Kinesiological Fine Wire EMG

A practical introduction to fine wire EMG applications

Thorsten Rudroff

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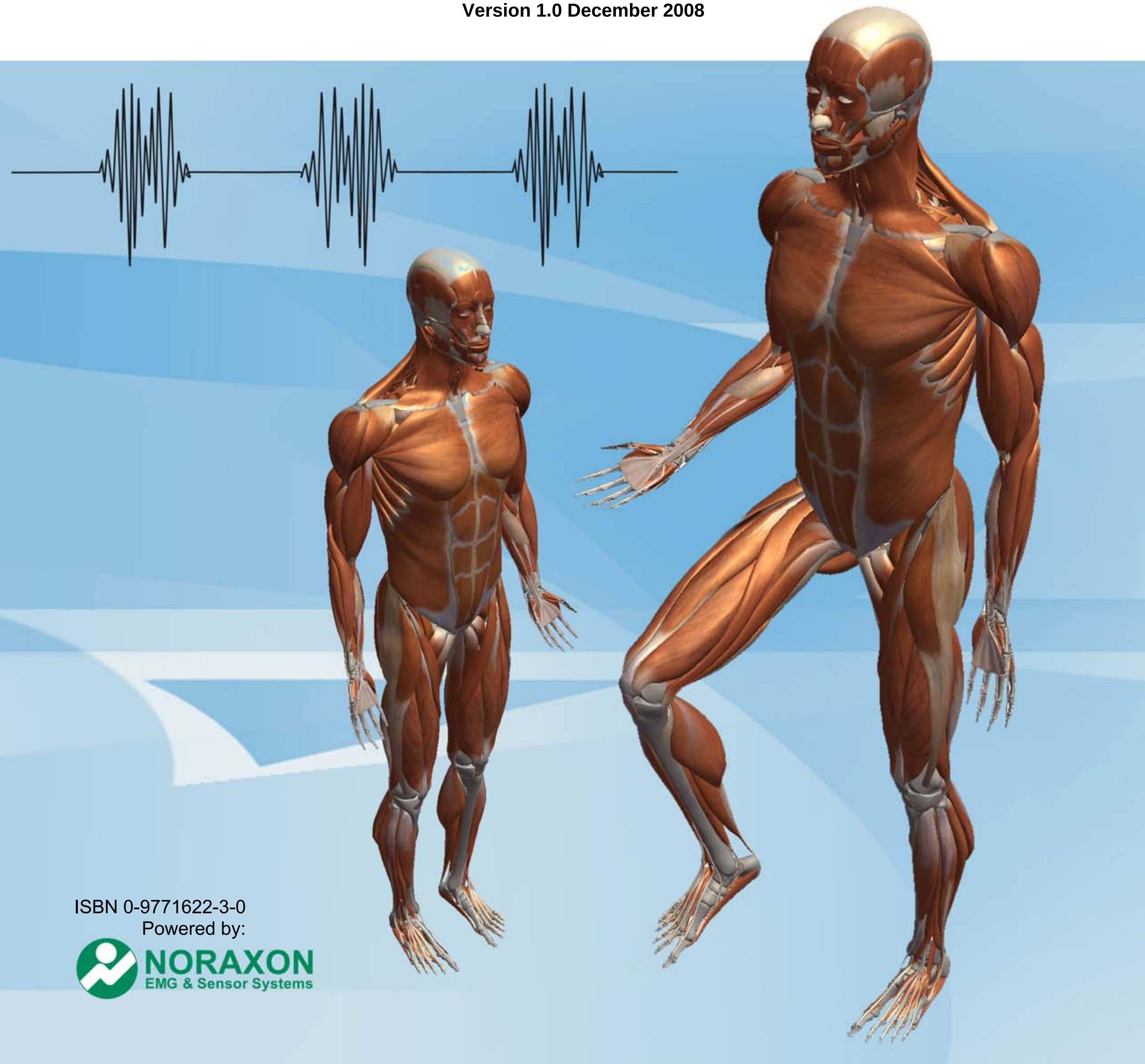

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INTRODUCTION

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About the Author

Dr. Thorsten Rudroff has completed his M.S. degrees in Sports and Exercise Science as well as Physical Therapy from the German Sport University, Cologne. He continued his education at the University of Konstanz, Germany to earn a Ph.D. degree in Sports and Exercise Science, summa cum laude. Subsequently, Dr. Rudroff became a post-doctoral fellow in the Neurophysiology of Movement Laboratory, in the Department of Integrative Physiology at the University of Colorado at Boulder, where he currently serves as a senior research associate.

