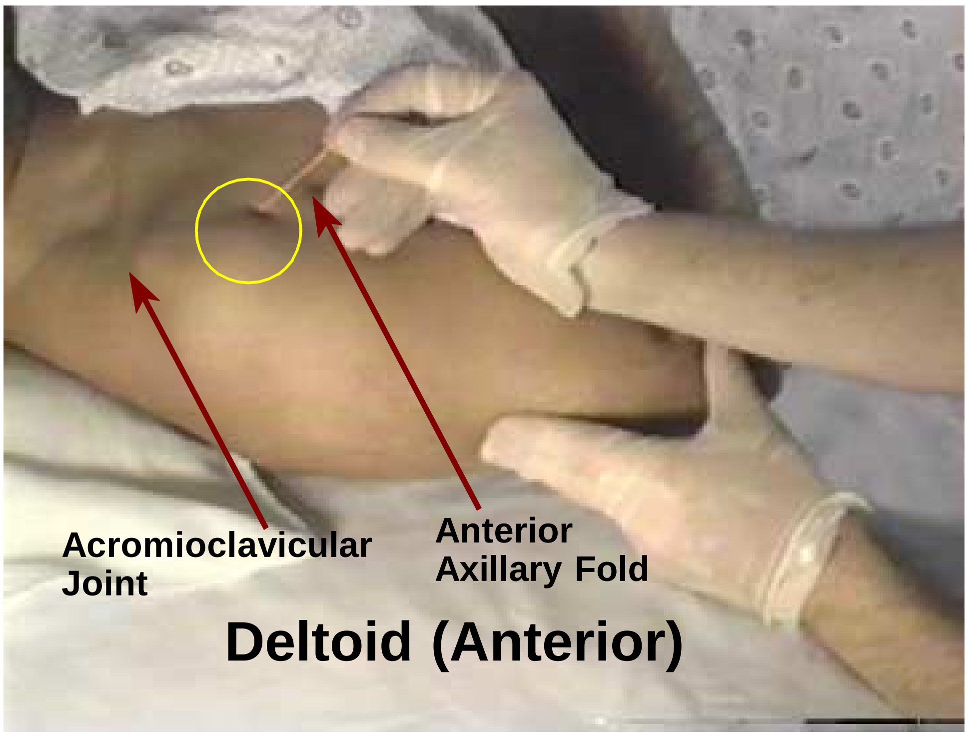
Electronic Myoanatomic Atlas for Clinical Electromyography



by

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Produced by CASA with assistance from Kappes Technical Writers

Note: The use of this program is intended to supplement, but not replace, formal instruction and training in Electrodiagnostic Medicine.

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Dedication

The pithiest dedication I ever read was by a colleague who inscribed his long delayed thesis on polymyositis, “To my relief”. While not out of sympathy with this sentiment, I dedicate this work to:

my wife, Joan, the hub of my sanity, and my children, Erik and Alexandra, who indulged and only minimally begrudged me that important extra margin of time to bring this to fruition. While I could claim exclusive rights to the wee matutinal hours, all others required periodic “sharing”, that is, being vulnerable to distraction: the digressions of “approving” Erik’s drawings or discussing issues of life important to a seven year old and of accommodating Alexandra’s surreptitious attacks on the keyboard, a delightfully niggling two year old co-editor. Such are life's true rewards!

and

my mother, a teacher who sacrificed much for my brothers and me but can now enjoy life's pleasures.

Paul E. Barkhaus, M.D.
Milwaukee, Wisconsin

Foreword

There are scientific methods to validate the usefulness and effectiveness of teaching tools like textbooks. There are other methods also. From my vantage point as the head of an academic electrodiagnostic medicine laboratory, I am convinced that relatively new textbooks which develop loose covers or have pages falling out are demonstrating strong evidence of usefulness to the residents and faculty. Unexplained, recurring disappearance of a textbook from the laboratory is also a sign, I believe, suggestive of high usefulness.

Based on any of these “seat of the pants” criteria, the *myoanatomic atlas* is a very important resource. We all have used such textbooks when learning the needle electrode examination and we revisit it when the need to evaluate a muscle not part of our standard repertoire arises. This new *Electronic Myoanatomic Atlas for Clinical Electromyography* is a natural evolution from the textbook medium we have all relied on. The CD-ROM multi-media format is an excellent method to present this type of information.

The two authors are a natural team to put together a teaching tool like this. Dr. Barkhaus is an experienced academic electromyographer with an education that has been accumulated from time spent in some of the best electrodiagnostic laboratories in the world. He has extensive experience in quantitative motor unit potential analysis both at the individual motor unit and the interference pattern level. Dr. Nandedkar is an electrical engineer who has worked extensively in electromyographic signal analysis and more lately in electrodiagnostic instrument operating system implementation. He and his family of engineers have a wizard-level command of the current computer-based presentation tools. The authors have worked together for over ten years, first in the same laboratory and over the last several years collaborating while in separate locations. That continuing association has produced this valuable new learning tool.

I predict that this *Electronic Myoanatomic Atlas for Clinical Electromyography* will be judged to be a major success. Based on the colloquial parameters of usefulness I outlined above, I suggest any academic or clinical laboratory chief consider purchasing two copies of this CD-ROM, one for shared use by all the laboratory physicians, and the other to be kept in some secure place known only to the chief.

John Kincaid, M.D.
Indiana University, Indianapolis IN, USA
August 1997

Introduction By EMG-CD Series Editor:

In the last two decades we have witnessed a revolution in the electronic and computing industry. Just a few years ago, the computers occupied several racks, had numerous buttons, knobs, air-conditioned rooms. Oh! And do not forget the mesmorizing lights from the control panel that were so prominant in the movies. Then the computers became personal. We now use them unknowingly as we entertain ourselves on the internet, play games, conduct bank transactions, and yes! even perform EMG studies.

In clinical neurophysiology, the computers have been used primarily for data collection, analysis and storage. When a few years ago, CASA Engineering approached me to prepare a CD for electromyographers, I could not find any significant use for this technology other than for some text or databases.

However, when the PCs became multi-media, I found the technology very exciting. I offered to edit a series of CDs that makes use of multi-media presentation. It is so much easier to see a technique being demonstrated as a video than to read pages of text or to look at sketches and photographs. If a picture is worth a thousand words, a video is worth millions. Our goals were also shared by Kappes Technical Writers who prepared the scripts for the videos and the text handout.

So here is the first CD of the series. Our guest editor on this project is Dr. Paul Barkhaus. After receiving his M.D. from Wayne State University, he worked as a Fellow at the University of Minnesota and then at the University of Arizona. Later he went to Uppsala University to study advanced quantitative technique under Prof. Stalberg.

I met Paul when he joined as a Senior Fellow at the EMG laboratory at the Duke University. I had the pleasure of collaborating with him on many projects on quantitative analysis and recording characteristics of EMG electrodes. Currently he is an Associate Professor of Neurology at the Medical College of Wisconsin in Milwaukee. He also directs the Neuromuscular Clinic at the Milwaukee VA Medical Center.

It has been a pleasure working with Paul on this project. Without the enthusiasm of CASA Engineering and Kappes Technical Writers, this project would not be complete in a timely fashion. I hope you find this CD educational and useful. Feel free to send us your comments and criticism. Until our next CD on Instrumentation, this is Dr. Sanjeev Nandedkar, better known as Sanjeev, wishing you a happy multi-media experience.

Table of Content

I. Introduction

In clinical electromyography (EMG), training in localizing muscles for needle electrode insertion has been primarily accomplished by referring to anatomy atlases and by observing experienced examiners. There is no universal standard and techniques may vary between laboratories. This presentation utilizes video and computer technology to demonstrate how muscles commonly studied in clinical EMG are optimally localized for needle electrode insertion in adult patients. Most of the principles in localization will also apply to pediatric patients. It is hoped that this work will animate what has previously been derived from photographs, atlases, and diagrams. The goal of this teaching approach is to help the basic electromyographer perform an efficient, thorough, minimally noxious needle electrode examination. The program does not cover the electrophysiologic basics of EMG or details of peripheral innervation.

The number of limb muscles that can potentially be studied is extensive, approximately one hundred per side. We have chosen not to accept the challenge for a number of reasons, not the least of which is the large amount of computer memory required for even the shortest of the video segments. Other reasons are admittedly subjective in terms of relative clinical importance, technical factors, and patient comfort, which considerably shortens the list. Hence, not every electrodiagnostic physician will find their complete repertoire of muscles. This presentation focuses on muscles that are most commonly studied in such clinical problems as radiculopathy and focal neuropathy.

The examination of paraspinal and bulbar muscles is also included. The former more for the technique of insertion in what may be considered the most useful segmental paraspinal muscle, the multifidus. Other muscles such as the splenius capitus and scalenes are covered not so much for the purpose of electrodiagnostic examination, but for their use in therapeutic intramuscular injection of botulinum toxin.

The verisimilitude of the needle electrode examination achieved in this program has many advantages, the principle one being the sequential demonstration of the activation and localization of the muscle followed by the insertion of the electrode. A number of obstacles, however, have become apparent in our preparation. The needle electrode has been substituted by a larger color probe, yet small enough to simulate the needle electrode insertion. Where the point of the probe may be difficult to see, observe the "dimple" created by the probe against the surface of the skin at the insertion site. Although the preferred angle of insertion is perpendicular to the muscle fibers in most situations, this could not always be shown in deference to demonstration of the electrode position.

Some of the landmarks are inadvertently obscured by the examiner's hand in the "still photos" that accompany the description and in the text. These are indicated by dashed arrows. All are basic surface anatomy and their demarcation on the photos is intended primarily to cue the user prior to starting the video sequence. At times, distances and landmarks may not appear accurate due to the visual distortion of the anatomic plane or angle of perspective.

The user of this program should be familiar with the fundamentals of clinical electromyography and human anatomy. It is the responsibility of the user to specifically familiarize themselves with basic human anatomy prior to any intramuscular insertion, particularly where there may be risk of penetration of major neural or vascular structures. In order to derive maximal benefit from the presentation, the user is strongly recommended to read the accompanying text prior to viewing the video segments. Unless stated otherwise, all descriptions of localization are derived from the basic anatomic position. One may argue that the inclusion of origins and insertions is archaic and unhelpful. It is a format, however, that if not universally enjoyed, is at least universally understood. Where possible, anglicized spellings of muscles are given.

In order to enhance the usefulness and application of this program, the author has gone beyond the customary boundaries of an atlas for clinical EMG. The user will find some discussion of intramuscular localization using the needle electrode as well as how the anatomy is applied in clinical problems and pathology. This will hopefully broaden the appeal of this program and make absorbing the anatomy, a traditionally lackluster exercise, more exciting and meaningful.

II. General Overview

Useful definitions and concepts

Activation of muscle: This is the voluntary contraction of a muscle or muscle group that results in the movement of a joint(s). In this context, muscle activation in the electrodiagnostic examination is similar to, but not the same as, activation for the purposes of manual muscle testing in the clinical examination. In the latter, maximum force is elicited to determine strength. In EMG, the emphasis is on minimal recruitment via gradated, steady, voluntary muscle activation.

In EMG, the observation of progressive activation is referred to as recruitment, and the maximal activation achieved is referred to as the interference pattern. In motor unit action potential (MUAP) analysis, it is the observation of the MUAP discharges at relatively low levels of activation that is critical in measuring their features (e.g., amplitude, area, duration, phases, etc.). Hence the emphasis is on facilitating the patient's ability to achieve and maintain minimal to moderate controlled activation of specific, isolated muscles.

Because anatomic localization of muscles in this program is frequently based on activation, it is important to understand their origins, insertions and actions. In the following text on specific muscles, the most important aspects of their origins and insertions are given along with the recommended method of activation. It should be noted that many muscles have more than one action or direction of movement of a joint. The method of activation given in this text is usually for a specific muscle's principle action or that action which can be most easily utilized with minimal limb movement.

In this program, activation of muscle is almost synonymous with localization since it is by activation that an individual muscle is ultimately isolated and identified. Occasionally some patients may have difficulty with activating a specific muscle, necessitating the examiner to literally provide a hand to help them offer resistance. Optimally, this is avoided in most circumstances so the examiner has one hand free at all times in order to manipulate the settings on the electromyograph. This is a critical issue when performing special studies such as quantitative MUAP analysis and single fiber EMG where sustained, minimal activation of the muscle is necessary. Helpful "tricks" in activation (e.g., see Adductor Longus, Deltoid, Frontalis) are given where possible.

As in the clinical examination, the needle electrode examination must be modified if the patient has significant weakness. The examination shown in these videos is a basic one where the patient is assumed to have at least Grade 3 strength (Medical Research Council). In the less frequent situation when greater weakness or complete paralysis is present, further modifications to the examination may be necessary. Here the electromyographer will require even greater skill in navigating the electrode through the subcutaneous tissue and musculature.

It may be argued that localization of muscles may be made solely on surface landmarks and relative anthropometric measurements, making activation unnecessary in localization. No matter how carefully localization is made or by what strategy, the use of activation is still the *sine qua non* in producing the MUAP and is legitimately part of the localizing process. Where atrophy or wasting of muscles may have occurred such as in paralysis, caution in interpretation must be made, especially with deeper muscles where their borders may have changed from reduction in muscle bulk.

On occasion, especially in larger limb muscles, the screen may be "silent" despite what clinically appears to be adequate activation on the part of the patient. The trainee's usual response is to solicit even greater effort from the patient, all to no result except patient fatigue and discomfort. In the author's experience this phenomenon is usually due to the patient activating muscle around, but not within, the insertion site. To the patient, activation of other muscles or portions of the same muscle may achieve the same desired result without the additional perceived discomfort from the needle electrode (e.g., elbow flexion via the brachioradialis when the electrode is in the biceps brachii). If the needle electrode is placed correctly and the activation maneuver correct, MUAP discharges should readily appear even at low levels of effort.

Anatomic Planes: In the anatomic position, a **coronal plane** vertically transects the body side to side resulting in anterior/ posterior segments. The horizontal or **axial plane** transects the body transversely resulting in rostral/ caudal, "cross-sectional" segments. The **sagittal plane** extends anterior to posterior, vertically dividing the body into right/ left segments.

Electrodes: This program emphasizes the placement of intramuscular needle electrodes for direct recording of the myogenic signal. The two most commonly used are the **concentric needle electrode** and the **monopolar needle electrode.** Other less commonly used electrodes include the single fiber EMG electrode used for jitter and fiber density studies; the macro-EMG electrode used for macro-EMG and fiber density studies; and an intramuscular needle electrode that allows recording of the myogenic signal and concomitant ability to inject therapeutic botulinum toxin. The localizations given in this program are not intended for use in recording motor conduction studies with surface electrodes.

Isometric Contraction: This is the most common type of contraction or pattern of activation used in EMG. Tension is generated in a muscle via activation without a change in its length. In turn there is less chance of unintentional needle electrode movement in the muscle.

Positioning of the Patient:
Lateral Decubitus: The positioning of the patient on his/her side. For purposes of this program, this position implies that the patient's trunk and legs are straight without any rotation of his/her shoulders or pelvis. The head is supported by a pillow or similar device to keep the head and neck from being unduly laterally deviated downwards, resulting in undesirable muscle activation of the cervical and shoulder musculature. In most instances, the limb or area to be examined in this position is optimally upward or superior.

Prone: The patient is lying face downwards on the examination table. If it is necessary to have the head and neck in neutral position, then the upper shoulders and neck should have a pillow placed underneath so that the face is not resting unsupported on the examination table. The feet should be positioned so that they are elevated slightly or are extended off the end of the table to avoid unnecessary leg rotation or activation of the leg muscles.

Supine: The patient is lying face upwards on the examination table.

Preparation of the patient: Patient tolerance is often relative to their awareness of the procedure. The procedure is therefore explained to the patient on entry into the laboratory. Patient comfort and confidence in the examiner is a priority.

Appropriate gowning depends on which muscles are to be studied. It may be argued that if the study is directed to a cervical radiculopathy, only partial disrobing of outer garments such as a shirt or blouse with gowning is needed. The coincidental identification of a polyneuropathy, however, may necessitate study of a lower limb. In most circumstances we find it less disruptive if the patient is ready for this contingency rather than stopping while the patient disrobes further, especially if they require assistance. This also facilitates the preliminary clinical examination.

Subjective impressions of pain vary greatly between individuals. Given that the needle electrode examination will be considered at least minimally noxious by most patients, it is essential to ascertain that the procedure is fully explained prior to beginning the test. After completing the preliminary clinical examination and any nerve conductions or other studies, the patient should again be informed about the needle electrode examination. At this time it is helpful to repeat inquiry about any history of infection (e.g., HIV, hepatitis, etc.)/ risk factors for infection or anticoagulant use, especially if their medical record is not available.

The electromyographer should review with the patient approximately 2-3 muscles to be examined at a time, including how to position and activate the muscle as well as demonstrating approximately where the needle will be placed. Although the patient may be anxious, it is much easier to "coach" the patient on activation while relatively relaxed, i.e., prior to needle insertion. Having patients involved with activating the muscle and in their planning tends to distract them somewhat from the discomfort of the procedure.

Patients often ask how many "sticks" or "pokes" they will receive with the needle. The experienced examiner knows that it is almost always impossible to give an exact number prior to the examination, and avoids offering a direct answer other than perhaps to say "several", or something similar. If asked again as the examination nears completion, the non-specific response of "a few more" is at least encouraging. To offer numbers gives the patient the opportunity to start counting and feel mistrust if the quoted estimate is exceeded.

Preparation of the examiner: Preparation for the electromyographer involves the development of a hypothesis or working diagnosis on the patient being examined. This is based on the referring physician's request, the examiner's clinical assessment, and the nerve conductions and other testing completed to this point. The challenging and artful part of the needle electrode examination is to plan the core study of a few select muscles to address the problem with the least amount of position changes. Based on these results, the examiner proceeds to study only those additional muscles that will help prove or disprove the diagnostic impression.

The efficiency and expedience of the needle electrode examination is proportionate to examiner experience. It is important that less experienced examiners refrain from turning insertion sites into what the author terms "inertion" sites. In this situation of the doldrums, the examiner becomes increasingly uncertain of the signal on the screen, their uncertainty accelerating in proportion to the length of time the electrode has been meandering in the muscle. Although most often encountered in trainees, most every electromyographer periodically experiences some degree of this phenomenon. Patients are very sensitive to the length of time an examiner spends in each muscle. The examiner must always be mindful as to what point they have exceeded the usefulness of a particular insertion site. If examination of a specific muscle is a problem, it is best to move along to the next muscle. The problem may be resolved by substituting or studying more muscles, or by coming back to the same muscle at the end of the study when more information from other muscles is available.

Needle electrodes: The choice of concentric versus monopolar needle electrode is usually based on the examiner’s training and bias. Some historical reasons are no longer valid since most laboratories use disposable electrodes of either type. Both are available in variable lengths. In general, use of a 50 mm electrode of either type is often needed to examine the deeper, larger muscles in many adults, particularly the multifidus at the cervical and lumbar levels. Occasional use of a 75 mm is necessary in obese patients. In the following discussion, the principles covered apply to both concentric and monopolar needle electrodes except where indicated (e.g., cannula potentials).

Some 25 mm concentric needle electrodes, sometimes referred to as facial concentric needle electrodes, are thinner (0.3 mm diameter) and have a smaller active recording surface (0.019 mm^2) than other standard concentric electrodes (i.e., 0.46 mm diameter; 0.07 mm^2 recording surface). Thus, the physical characteristics such as the higher resistance and reduced recording surface of this electrode differ from the standard gauge concentric needle electrode. Actual differences measured in MUAP features such as the amplitude, duration, complexity, etc. between the standard and smaller concentric needle electrodes remain uncertain.

The advantages of the concentric needle electrode are that it requires only one placement for both the active and reference (or cannula) recording electrode surfaces and that there is a large base of quantitative data on the various MUAP features for numerous muscles in subjects of various ages. Other electromyographers feel that the monopolar electrode is less noxious and better tolerated by patients. In our experience, patient tolerance is mainly contingent upon the experience and skill of the electromyographer.

Principles of insertion of needle electrodes: In this program's video demonstrations, the focus is on the insertion site. Also important is maintaining the continuity and ease of patient and physician movement during the examination. This can be facilitated by keeping the electrode wire to the preamplifier over the examiner's hand so that it, or the electrode, do not become dislodged or disconnected. Proper care of the needle electrode cable (i.e., connecting/disconnecting the needle electrodes via the hub or preamplifier via the connector) by firmly holding it only at these points will avoid premature breakage and possible introduction of artifact in the signal.

At insertion, it is helpful for the examiner to slightly tense the skin at the insertion site using the thumb and index finger of the hand that is not holding the needle electrode. This facilitates quick penetration of the electrode through the skin and subcutaneous tissue. In some muscles, this maneuver also serves to identify and isolate the borders of the muscle under investigation. It has not always been possible to demonstrate the “skin tensing” maneuver while demonstrating insertion sites in the videos.

When intrinsic muscles of the hand or foot are studied, the examiner should try to insert the electrode in the less sensitive dorsal skin, rather than the glabrous skin of the palm or sole. In most instances the insertion of the needle electrode should be in a direction perpendicular to the orientation of the muscle fibers, i.e., skin. The needle electrode is inserted in a progressively deep track or “corridor” so as to sample both superficial and deep sites within the muscle.

In most muscles, the electrode placement should be midway between the midbelly or presumed endplate zone of the muscle and its origin or insertion. Although the electrode can be inserted more obliquely going in a direction more parallel to the muscle fibers, the risk is that in most muscles, particularly the larger ones, the same motor units will be sampled as the electrode crosses through fewer muscle fibers with the same length of penetration (figure 1). Periodic activation before the needle is advanced through the corridor may reduce some patient discomfort.

In addition to a corridor directly perpendicular to the long axis of the muscle fibers, one can usually sample two additional corridors approximately 45 degrees to each side of the first corridor going away from the long axis of the muscle fibers (figure 2). The corridor and angles are estimated from the surface of the muscle, not the skin. The electrode should not be re-directed in a corridor parallel to the long axis of the muscle fibers or placed in a new insertion site more proximal or distal to the original insertion site. This almost assures the likelihood of sampling the same motor units. Additional insertion sites should be made lateral or medial to the original site, far enough away so that the laterally angled corridors do not overlap. The exception to this is in the paraspinal musculature which is discussed in a separate section.

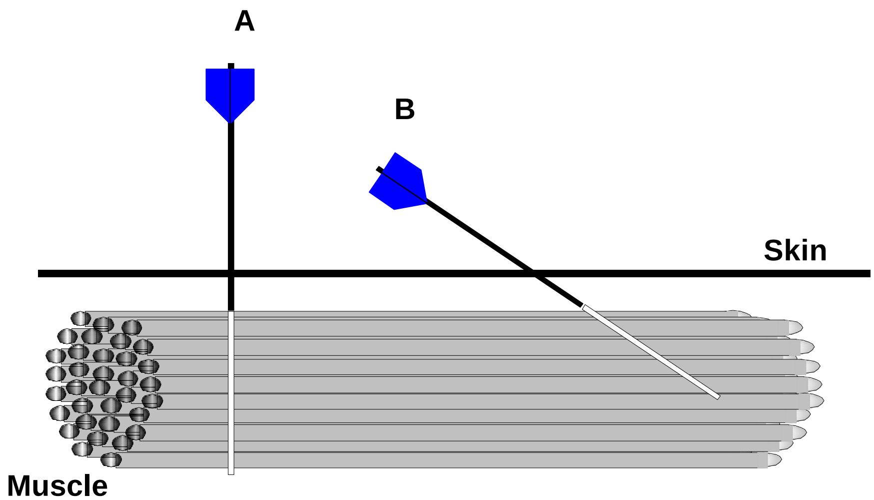


Figure 1. A. The needle electrode is inserted as perpendicular as possible to the direction of the muscle fibers as shown in this schematic view. A maximal number of muscle fibers and therefore MUAPs are sampled, limited only by the length of the electrode or the muscle’s size. In **B**, the electrode is inserted at a very oblique angle, relative to the direction of the sarcomeres. Note that it traverses considerably fewer muscle fibers for the same length of electrode penetration. This increases the chance of sampling the same motor unit even though the shape of the MUAP may change as the electrode enters a different portion of the motor unit’s territory.

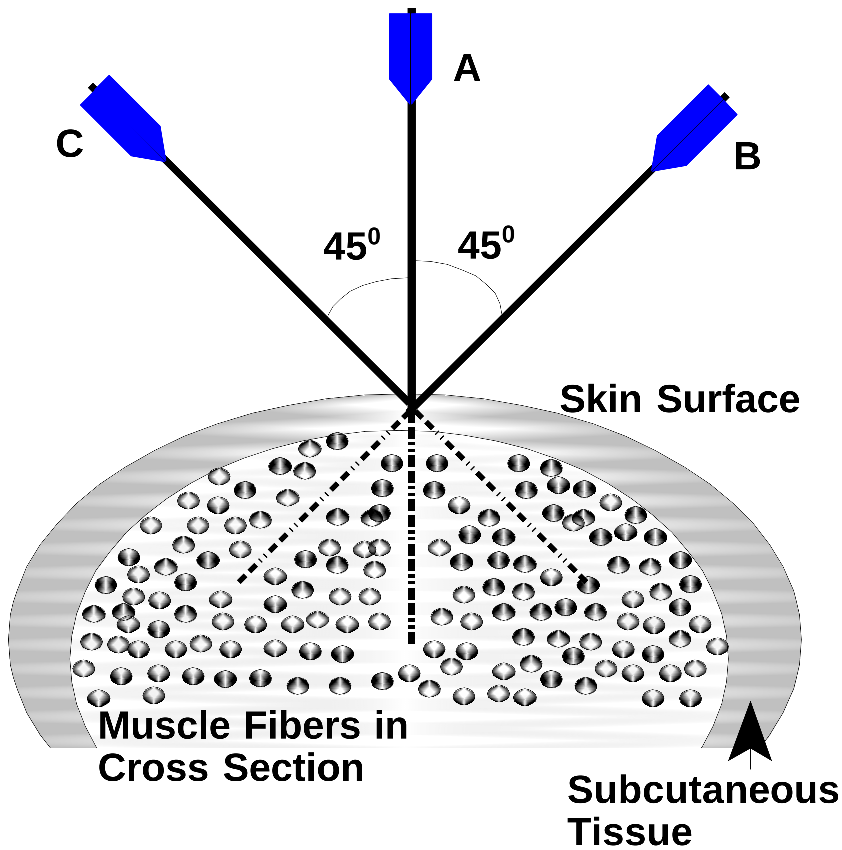


Figure 2. Schematic showing the desired direction of the electrode insertion into the muscle. Ideally perpendicular, this may be directed slightly obliquely as needed into, or out of, the plane of the paper (See figure one). By withdrawing the electrode just subcutaneous, two additional corridors may be studied with minimal chance of overlap in studying the same motor units except for the very superficial part of the muscle at the insertion points.

Even with perpendicular insertion, the appearance of the MUAP may change considerably as the electrode "views" it from different positions within the motor unit territory (see Stalberg, 1991). In either figure **1.A** or **1.B** the same MUAP(s) may continue to be recorded yet look “different” so long as the recording tip is within the motor unit's territory. Assuming no change in the level of activation, the examiner may therefore have the false impression of sampling a greater number of motor units than are actually being seen, analogous to an artist painting the same subject but from different perspectives or other variables. For example, the *fin de siècle* French impressionist Claude Monet painted a series of canvases depicting the same haystack at different times of the day, i.e., variation in lighting. While the haystack in some paintings appears similar, in other canvases it does not.

This risk is reduced going medial or lateral as shown in figure **2**, however, the only certain way is to exceed the boundaries of the motor unit territory. How large is a motor unit territory? This is variable depending on the muscle's size, i.e., smaller distal ones versus larger proximal ones. In the biceps brachii it is estimated to be 10 mm in diameter. If additional insertion sites are needed within the same muscle, it is recommended to make these far enough from the original site so that the corridors extending medial or lateral do not overlap.

Although usually unnecessary in the examination of some of the larger or superficial muscles, smaller or deeper muscles should be identified and isolated using activation to confirm localization prior to, and immediately after, needle insertion. The insertion sites given for specific muscles in this program are recommended based on experience and are considered optimal insertion sites. This assumes absence of other mitigating factors such as superficial veins, scars, vascular anastamoses for dialysis, superficial infections, etc.

If a muscle is palpated and activated, yet the needle electrode records no activity, re-positioning is necessary before checking insertional and spontaneous activity (see **Activation of Muscle** above). In most muscles, confirmation of localization by way of brief activation is helpful prior to assessing insertional and spontaneous activity. The muscle is then easily “deactivated” to permit assessment of insertional and spontaneous activity.

After examining insertional and spontaneous activity but before activating the muscle to assess the MUAPs, it is helpful to withdraw the needle electrode to a point just subcutaneous to the insertion point. The patient should then activate the muscle to a mild or moderate degree and the needle progressively re-inserted through the same corridor(s). Activation can be modulated so that the MUAPs can be optimally visualized on the display screen. If some muscles, e.g., flexor carpi radialis or anterior tibial, are activated while the needle electrode is deeply inserted, the needle may "bow" or bend, making manipulation difficult. More importantly, the patient may experience pain.

If minor bleeding should occur after withdrawal of the electrode, compression with a gauze is quickly applied. Sometimes minor bleeding is delayed a few moments. It is an important point of patient etiquette and concern that bleeding be minimized. After each site is completed, the examiner may wish to routinely apply compression for a few moments. This need not slow the examination: while the examiner is applying gentle compression with one hand, the next site can be studied or prepared for study. Although electrodes are typically quite sharp, they quickly dull with repeated insertions, particularly when the tip is pushed against bone. In the latter instance, the patient's reaction will again confirm for the examiner that pain receptors are indeed present in the periosteum.

Principles of intramuscular localization: Examiners may vary in where they position the electrode within the same muscle. This can have potentially important effects on the myogenic signal. The normal MUAP varies in shape depending on where along the longitudinal axis of the sarcomeres it is recorded (Stalberg et al, 1986; Barkhaus and Nandedkar, 1996; Barkhaus and Nandedkar, 1997). By recognizing some of these variations, it is possible to infer one's relative position within the muscle with respect to endplate region, tendon, etc. Such knowledge allows the examiner to optimally position the electrode and to be cautious about misinterpretation of otherwise normal MUAPs.

Endplate Region Motor Unit Action Potentials: This is a biphasic potential with an initial negative or upgoing phase. They may still be recorded when close to the endplate region but in the absence of endplate noise. Although acceptable for analysis, these MUAPs may be slightly shorter in duration than triphasic MUAPs recorded more distal to the endplate zone. Therefore, these do not necessarily indicate a myopathic process. If the electrode is too close to, or within the endplate zone, the patient may indicate the site as discretely uncomfortable.

Cannula Motor Unit Action Potentials: These are only recorded with concentric needle electrodes as monopolar electrodes have no cannula. These appear as large positive-going waves with occasional negative-going spikes within the main positive wave. The negative spikes do not protrude above the baseline. These MUAP recordings derive from the cannula of the concentric electrode, hence their appellation. Cannula potentials are recorded when the recording tip of the electrode is outside of the motor unit territory or in smaller muscles, outside of the actual muscle. They may be large and sound enlarged or "neurogenic" on the audio monitor. Ignore them. One might say that with Cannula MUAPs, the examiner is “missing the point”, i. e., the recording electrode tip is outside that motor unit’s territory. Reposition the electrode or activate the muscle so as to record MUAPs generated near the electrode's recording surface.

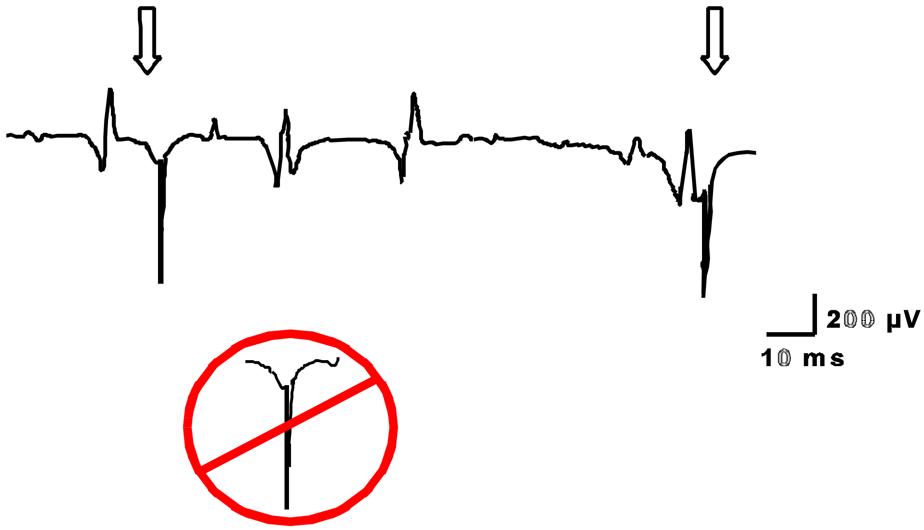


Figure 3. Typical cannula potential recorded with a concentric needle electrode. Identify and ignore those seen and if necessary, advance or withdraw the electrode to a new recording position so they are eliminated. Acceptable MUAP's discharging concurrently with cannula potentials may be counted in analysis as in the epoch shown. Note how easily the cannula potential is to identify by the arrow on the left while the arrow to the right coincides with a normal triphasic wave. The resulting phase interaction produces a spurious MUAP that appears increased in duration and "complex".

