, clinical pearl highlights polling questions	Videos exploring forearm and hand by retracting overlying layers, following nerves, correlating with clinical scenarios	+ 11
Outline the sensory and motor branches of the cervical plexus.	Stab wound neck severing ansa: Motor loss sternothyroid	Atlas diagrams, charts, clinical pearl highlights polling questions	Video exploring neck, retracting skin, platysma, following strap muscles, highlighting function	0
Outline the branches of the external carotid and subclavian arteries and tributaries of the jugular veins.	Thyroidectomy, bleeding, venous blood from middle thyroid vein via internal jugular	Atlas diagrams, charts, clinical pearl highlights polling questions	Video exploring neck, following blood supply to and from thyroid	+ 13
Discern the bony and fascial structures of the hand as well as the spaces and bursa.	Stabbing involving radial bursa, which tendon? FPL.	Atlas diagrams, charts, clinical pearl highlights polling questions	Video following muscles through forearm and wrist, correlating with nerves and bursae	+ 49
Given a nerve lesion in the elbow, forearm, or wrist, predict expected loss of function.	Ruptured biceps with weight training, in add to elbow flexion, also weakening of supination	Atlas diagrams, charts, bone models, clinical pearl highlights polling questions	Video exploring cubital fossa highlighting neurovascular relationships and muscle insertions and functions	+ 23
Integrate the great vessels with adjacent thoracic, neck, and upper extremity anatomy.	First branch off aortic arch: brachiocephalic	Atlas diagrams, charts, clinical pearl highlights polling questions	Videos exploring chest, heart and lungs in place, following great vessels	- 1
Diagram the sympathetic trunks and fiber composition of the white and gray communicans and thoracic splanchnic nerves.	Injury symp chain, white communicans = preganglionic efferent sympathetic	Atlas diagrams, charts, drawing, clinical pearl highlights polling questions	Videos exploring chest, heart and lungs in place, retracting heart and lungs to see sympathetic chain	+ 24
			Average	+22

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