His research has focused on the combination of neurophysiology and the biomechanics of human movement. Currently, his research interests include the adaptations in neural control of skeletal muscle across aging and fatigue, as well as, understanding the mechanisms responsible for the gender and task differences in muscle fatigue between children, adolescents and adults. He acts as referee for more than 10 scientific international journals and is a member of the Society for Neuroscience.

How to use this booklet

This first edition of "Kinesiological fine wire EMG" is a short teaching manual about the usage of fine wire electrodes for electromyographic recordings. This booklet is not intended to replace the fundamental EMG literature (e.g.Merletti & Parker 2005). It cannot reflect the variety of different views, opinions and strategies that have to be considered for responsible scientific use of EMG. Therefore, it is recommended to study the scientific publications related to a certain topic.

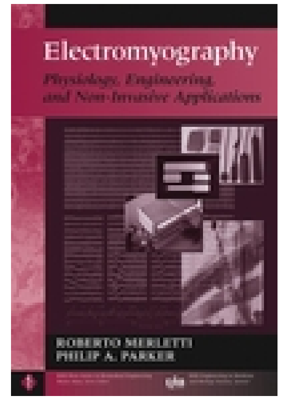


***Fig. 1** A fundamental EMG text book. Merletti & Parker: Electromyography*

The main intention is to simplify the first steps in the use of fine wire EMG as a research and evaluation tool and "get started". This book overviews the basic knowledge needed to apply and perform meaningful fine wire EMG setups and focuses on practical questions and solutions. It is based on the first booklet *ABC of EMG* (see chapter "Recommended books") which introduces signal origin, detection and analysis techniques of kinesiological *surface* EMG recordings. It is recommended to also study the ABC of EMG booklet, especially the chapters about test standardization, analysis and interpretation strategies.

Definition of EMG

"**Electromyography** (EMG) is an experimental technique concerned with the development, recording and analysis of myoelectric signals. Myoelectric signals are formed by physiological variations in the electrical behavior of muscle fiber membranes."

Electromyography…

"..is the study of muscle function through the inquiry of the electrical signal the muscles emanate."

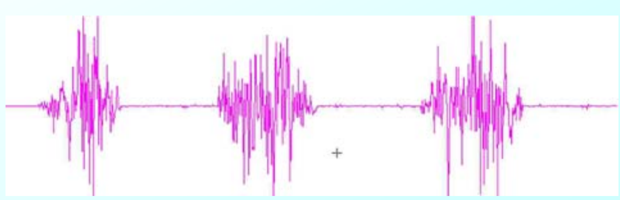


***Fig. 2** Basmajian & DeLuca: Definition Muscles Alive (2 - p. 1)*

Unlike the classical Neurological EMG, where an artificial muscle response due to external electrical stimulation is analyzed in static conditions, the focus of Kinesiological EMG can be described as the study of the voluntary neuromuscular activation of muscles within postural tasks, functional movements, work conditions and treatment or training regimes.

Signal Origin and Acquisition

When an end-plate potential is generated at a nerve-muscle synapse, it results in a muscle fiber action potential that propagates from the synapse to the ends of the muscle fiber. The changes in the electrical potential of the muscle membrane produced by the propagation of the action potential can be measured with electrodes: such a recording is known as an electromyogram (EMG).

EMG measurements have been used to (1) assess muscle function during or as a result of exercise and therapeutic procedures, (2) provide biofeedback to patients, (3) evaluate muscular control by assessing muscle onset time duration or to establish motor unit discharge rates, (4) assess gait, (5) determine the requirements of job-related tasks, and (6) assess fatigue. EMG recordings are typically made with two electrodes, known as bipolar recordings. The resulting signal represents the potential difference between the two electrodes. For recording an EMG signal, the electrodes can be placed on the skin over a muscle (surface EMG), under the skin but over the muscle (subcutaneous EMG), or in the muscle between the fibers (intramuscular EMG).