Tendon Motor Unit Action Potentials: This waveform derives from the MUAP recorded near the tendon. Occasionally a small "Gydikov potential" (Stalberg et al, 1986; Barkhaus and Nandedkar, 1996) may be seen, particularly with monopolar electrodes. This MUAP appears unremarkable in the initial positive-going phase and the negative-going main spike is of normal amplitude and duration. The positive-going after-wave is deep with a slow return to the baseline. This MUAP has been referred to as a "pelican potential" (Barkhaus, 1997) because the profile of the positive after-wave resembles a pelican's beak in profile. The large "pouch" portion is close to the main spike of the MUAP, followed by the tapered point where it gradually returns to the baseline.

These are more likely to be seen in smaller muscles and the multifidus where the electrode is more likely to be in the tendinous region because of their relatively shorter sarcomeres. Duration measurement where the after-wave returns to baseline should be adjusted to where the sharp negative-going part of the slope tapers to a slower rate of return. These should not be construed as representing long duration "neurogenic" potentials. The tip-off is that the main spike is narrow or normal in duration relative to the longer duration positive after-wave. Genuinely enlarged MUAPs in reinnervation almost always have proportional increases in the main spike and positive after-wave.

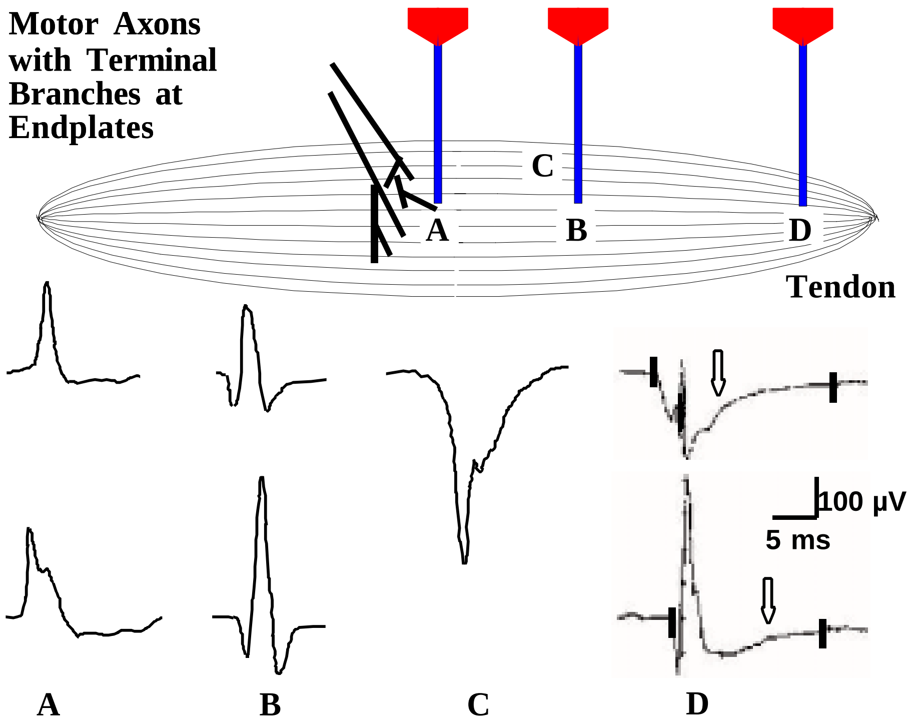


Figure 4. MUAPs recorded from different positions in a schematic muscle between the endplate region and the tendon.

A. Endplate Region MUAPs: note the sharp initial negative-going phase.

B. "Typical" triphasic MUAPs: the recording tip of the electrode is within the territory of two different motor units when recorded in the same epoch of signal, but not within the motor unit territory of MUAP "**C**" (see following). If the electrode tip moves slightly so that the MUAPs shown for **B** are recorded successively in two different epochs and not concurrently in the same epoch, they could possibly represent the same motor unit recorded from different positions in the motor unit's territory.

C. Cannula potential (see also figure **3**): this signal is recorded exclusively by the cannula as the recording tip of the electrode is deeper into the muscle at point “B”, outside of this motor unit’s territory.

D. Tendon MUAPs: note the prolonged positive after-wave. The cursors show where the duration markers might be set suggesting a relatively long duration or neurogenic appearing MUAP: the arrows indicate actual duration endpoint, i.e., at the terminus of the steepest rate of return to baseline.

Sampling size of MUAPs in muscle: A muscle may be considered a group of motor units. In turn, the motor unit is the basic functional unit of a muscle. The estimated number of motor units in each muscle varies depending on its size and function. These motor units in turn generate the MUAPs that are recorded by the needle electrode. In clinical EMG, the examiner is typically recording a relatively small portion of a muscle's total number of motor units. This depends on the amount of muscle actually explored by the recording electrode and recognizing that the MUAPs sampled represent the smaller, lower threshold motor units recruited at low levels of voluntary activation.

In quantitative analysis, a sample size of 20 MUAPs representing 20 different motor units is considered standard. Sample sizes of fewer MUAPs may distort the assessment of a muscle when mean values are used. Recently the concept of “outliers” has been utilized in quantitative analysis (see Stalberg, 1994). In this approach, identifying a minimum few abnormal MUAPs may be sufficient to establish abnormality in lieu of the traditional mean value of 20.

A similar approach can be applied to routine subjective EMG. As a muscle is examined, the identification of 3-5 unequivocally abnormal MUAPs should be sufficient to determine the presence of pathology, allowing the examiner to move on to the next muscle. The examiner should ensure, however, that the abnormal MUAPs recorded represent different motor units. Two to three clearly different MUAPs may usually be recorded at one site alone. If the needle electrode has fully explored the corridors as described above, there should be minimal overlap between motor unit territories. If no abnormality is encountered after beginning study on a muscle using routine subjective EMG, then sampling and measuring about 20 different MUAPs should suffice to consider the muscle as being within normal limits.

Segmental innervation of muscle: The motor unit is ultimately represented in its respective spinal segment by a single anterior horn cell in the anterior gray matter of the spinal cord. The relative representation of a myotome or root in each muscle is critical to deducing segmental localization. A muscle’s total number of motor units may be innervated by 2 to 4 nerve roots in various proportions. For example, most authors consider the biceps brachii to be supplied by the fifth and sixth cervical roots, with neither root being consistently predominant.

The concept of segmental pointer muscles of the limbs has been advocated by some (see Schliak). Specific muscles, by virtue of their spinal segment or myotome innervation, are considered to precisely localize focal lesions of the spinal roots.

Unfortunately, this concept has limited practical use as discussed above. Each limb muscle is typically supplied by more than one myotome or spinal segment, one of which may be predominant. Use of comparative charts to determine segmental innervation (see Kendall et al, pp. 406-409) is helpful, but should be viewed with care as these may have been derived by different methods.

Anatomic variability may occur in the root supply to muscles between individuals (see Phillips & Park). There are also individuals who have a pre- or post-fixed plexus and, more peripherally, anomalous innervations (see Gutmann) in some distal muscles. In one series, asymmetry in lower extremity segmental innervation (i.e., side-to-side) has been reported in almost 30% of individuals (see Phillips & Park). Therefore the diagnosis of a mononeuropathy, radiculopathy, etc. cannot be confirmed on the basis of pathology in a single muscle or in the study of a suboptimal number of muscles.

Principles and strategies in using the needle electrode to localize pathology: Pathologic processes should not be presumed to affect each motor unit in a homogeneous manner. The detection of pathology in a given muscle will depend on adequate sampling of MUAPs within the affected muscle, the severity of the pathologic process, and the time in the evolution of the pathologic process that the muscle is studied. Any of these factors can have a significant influence in how the assessment of a muscle may contribute to the localization of a pathologic process.

In radiculopathy, this has important implications. For example, a muscle having 80% representation of myotome A and 20% representation of myotome B in a radiculopathy of mild to moderate severity affecting only myotome B will likely have minimal findings on the needle electrode examination of this muscle. A common example is the frequent finding of mild reinnervation changes (e.g., mild increase in MUAP amplitude or complexity) in the gluteus maximus in an otherwise isolated L5 radiculopathy.

This emphasizes the need for examining at least three muscles having common innervation by the same spinal segment under investigation. There should be caution in over-interpreting pathology in more myotomes than may be actually involved in a single level radiculopathy. The finding of mild reinnervation changes in the gluteus maximus as described in the above example does not necessarily mean that the S1 root is involved. It is more likely the manifestation of the pathology occurring in the relatively minor contribution from L5 to the gluteus maximus. In such instances this may represent a limitation of the interpretation of the needle electrode examination. Further confirmation may be required from other investigations, such as imaging studies.

If an examination for radiculopathy is “positive” for pathological changes, additional ipsilateral limb muscles should be studied. This includes muscles having predominant innervation one segment caudal to, and one segment rostral to, the root level under investigation. Possible multiple root involvement should be excluded as opposed to manifestation of a severe single level radiculopathy, recalling that a single root may have variable amounts of innervation to multiple muscles (see above). To exclude bilateral involvement, it is reasonable to examine at least one contralateral muscle. Optimally this would be the counterpart of the most severely affected ipsilateral muscle, examining other contralateral muscles as indicated.

Radiculopathy remains one of the most common indications for performing an EMG. In this presentation, the myotome or segmental supply of each muscle is given with the predominant segment in boldface (personal observations; also see Warwick & Williams; Kendall, McCreary & Provance, pp. 406-409). The table lists frequently studied muscles in common radiculopathies. Examination of the paraspinal muscle at the corresponding segment may also be used to validate a radiculopathy. There may be, however, a variable spatial divergence between the actual vertebral level and the segmental supply to the paraspinal musculature at a specific vertebral level. For example, the level of the multifidus supplied by the C7 root is often well caudal to the C7 (i.e., 2-4 cm) vertebral body (personal observation; see also Warwick & Williams). In a mild monoradiculopathy, it may be easy to "miss" the paraspinal segment involved if insufficient, widely spaced sites are studied.

Table. Limb muscles frequently studied in common radiculopathies

Spinal Segment	**Limb Muscles**
C5	Deltoid, Rhomboid, Biceps Brachii, Supraspinatus, Infraspinatus
C6	Biceps Brachii, Brachioradialis, Deltoid, Supinator, Infraspinatus, Pectoralis (Clavicular Portion)
C7	Triceps Brachii, Flexor Carpi Radialis, Extensor Digitorum Communis, Pectoralis (Sternocostal Portion)
C8	First Dorsal Interosseous, Abductor Pollicis Brevis, Extensor Indicis, Flexor Pollicis Longus, Flexor Carpi Ulnaris
L2,3	Iliacus, Adductor Longus
L4	Vastus Lateralis or Medialis, Anterior Tibial
L5	Gluteus Medius, Anterior Tibial, Peroneus Longus, Extensor Hallucis Longus, Extensor Digitorum Longus
S1	Gluteus Maximus, Semimembranosus, Medial Gastrocnemius, Soleus

Nerve conduction studies form the basis for defining a mononeuropathy. The strategy on the needle electrode examination is to further confirm localization by sampling, if possible, muscles supplied by the specific nerve both proximal to, and distal to, the suspected level of involvement. For instance, in a median neuropathy involving only the anterior interosseous branch, the flexor carpi radialis and pronator teres would be spared as they are proximal, as well as the distal median-innervated thenar muscles such as the abductor pollicis brevis, since they are derived from a different fascicular branch. Muscles supplied by the anterior interosseous branch, such as the flexor pollicis longus, should be affected. In addition, at least two ipsilateral muscles having common segmental innervation but different peripheral nerve innervation should be studied (e.g., first dorsal interosseus, extensor indicis, extensor carpi radialis, flexor carpi ulnaris, etc.).

When fully manifest, diffuse processes such as myopathy or motor neuron disease should be demonstrable in at least 3 muscles in 3 limbs. These muscles should be supplied by different peripheral nerves that are in turn derived from 3 different roots within each limb. In some situations, at least two bulbar muscles supplied by two different cranial nerves may be substituted for one of the limbs. Commonly studied cranial-innervated muscles are described below.

Pathology of Uncertain Significance: Occasional findings or "abnormalities" are noted on the needle electrode examination that may appear isolated and difficult to interpret. Examples include diffuse enlarged MUAPs in the intrinsic foot muscles of middle age to older adults, suggesting reinnervation. Similar patchy, minimal findings may be seen in the intrinsic hand muscles of manual laborers. The gluteus maximus and deltoid are traditional sites for intramuscular injections where “abnormal” MUAPs may be recorded. Changing sites to the anterior belly of the deltoid or altering the insertion site in the gluteus maximus may be helpful in clarifying such findings.

Miscellaneous Comments: The author has occasionally utilized measurements in centimeters (cm) to localize muscles in the average adult. Obviously there may be great variability in body size and habitus making strict anthropometric measurements unhelpful in many cases. Therefore, the origin and insertion of the muscles are given, along with anatomic landmarks, to facilitate localization by way of activation of the muscle.

In keeping with the current standard of practice, the examiner must also be aware of the concept of standard or universal precautions. The use of gloves in the video highlights the examiner’s hands, but also emphasizes the importance of infection control. Although both hands are usually gloved, the examiner may wish to keep one hand free from contact with blood or other potentially infectious sources. This hand would be the one manipulating the electromyograph so that the instrument itself does not become contaminated. In customary practice, examiners perform nerve conductions without gloves and the needle electrode examination with gloves, freely touching the electromyograph while performing both procedures. To the author’s knowledge, the potential risk of contamination from the electromyograph under the above circumstances has not been addressed.

The examination table should be sturdy and constructed, as much as possible, of electrically nonconductive material. The author uses a customized, extra-wide (38 inch), long (76 inch), and low (28 inch) table on 4 inch diameter locking wheels to allow comfortable maneuverability of most patients. It is usually quicker and more comfortable for the examiner or table to be maneuvered than the patient. The lower height makes patient transfer safer and easier.

III. The Upper Extremity Muscles

Intrinsic Muscles of the Hand

Abductor Digiti Minimi (Hand)

Innervation: Ulnar Nerve (C7, **C8**, **T1** myotomes).

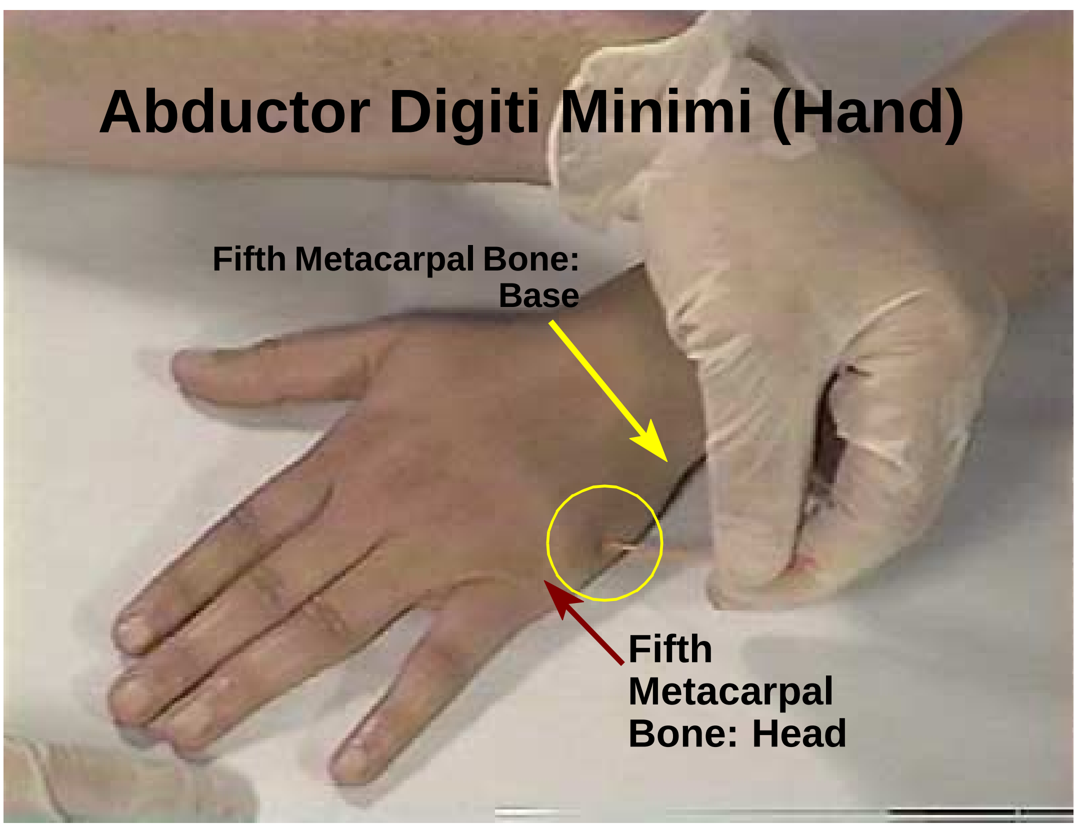
Origin: Pisiform bone and tendon of the flexor carpi ulnaris.

Insertion: Via two slips to the proximal phalanx of the fifth finger and to the ulnar border of the extensor expansion.

Position/Activation: Abducting the fifth finger with the hand in pronation.

Electrode Insertion: At the midpoint of the fifth metacarpal, just anterior to the bone which should approximate the border of the glabrous skin of the palm.

Caveat: If the electrode is inserted more anterior or palmar, it may enter the flexor digiti minimi, if too deeply it may penetrate the opponens digiti minimi.



Abductor Pollicis Brevis

Innervation: Median Nerve (C6, C7, **C8**, **T1** myotomes).

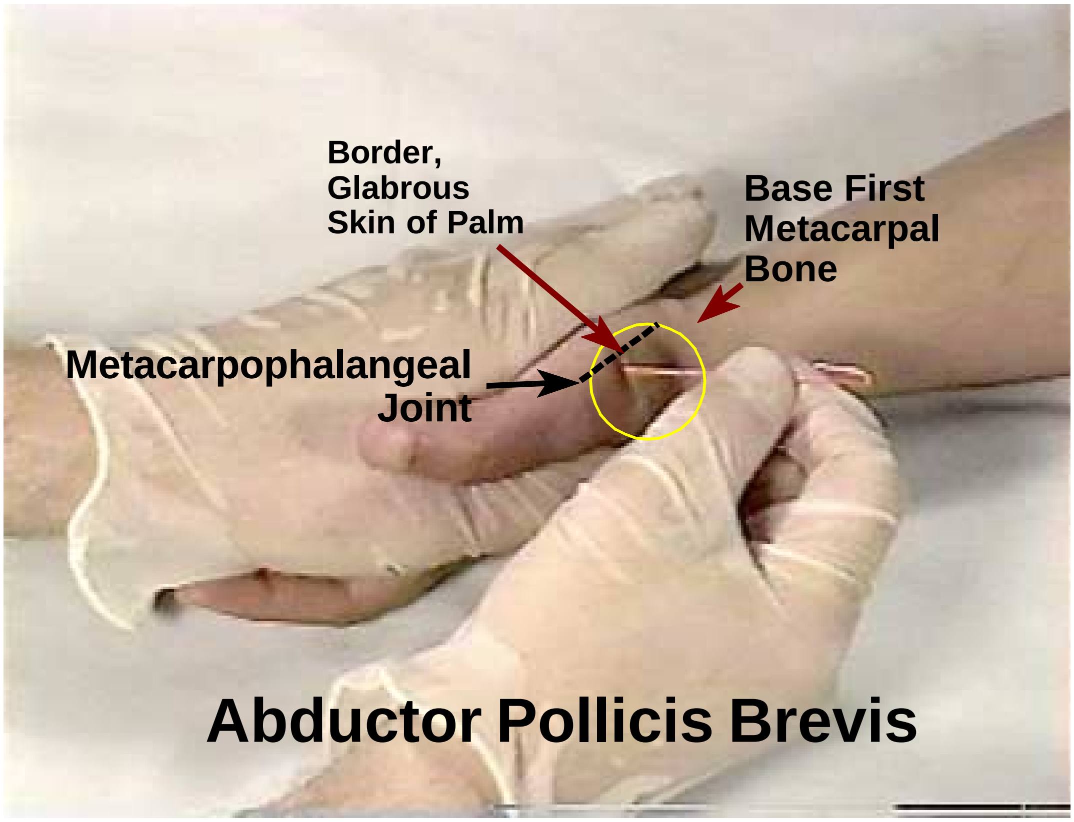
Origin: Flexor retinaculum, tubercle of the trapezium bone and tubercle of the scaphoid bone.

Insertion: Lateral aspect of the base of the proximal phalanx of the thumb.

Position/Activation: The patient's thumb is in minimal abduction with the distal phalanx slightly flexed. Stabilize the patient's thenar eminence between the examiner's thumb and index finger.

Electrode Insertion: Using a medial-directed approach just anterior to the bone at the mid-point of the first metacarpal bone.

Caveat: Avoid inserting and advancing the electrode parallel to the muscle fibers (see figure 1B) as this increases the chance of sampling the same motor units and also tends to penetrate the deeper thenar muscles. If the electrode is too medial it may penetrate the flexor pollicis brevis. If too deep (posterior) it will be in the opponens pollicis.



First Dorsal Interosseous (Hand)

Innervation: Ulnar Nerve (**C8**, **T1** myotomes).

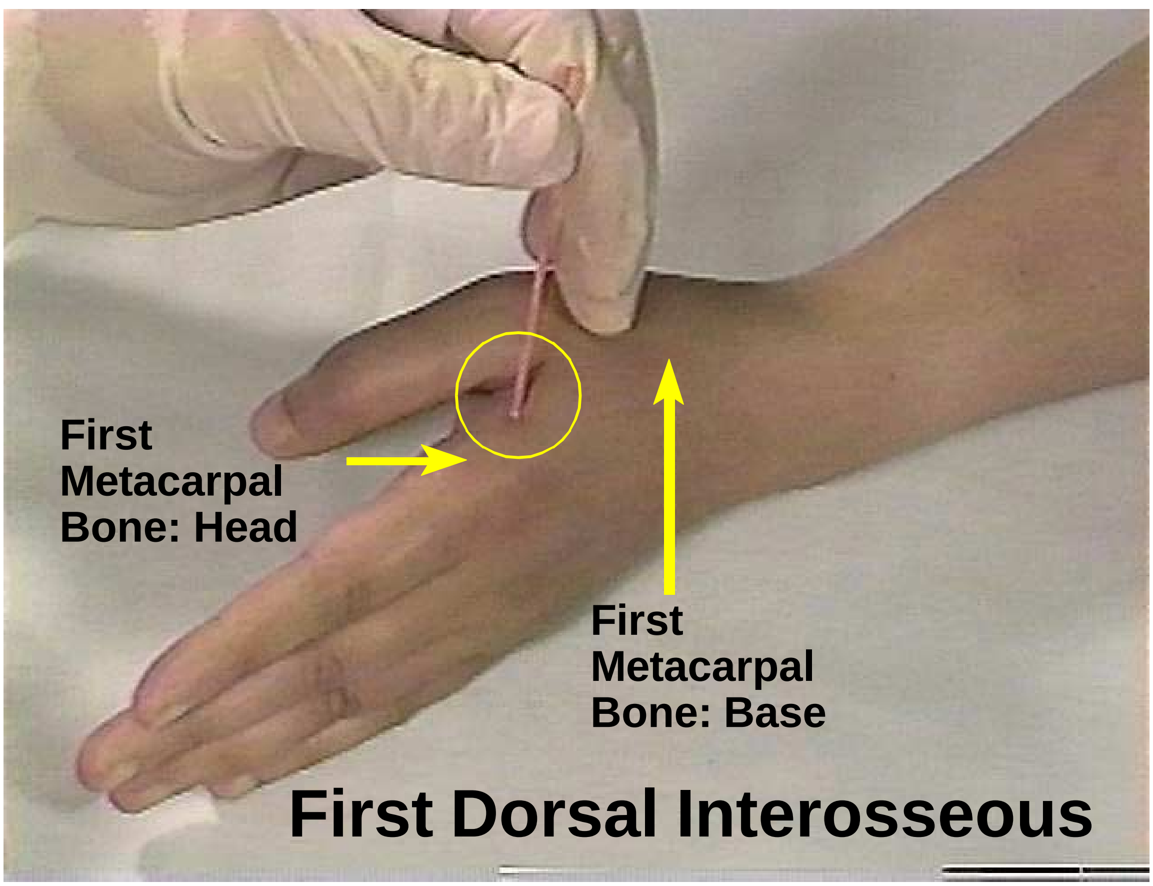
Origin: Radial aspect of the second metacarpal (medial head); proximal half of the ulnar border of the first metacarpal (lateral head).

Insertion: Base of the proximal phalanx of the second finger.

Position/Activation: Hand resting on its medial aspect, perpendicular to the table or on its palmar surface. The muscle is activated by abducting the second finger.

Electrode Insertion: Midportion of the muscle, perpendicular to the muscle's long axis. Generally two corridors can be explored by deviating the electrode slightly toward the palmar and toward the dorsal aspect of the hand.

Caveat: If the muscle is atrophied or if inserted too deeply, the electrode may enter the adductor pollicis or first lumbrical.



Distal Arm

Anconeus

Innervation: Radial nerve (**C7,** C8)

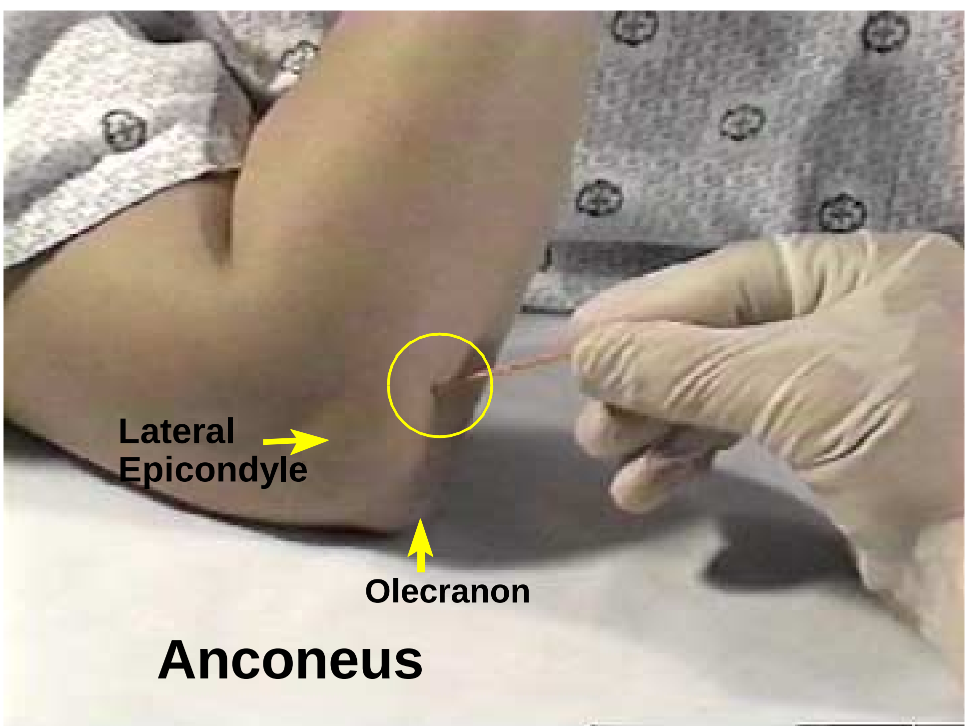
Origin: Posterior surface of the lateral epicondyle of the humerus

Insertion: Lateral olecranon process and proximal posterior surface of the ulna.

Position/Activation: The patient is supine with the forearm pronated over the trunk and the elbow flexed at 90 degrees. The patient extends their elbow in pronation against resistance. The latter can be provided by the examiner or by the patient's contralateral hand.

Electrode Insertion: In a line between the olecranon and the lateral epicondyle the midpoint is identified and the electrode is inserted immediately distal to the line.

Caveat: Functionally the anconeus may be considered a distal extension of the triceps brachii below the elbow. It is supplied by a separate, long, motor branch from the proximal radial nerve at the midhumeral level.



Brachioradialis

Innervation: Radial Nerve (C5, **C6**)

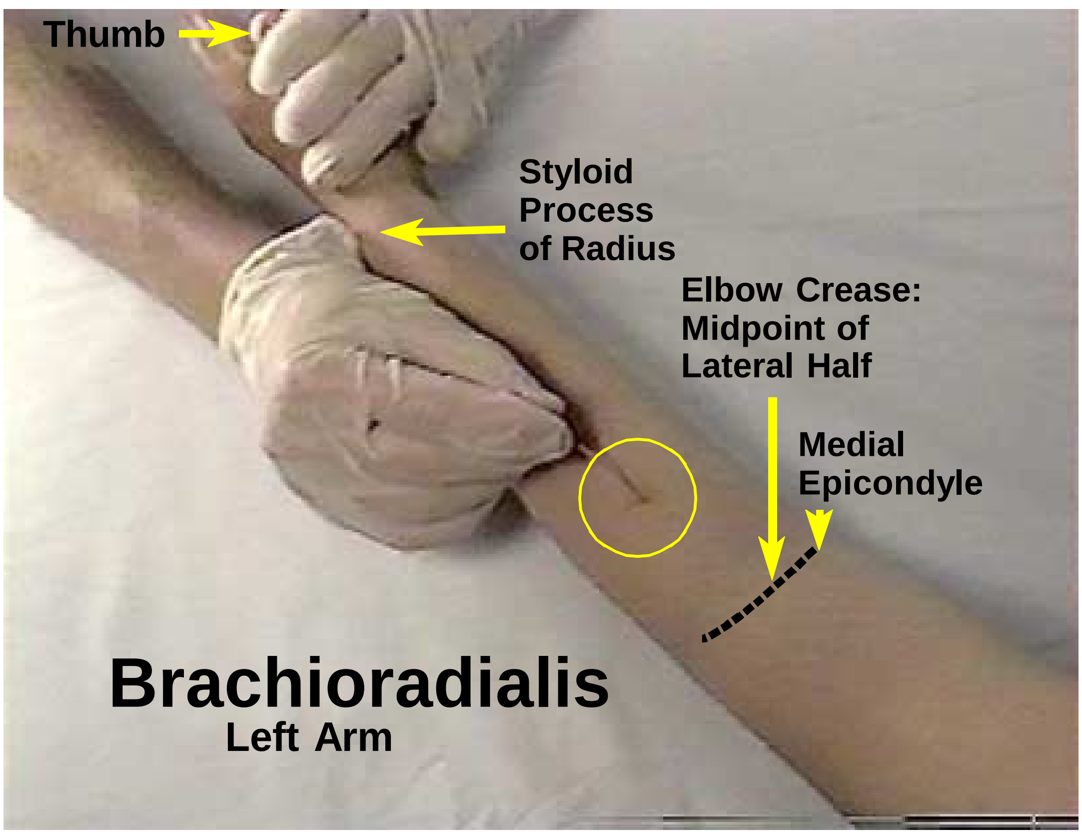
Origin: Proximal two thirds of the lateral supracondylar ridge of the humerus.

Insertion: Lateral radius at the base of the styloid process.

Position/Activation: The forearm is in semi-pronation with the patient supine. The elbow is flexed in semi-pronation.

Electrode Insertion: In a line between the mid-lateral half of the elbow crease and the radial styloid process, divide into three segments and insert the electrode into the mid proximal third segment.

Caveat: If the electrode is too lateral, it may penetrate the extensor carpi radialis.



Extensor Carpi Radialis Longus & Brevis

Innervation: Radial nerve (C5, **C6**, **C7**, C8). They are considered together because of their close anatomic proximity and similarity of action.

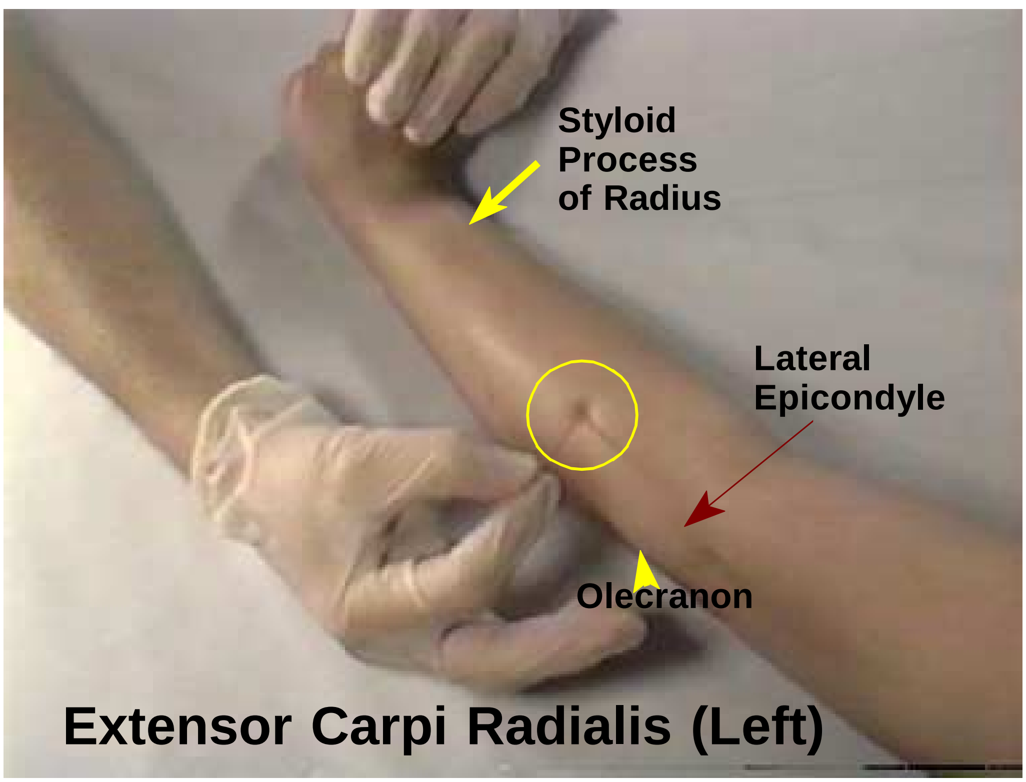
Origin: Distal one third of the lateral supracondylar ridge of the humerus and lateral intramuscular septum.

Insertion: Dorsal surface of the base of the second metacarpal bone.

Position/Activation: Forearm is in pronation. The muscle is best activated by extending the wrist in radial deviation (abduction).

Electrode Insertion: In a line between the radial styloid process and the lateral epicondyle, insert the electrode approximately one third the distance from the lateral epicondyle. The Extensor Carpi Radialis Longus is more likely to be examined as it is more superficial.

Caveat: If the electrode is too radial it may penetrate the brachioradialis, if too far toward the ulnar border, it may penetrate the extensor digitorum communis.



Extensor Digitorum Communis

Innervation: Radial nerve (C6, **C7**, C8 myotomes).

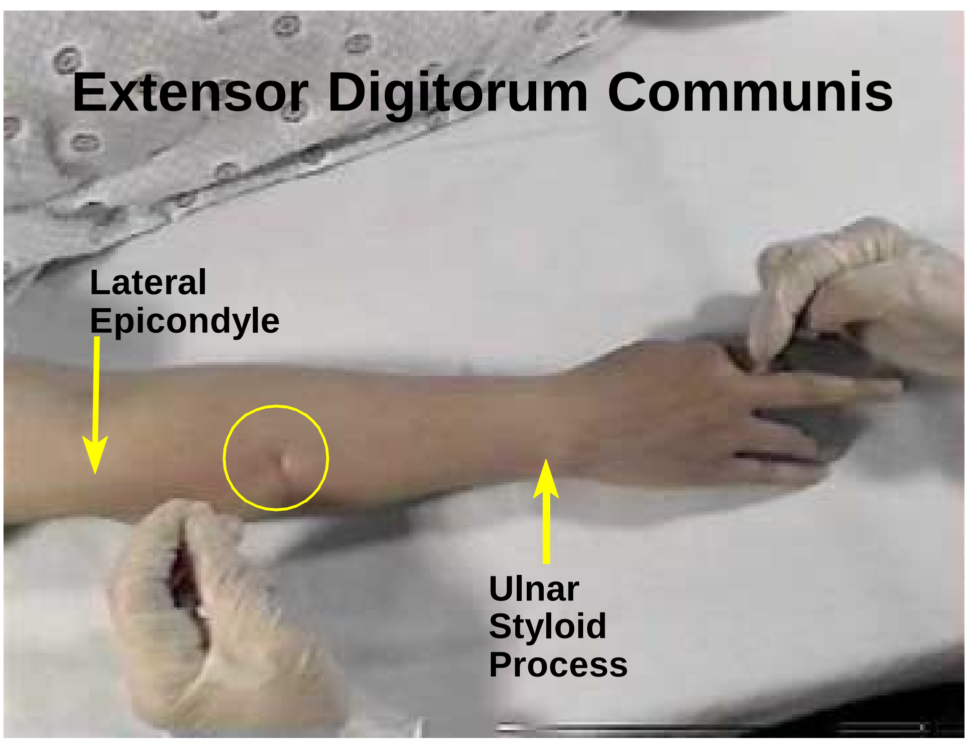
Origin: Common extensor tendon on the lateral epicondyle of the humerus and from the deep antebrachial fascia.

Insertion: Via four tendons on the dorsal surface of the 2nd to 5th middle and distal phalanges.

Position/Activation: The forearm is in pronation. The third or fourth digits are then extended at the metacarpophalangeal joints.

Electrode Insertion: Go to the midpoint in a line between the ulnar styloid and the lateral epicondyle. Define the border of the extensor digitorum communis and wrist extensor group (see Extensor Carpi Radialis Longus & Brevis) by activating each separately. Insert the needle electrode after confirming localization by again activating the extensor digitorum communis as above. The segment supplying the third digit is most easily activated in isolation and is commonly used in single fiber electromyography. It is more radial to the segment supplying the fourth digit.

Caveat: If the electrode is too radial (lateral), it may penetrate the extensor carpi radialis; if too deep (anterior) it may penetrate the abductor pollicis longus.



Extensor Indicis

Innervation: Radial nerve (C6, **C7, C8** myotomes).

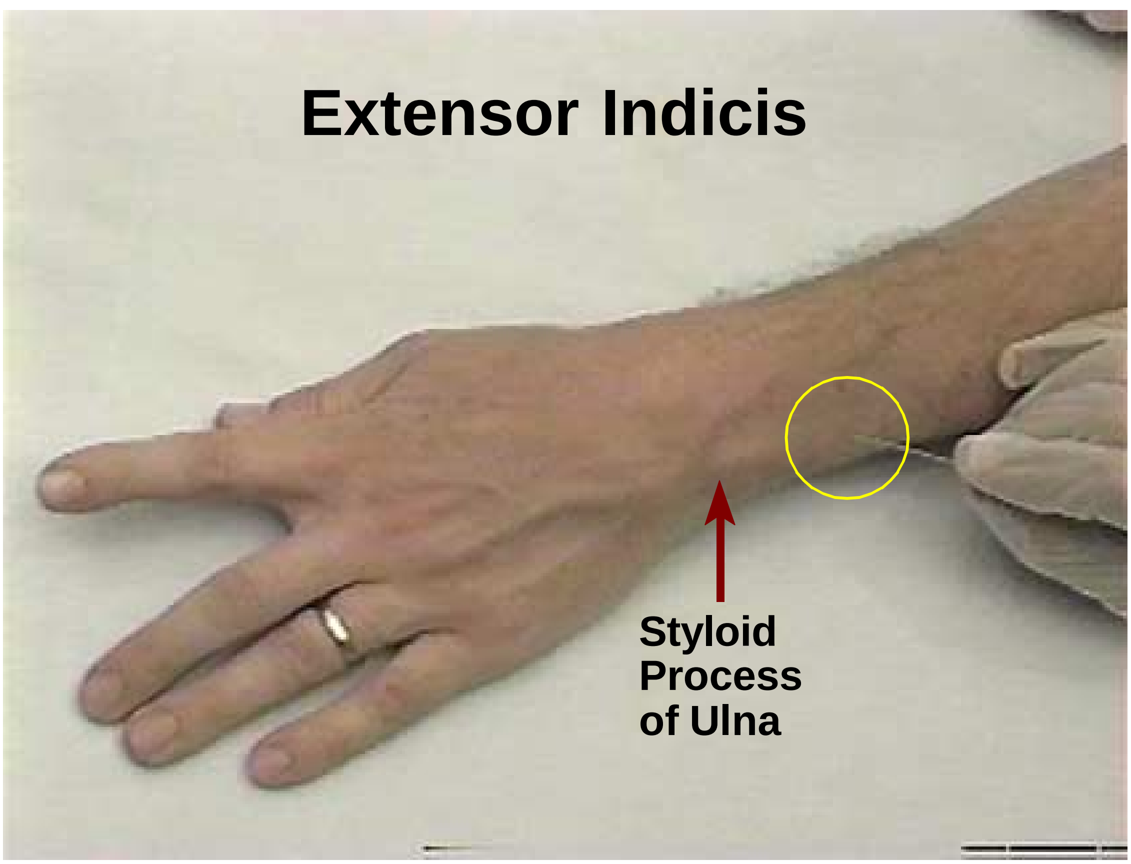
Origin: Dorsal surface of the distal ulna.

Insertion: Inserts into the extensor expansion of the index finger.

Position/Activation: The patient extends the second finger with the hand fully pronated on the examination table.

Electrode Insertion: Perpendicular to the long axis of its muscle fibers approximately 2-4 cm proximal to the ulnar styloid, just radial to the lateral border of the ulna.

Caveat: If the electrode is too proximal it may penetrate the extensor digitorum communis; if too medial it may penetrate the extensor carpi ulnaris; if too lateral (or radial), it may penetrate the abductor pollicis longus.



Flexor Carpi Radialis

Innervation: Median nerve (C6, **C7**, C8 myotomes):

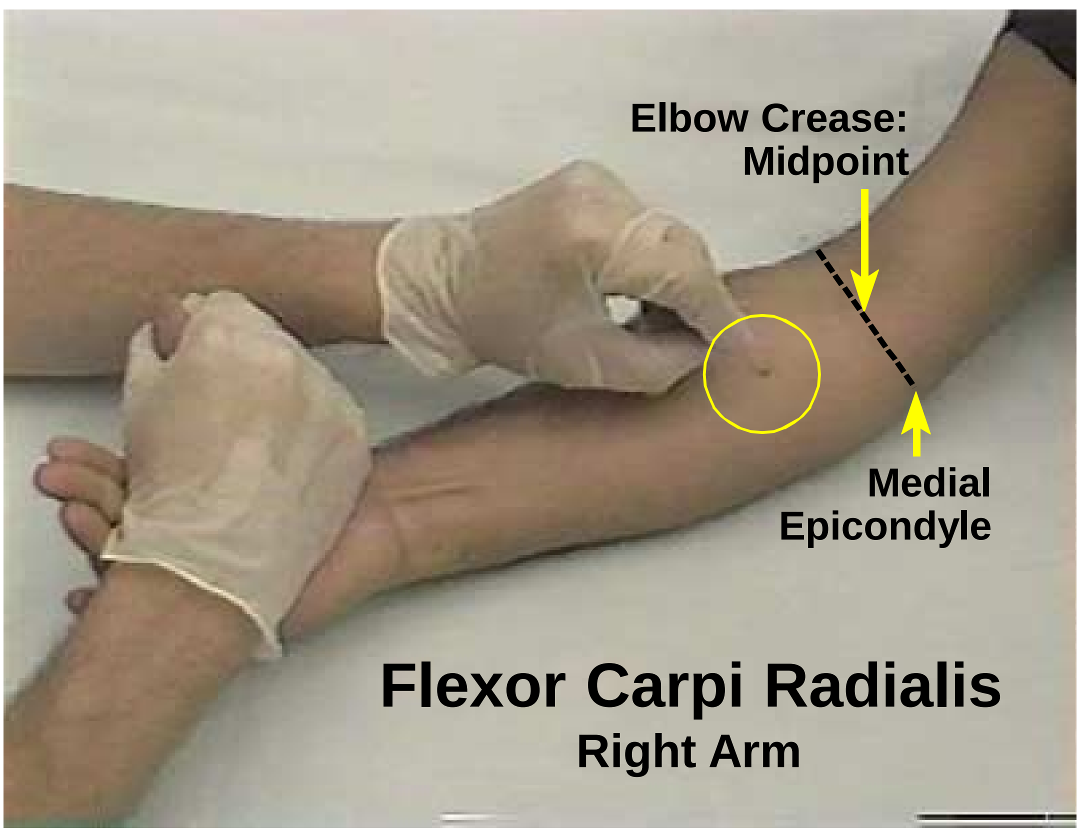
Origin: Common flexor tendon on the medial epicondyle of the humerus and deep antebrachial fascia.

Insertion: Inserts on the volar surface of the second metacarpal bone with a slip to the third metacarpal.

Position/Activation: The patient flexes the wrist in radial deviation with the forearm in supination on the examination table.

Electrode Insertion: Approximately 5-6 cm from the midpoint of the elbow crease into the proximal forearm, just medial to center. The electrode should be directed proximally at a slight angle. The reason for "angling" the electrode slightly is that activation of this muscle in particular readily shifts the electrode's position, bowing it, and producing pain.

Caveat: The Flexor Carpi Radialis is the most superficial muscle encountered, deeper insertions may penetrate the flexor digitorum sublimis, lateral insertions may penetrate the pronator teres and medial insertions may penetrate the palmaris longus.



Flexor Carpi Ulnaris

Innervation: Ulnar nerve (C7, **C8**, T1 myotomes).

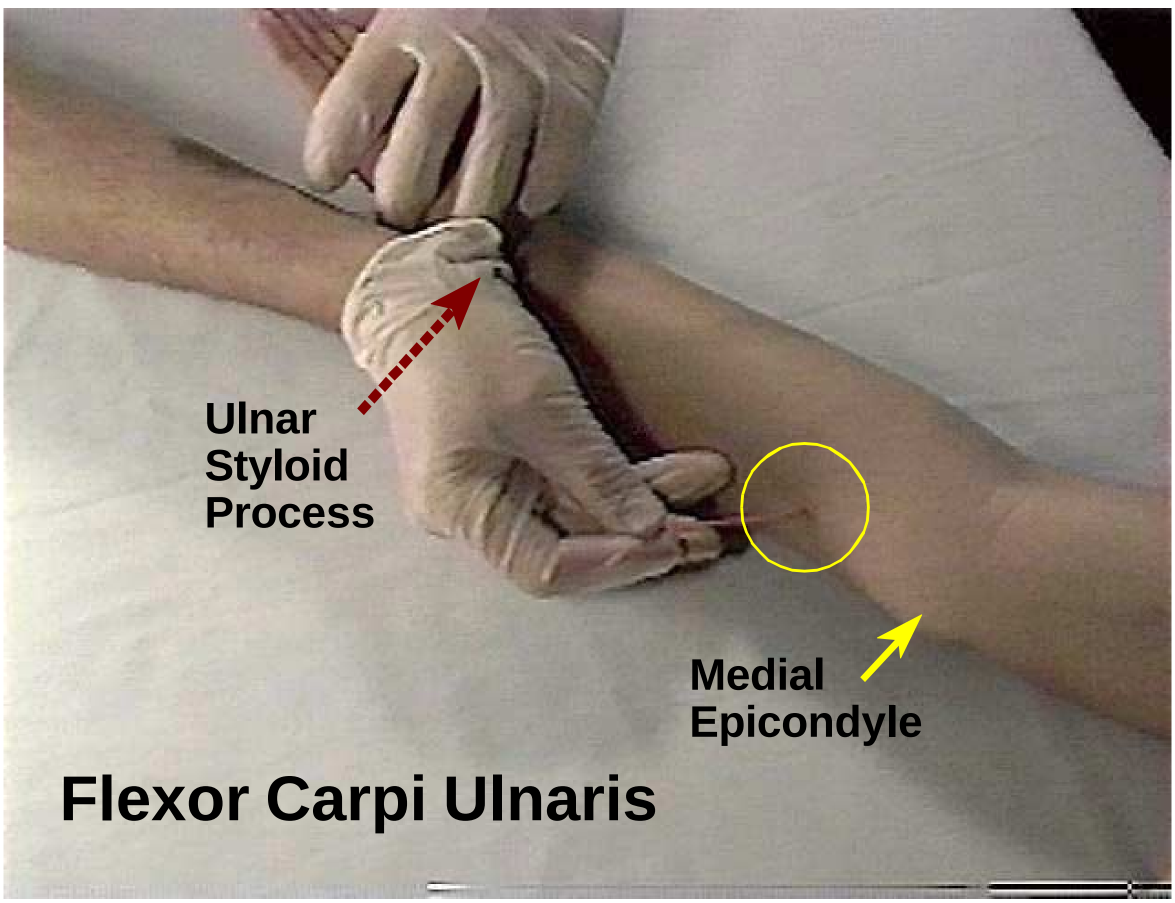
Origin: Humeral head at the common flexor tendon on the medial epicondyle of the humerus and an ulnar head by an aponeurosis from the medial border of the olecranon.

Insertion: Pisiform bone and, by ligaments, to the hamate and fifth metacarpal bones.

Position/Activation: With the forearm supinated, the fifth finger is abducted. Alternatively, the wrist can be flexed in ulnar deviation as shown in the video.

Electrode Insertion: Define the line from the ulnar styloid to the medial epicondyle. Divide into three segments and insert the electrode into the mid proximal third segment.

Caveat: If the electrode is too posterior it may penetrate the flexor digitorum profundus.



Flexor Digitorum Profundus (Medial Portion)

Innervation: Ulnar nerve: Medial Portion (C7, **C8, T1** myotomes).

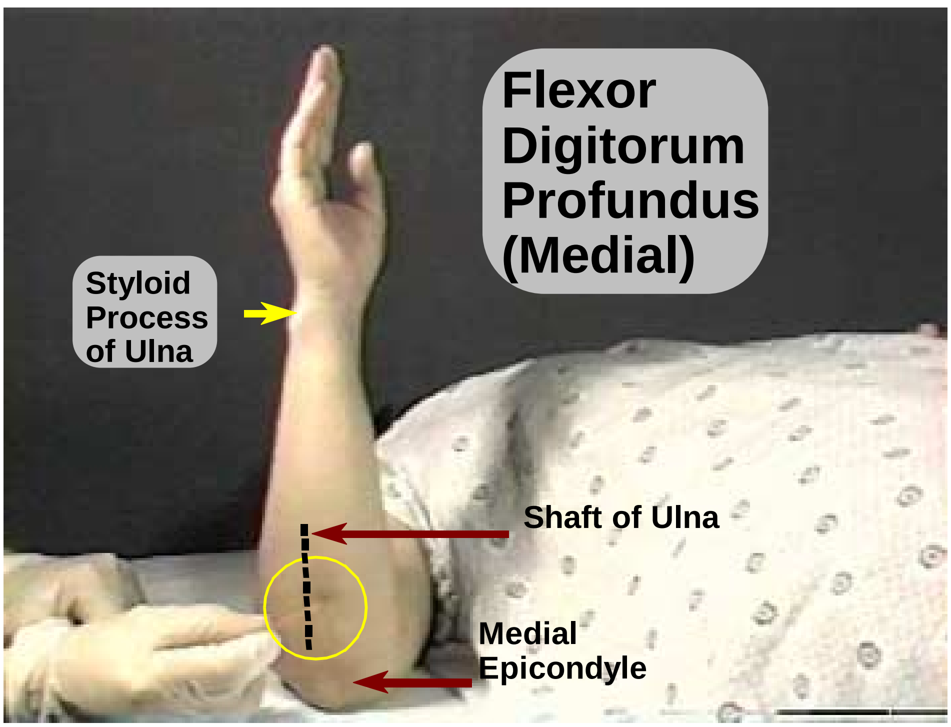
Origin: Anteromedial surface of the proximal ulna and adjacent interosseous membrane

Insertion: Volar surfaces of the distal fourth & fifth phalanges.

Position/Activation: The patient is supine with their forearm pronated across their trunk and with their elbow off the table; alternatively they may have their forearm positioned vertically with their elbow resting on the examination table. The patient flexes the individual distal phalanges of the fourth or fifth digits, usually against resistance. This can be accomplished by bringing the patient's thumb across his/her palm in opposition, allowing the distal phalanx of digits four or five to be firmly pressed down on the thumbnail in flexion, as if preparing to flick the thumb.

Electrode Insertion: Define the line from the medial epicondyle to the ulnar styloid process. Divide into three segments and insert the electrode into the distal portion of the proximal third segment, just anterior to the medial border of the ulna.

Caveat: If the electrode is too anterior, it may penetrate the Flexor Carpi Ulnaris.



Flexor Digitorum Profundus (Lateral Portion)
(not shown in video)

Innervation: Median nerve: Lateral Portion (C7, **C8, T1** myotomes).

Origin: Anteromedial surface of the proximal ulna and adjacent interosseous membrane

Insertion: Volar surfaces of the distal second & third phalanges.

Position/Activation: The patient is supine with their forearm pronated across their trunk and with their elbow off the table; alternatively they may have their forearm positioned vertically with their elbow resting on the examination table. The patient flexes the individual distal phalanges of the second or third digits, usually against resistance. This can be accomplished by bringing the patient’s thumb across his/her palm in opposition, allowing the distal phalanx of digits two or three to be firmly pressed down on the thumbnail in flexion, as if preparing to flick the thumb. The examiner should be able to palpate the selectively activated portions (i.e., those to specific digits) of this muscle.

Electrode Insertion: Define the line from the medial epicondyle to the ulnar styloid process. Divide into halves and insert the electrode into the midpoint, just anterior to the medial border of the ulna.

Caveat: The medial portion to the fourth and fifth fingers is always proximal to the lateral portion to the lateral head. The contribution to the third finger is usually the easiest to palpate. It is proximal to the contribution to the second finger. If the electrode is too anterior, it may penetrate the Flexor Carpi Ulnaris.

Flexor Pollicis Longus

Innervation: Median nerve (C7, **C8**, T1 myotomes).

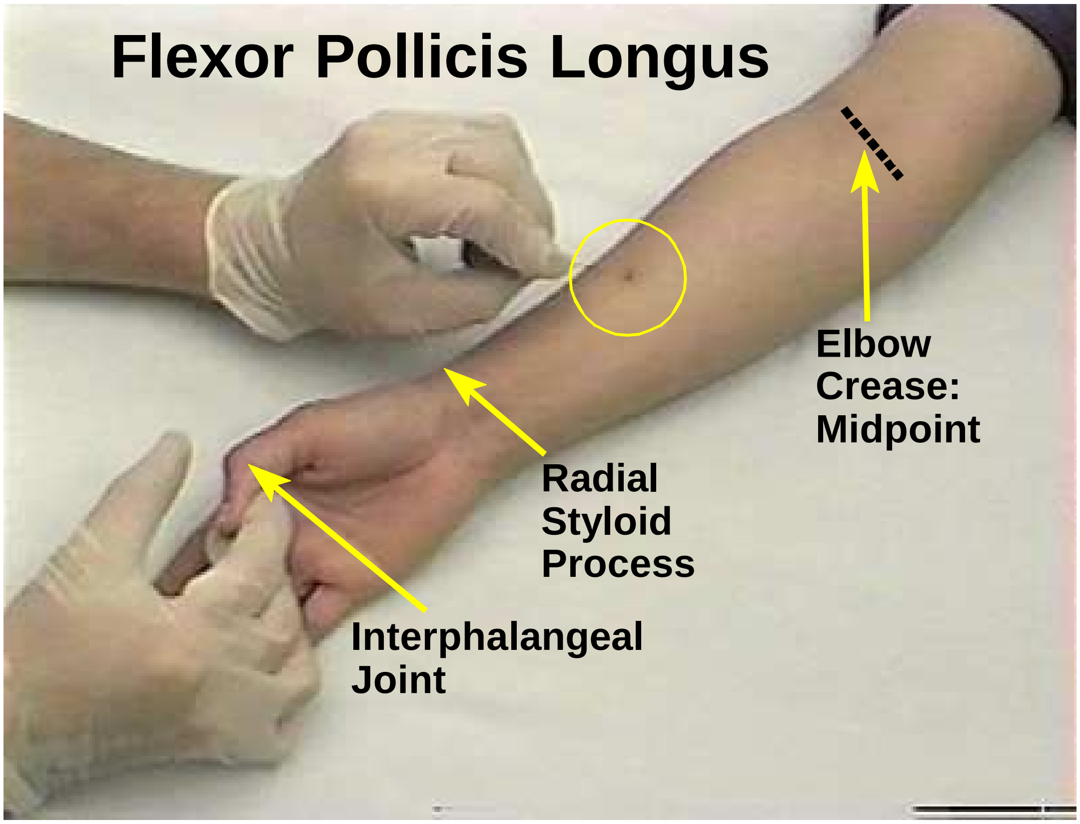
Origin: Variable but typically originates from the middle to distal anterior surface of the radius, medial border of the ulna's coronoid process, and interosseus membrane.

Insertion: Palmar surface of the base of the distal phalanx of the thumb.

Position/Activation: The patient and forearm are supine. Activate by flexing the distal phalanx of the patient's thumb against the examiner's finger. Alternatively, by flexing the second digit at the metacarpophalangeal joint so that it lies over the thenar eminence, a reasonably cooperative patient may flex the distal phalanx of their thumb over the dorsum of the middle interphalangeal joint of their index finger.

Electrode Insertion: Define the line from the midpoint of the elbow crease to the radial styloid process. Two thirds of the distance from the elbow crease, insert the electrode just medial to the radius. This muscle is deep, hence localization is best achieved by periodic activation of the muscle. The electrode is inserted deeper toward the muscle until “crisp” MUAPs are recorded (General Overview, **Figure 4B**).

Caveat: Caution must be exercised by inserting the electrode sufficiently deep (or posterior) to pass through the flexor digitorum sublimis.


Flexor Pollicis Longus
Elbow Crease: Midpoint
Radial Styloid Process
Interphalangeal Joint

Pronator Teres

Innervation: Median nerve (**C6**, **C7**)

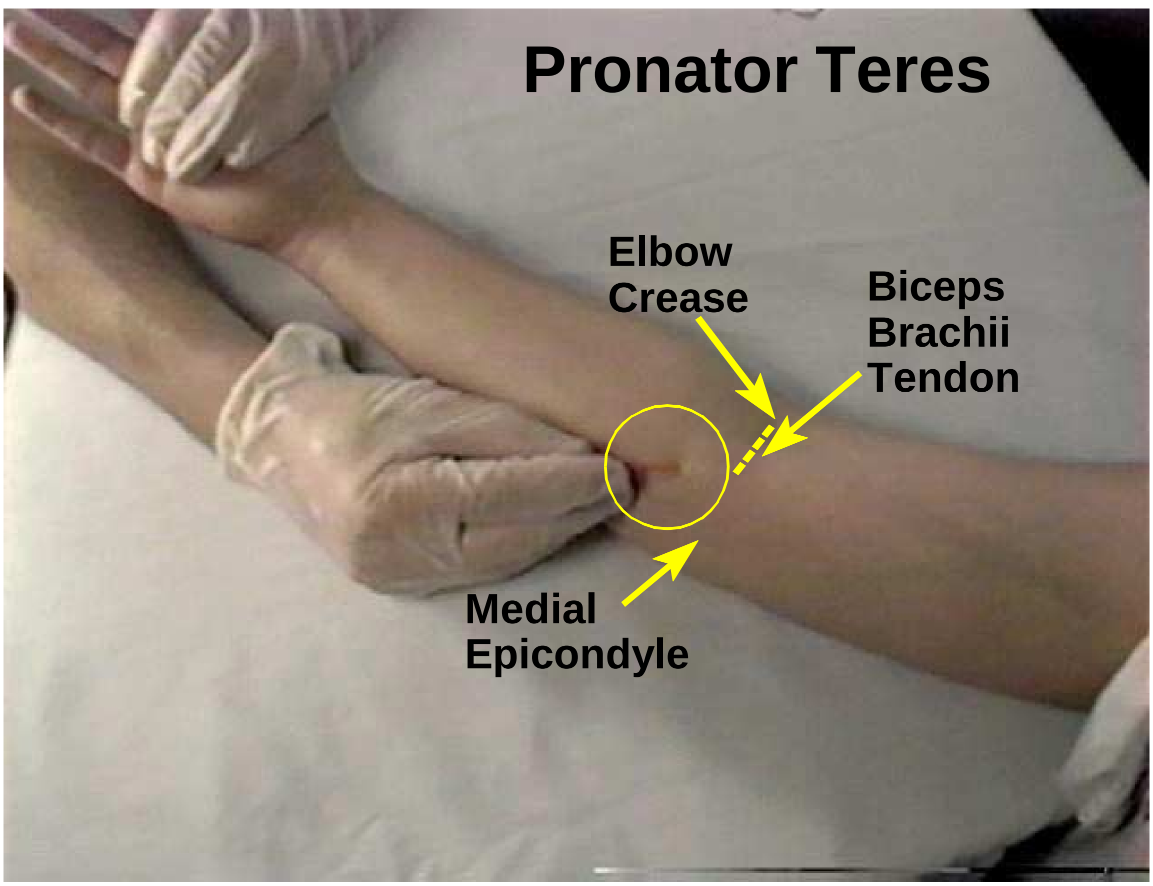
Origin: Via two heads, a humeral head originating from the medial epicondyle of the humerus and common flexor tendon and an ulnar head originating from the medial side of the coronoid process of the ulna.

Insertion: Mid-lateral surface of the radius.

Position/Activation: The forearm is in supination with the muscle being optimally activated by pronating the forearm from this position.

Electrode Insertion: Just distal to the elbow crease at a point midway between the biceps tendon and the medial epicondyle.

Caveat: If the electrode is too medial, it may penetrate the flexor carpi radialis.



Supinator

Innervation: Radial nerve (C5, **C6**, C7)

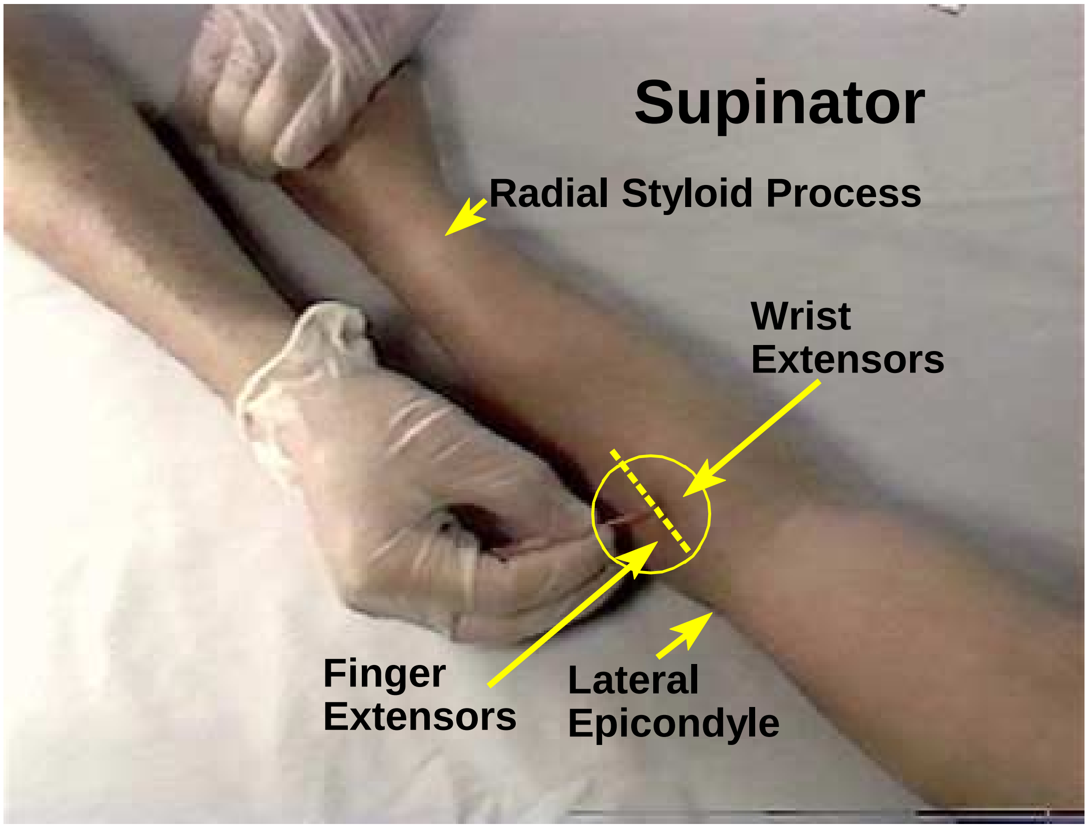
Origin: Lateral epicondyle of the humerus, radial collateral ligament of the elbow joint and supinator crest of the ulna.

Insertion: Lateral surface of the upper third of the shaft of the radius.

Position/Activation: The patient is supine with the forearm in pronation on the examination table. Activate by supinating the forearm against resistance while it remains on the table surface.