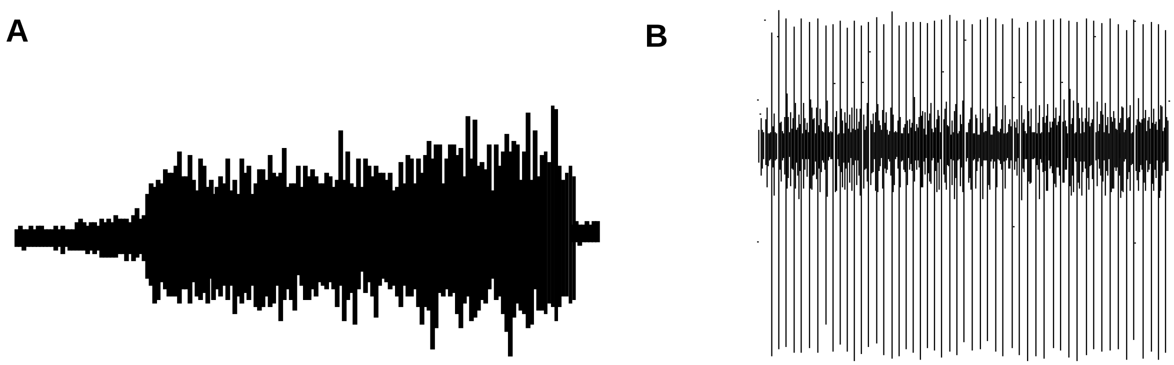


Fig. 3 *Examples of EMG recordings: (A) multiple, overlapping action potentials due to the concurrent activation of many motor units; (B) a train of action potentials for muscle fibers belonging to one motor unit (Figure from Rudroff et al. 2007c).*

The size and location of the electrode determine the composition of the recording, which can range from single action potentials to global muscle activity (Fig. 3). Surface EMG recordings with many overlapping action potentials are known as interference EMG (Adrian, 1925; Fuglesang-Frederiksen, 2000; Sanders et al., 1996). Electrodes placed on the skin provide a global measure of action potential activity in the underlying muscle, whereas fine wire electrodes placed in the muscle are able to record both interference EMG and single action potentials from adjacent muscle fibers.

Before collecting EMG data, the investigator should consider the following: (1) What is the purpose of the study? (2) What type of electrodes are appropriate for the recording? (3) Should the investigator use cabling or telemetry in their setup?

The **study purpose** determines whether surface or intramuscular electrodes are used. Surface electrodes are frequently used to assess superficial muscle activity. Intramuscular electrodes are used to derive information about the activity from muscles located deep in the body and to record motor unit activity. The advantages and disadvantages of the different electrode types are described on page 9 and discussed in detail elsewhere (Merletti & Parker, 2005; Turker, 1993).

In kinesiological EMG studies, the most common **type of intramuscular electrode** is the fine wire electrode. It consists of a pair of extremely fine nylon-coated wires (diameter of 50µm or less) placed in situ by means of a hypodermic needle. The needle is withdrawn and a small hook or barb at the end of the wires keeps them in the muscle. Such electrodes may be driven easily into a muscle without anesthesia causing no more pain than that resulting from the needle puncture itself. If sharp 25-gauge needles are used, the pain is minimal and transitory. The needle withdraws easily and rarely dislodges the fine wire electrodes due to the hooks at their ends. These electrodes do have potential complications including patient discomfort (Jonsson et al., 1968) and wire fracture (Jonsson, 1968). However, the incidence of these problems is extremely low (Jonsson, 1968) and is not considered a significant threat to subjects by most experienced electromyographers.

Specialized versions of fine wire electrodes have also been developed. For example, Enoka et al., 1988 described a special version of an indwelling electrode that apparently maximizes signal stability and muscle action potential selectivity. Their electrode is a branched, bipolar electrode positioned subcutaneously over the belly of the muscle. This electrode allows recording of motor unit action potentials during maximal voluntary contractions (MVC), slow movements, and fatiguing contractions of long durations (Mottram et al., 2006; Rudroff et al., 2007a,b). Needle electrodes are another type of intramuscular electrode that can be used for diagnostic EMG (Kimura, 1988) or to record motor unit action potentials during fast or sustained contractions in arm and lower leg muscles (Van Cutsem et al., 1998; Carpentier et al., 2001; Klaas et al., 2008). The application of these electrodes is limited because needle displacement during muscle contraction can be painful and can cause muscle damage (Blanton et al., 1971a, b; Lebedev, 1991).

Another consideration is whether to use a **telemetry** system or one requiring **cabling**. Telemetry systems are ideal for monitoring and recording muscle functionality from long distances without wires or cables. Telemetric recording is more convenient to record muscle activity during locomotion or complex movements as no cables limit or restrain the range of motion. Surface and intramuscular EMG signals are transmitted from the subject to the recording computer by radio waves from as far as 300 yards.