Electrode Insertion: Define the line between the lateral epicondyle and the radial styloid process and mark that point which is one fourth the way distal to the lateral epicondyle, coinciding with the dividing line between the finger extensors and the wrist extensors (see extensor digitorum communis and extensor carpi radialis longus and brevis). Insert the electrode between these muscle groups, deviating the electrode tip toward the radius bone. This muscle is deep, hence localization is best achieved by periodic activation of the muscle. The electrode is inserted deeper toward the muscle until “crisp” MUAPs are recorded (General Overview, figure **4B**).

Caveat: The supinator is a deep muscle, partially enveloping the radius bone at this level. Periodic activation may be necessary to confirm localization.


Supinator
Radial Styloid Process
Wrist Extensors
Finger Extensors
Lateral Epicondyle

Proximal Arm & Shoulder

Biceps Brachii

Innervation: Musculocutaneous nerve (**C5**, **C6**)

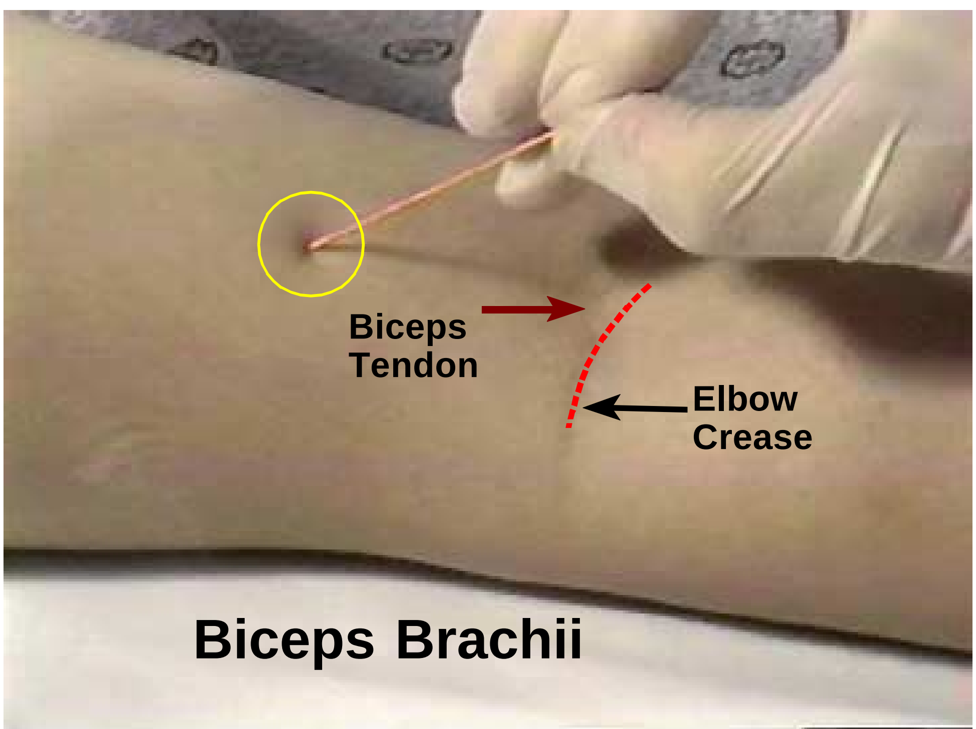
Origin: Via two heads. The short medial one originates from the coracoid process of the scapula and the long lateral one originates from the supraglenoid process of the scapula.

Insertion: Tuberosity of the radius.

Position/Activation: The patient is supine and the arm is extended in supination. Activation is by having the patient flex their elbow maintaining supination of the forearm. Greater activation can often be achieved by having the patient externally rotate or "hyper-supinate" their forearm, as this is an additional action of the biceps brachii. The latter maneuver produces minimal upper arm movement.

Electrode Insertion: Divide the muscle longitudinally into three segments and insert the electrode at the junction of the middle and distal segments.

Caveat: If the electrode is too distal and lateral, it may penetrate the brachialis.



Deltoid (Middle)

Innervation: Axillary (**C5**, **C6**).

Origin: The deltoid is divided into its anterior, middle and posterior fibers which originate from the clavicle, superior acromion and posterior spine of the scapula, respectively.

Insertion: Common tendon on the deltoid tuberosity of the humerus.

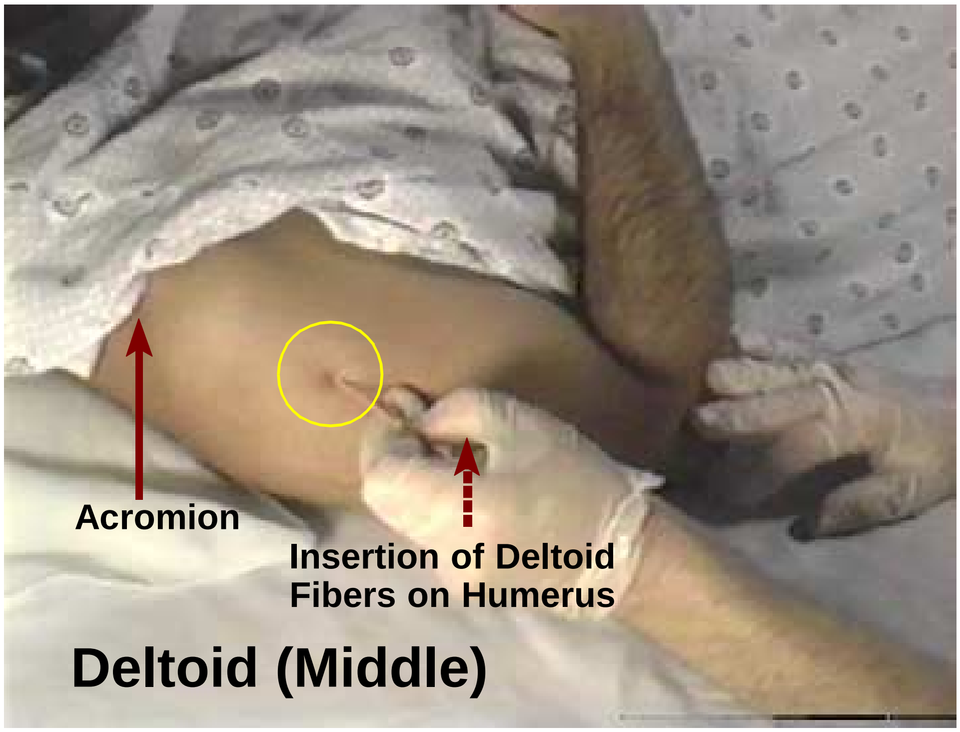
Position/Activation: The patient is supine with their elbow flexed and forearm pronated over their trunk. The patient abducts their shoulder without lifting their elbow off the table surface. Although their arm can also be fully extended at their side, the flexed elbow position allows some internal rotation of the shoulder which facilitates activation of the anterior fibers.

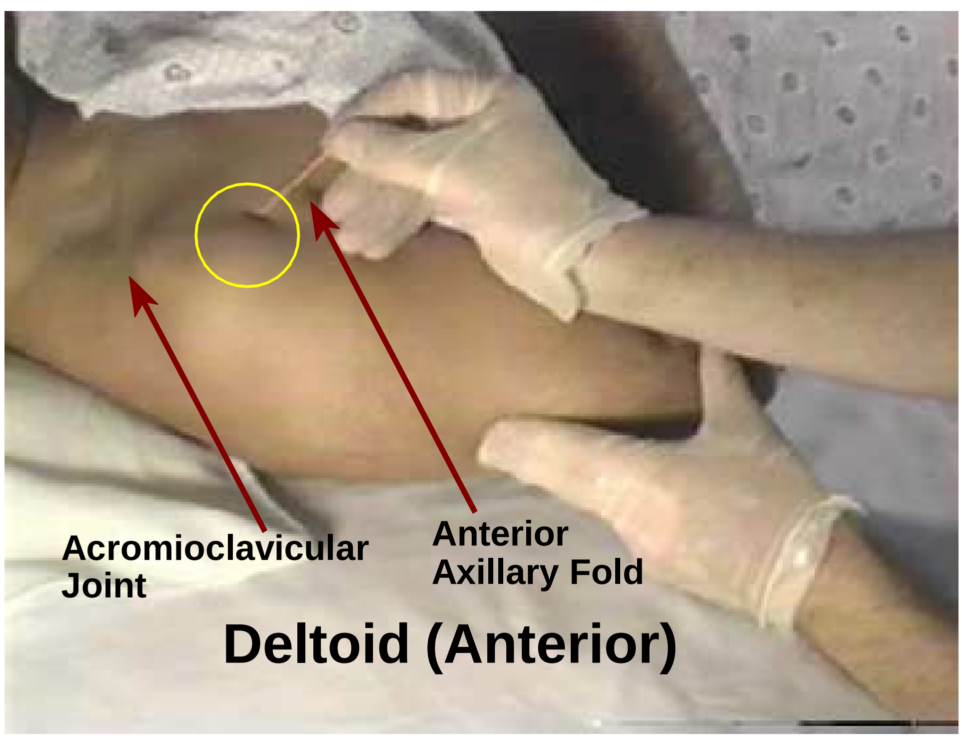
If resistance is necessary, the examiner applies their hand against the patient's elbow as it is abducted away from the patient's side. Another strategy is to have the patient take their contralateral hand and grasp the back of the hand on the side being studied as it lies prone over their trunk. The patient then abducts their shoulder which should cause this hand to be pulled away, but not through, the other hand restraining it.

If sustained, minimal activation is necessary such as in single fiber electromyography, a webbed restraint belt is minimally snugged around the trunk and arms just proximal to the elbows, or at least the trunk and arm to be examined. The author stresses prior explanation of this maneuver to the patient. The belt does not wrap around anything else, e.g., the table, so the patient is not "belted" to anything! There should only be slack for about 1-2 cm abduction of the elbow from their side. The patient then abducts their shoulder from their trunk into the belt in a principally isometric contraction as described above. In the author's experience, this maneuver produces the best activation for recording single fiber studies and is well tolerated by patients. If a belt is not available, then a sheet folded lengthwise and knotted may be substituted.

Electrode Insertion: Halfway between the acromion and the insertion of the deltoid on the humerus.

Caveat: When a patient is suspected of having extensive previous intramuscular injections to the middle deltoid, the ***Anterior Deltoid*** may be substituted. With the shoulder adducted against their side in mid-rotation (i.e., elbow on the table and forearm vertical), define the line between the acromioclavicular joint and the anterior axillary fold. From the midpoint of this line, go one quarter the distance lateral toward the lateral border of the shoulder and insert the electrode. Activate by having the patient abduct and forward flex their shoulder.





Infraspinatus

Innervation: Suprascapular nerve (C4, **C5**, **C6**).

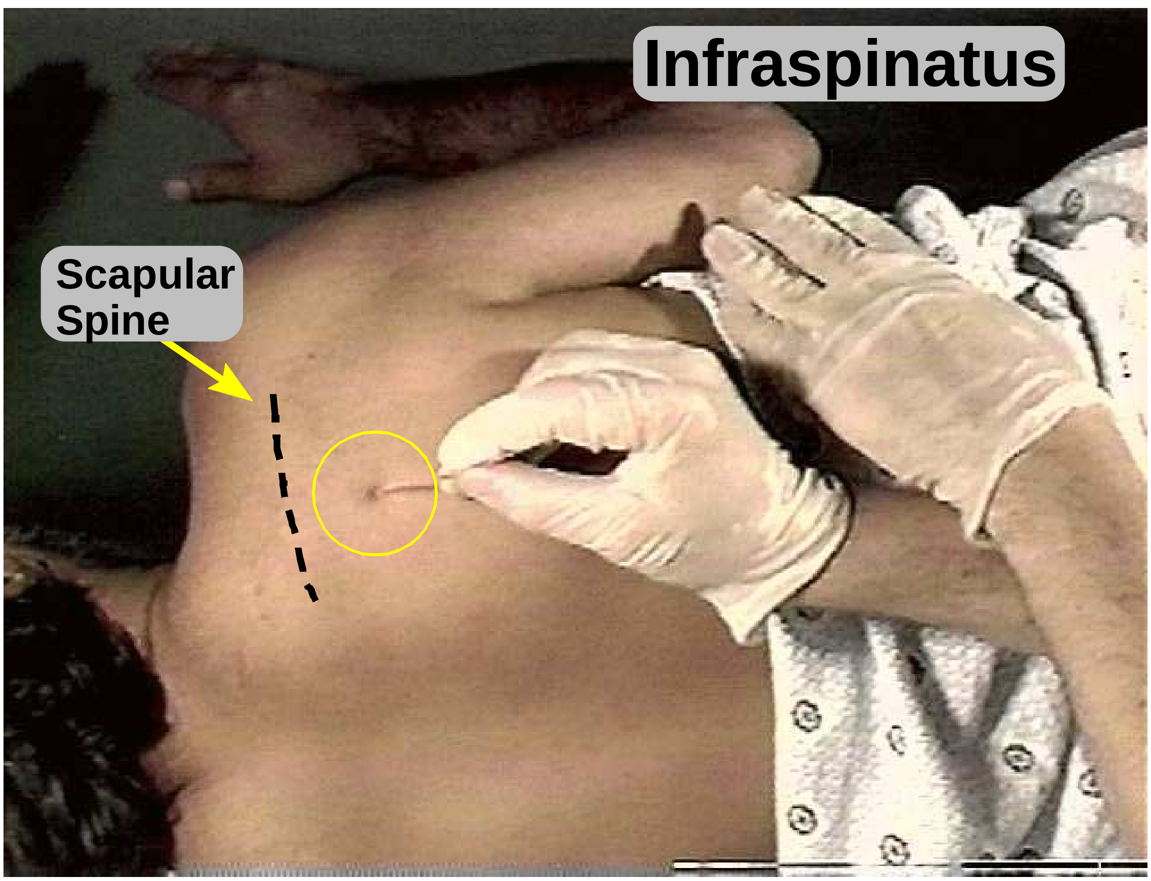
Origin: Medial infraspinous fossa of the scapula.

Insertion: Inserts on the greater tubercle of the humerus and shoulder joint capsule.

Position/Activation: The patient is in the lateral decubitus position with the side to be studied superior, the arm resting along their side with the elbow flexed and forearm pronated anteriorly (i.e., hanging downward over their trunk), and, if necessary, the hand resting on the table surface. The muscle is activated by external rotation of the shoulder while maintaining the elbow's position against their trunk.

Electrode Insertion: 3-4 cm inferior to the midpoint of the scapular spine.

Caveat: If the electrode is too superficial, it may be in the middle trapezius.



Levator Scapula

Innervation: Direct branches from the C3, **C4** roots and by the dorsal scapular nerve derived from the **C4**, **C5** roots.

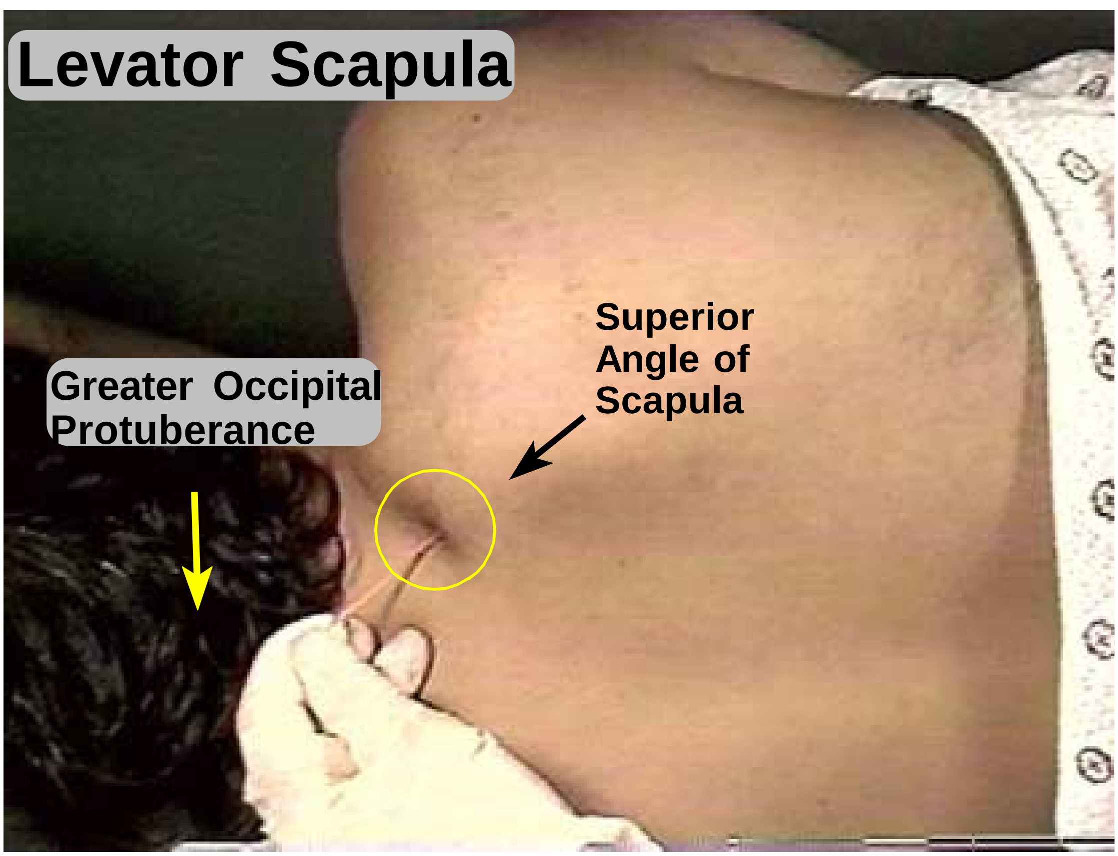
Origin: Transverse processes of C1-4 vertebrae.

Insertion: Medial border of the scapula just below the superior angle, but above the root of the scapular spine.

Position/Activation: The patient is in the lateral decubitus position with the side to be studied superior, the arm resting along their side with the elbow optionally flexed. Activate by elevation of the scapula or "shrugging" the shoulder.

Electrode Insertion: Define the line between the external occipital protuberance and the superior angle of the scapula and insert just less than half way from the superior medial border of the scapula.

Caveat: As with the rhomboids, if the electrode is too superficial it will be in the trapezius; if too deep it will be in the paraspinal musculature.



Pectoralis Major: Clavicular or Upper Portion

Innervation: Lateral Pectoral Nerve (**C5**, **C6**, **C7**)

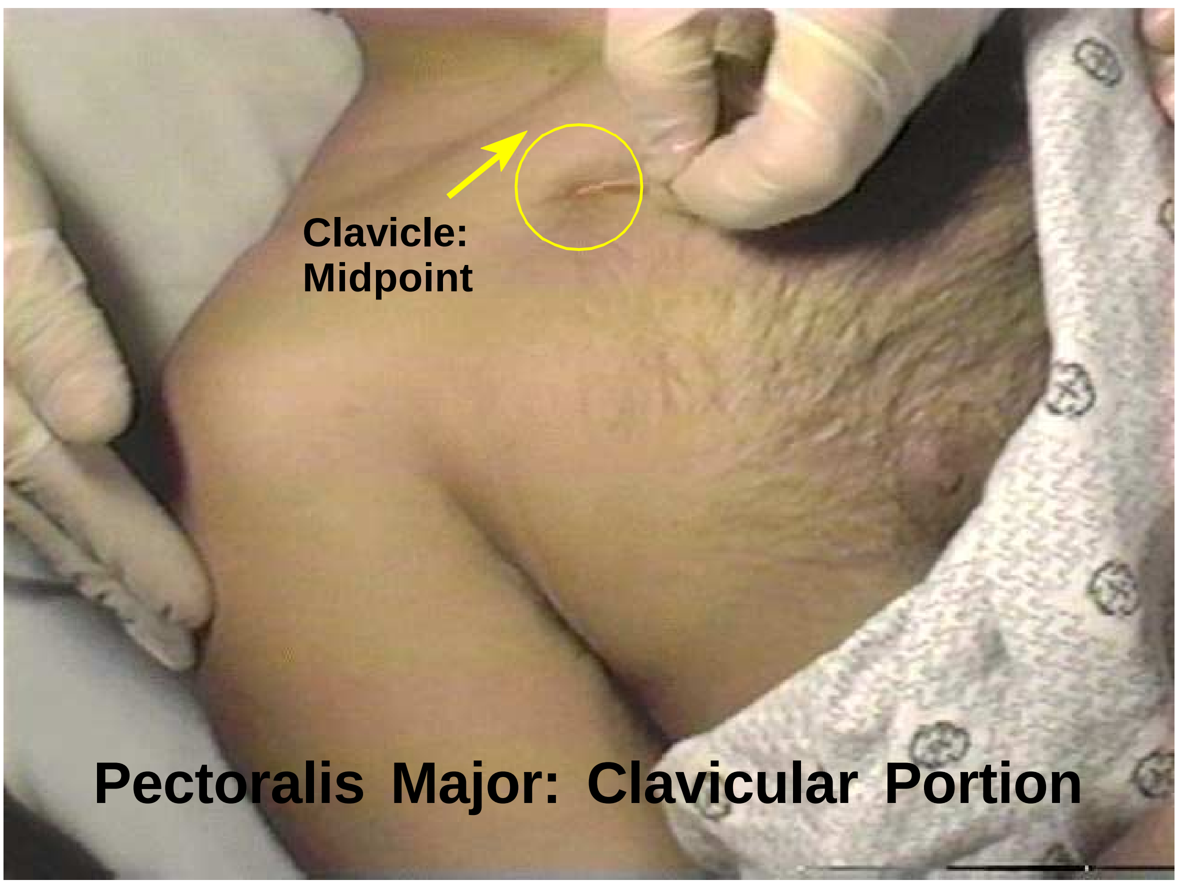
Origin: Anterior surface of medial half of clavicle.

Insertion: Crest of the greater tubercle of the humerus.

Position/Activation: The patient is supine with the arm extended along side, adducting their arm against their side.

Electrode Insertion: Identify the midpoint of the clavicle and insert just inferior.

Caveat: Excessively deep insertion may potentially result in pneumothorax.



Pectoralis Major: **Sternocostal or Lower Portion**

Innervation: Medial Pectoral Nerve (C6, **C7**, **C8**, T1).

Origin: Anterior surface of sternum, cartilages of first 6-7 ribs

Insertion: Greater tubercle of the humerus.

Position/Activation: The patient is supine with the arm extended along side, adducting their arm against their side.

Electrode Insertion: Approximately 2 cm medial and 2 cm superior to the anterior axillary fold.

Caveat: If the electrode is too lateral, it may penetrate the biceps brachii or anterior deltoid.

Rhomboids (Minor and Major)

Innervation: Dorsal scapular nerve (C4, **C5**, C6)

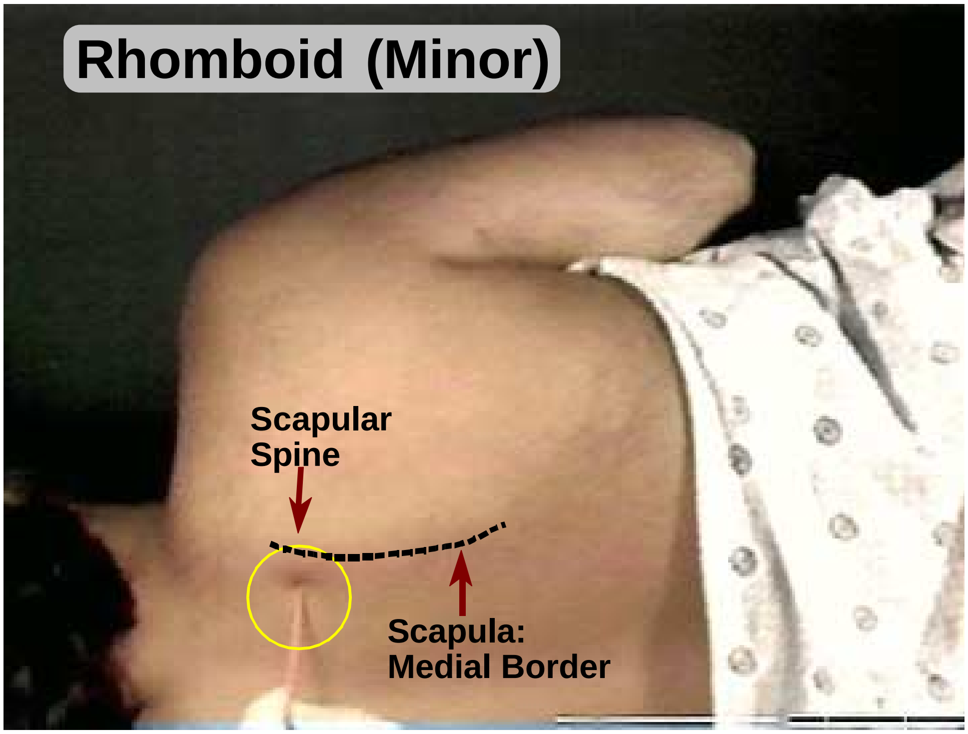
Origin: The Minor Rhomboid originates from the nuchal ligament and C7 and T1 spinous processes whereas the Major Rhomboid originates from the T2-5 spinous processes.

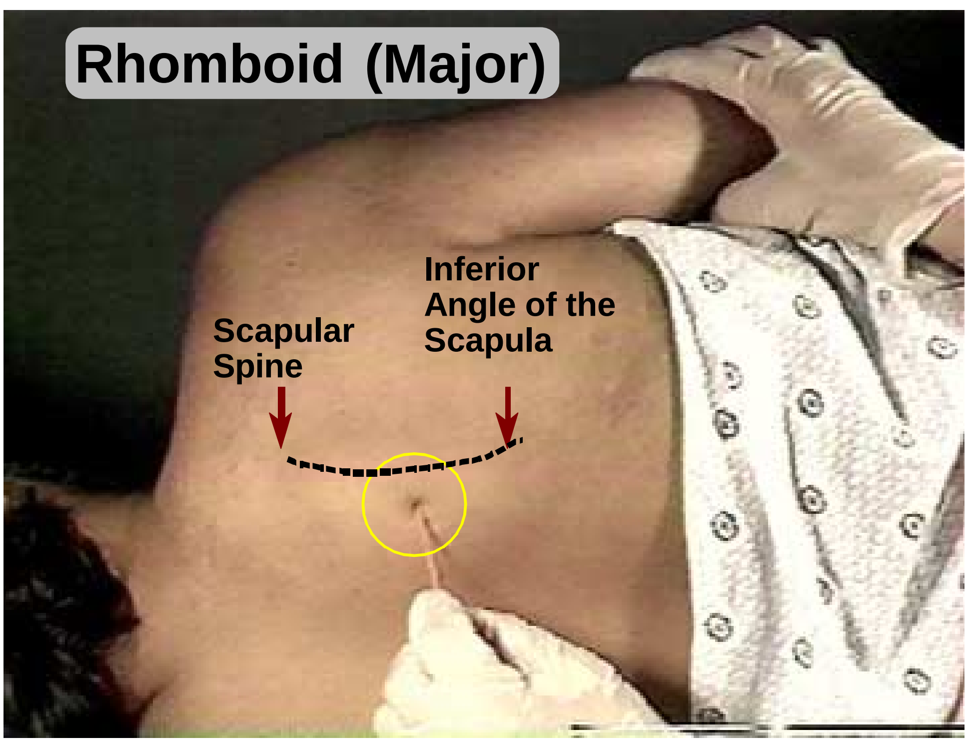
Insertion: Both insert on the medial aspect of the scapula, the minor rhomboid at the level of the scapular spine and the major rhomboid below the scapular spine extending inferiorly to the inferior angle of the scapula.

Position/Activation: The patient is in the lateral decubitus position with the side to be studied superior, the arm resting along their side with the elbow optionally flexed. Activation is by having the patient elevate and adduct their scapula, similar to a military "attention" position. If activating the one side to be studied is difficult, the patient can activate both sides simultaneously which is often easier and more readily accomplished.

Electrode Insertion: Minor rhomboid: just medial to the medial edge of the scapular spine. Major rhomboid: just medial to the medial scapular border at the midpoint between the scapular spine and the inferior angle of the scapula.

Caveat: If the electrode is too superficial, it will be in the middle trapezius; if too deep it will penetrate the paraspinal musculature.


Rhomboid (Minor)
Scapular Spine
Scapula: Medial Border


Rhomboid (Major)
Inferior Angle of the Scapula
Scapular Spine

Serratus Anterior

Innervation: Long Thoracic Nerve (**C5**, **C6**, **C7**, C8)

Origin: External and superior borders of the upper eight to nine ribs.

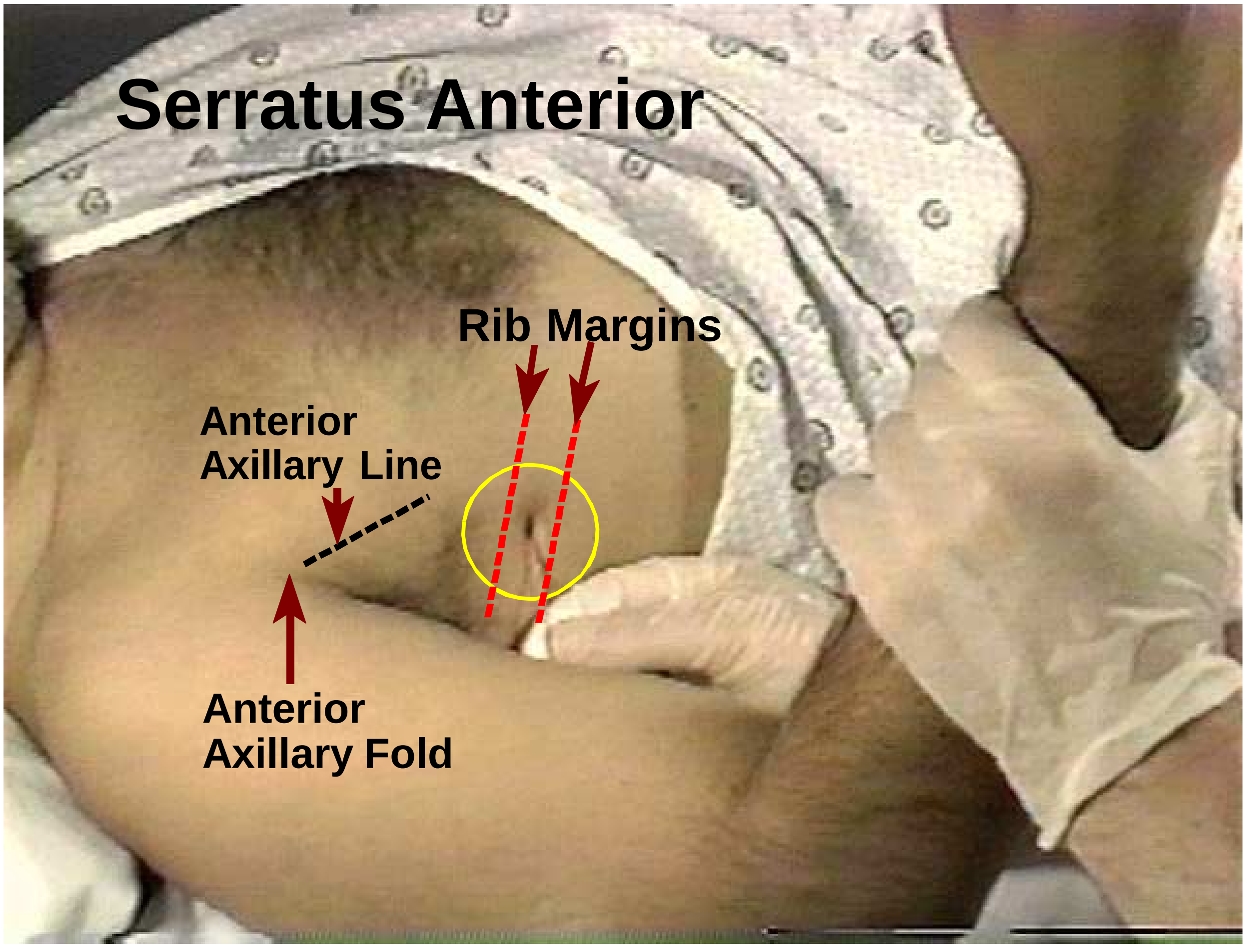
Insertion: Costal surface of the medial border of the scapula.

Position/Activation: There are different techniques for activation. One traditional method involves having the patient prone with their shoulder maximally internally rotated, elbow flexed, with the dorsum of their forearm against their back as if in a half-nelson wrestling hold. The author has not found this technique useful.

The author's preference is to have the patient supine with their elbow flexed and resting on the table. The forearm is perpendicular to the examination table and the shoulder is slightly abducted. Alternatively, the arm may be extended with the forearm in pronation. Activate by having the patient elevate their elbow off the table approximately 3-5 centimeters, moving the shoulder in forward flexion.

Electrode Insertion: The anterior and middle axillary lines are identified. Note the anterior limit of the latissimus dorsi which is posterior, and the posterior extent of any breast tissue in a female. Both are to be avoided. Immediately posterior and inferior to the anterior axillary fold, a rib (usually the 4th or 5th) is identified and isolated between the examiner's index and third fingers of their "free hand" (i.e., the hand not holding the needle electrode). The fingers should be pointed inferior and anterior, following the direction of the rib toward the sternum. This is maintained throughout the insertion to maintain localization. The electrode is inserted between the examiner's fingers and slowly advanced in an anteroinferior oblique direction, following the direction of the rib. Advancing the electrode at gentle, short increments is recommended. The electrode should just touch the rib surface, then be slightly withdrawn before activation.

Caveat: With the rib underneath, the limiting point of the insertion will be the rib itself. It is important to maintain rib identification and isolation so that the needle does not penetrate the chest wall, resulting in a pneumothorax. If the electrode is inserted too posteriorly to the midaxillary line, it may penetrate the latissimus dorsi or teres major. If additional sites need to be studied, then an additional insertion on an adjacent rib may be required.


Serratus Anterior
Rib Margins
Anterior
Axillary Line
Anterior
Axillary Fold

Supraspinatus

Innervation: Suprascapular nerve (C4, **C5**, C6).

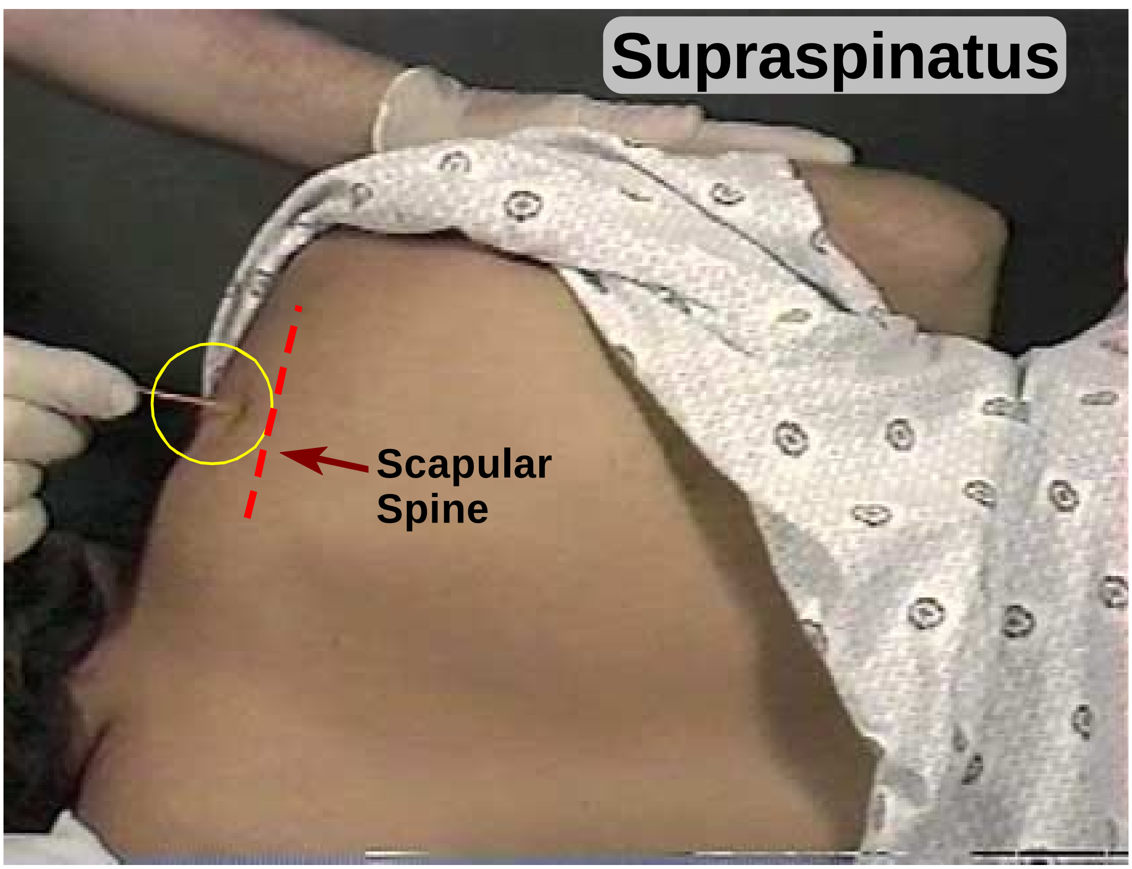
Origin: Supraspinous fossa of the scapula.

Insertion: Greater tubercle of the humerus.

Position/Activation: The patient is in the lateral decubitus position with the side to be studied superior, the arm resting along their side with the elbow optionally flexed. Activate by shoulder abduction and forward flexion if necessary.

Electrode Insertion: Define the medial and lateral borders of the scapular spine. Insert the electrode at a point midway, superior to the scapular spine, deep into the supraspinous fossa.

Caveat: If the electrode is too superficial, it may be in the upper trapezius.



Triceps Brachii

Innervation: Radial nerve (C6, **C7**, **C8**, T1)

Origin: Via three heads: long, lateral, and medial, which originate on the infraglenoid tubercle of the scapula, posterolateral proximal humerus and distal posteromedial humerus, respectively.

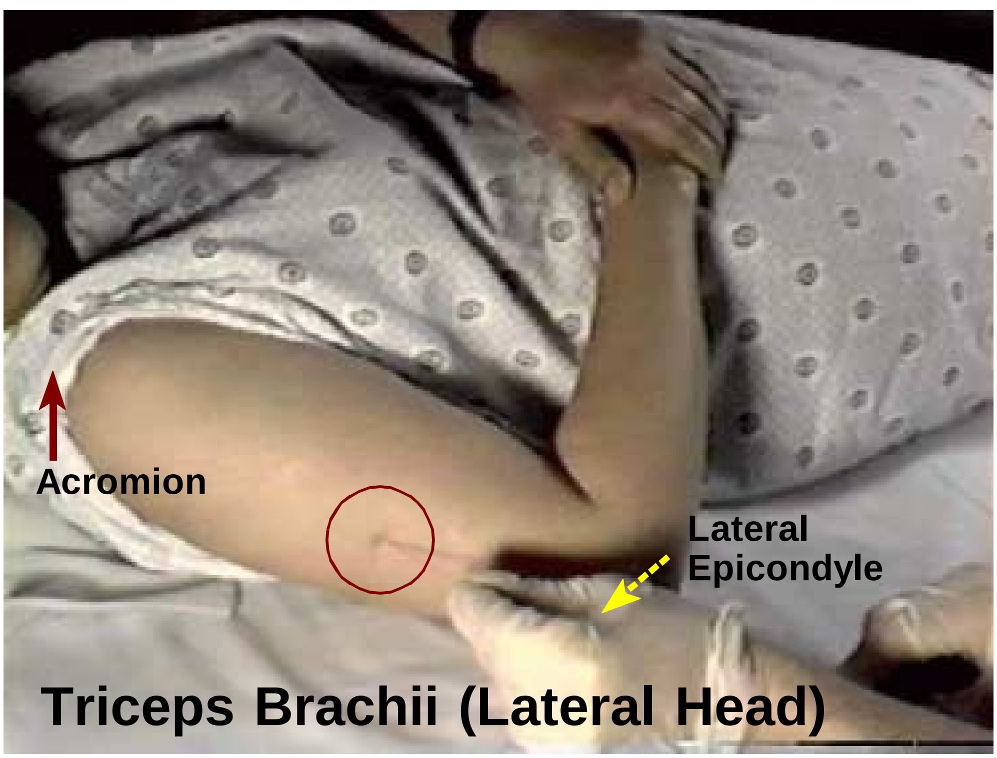
Insertion: A common tendon on the olecranon process of the ulna and antebrachial fascia.

Lateral head:

Position/Activation: The patient is supine. The lateral head is activated by placing the elbow in flexion and the shoulder internally rotated so their hand is resting on their chest, but going in a downward or inferior direction. The patient applies resistance with their "free" hand to the opposite wrist on the side being studied to achieve isometric activation.

Electrode Insertion: Mid-posterolateral aspect of the upper arm along a line from the acromion distal to the lateral epicondyle.

Caveat: If the electrode is too proximal, it may penetrate the deltoid. If the insertion is too posterior in obese individuals, the muscle may be missed altogether.



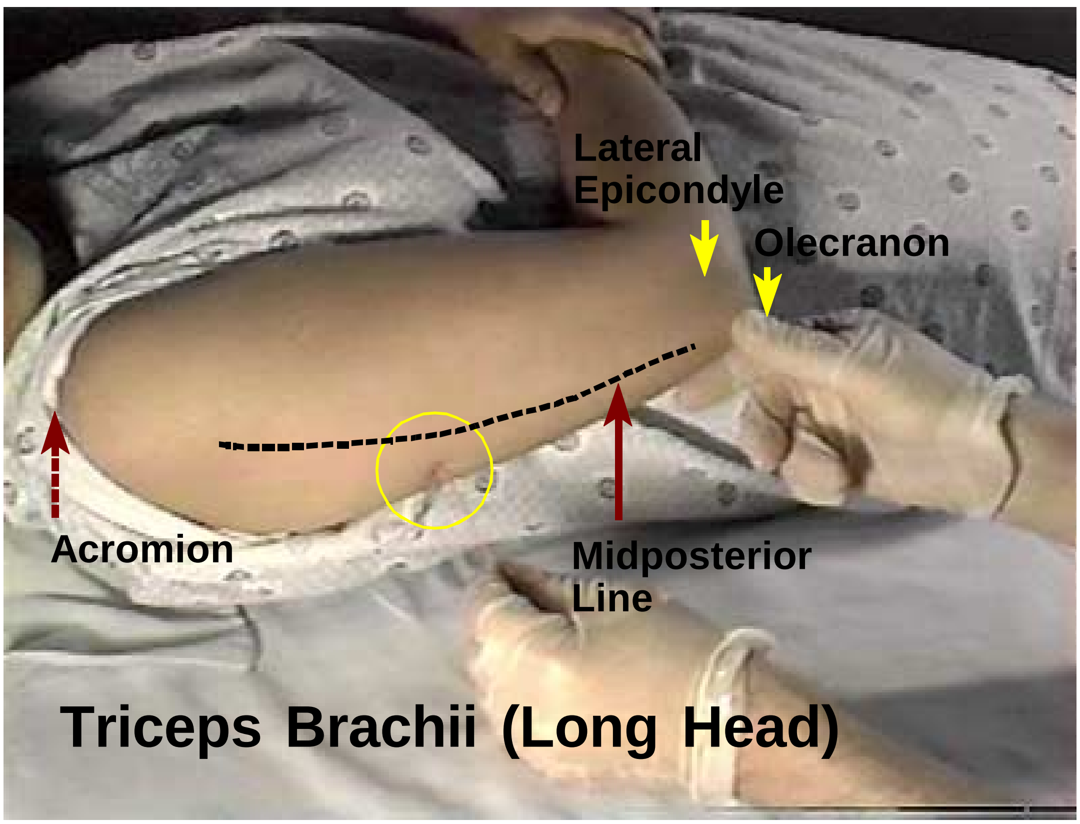
Triceps Brachii (Continued)

Long Head:

Position/Activation: Similar to the lateral head, however the shoulder is placed in adduction and greater internal rotation. The long head is activated by placing the elbow in flexion and the shoulder internally rotated so their hand is resting on their chest, but going in a downward or inferior direction. The patient applies resistance with their "free" hand to the wrist on the side being studied to achieve isometric activation.

Electrode Insertion: Identify the same longitudinal point as in the lateral head, however insertion is medial to the mid-posterior line of the upper arm.

Caveat: If the electrode is too proximal, it may penetrate the deltoid.



Triceps Brachii (Continued)

Medial Head (not shown in video):

Position/Activation: The shoulder is abducted and externally rotated, with the forearm either flexed at the elbow or fully extended. It is easy to activate from the latter position by having the patient hyperextend the elbow. In the former position, the elbow is resting on the examination table with the forearm deviated outward, away from the trunk. Activation is via extension of the elbow with resistance applied as necessary.

Electrode Insertion: Define the line between the anterior axillary fold and the olecranon. Insert the electrode on the posteromedial aspect of the upper arm at a point one third the way proximal to the olecranon.

Caveat: If the electrode is too anterior it may penetrate the brachialis muscle.

IV. The Lower Extremity Muscles

Intrinsic Muscles of the Foot

Abductor Digiti Quinti (Foot)

Innervation: Tibial (**S1**, **S2**).

Origin: Originates from the lateral calcaneus.

Insertion: Inserts on the lateral aspect of the fifth proximal phalanx.

Position/Activation: The patient is supine. The muscle is activated by having the patient abduct their toes. If this maneuver is difficult, concurrent minimal toe flexion is usually successful.

Electrode Insertion: Approximately 3 cm proximal to the head of the fifth metatarsal, just inferior to the fifth metatarsal. This should approximate the border of the glabrous skin of the foot.

Caveat: This muscle may be reduced in size in otherwise normal, particularly older, adults. The finding of “enlarged”, stable MUAPs without fibrillation potentials (i.e., no abnormalities found in the nerve conductions and patchy enlarged MUAPs found in other intrinsic foot muscles) should be interpreted with caution. Deep insertions may cause penetration of the flexor digitorum brevis or flexor digiti minimi, however these have the same innervations.


Abductor Digiti Quinti (Foot)
Border, Glabrous Skin of Sole
Base of Fifth Metatarsal Bone

Abductor Hallucis

Innervation: Tibial nerve (L4, **L5**, **S1**, S2)

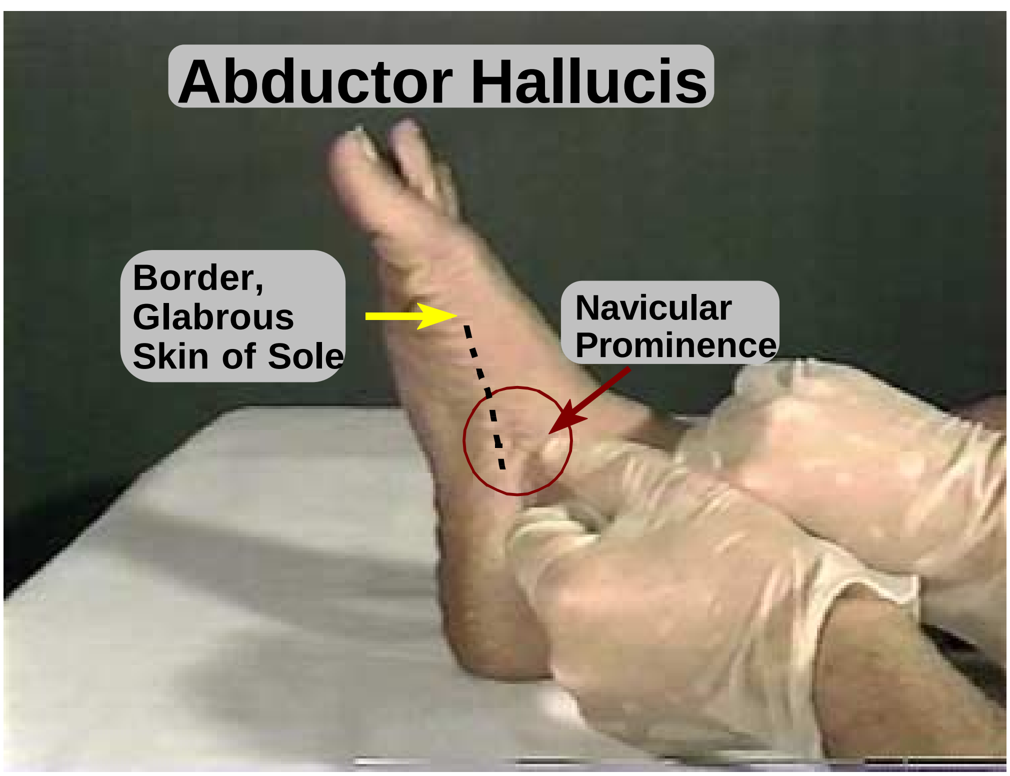
Origin: Medial calcaneus.

Insertion: Medial base of the proximal first phalanx.

Position/Activation: The patient is supine. The muscle is optimally activated by having the patient perform abduction and flexion of the large toe. Some individuals may have difficulty with this maneuver. It may be necessary to have the patient resist against the examiner's hand.

Electrode Insertion: Identify the navicular prominence and insert the electrode from a medial approach just inferior to this point at the border of the glabrous skin of the sole.

Caveat: If the electrode is too deep it may penetrate the flexor hallucis brevis or flexor digitorum brevis. This muscle may be reduced in size in otherwise normal, particularly older, adults. The finding of "enlarged", stable MUAPs without fibrillation potentials (i.e., no abnormalities found in the nerve conductions and patchy enlarged MUAPs found in other intrinsic foot muscles) should be interpreted with caution.



Extensor Digitorum Brevis

Innervation: Deep peroneal (L4, **L5**, **S1**)

Origin: Calcaneus and extensor retinaculum.

Insertion: Via four tendons to the first through the fourth digits, the most medial slip being referred to as the extensor hallucis brevis.

Position/Activation: The patient is supine. The muscle is activated by having the patient perform toe extension without ankle extension against the resistance of the examiner's hand or by having the patient place their contralateral foot over their toes to provide resistance.

Electrode Insertion: Approximately 4 cm anterior to the midpoint of the inferior border of the lateral malleolus into the midbelly of the muscle, directing the electrode downward toward the periosteum.

Caveat: This muscle is well isolated from other muscles but may be reduced in size in otherwise normal, particularly older, adults. The finding of “enlarged”, stable MUAPs without fibrillation potentials (i.e., no abnormalities found in the nerve conductions and patchy enlarged MUAPs found in other intrinsic foot muscles) should be interpreted with caution.


Extensor Digitorum Brevis
Lateral
Malleolus
(Inferior Border)

First Dorsal Interosseous (Foot)

Innervation: Tibial nerve (**S1**, **S2**)

Origin: Via two heads from the bases of the first and second metatarsal bones.

Insertion: Medial side of the proximal phalanx of the second toe.

Position/Activation: The patient is supine. The patient abducts their 2nd-4th toes from an axial line through the second toe. Concurrent flexion of the metatarsophalangeal joints or extension of the interphalangeal joints may facilitate activation as the dorsal interossei of the toes also participate in the movement of these joints. Activation of this muscle may be difficult in some individuals. An alternate method of activation is to place the examiner's finger or a similar sized object (the author uses the barrel of a hypodermic syringe) placed between the patient's large and second toes and ask them to "squeeze" or "pinch" it.

Electrode Insertion: The examiner places their finger on the dorsum of the distal foot between the first and second toes, advancing the finger until it reaches the metatarsal heads. The finger is withdrawn slightly (a few millimeters), then the electrode is inserted directly downward into the space, directing the electrode toward the second toe.

Caveat: The needle should not be inserted too deeply, i.e., beyond the midpoint of the long axis of the metatarsal bones. The finding of "enlarged", stable MUAPs without fibrillation potentials (i.e., no abnormalities found in the nerve conductions and patchy enlarged MUAPs found in other intrinsic foot muscles) should be interpreted with caution. Compared to the above intrinsic foot muscle, such findings tend to occur less in this muscle.


First Dorsal Interosseous (Foot)
Second
Metatarsal
Head

Distal Leg

Anterior Tibial

Innervation: Deep peroneal (**L4**, **L5**, S1)

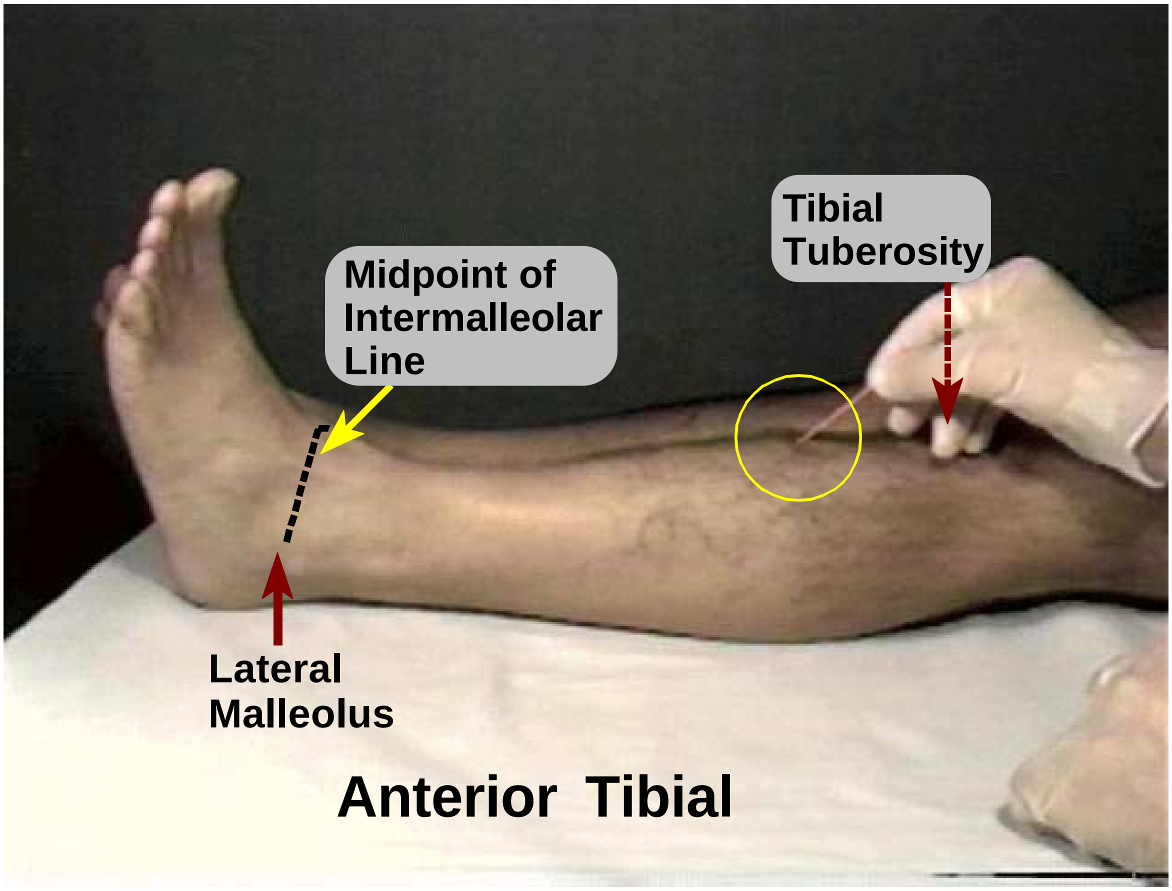
Origin: Lateral tibial condyle and the proximal half of the lateral tibia.

Insertion: Posteromedial surface of the cuneiform bone and base of the first metatarsal.

Position/Activation: The patient is supine and dorsiflexes the ankle while the ankle is slightly inverted. The toes should be in neutral position and not extended so as to avoid activation of the extensor digitorum longus. With adequate patient preparation, the anterior tibial may be minimally, but satisfactorily activated for MUAP analysis using only ankle inversion. The author usually finds that in order to accomplish the latter, the patient needs to place their inverted ankle against the medial aspect of the opposite foot for resistance.

Electrode Insertion: Define the midpoint of the line between the lateral and medial malleoli (i.e., anterior intermalleolar line). Between this point and the tibial tuberosity, insert the electrode into the proximal third segment just lateral (approximately 2 cm) to the anterior border of the tibia. A more oblique insertion is helpful to reduce “bowing” of the electrode as a result of activation. It does not matter whether the electrode is pointing proximally or distally: the author favors the latter as being easiest to perform based on where the examiner is typically sitting. Minimal activation before inserting the electrode deeper beyond the subcutaneous tissue into the muscle also reduces pain from electrode penetration.

Caveat: If the electrode is placed too lateral, it may penetrate the extensor digitorum longus.


Tibial
Tuberosity
Midpoint of
Intermalleolar
Line
Lateral
Malleolus
Anterior Tibial

Extensor Digitorum Longus

Innervation: Peroneal nerve (L4, **L5**, S1)

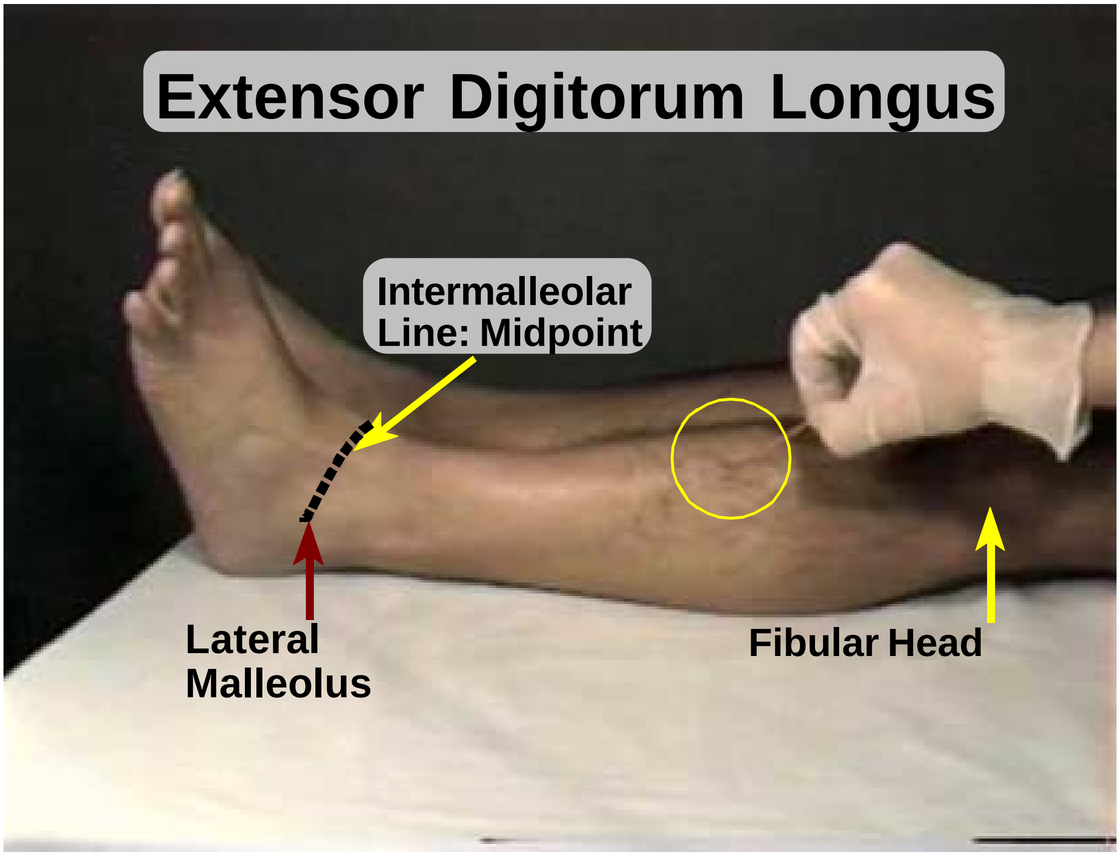
Origin: Lateral condyle of the tibia, proximal three quarters of the anterior fibula and proximal portion of the interosseus membrane.

Insertion: Via four tendons to the second through the fifth toes on a dorsal expansion of the tendons on the toes at the middle and distal phalanges.

Position/Activation: The patient is supine. The patient extends their 2nd through 5th toes at the metatarsophalangeal and interphalangeal joints with their ankle fixed in a neutral to slightly plantar flexed position. The latter reduces activation of the principal ankle evertors and dorsiflexors although the extensor digitorum longus also has a minor role in both these actions. Additional resistance can be provided by the examiner’s hand to facilitate isometric contraction. This can also be achieved by placing the patient’s contralateral heel on the dorsum of the distal foot being activated and having them extend their toes against it.

Electrode Insertion: Identify the midpoint of the line between the fibular head and the tibial tuberosity. From this point to the midpoint of the anterior intermalleolar line (i.e., the line between lateral and medial malleolus going over the dorsum of the ankle), divide into three segments and insert the electrode at a point one third the distance distal to the proximal landmark.

Caveat: If the electrode is inserted too anterior and medial it may penetrate the anterior tibial; if too lateral and posterior it may penetrate the peroneus longus; if too deep it may penetrate the extensor hallucis longus. It is important to monitor movement of the ankle so that unwanted activation from the neighboring anterior tibial and peroneus longus does not occur.


Extensor Digitorum Longus
Intermalleolar Line: Midpoint
Lateral Malleolus
Fibular Head

Extensor Hallucis Longus

Innervation: Peroneal nerve (L4, **L5**, S1)

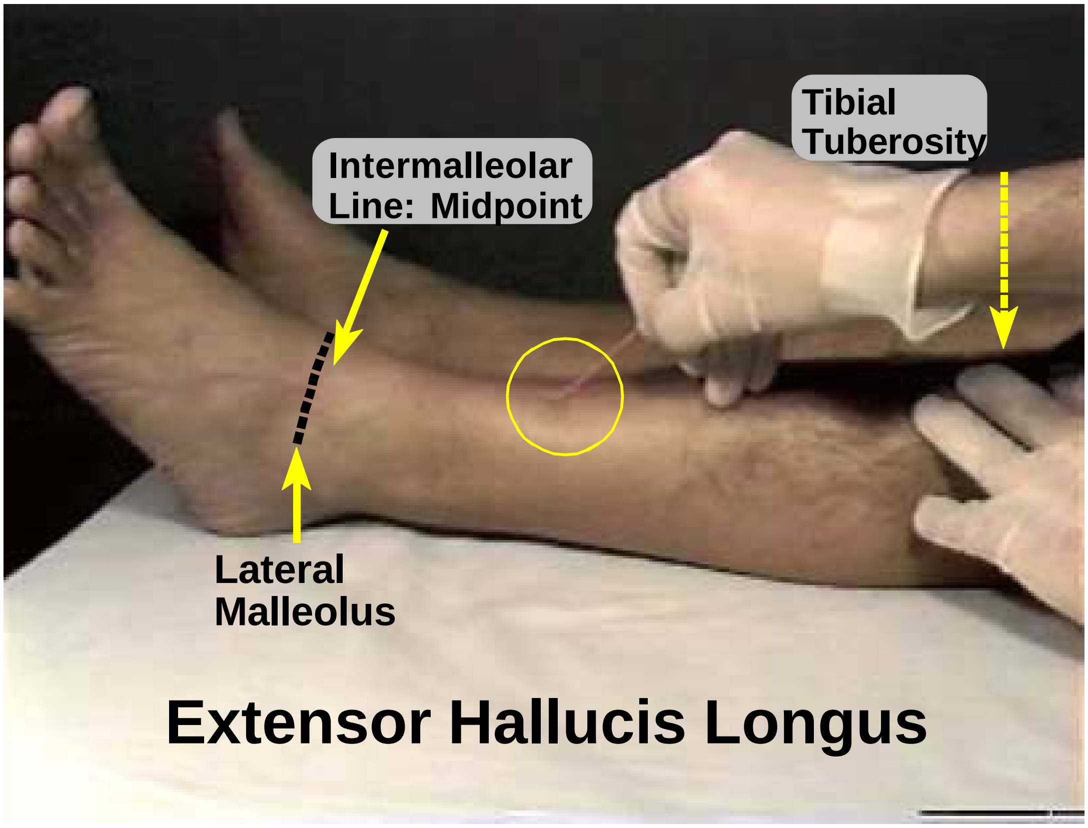
Origin: Middle half of the anterior surface of the fibula and interosseous membrane.

Insertion: Base of the distal phalanx of the hallux.

Position/Activation: The patient is supine and extends their large toe with their ankle in neutral to slightly plantar flexed position to avoid activating the ankle dorsiflexors or evertors. The extensor hallucis longus does have a minor contribution to ankle dorsiflexion and inversion.

Electrode Insertion: Identify the midpoint of the anterior intermalleolar line (i.e., a line between the lateral and medial malleolus going over the dorsum of the ankle). In a line from this point to the tibial tuberosity, divide into three segments and go one third the way proximal to the midpoint of the intermalleolar line, just lateral to the anterior border of the tibia.

Caveat: If the electrode is too medial and superficial, it will be in the anterior tibial. If the electrode is too lateral, it may be in the evertors or extensor digitorum longus. As with the extensor digitorum longus, it is important to monitor movement of the ankle so that undesirable activation from adjacent muscle does not occur.


Tibial
Tuberosity
Intermalleolar
Line: Midpoint
Lateral
Malleolus
Extensor Hallucis Longus

Gastrocnemius (Medial and Lateral Heads)

Innervation: Tibial nerve (**S1**, **S2**).

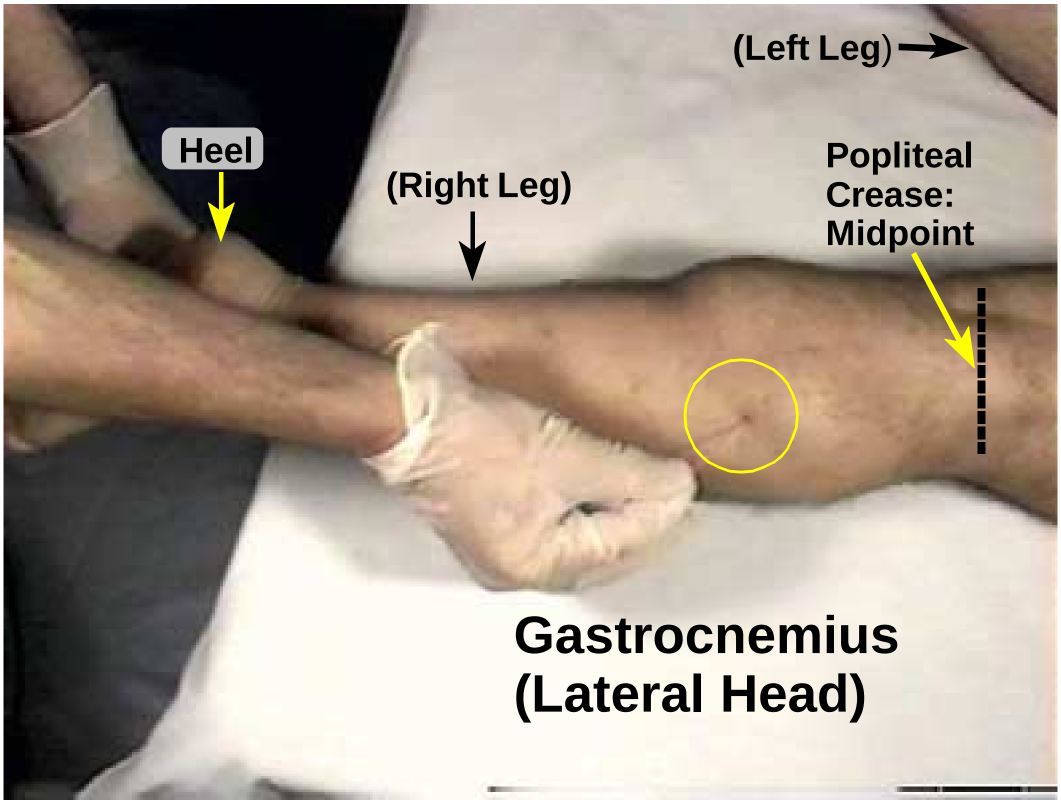
Origin: The medial head originates from the proximal and posterior aspect of the medial condyle plus adjacent portion of the femur. The lateral head originates from the proximal and posterior aspect of the lateral condyle plus adjacent portion of the femur and capsule of the knee joint.

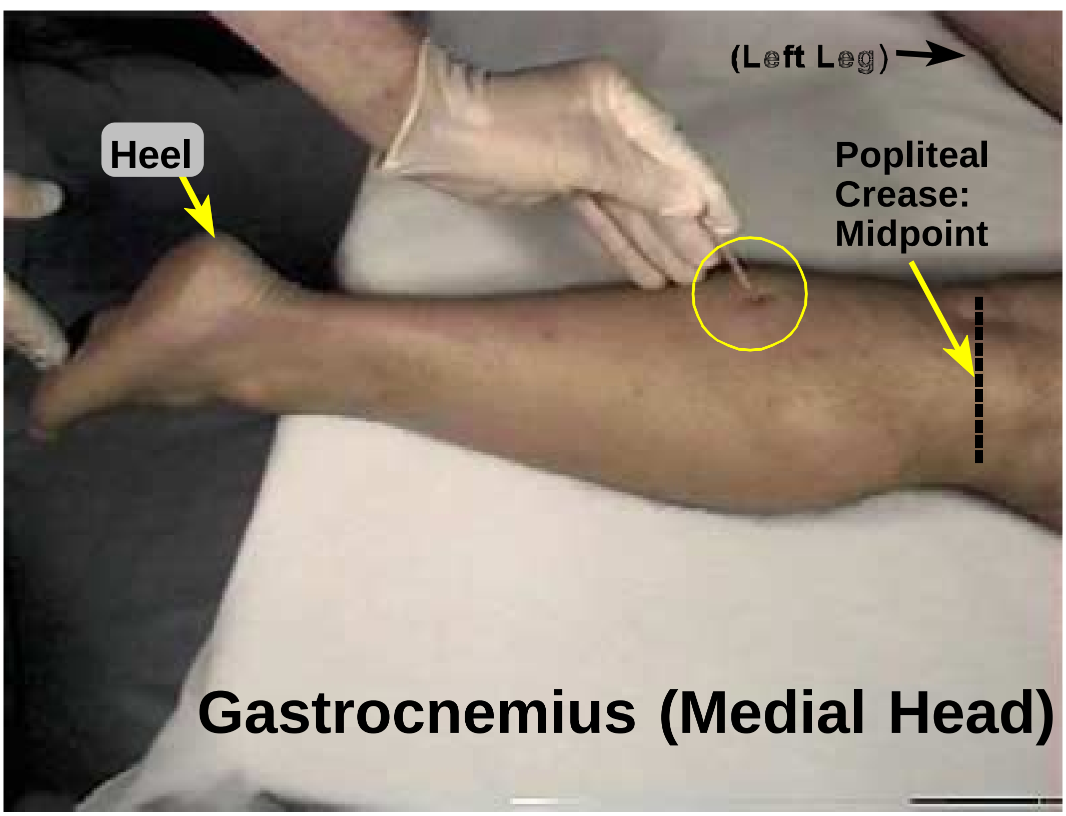
Insertion: Mid-posterior aspect of the calcaneus via the Achilles tendon.

Position/Activation: The patient may be supine for examination of only the medial head; or in the lateral decubitus or prone position to study either the medial or lateral heads. The muscle is optimally activated by plantar flexing the ankle in slight inversion with the leg extended (medial head) or plantar flexing the ankle in slight eversion with the leg extended (lateral head).

Electrode Insertion: In a line between the midpoint of the popliteal crease and the heel, the electrode is inserted into the middle of the proximal third segment, 3-4 cm from the posterior midline: medially to study the medial head and laterally to study the lateral head.

Caveat: If the electrode is inserted too anteriorly or deeply it may penetrate the soleus or flexor digitorum longus.


(Left Leg)
Heel
(Right Leg)
Popliteal
Crease:
Midpoint
Gastrocnemius
(Lateral Head)


(Left Leg)
Heel
Popliteal
Crease:
Midpoint
Gastrocnemius (Medial Head)

Peroneus Longus

Innervation: Superficial peroneal nerve (L4, **L5**, S1)

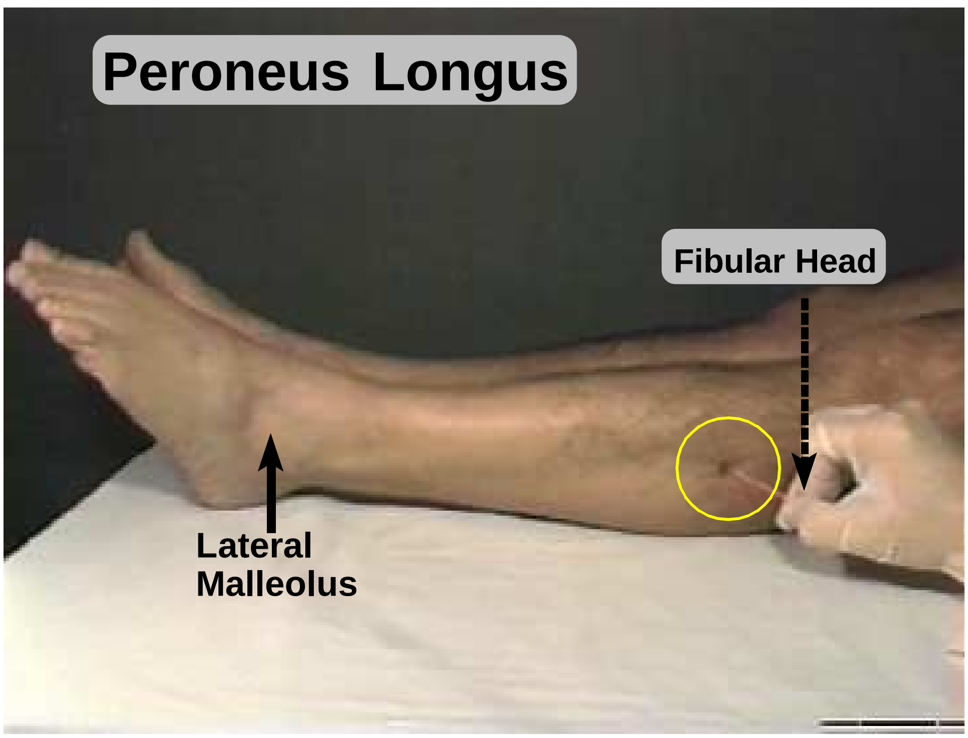
Origin: Lateral condyle of the tibia and head and proximal two-thirds of the lateral fibula.

Insertion: Posterolateral base of the first metatarsal and medial cuneiform bone.

Position/Activation: The patient is supine. The patient everts their ankle in plantar flexion. The latter reduces potential for coactivation of the ankle dorsiflexor.

Electrode Insertion: In a line from the fibular head to the lateral malleolus, divide into three segments and identify the point one third the way distal to the fibular head.

Caveat: If the electrode is too anterior, the electrode may penetrate the extensor digitorum longus or peroneus tertius, both of which will activate with ankle eversion. If too posterior, it may penetrate the lateral gastrocnemius.



Soleus

Innervation: Tibial nerve (L5, **S1**, S2)

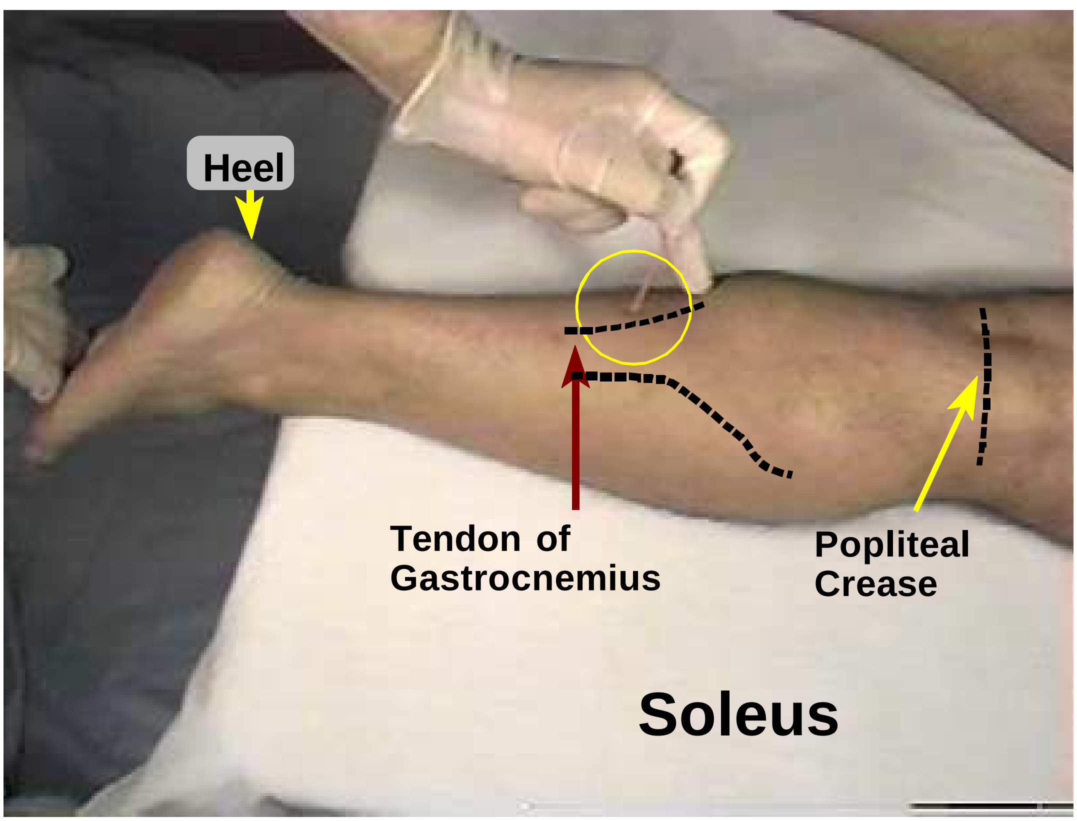
Origin: Posterior fibular head, proximal third of the fibula, soleal line, and middle third of the medial border of the tibia.

Insertion: Calcaneus bone with the gastrocnemius via the Achilles tendon.

Position/Activation: The patient is prone with the ankle in plantar flexion. Flexing the knee may facilitate activation by reducing the gastrocnemius' contribution to plantar flexion of the ankle.

Electrode Insertion: Identify the line between the midpoint of the popliteal crease and the heel and divide into three segments. Insertion is into the proximal part of the distal third segment, just medial or lateral to the midline so as to avoid the tendon of the gastrocnemius muscle.

Caveat: If the electrode is too superficial and rostral, it may be in the gastrocnemius.



Thigh and Pelvis

Adductor Longus

Innervation: Obturator nerve (**L2**, **L3**, L4)

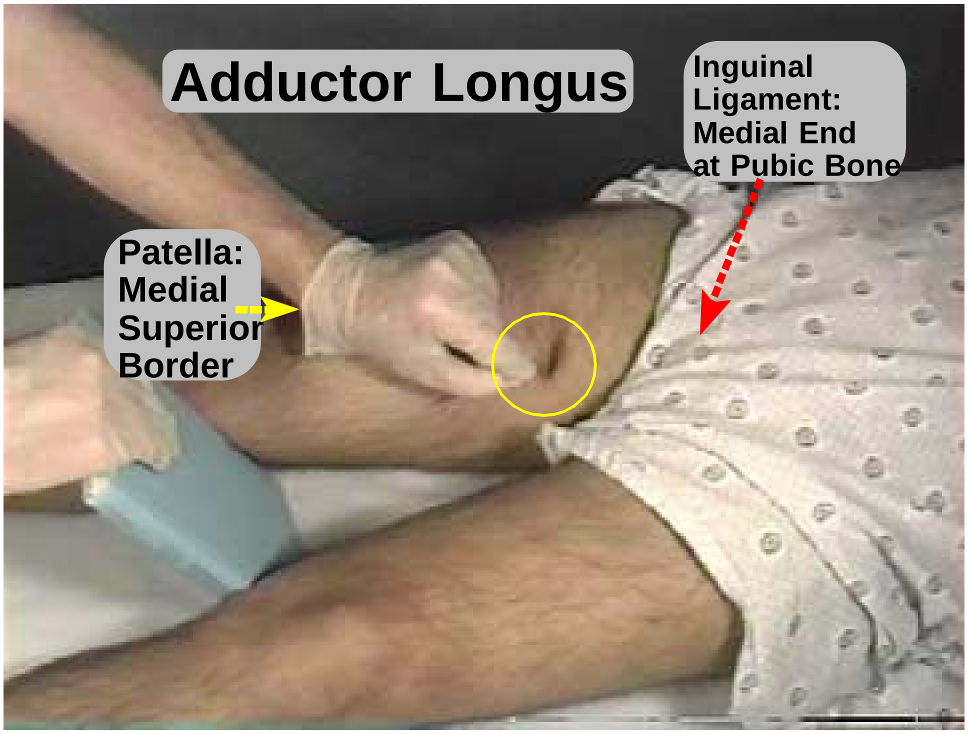
Origin: Anterior surface of the pubic bone.

Insertion: Inserts on the middle third of the linea aspera on the femur.

Position/Activation: The patient is supine with their legs slightly abducted and slightly externally rotated. A common pitfall is to allow the patient to internally rotate the limb in activation. To avoid this, make certain the patient's foot is always in a neutral to slightly externally rotated position. A helpful activating method learned from a colleague is to place a stiff plastic basin approximately 25 cm in diameter between their thighs at the knees and ask the patient to adduct both their legs against it. If none is handy, then a book of similar size, padded with a towel, can be used.

Electrode Insertion: In a line going between the medial superior border of the patella to the medial end of the inguinal ligament at the pubic tubercle, insert the electrode approximately 25% of the way from the inguinal ligament, just posterior to this line.

Caveat: If the electrode is too medial and posterior, it may penetrate the gracilis; if too lateral and anterior, it may penetrate the sartorius or quadriceps; if too distal it may penetrate the adductor magnus.


Adductor Longus
Inguinal Ligament: Medial End at Pubic Bone
Patella: Medial Superior Border

Biceps Femoris (Short Head)

Innervation: Peroneal portion of the sciatic nerve (**L5**, **S1**, S2)

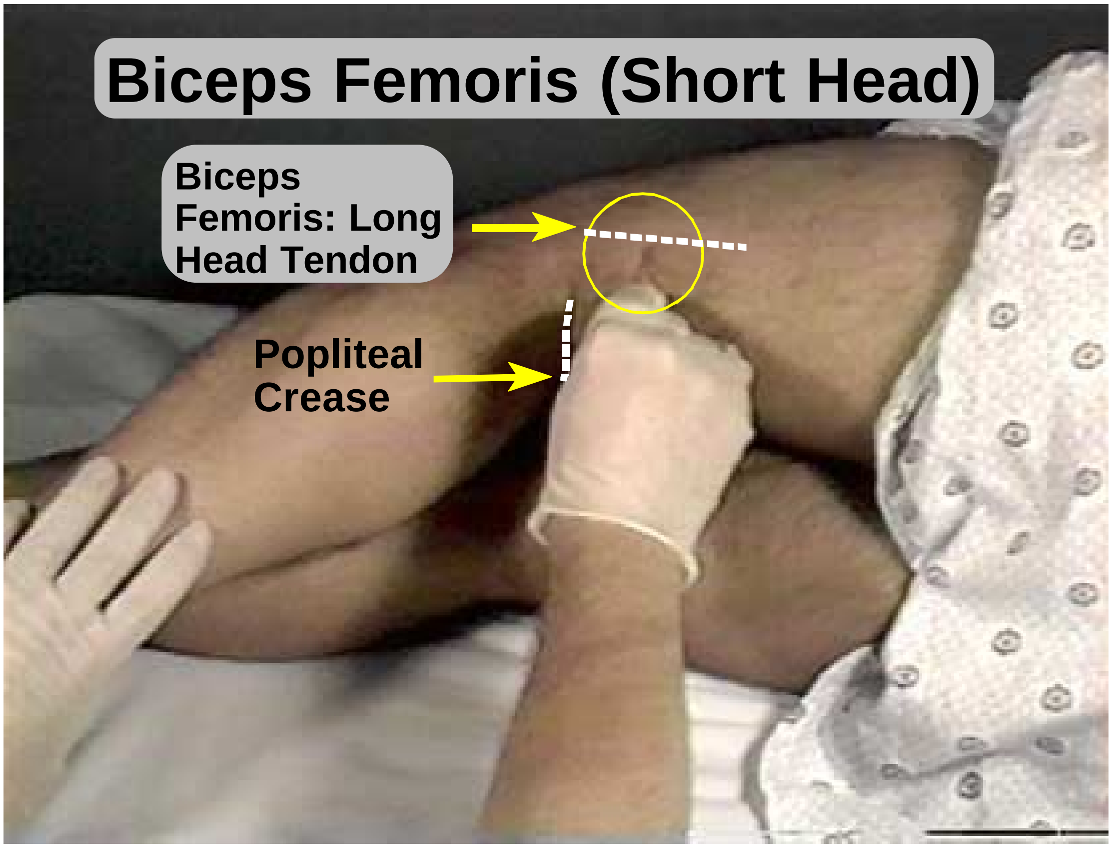
Origin: Lateral lip of the linea aspera, proximal supracondylar line and lateral intermuscular septum.

Insertion: Lateral side of the fibular head and the lateral tibial condyle.

Position/Activation: In this demonstration, the lateral decubitus position is used with the side to be studied superior. The prone position may also be used, but the lateral decubitus position is less fatiguing for weak patients and allows greater control in minimal activation. The patient's knee should be flexed with their foot on the examination table so that the hip is slightly externally rotated. The latter position should facilitate activation at minimal effort or resistance, allowing easy palpation of the tendon of the Biceps Femoris Long Head. Alternatively the patient may be prone with their knee flexed so that the distal leg is vertical to the table.

Electrode Insertion: Approximately 5 cm proximal to the popliteal crease, either medially or laterally but deep to the tendon of the long head of the biceps femoris.

Caveat: In obese individuals, superficial landmarks may appear altered in the lateral decubitus position. If the electrode is too proximal, it may penetrate the Long Head of the Biceps Femoris. If too medial, the electrode may penetrate the semimembranosus.


Biceps Femoris (Short Head)
Biceps Femoris: Long Head Tendon
Popliteal Crease

Biceps Femoris (Long Head)

(not shown in video)

Innervation: Tibial portion of the sciatic nerve (L5, **S1**, **S2**)

Origin: Distal sacrotuberous ligament and posterior part of the ischial tuberosity.

Insertion: Lateral side of the fibular head and the lateral tibial condyle.

Position/Activation: See Biceps Femoris (Short Head). The lateral decubitus position is used with the side to be studied superior. The patient's knee should be flexed with the foot on the examination table so that the hip is slightly externally rotated. The latter position should facilitate activation at minimal effort or resistance, allowing easy palpation of the tendon of the long head biceps femoris. Alternatively the patient may be prone with their knee flexed so that the distal leg is vertical to the table.

Electrode Insertion: Follow the tendon of the long head of the biceps femoris proximally and insert into the posterior mid-thigh, just lateral to the midline.

Caveat: If the electrode is too lateral, it may penetrate the vastus lateralis; if too medial, it may penetrate the semitendinosus.

Gluteus Maximus

Innervation: Inferior gluteal nerve (L5, **S1**, S2)

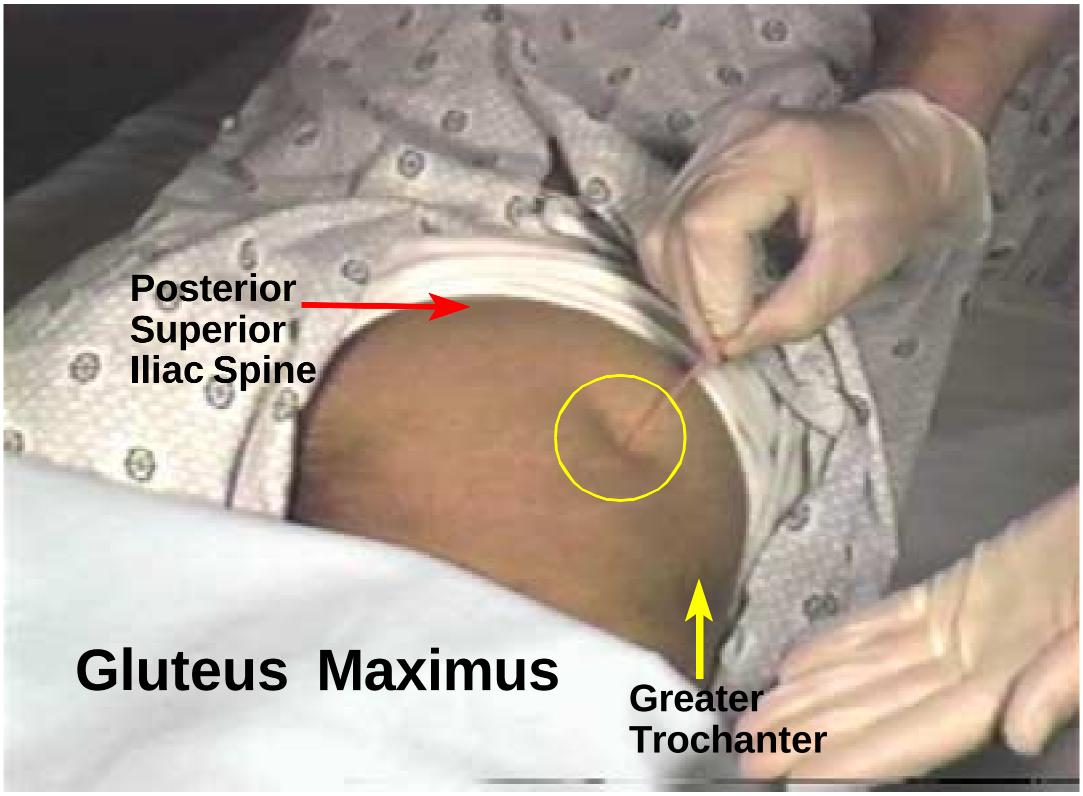
Origin: Posterior gluteal line of the ilium, posterior distal sacrum, lateral coccyx, erector spinae & gluteal aponeurosis, and sacrotuberous ligament.

Insertion: Iliotibial tract of the fascia lata and gluteal tuberosity of the femur.

Position/Activation: The patient is prone with their foot over the end of the examination table or in the lateral decubitus position (leg to be examined superior). The muscle is best activated by either having the simultaneous adduction of both buttocks or by extending the hip with the knee flexed. The latter maneuver reduces the extension of the hip because tension in the rectus femoris anteriorly is reduced. The author favors adduction of the buttocks, as if to move the pelvis anteriorly, because it involves the least limb movement and effort for the patient.

Electrode Insertion: Midway between the posterior superior iliac spine and the greater trochanter.

Caveat: Isolated MUAP abnormalities may occasionally be noted within the gluteus maximus, usually due to remote intramuscular injections. If such findings are encountered that cannot be found at another site(s) in the gluteus maximus or other muscles with similar segmental innervation, then consider an iatrogenic etiology due to prior injections. These are not of localizing significance.


Posterior
Superior
Iliac Spine
Gluteus Maximus
Greater
Trochanter

Gluteus Medius

Innervation: Superior gluteal nerve (L4, **L5**, S1)

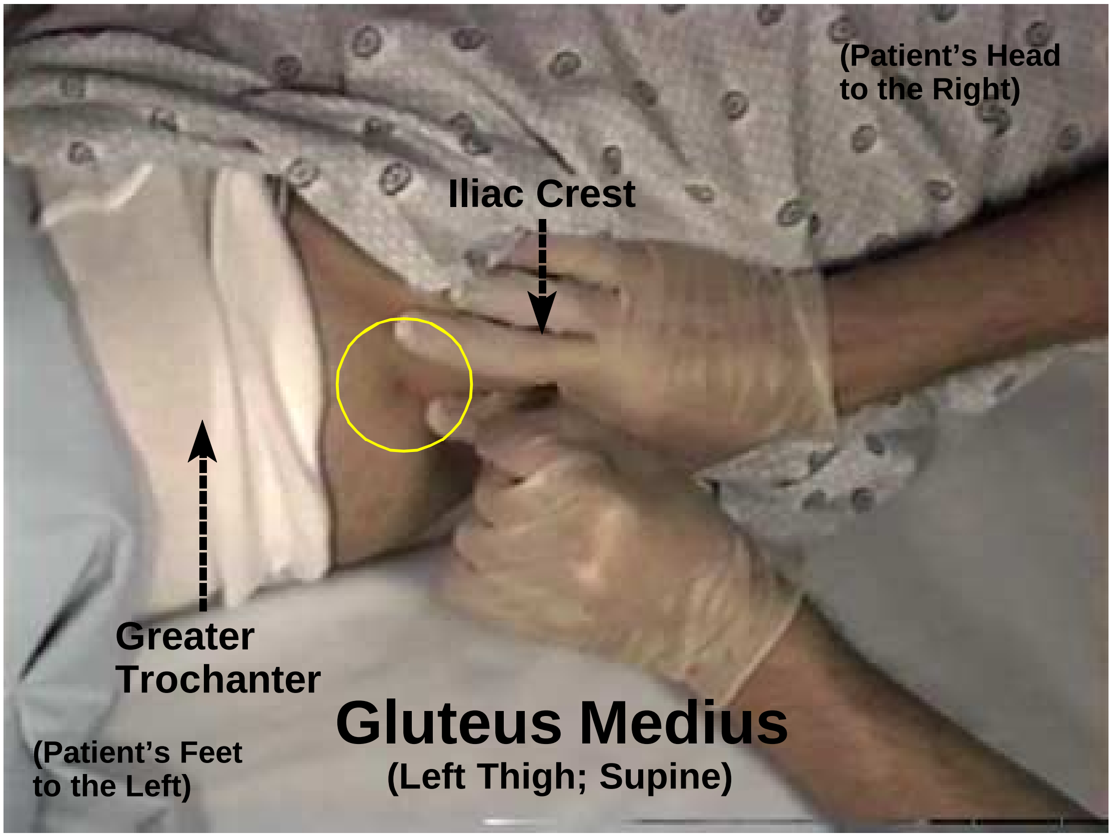
Origin: External surface of the ilium and gluteal aponeurosis.

Insertion: Inserts on the lateral surface of the greater trochanter of the femur.

Position/Activation: With the patient in the supine position, the muscle is activated by having them either slightly abduct the leg or internally rotate it. Internal rotation selectively activates the more anterior muscle fibers. The author favors the latter as easier in achieving greater activation with less overall limb movement.

Electrode Insertion: In a line between the lateral iliac crest and the greater trochanter, insert the electrode 3-4 cm distal to the iliac crest slightly anterior to this line.

Caveat: If the electrode is too deep or distal, it may penetrate the gluteus minimus. If the electrode is too medial or anterior, it may penetrate the tensor fasciae latae; if too posterior it may penetrate the gluteus maximus.


(Patient's Head
to the Right)
Iliac Crest
Greater
Trochanter
Gluteus Medius
(Left Thigh; Supine)
(Patient's Feet
to the Left)

Iliacus

Innervation: Femoral nerve (L1, **L2**, **L3**, L4).

Origin: Superior two thirds of the iliac fossa, internal lip of the iliac crest, sacral ala and iliolumbar/sacroiliac ligaments.

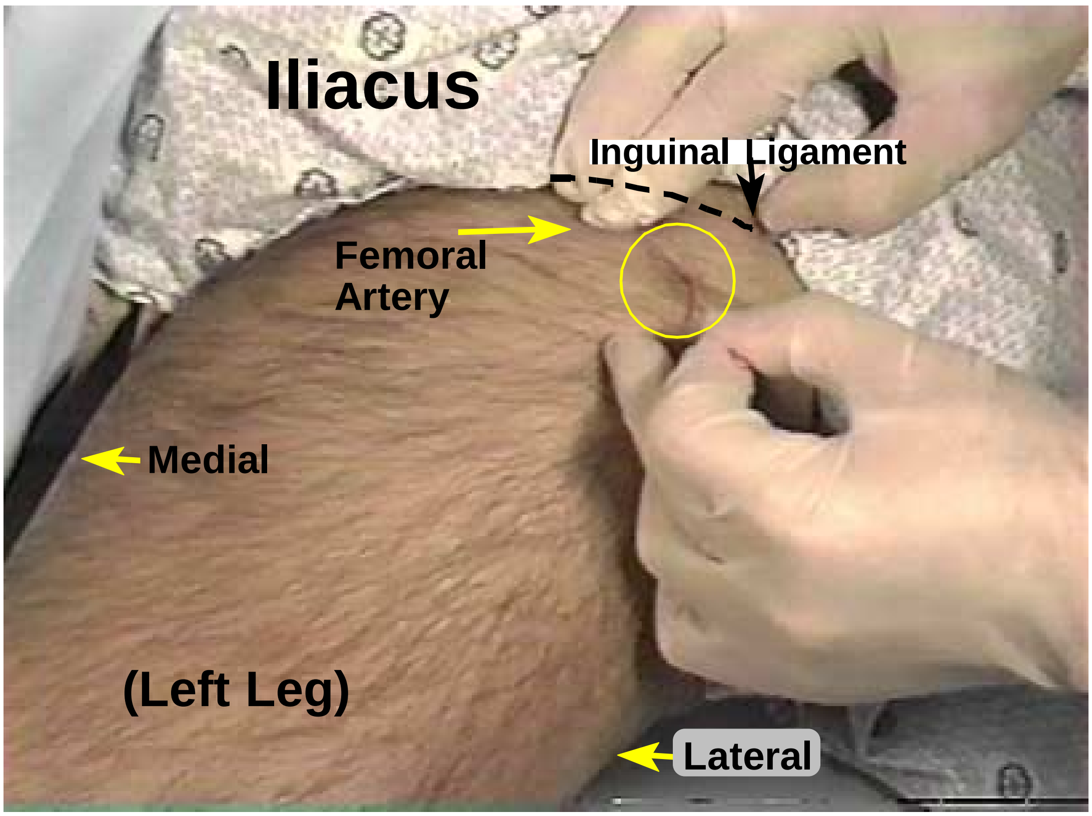
Insertion: Lateral aspect of the psoas major tendon, just distal to the lesser trochanter.

Position/Activation: The patient is supine with the leg to be examined in slight abduction and external rotation. Activate by having the patient lift the leg to be examined without otherwise altering position. This fixates the iliacus' origin. Conversely, the legs can remain on the examination table and the patient asked to slightly lift their trunk, as if initiating a sit up. This fixates the iliacus' insertion.

Electrode Insertion: Palpate the femoral pulse just inferior to the inguinal ligament. Insert the electrode approximately 3 cm lateral to the artery to avoid penetrating the neurovascular bundle in the femoral triangle, again just inferior to the inguinal ligament.

Caveat: The main precaution in this insertion is to avoid penetration of the neurovascular group in the femoral triangle which from medial to lateral is the femoral vein, artery and nerve, respectively. If the electrode is placed too medial, the electrode may penetrate one of these structures or the pectineus muscle; if too lateral, the electrode may penetrate the sartorius.

Note: The iliacus is commonly referred to as the iliopsoas, in combination with the psoas major. Although the actions of these two muscles are essentially identical, we choose not to mention the psoas major because only its tendon extends beyond the inguinal ligament and in actuality only insertions of the iliacus are made in routine clinical EMG at the level described.



Semimembranosus

Innervation: Tibial nerve (L4, **L5**, **S1**, S2)

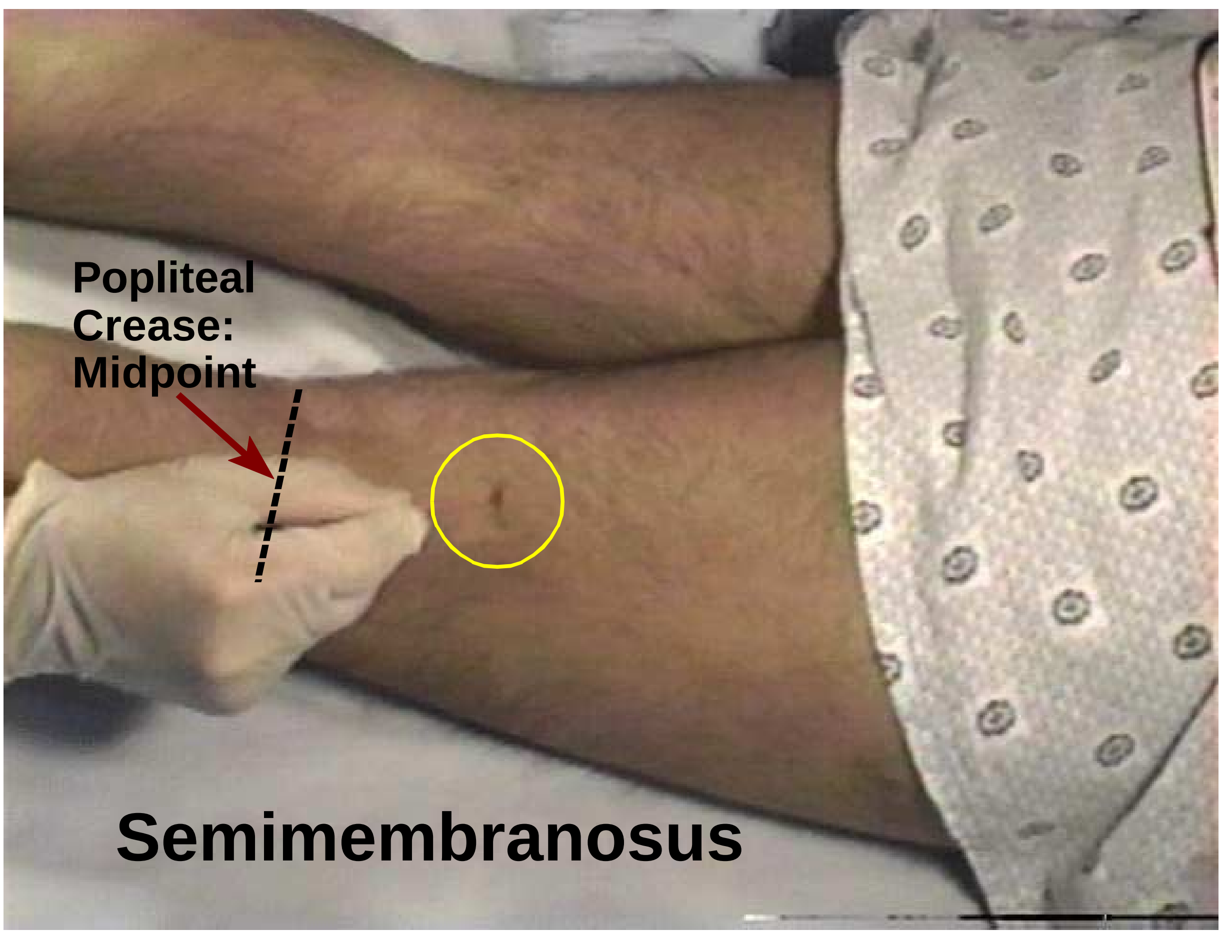
Origin: Tuberosity of the ischium.

Insertion: Posteromedial aspect of the medial tibial condyle.

Position/Activation: The patient is in the prone or lateral decubitus position, flexing their knee.

Electrode Insertion: Go approximately 5 cm proximally to the midpoint of the popliteal crease, inserting the electrode slightly medially.

Caveat: If the electrode is too medial, it may penetrate the semitendinosus; if too lateral it may penetrate the biceps femoris (short head).



Semitendinosus

Innervation: Tibial nerve (L4, **L5**, **S1**, S2)

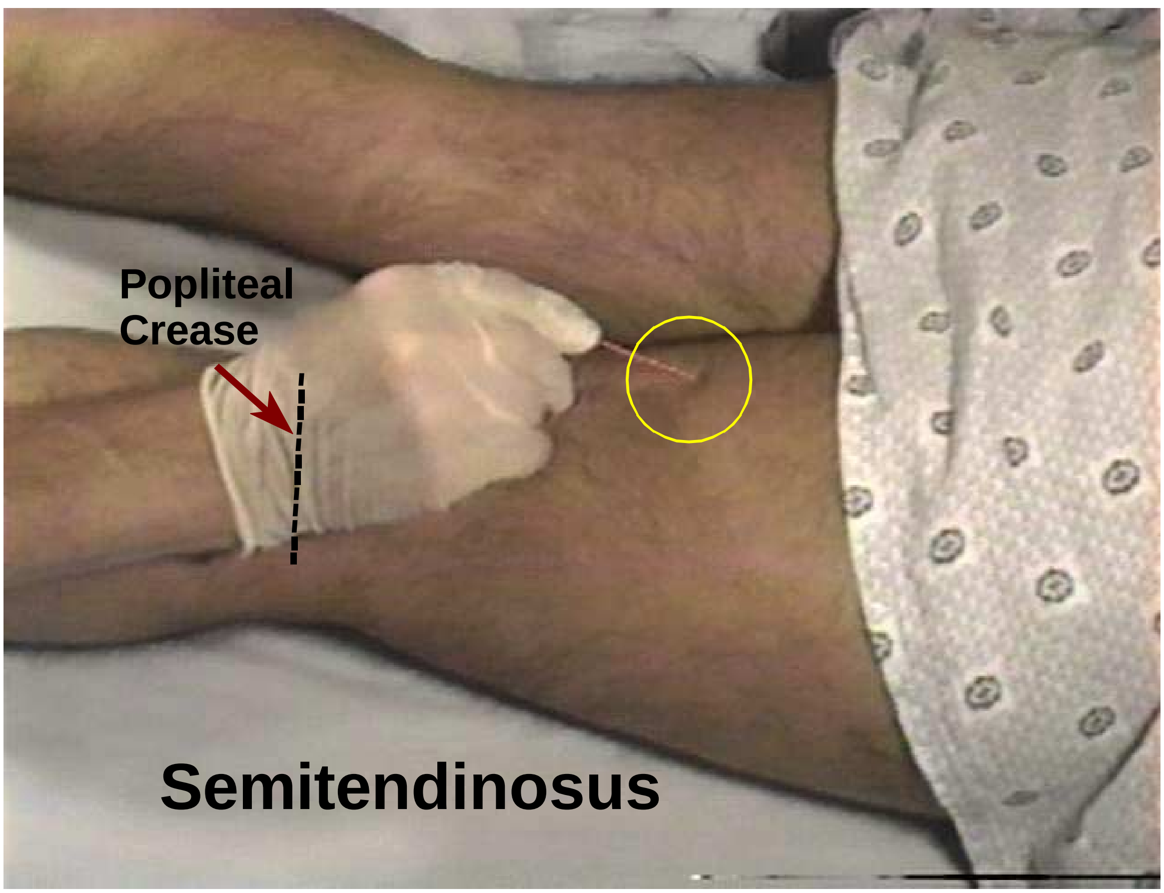
Origin: Ischial tuberosity by a common tendon with the biceps femoris.

Insertion: Proximal portion of the medial tibia and deep fascia of the leg.

Position/Activation: The patient is in the prone or lateral decubitus position, flexing their knee.

Electrode Insertion: Midthigh, just medial to the midline.

Caveat: If the electrode is too lateral, it may penetrate the biceps femoris.



Vastus Lateralis

Innervation: Femoral nerve (**L2**, **L3**, **L4**)

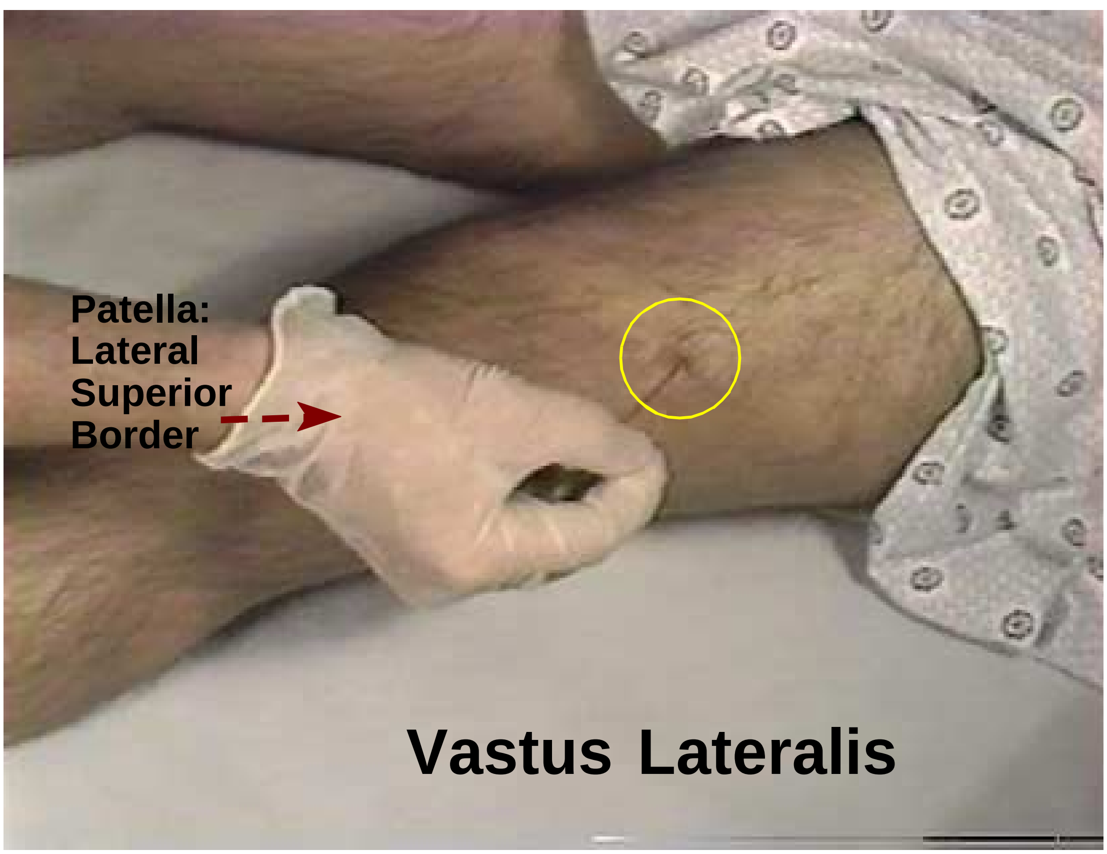
Origin: Proximal intertrochanteric line, anteroinferior border of the greater trochanter, proximal half of the linea aspera and lateral intermuscular septum.

Insertion: Proximal border of the patella and via the patella ligament to the tibial tuberosity.

Position/Activation: The patient is supine, extending their knee and slightly lifting their heel off the table, or performing knee hyper-extension, i.e., pushing their knee on to the examination table surface simultaneous with trying to lift their ankle off the table.

Electrode Insertion: Approximately mid-thigh in a line going proximal from the lateral superior border of the patella.

Caveat: If the electrode is too lateral and posterior, it may penetrate the biceps femoris; if too medial or anterior, it may penetrate the rectus femoris.



Vastus Medialis

Innervation: Femoral nerve (**L2**, **L3**, **L4**)

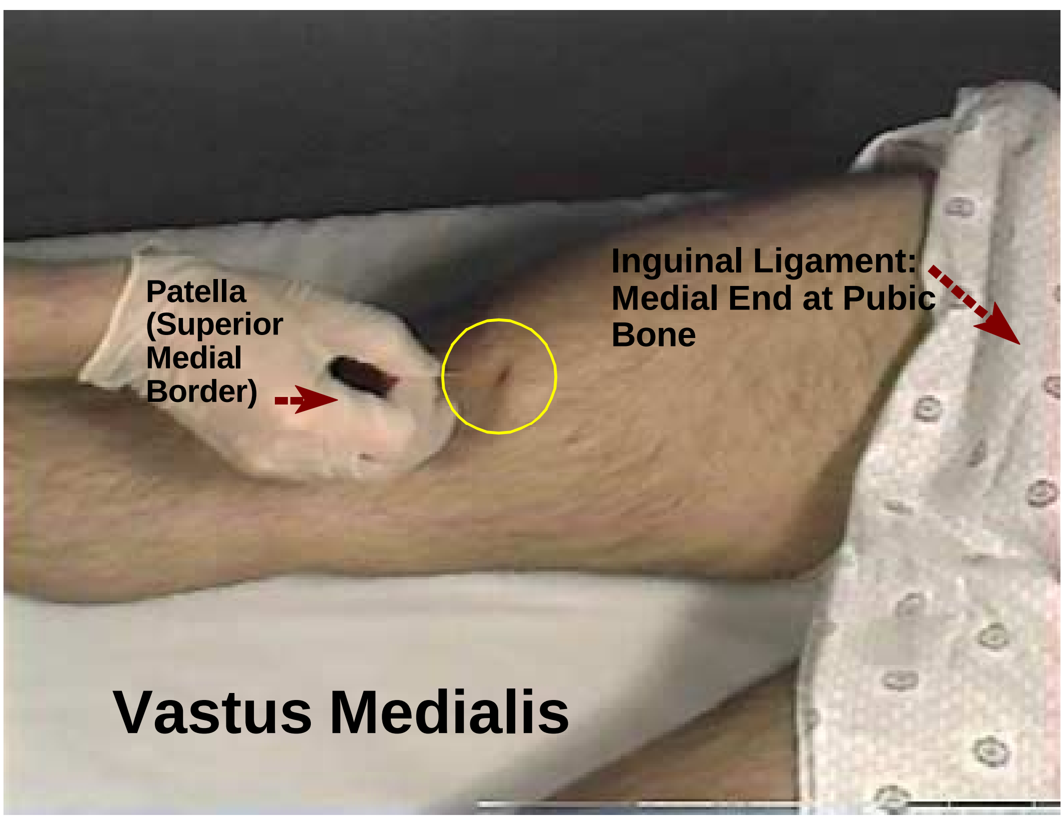
Origin: Distal intertrochanteric line, medial lip of the linea aspera, proximal medial supracondylar line, intermuscular septum, and tendons of the adductor longus and magnus.

Insertion: Proximal border of the patella and via the patella ligament to the tibial tuberosity.

Position/Activation: The patient is supine, extending their knee and slightly lifting their heel off the table, or performing knee hyper-extension, i.e., pushing their knee on to the examination table surface simultaneous with trying to lift their ankle off the table.

Electrode Insertion: In a line going between the medial superior border of the patella and the medial end of the inguinal ligament at the pubic tubercle, insert approximately 25% of the distance from the patellar border.

Caveat: If the electrode is too lateral, it may penetrate the rectus femoris, if too medial and posterior, it may penetrate the sartorius or gracilis.



V. Paraspinal Muscles

Multifidus

The larger paraspinal muscles extend most of the length of the back. These include the more superficial and medial longissimus, and the laterally placed iliocostalis. The multifidus is medial and at some levels may be deep to the longissimus. It is a multisegmental-innervated muscle supplied by the C4 through sacral myotomes. The muscle fibers originate from the transverse process of the vertebral bodies, span 2-4 vertebra, and insert on the transverse process of a vertebral body superior to its origin. The muscle fibers are thought to be relatively short, thereby tending to have less overlap in segmental innervation. For example, in an acute single level radiculopathy, denervation would be more focal and confined than in the larger, more superficial paraspinal muscle.

The multifidus may be studied in the prone or lateral decubitus position. In the latter, it is important that the shoulders and pelvis be perpendicular and not rotated. The muscle is best activated extending the back or neck. To help activate the thoracic and lumbar segments, the patient may concomitantly extend their thigh posteriorly, knee in extension. While slightly tensing the skin, the needle electrode is inserted perpendicular to the long axis of the multifidus' fibers, approximately 2-3 cm lateral to the spinous process of the vertebra. The midline skin crease should not be assumed to represent the actual midline (or spinous processes), especially in obese individuals.

The electrode is deviated slightly medially so that its tip should reach the junction between the spinous and transverse processes of the vertebral body (see figure 5). After establishing the location of the needle tip, it is then easier to study the segment by withdrawing along the corridor, noting that the deeper part of the insertion is in the multifidus. In many average-sized adults, it may be preferable to use a 50 mm electrode for the cervical or lumbar portions of the multifidus.

When the needle electrode is withdrawn to the subcutaneous level, the electromyographer may wish to reduce the number of skin insertions by examining additional rostral and caudal corridors. This is accomplished by deviating the electrode rostrally or caudally, aiming for the same medial deep landmarks described above. The needle electrode should initially be inserted at the level of the spinous process of the vertebra of the segment to be studied. Additional insertions may be required rostrally or caudally, particularly caudally, to fully evaluate the paraspinal musculature. The spinal segmental myotome is often caudal to the actual vertebral level.

The use of corridors running parallel to the direction of the muscle fibers goes against what has been described in the **General Overview** section. The goal, however, is to sample several segments or myotomes along the long axis of the spine. Since the paraspinal musculature is a long nexus of muscle fibers that have variable overlap in their segmental innervation, serial sampling of the multifidus along its long axis should achieve this better than in the other paraspinal muscles. In the multifidus, the overlap in the segmental innervation is considered to be less than in other paraspinal musculature.

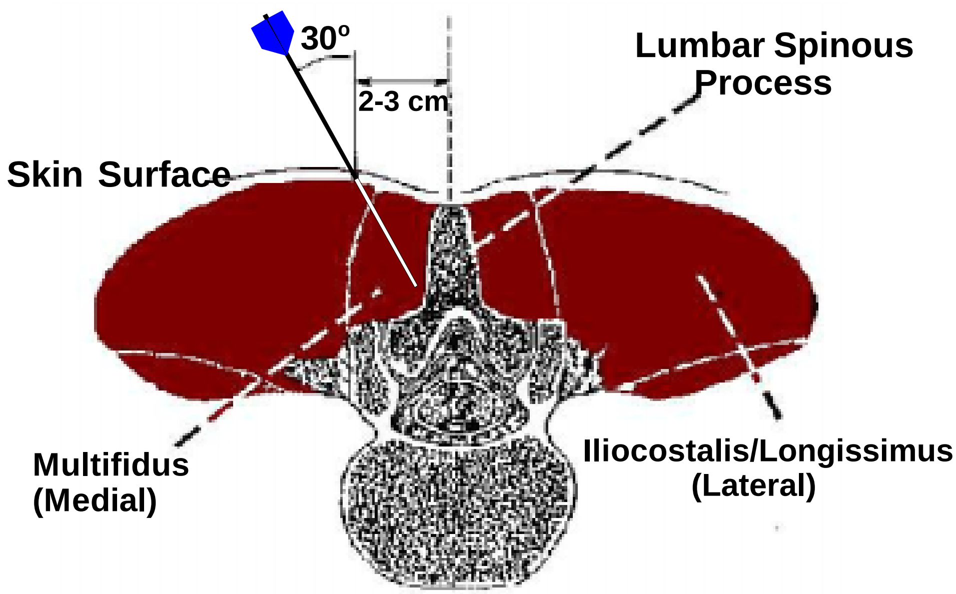
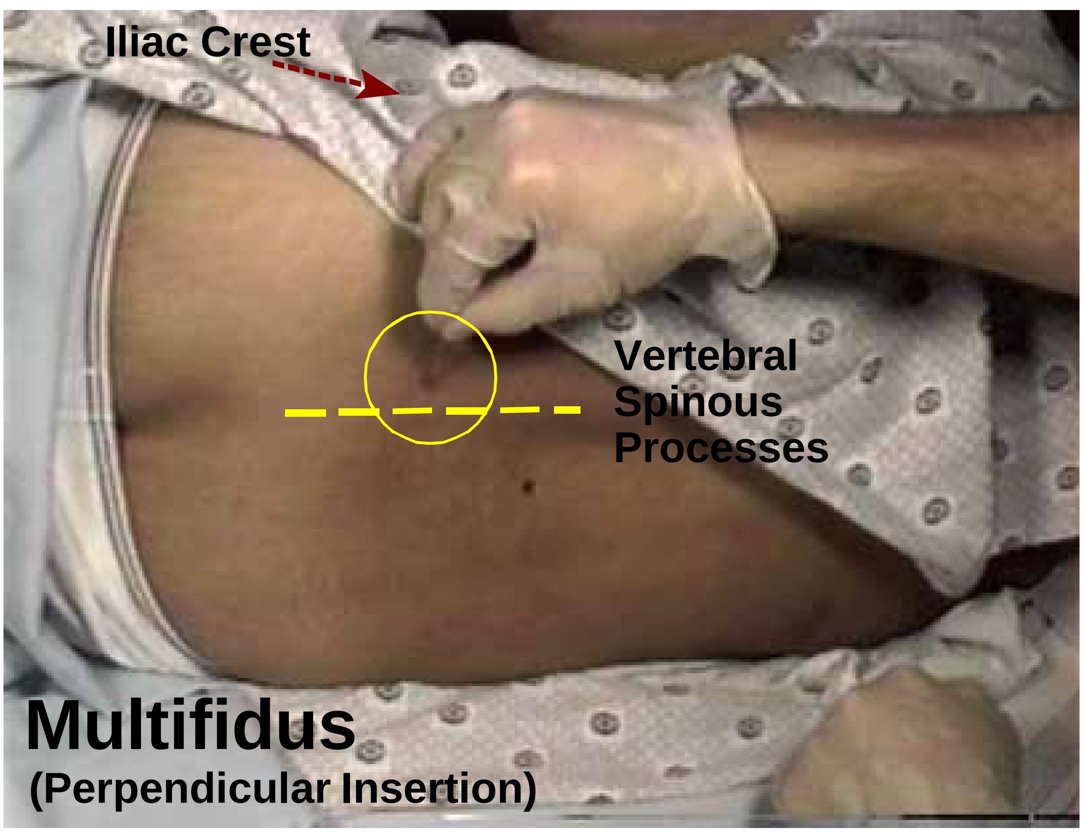
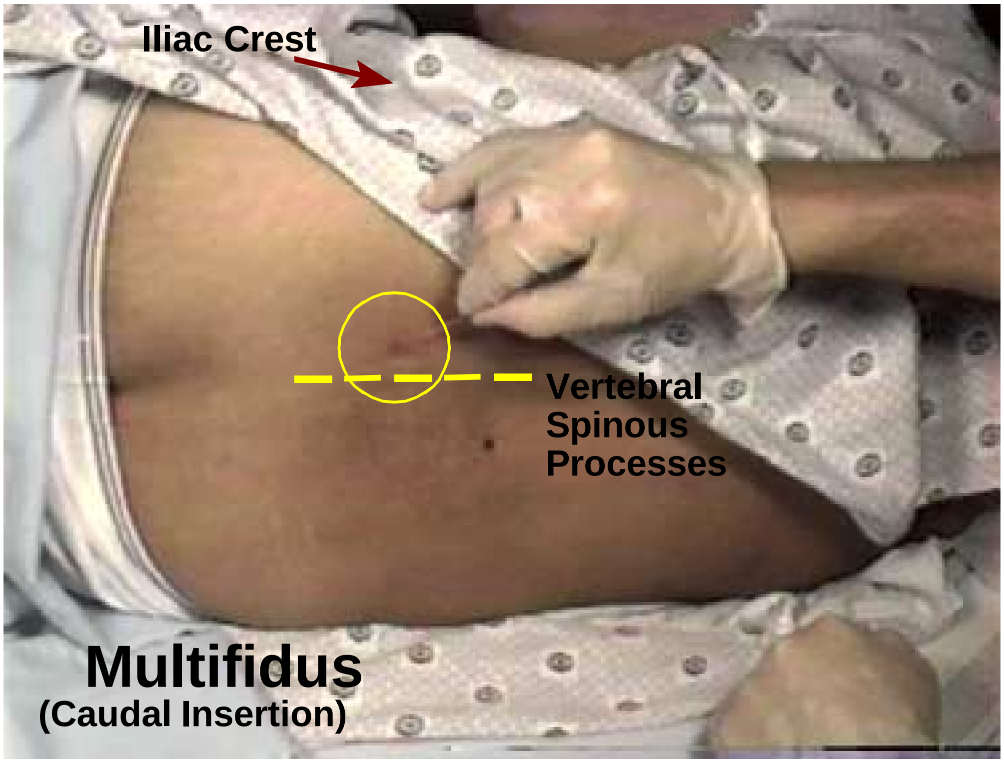


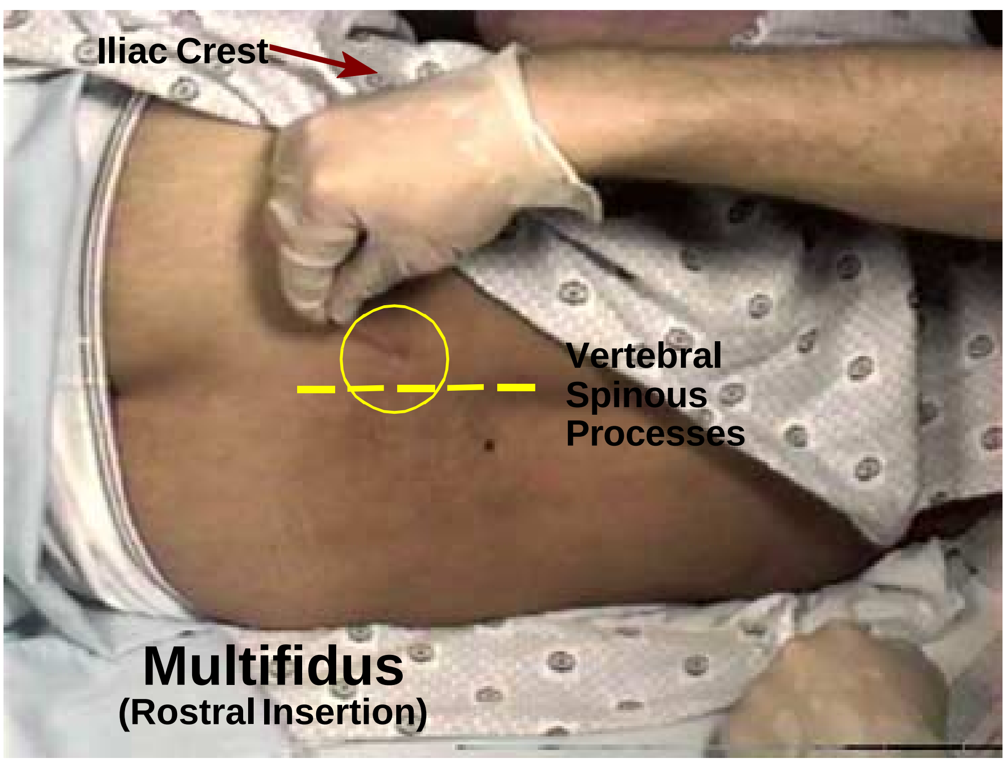
Figure 5. Schematic showing the insertion of the needle electrode into the multifidus. The electrode is inserted until it touches bone as shown, then withdrawn slowly while the muscle is activated. Note that although the multifidus may extend to superficial levels, only the deeper portion of the corridor should be considered as being definitely within the multifidus. Additional corridors are made directing the electrode rostrally and caudally, i.e., into and out of the plane of the paper, but at the same angle so that the electrode reaches the juncture of the spinous and transverse spinous processes.

If nothing is noted at the perpendicular insertion, the adjacent corridor may easily pick up an area of abnormality supplied by an adjacent segment. This is not because the rostral or caudal deviation of the electrode exceeded the length of the sarcomeres which runs 2-4 vertebral segments. Rather the electrode likely penetrated overlapping muscle fibers from an adjacent segment, hence the need for often examining 3-4 serial sites along the region of suspected pathology (figure 5). Although the video shows the insertion technique for only the lumbar level, the principles for insertion at other spinal levels are identical.

The MUAPs recorded in the multifidus are similar to limb muscle in size, however MUAPs recorded more laterally in the longissimus may appear slightly longer in duration. Mean MUAP amplitudes in the multifidus may run about 30% higher compared to the biceps brachii. The percentage of polyphasic MUAPs may be slightly higher than in the biceps brachii (Barkhaus et al, 1997).




Iliac Crest
Vertebral Spinous Processes
Multifidus
(Caudal Insertion)


Iliac Crest
Vertebral Spinous Processes
Multifidus
(Rostral Insertion)

Scalenes (Anterior, Middle, and Posterior)

Innervation: Cervical plexus and branches from the ventral rami of the cervical spinal nerves (C3, C4, C5, C6).

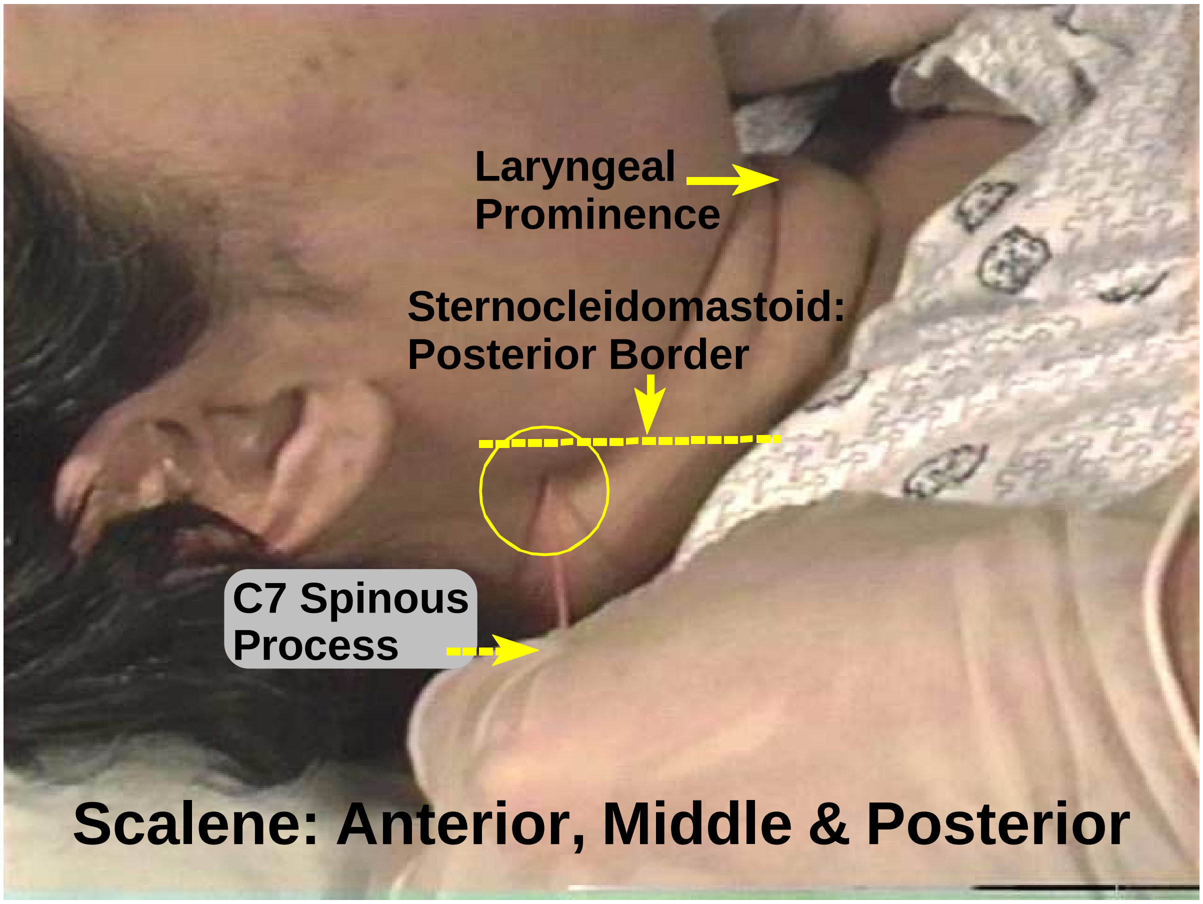
Origin: Transverse processes of the C2-C6 vertebra. The scalenes vary slightly with respect to their levels of origin.

Insertion: Scalene tubercle of the first rib (Anterior Scalene); first rib near the subclavian groove (Middle Scalene); and second rib (Posterior Scalene).

Position/Activation: The patient is supine. For functional purposes the Scalenes will be considered together. The patient performs lateral neck flexion to the side being examined without shoulder elevation or adduction. Activation may be enhanced by slight contralateral cervical rotation. It is important to instruct the patient in activation prior to insertion.

Electrode Insertion: The head and neck are in neutral position. First identify the posterior border of the clavicular head of the sternocleidomastoid by contralateral cervical rotation. The external jugular vein is also identified visually or by brief, gentle compression at the base of the neck. The head and neck are returned to neutral position. The electrode is inserted directly perpendicular to the skin surface near the base of the lateral neck, midway between the laryngeal prominence and the C7 spinous process, approximating a perpendicular vertical line extending inferior to the tragus of the ear. The electrode is advanced gently and slowly with periodic minimal activation to confirm localization. The scalene muscle group is relatively deep.

Caveat: The electrode should not be directed anteriorly behind the sternocleidomastoid so as to avoid the major deep vascular structures of the neck. If too superficial, the electrode will be in the platysma; if too posteriorly, the levator scapula; if too anterior, the sternocleidomastoid. The patient should be observed for any evidence of bleeding after withdrawal of the electrode. The scalenes are utilized more in botulinum toxin injection than in clinical EMG.


Laryngeal Prominence
Sternocleidomastoid: Posterior Border
C7 Spinous Process
Scalene: Anterior, Middle & Posterior

Splenius Capitus

Innervation: Dorsal rami of the middle cervical spinal nerves.

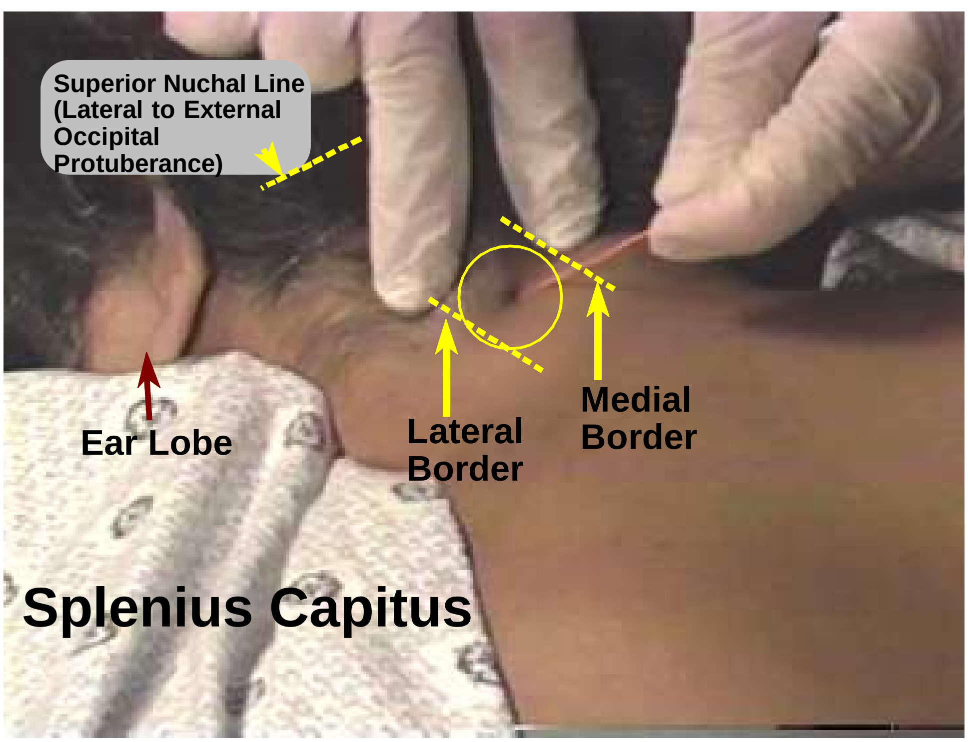
Origin: Caudal half of the nuchal ligament and spinous processes of the first 4 thoracic vertebra.

Insertion: Mastoid process of the temporal bone and on the occipital bone, the latter being inferior to the lateral superior nuchal line.

Position/Activation: The patient is prone with their head and neck in neutral position as described above in the General Overview section. The medial and lateral borders of the muscle are isolated by the examiner’s fingers 3-4 cm distal to the muscle’s medial insertion at the superior nuchal line, just distal to the hairline on the posterior neck. The patient simultaneously performs cervical extension and rotation of the neck ipsilateral to the side being studied.

Electrode Insertion: Between the borders of the muscle.

Caveat: If the electrode is too medial or caudal, it may penetrate the upper trapezius.



VI. Cranial Muscles

Frontalis

Innervation: Facial nerve (cranial nerve VII) supplied by the motor neurons of the facial nucleus located in the pons.

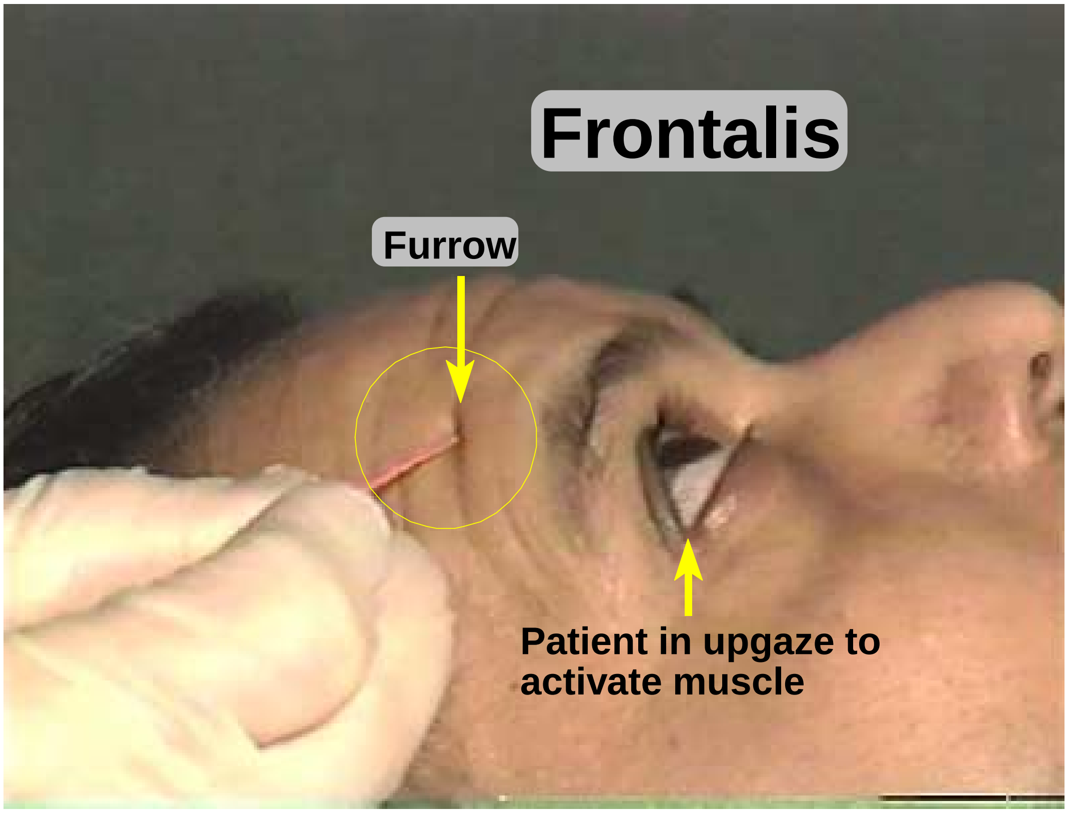
Origin: Galea aponeurotica.

Insertion: Muscles and skin of the eyebrow and root of the nose.

Position/Activation: The patient is supine. The muscle is then activated by either having them "wrinkle their forehead" or having them fixate on a spot on the ceiling slightly superior (about 0.5 meters) from a point directly above their line of gaze. The latter should result in an associated slight activation of the frontalis which should be evidenced by a wrinkling or furrowing of their forehead. If not, ask them to direct their gaze slightly more superiorly until this occurs. This latter maneuver is quite helpful in single fiber EMG when minimal increments or decrements in activation are necessary.

Electrode Insertion: The skin is slightly tensed between the examiner's index finger and thumb in a superior-inferior direction. The needle electrode is then inserted between the examiner’s fingers into the first or second furrow above the eyebrow, perpendicular to the long axis of its muscle fibers. The angle of the needle electrode insertion is about 30 degrees anterior to the coronal plane.

Caveat: If the electrode is inserted too close to the eyebrow, it may penetrate the orbicularis oculi. The frontalis is relatively thin and the needle electrode may quickly traverse it. If additional sites are needed, insertion should be made medial or lateral to the initial site. Because the muscle fibers run in a superior/ inferior direction, insertions immediately superior and inferior to the initial site should be avoided.


Frontalis
Furrow
Patient in upgaze to
activate muscle

Masseter

Innervation: Mandibular or third division of the trigeminal nerve (cranial nerve V). It is in turn supplied by the motor neurons of the motor nucleus of the fifth cranial nerve in the pons.

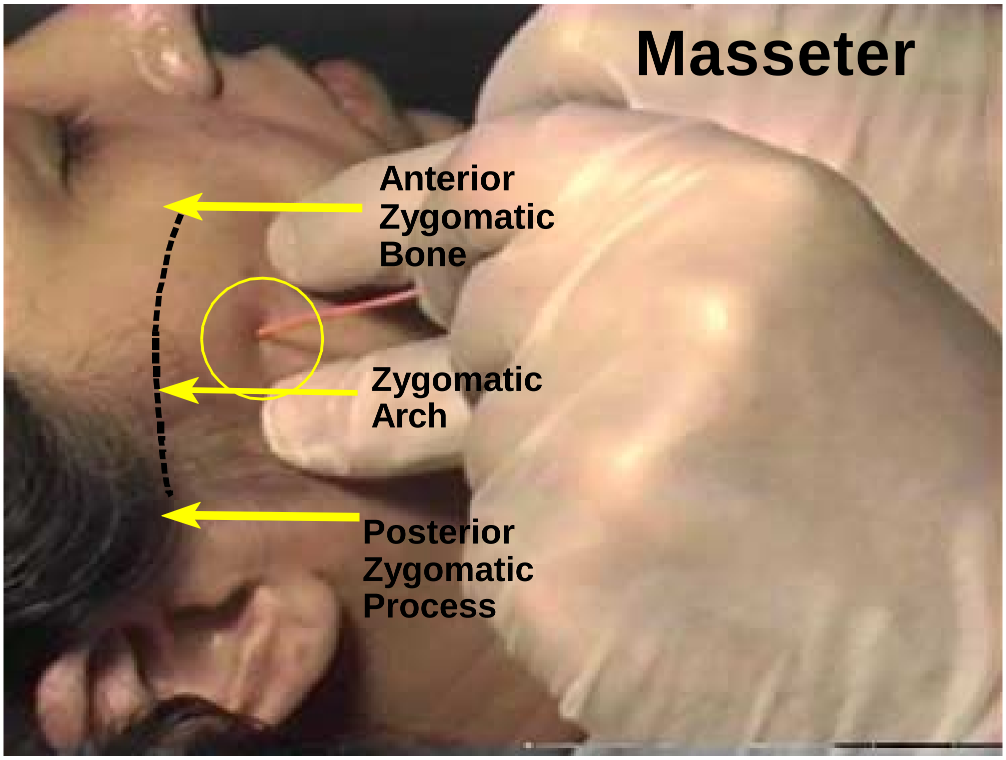
Origin: Zygoma (superficial portion); inferior border and medial surface of the zygomatic arch (deep portion).

Insertion: Angle and ramus of the mandible (superficial portion); superior ramus and lateral coronoid process of the mandible (deep portion).

Position/Activation: The patient should be supine and their head and neck in a neutral position. The patient bites or clenches their teeth together firmly, slightly protruding their mandible. As this may be difficult or uncomfortable for some patients, activation may be facilitated by having them clench their teeth against a padded tongue blade or similar object.

Electrode Insertion: Identify the midpoint on the zygomatic arch and go 2-3 cm inferiorly where the muscle should be easily palpable from activation as above. The examiner isolates the anterior and posterior borders of the masseter between two fingers of their "free" (i.e., non-electrode holding) hand. The electrode should be inserted slowly, perpendicular to the face, between the examiner's fingers that isolate the borders of the muscle.

Caveat: If the electrode is inserted too inferior to the zygomatic arch, it may be in the platysma or other facial-innervated musculature; if too posteriorly, it will penetrate the parotid gland.


Masseter
Anterior Zygomatic Bone
Zygomatic Arch
Posterior Zygomatic Process

Orbicularis Oculi

Innervation: Facial nerve (cranial nerve VII) supplied by the motor neurons of the facial nucleus located in the pons.

Origin: Anterior surface of the medial palpebral ligament, the maxilla and the nasal process of the frontal bone.

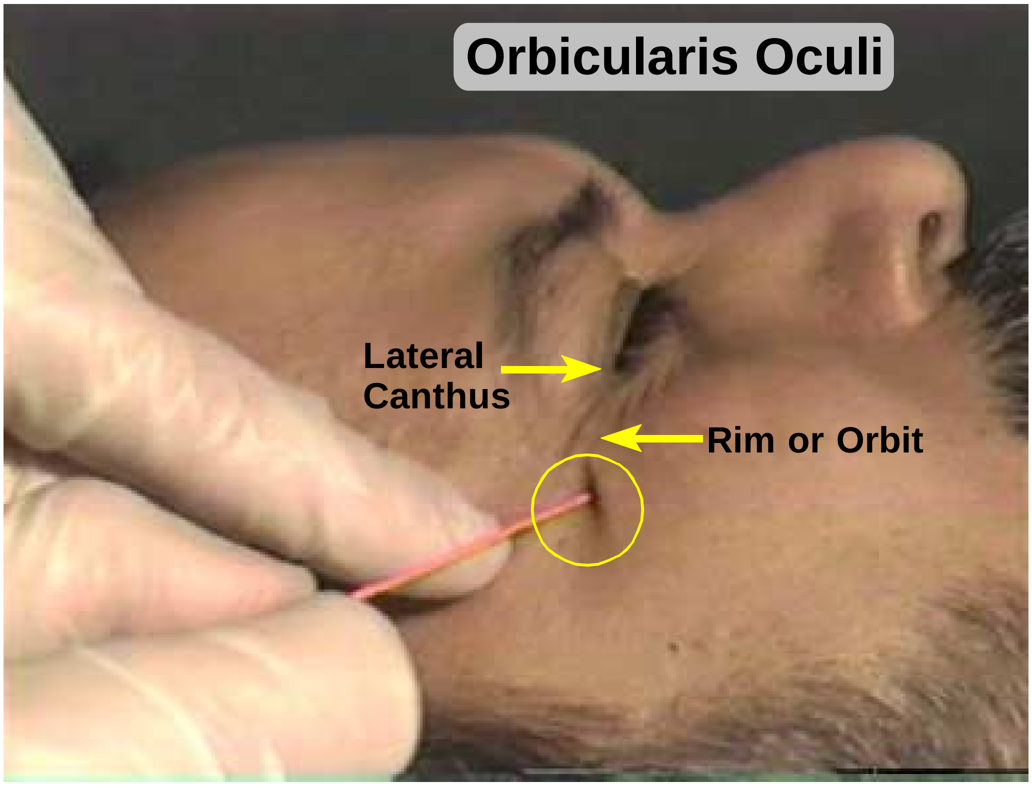
Insertion: Diffuse, as its muscle fibers go around the orbit of the eye, gradually blending in with adjacent facial muscles and ligaments.

Position/Activation: The patient should be supine and their head and neck in a neutral position. The patient closes the eye to be examined. If this is difficult or if the patient has difficulty with gradual unilateral eye closure, have them simultaneously and gradually close both eyes.

Electrode Insertion: While palpating the activated muscle and slightly tensing the skin between the index finger and thumb, the electrode is inserted with the other hand almost parallel to the surface of the skin. The needle electrode tip is directed slightly anterior to the coronal plane at the level of the lateral canthus, just lateral to the edge of the orbit, deviating the electrode inferior away from the globe (i.e., toward the tip of the nose). It is useful to keep the examiner's free hand or fingers against the patient's orbital area so as to minimize any unwanted head turning by the patient.

The Orbicularis Oculi is a very thin muscle located just subcutaneously at this point and easily traversed if the electrode is inserted too deeply, i.e., greater than 5 mm in most individuals. An additional corridor may be examined by withdrawing just subcutaneously and directing the electrode in a similar manner just described but in a superior direction. If needed, additional insertion sites may be made more inferiorly along the edge of the orbit as described above.

Caveat: If the electrode is too lateral to the orbit, the electrode may penetrate the temporalis muscle.


Orbicularis Oculi
Lateral Canthus
Rim or Orbit

Orbicularis Oris

Innervation: Facial nerve (cranial nerve VII) supplied by the motor neurons of the facial nucleus located in the pons.

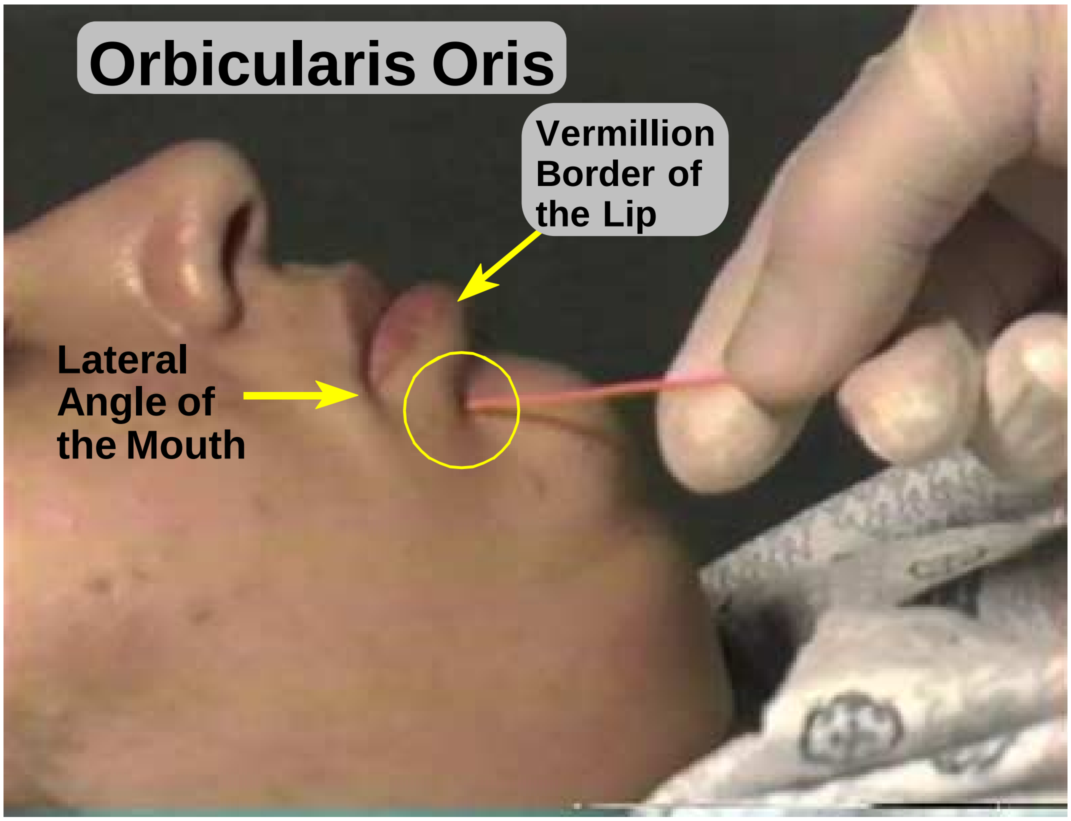
Origin: The muscle fibers of other facial muscles near the mouth and is actually derived in part from other facial muscles.

Insertion: Like the Orbicularis Oculi, the Orbicularis Oris has a similar diffuse insertion, specifically into the skin and mucous membranes of the lips, in addition to blending back into other facial muscles.

Position/Activation: The patient should be supine with his/her head and neck in a neutral position. The patient is asked to purse their lips and protrude them as if to whistle.

Electrode Insertion: Approximately one centimeter away from the vermilion border of the lips in a position medial to the angle of the mouth. This can be either inferior or superior so as to avoid interference from other facial muscles (e.g. levator or depressor angularis oris, zygomaticus major, etc.) converging at the lateral angle of the mouth. The electrode should be directed toward the lip.

Caveat: If the electrode is too far from the lips or too close to the angle of the mouth (see above), it may penetrate other facial innervated muscles.


Orbicularis Oris
Vermillion Border of the Lip
Lateral Angle of the Mouth

Sternocleidomastoid

Innervation: By both the C2,3 myotomes known as the external ramus, or spinal portion, and the cranial portion, or internal ramus, derived from the accessory nerve (cranial nerve XI). The motor neurons of the latter arise from the dorsal efferent nucleus and caudal nucleus ambiguus in the medulla.

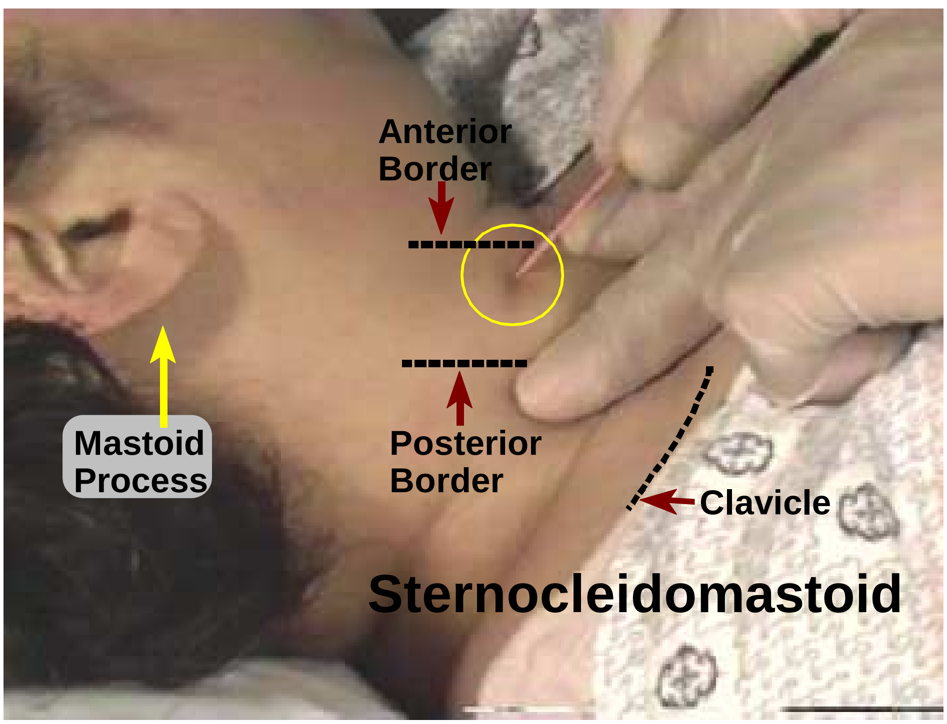
Origin: Medial or sternal head via the manubrium; the lateral or clavicular head via the medial third of the clavicle.

Insertion: Both heads insert on the lateral mastoid process and lateral superior nuchal line of the occipital bone.

Position/Activation: The patient is supine with their head and neck in neutral position. For unilateral activation, the patient rotates their head and neck to the side opposite that being studied while the examiner isolates the anterior and posterior borders between their fingers.

Electrode Insertion: Identify the external jugular vein visually or by gentle compression at the base of the neck. The electrode is inserted into the midportion of the muscle between the mastoid process and the clavicle.

Caveat: Deep insertions through the muscle run the risk of penetrating the major internal vascular structures of the neck.



Tongue (Extrinsic Muscle Genioglossus)

Innervation: Hypoglossal nerve (cranial nerve XII) supplied by motor neurons of the hypoglossal nucleus in the medulla. Some anatomists feel that there may be a contribution by the first two cervical myotomes.

Origin: Mental spine.

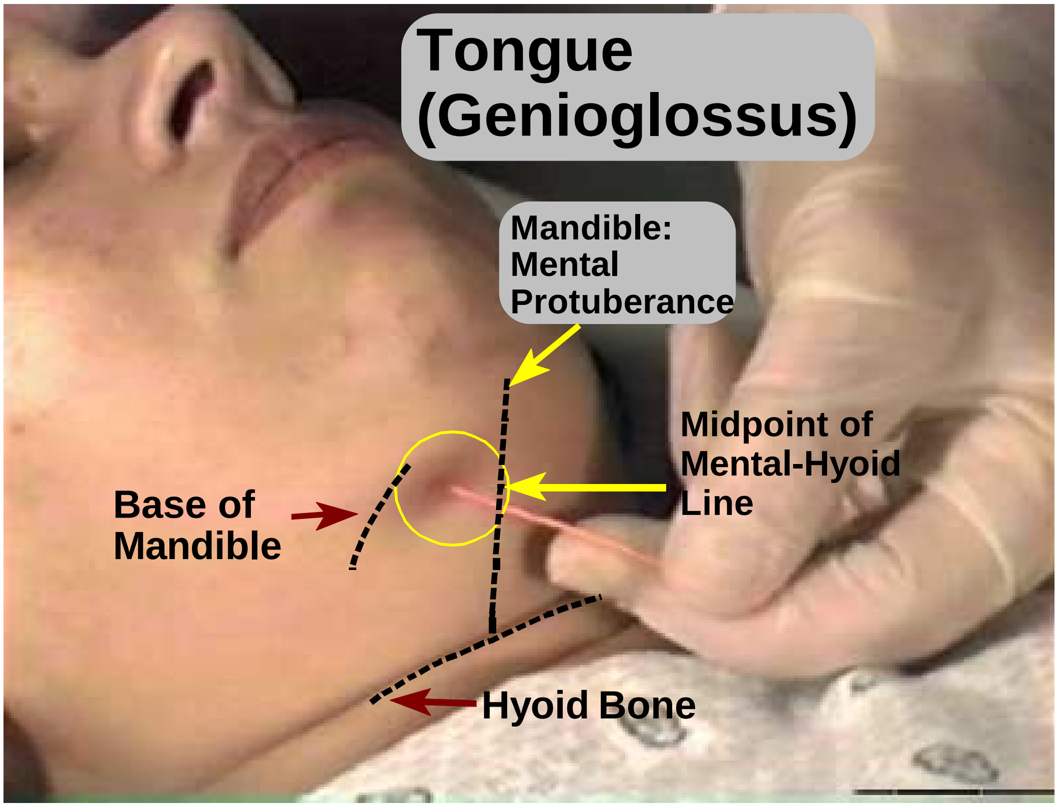
Insertion: Tongue and the hyoid bone.

Position/Activation: The patient is supine with their head and neck in neutral position. The Tongue is composed of a number of specific muscles that move it in various directions as well as participate in deglutition. For simplicity of examination, the genioglossus is one of the major muscles of the tongue that is easily identified by its activation. The anterior muscle fibers of the genioglossus draw the tongue back into the mouth. The posterior muscle fibers draw the tongue forward, protruding the apex of the tongue. The latter muscle fibers are more inferior in the base of the tongue. With both sides acting together, the anterior and posterior muscle fibers depress the tongue in the mouth with the surface appearing concave from side to side.

The muscle is optimally activated by having the patient gently press the tip of his/her tongue against the lower teeth while the mouth is closed. This maneuver selectively activates the more posterior fibers of this large muscle. Do not have the patient extend their neck and head.

Electrode Insertion: Define the midpoint of the line between the mental protuberance of the mandible and the hyoid bone. The electrode is slowly inserted midway between this point and the base of the mandible with periodic slight activation to confirm localization.

Caveat: If the electrode is too superficial, it may be in the mylohyoid or geniohyoid. Complete relaxation of this muscle may be difficult while the electrode is in situ. Relaxation is made easier by avoiding cervical extension


Tongue
(Genioglossus)
Mandible:
Mental
Protuberance
Midpoint of
Mental-Hyoid
Line
Base of
Mandible
Hyoid Bone

Trapezius (Upper)

Innervation: Via the C2, **C3**, **C4** myotomes known as the external ramus or spinal portion, and the cranial portion or internal ramus derived from the accessory nerve (cranial nerve XI). The motor neurons of the accessory nerve arise from the dorsal efferent nucleus and caudal nucleus ambiguus in the medulla. Some anatomists consider the internal ramus to be predominant in motor innervation in the upper trapezius while the sensory (proprioceptive) fibers are derived from the ventral rami of the cervical myotomes.

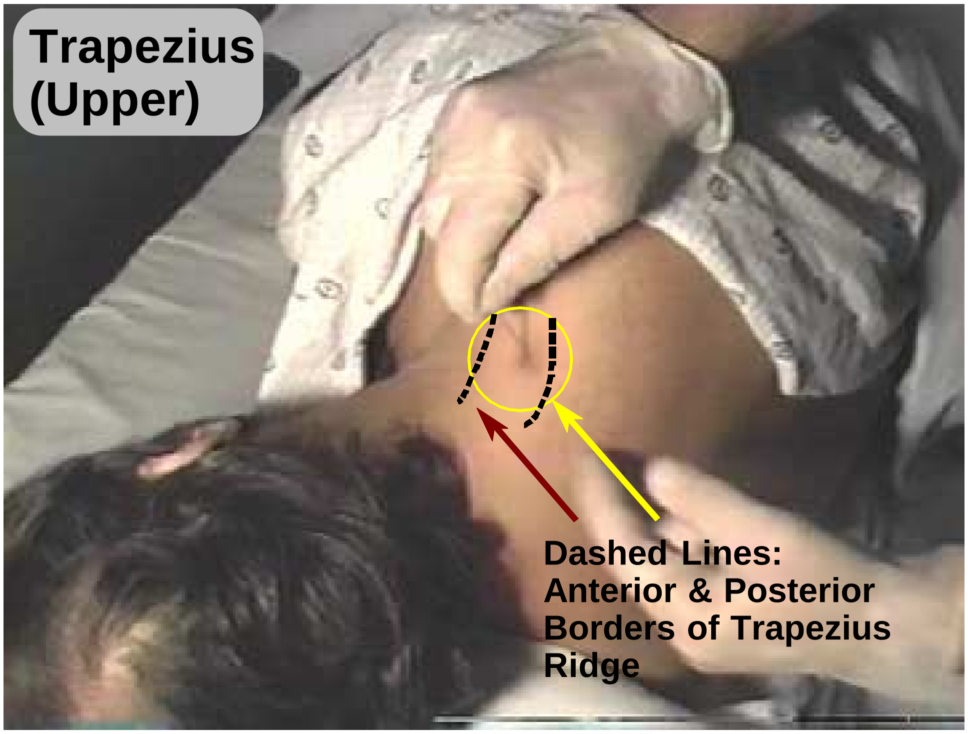
Origin: External occipital protuberance and nuchal ligament.

Insertion: Lateral third of the clavicle and acromion process of the scapula.

Position/Activation: The patient may be supine, prone or in the lateral decubitus position with the side to be studied superior. The shoulder is elevated as in a shoulder shrug and the posterior and anterior borders of the trapezius isolated between the examiner’s fingers. There should be no associated lateral neck flexion made. If the patient has difficulty in maintaining their neck straight with a unilateral shoulder shrug, then have them perform a simultaneous bilateral shoulder shrug. The latter should keep their neck positioned straight.

Electrode Insertion: Perpendicular to the trapezius ridge, about 2 cm lateral to the base of the neck in caudal direction parallel to the sagittal and horizontal planes.

Caveat: If the electrode is deviated too anteriorly, it may penetrate the levator scapula muscle.


Trapezius
(Upper)
Dashed Lines:
Anterior & Posterior
Borders of Trapezius
Ridge

VII. Further Reading

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