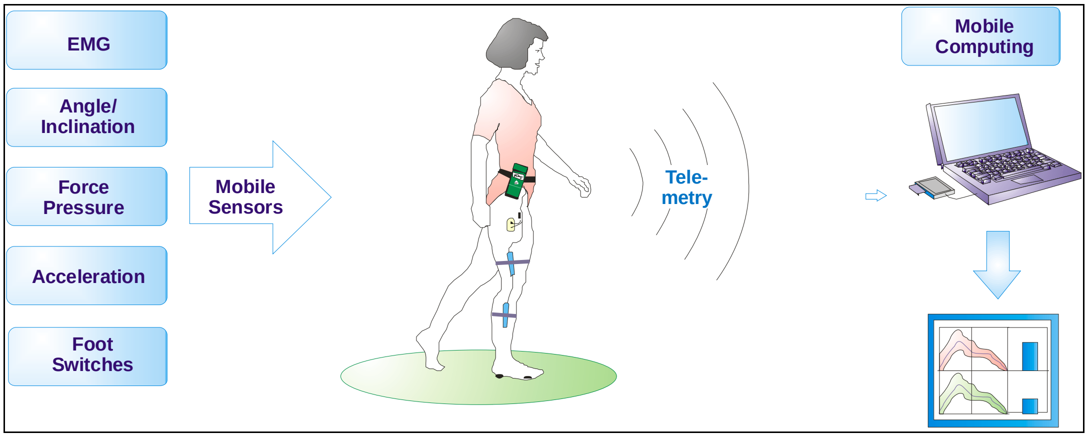


Fig. 4 EMG, force, angle and other types of biomechanical sensors can be connected to a telemetry system. Data is then transmitted from the system directly to a computer or laptop.
System TELEMYO G2 – Noraxon INC. USA

Use of fine wire EMG

In instances when muscles are deeply located in a body segment or covered by other surface muscles, recordings using fine wire electrodes are necessary for accuracy. The use of the fine wire technique requires adequate anatomical and physiological knowledge and training.

Advantages	**Disadvantages**
- Extremely sensitive	- Invasive
- Record single muscle activity	- Repositioning nearly impossible
- Access to deep musculature	- Small detection area
- Low concern of cross-talk	- Minor discomfort

Electromyographic (EMG) recordings from thin and deep muscles are difficult to obtain due to cross-talk from adjacent muscle layers. For this reason, surface electrodes are unsuitable for recording muscle activity in these muscles.

Although fine wire electrodes can be manipulated while monitoring EMG activity and are suitable for clinical investigations, accurate placement of fine wire electrodes is more difficult than with surface EMG. They must hook into the desired muscle layer and cannot be repositioned once inserted. Once inserted fine wire electrodes are superior for prolonged and non-clinical investigations of muscle function because they are hooked in the muscle fibers and therefore move with the fibers ensuring that the recording area is the same.

A typical fine wire electrode is shown in Figure 4. Although it is possible to make fine wire electrodes, it is recommended for a beginner to start with pre-manufactured electrode (Nicolet, VIASYS ™). These disposable EMG Paired Hook-Wire Electrodes are ideal for long-term intramuscular recording in movement/kinesiology studies. They are pre-sterilized and the un-insulated endings are coloured red for easy recognition. The ends of the wires are positioned so 2 mm of one wire and 5 mm of the second wire exit at the end of the needle. The first wire is stripped of insulation on the first 2 mm, while the second wire is insulated for the first 3 mm and stripped the next 2 mm. The electrodes are available in different sizes (30 mm (1.2'') Gauge 27 and 50 mm (2.0'') Gauge 25). The size of the needle depends on the depth of the muscle under investigation.

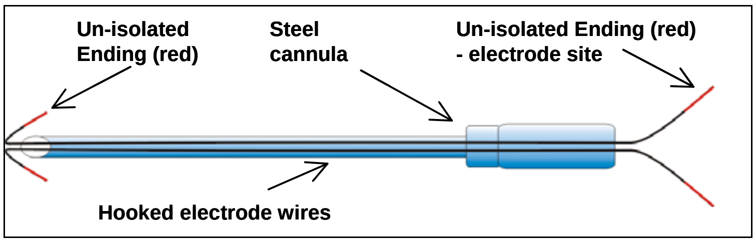


Fig. 5. *Schematic of a fine wire electrode: two fine wires with un-insolated endings are located with a steel cannula. From ABC of EMG*

Amplifier and recording recommendations

The International Society of Electrophysilogy and Kinesiology (ISEK) recommends to use a bandpass of 5-10 Hz high pass to minimum 1500 Hz low pass frequency (https://www.isek-online.org/standards_emg.asp).

The A/D conversion and sampling rate should at least be set to double EMG bandpass (e.g. 3000 Hz) to avoid aliasing problems (see ABC of EMG Chapter "Computation of EMG Signal").

Procedures for the use of fine wire EMG electrodes

1. Screen the subject to assure that he/she satisfies the inclusion and exclusion criteria for the experimental purpose depending on the requirements of your local human research committee.

2. Prior to arrival of the subject ensure the setup is complete. Wash your hands and arrange the fine wire EMG table with alcohol swabs, cotton balls, tape, and sterile medical examination gloves.

3. Before the first experimental session begins, an informed consent form must be read and signed by the subject. During this time, experiment procedures can be discussed before data collection.

4. When the subject arrives for data collection, review the procedures for the experiment and answer all questions asked by the subject. Ensure the subject has read and filled out necessary additional forms required for the study. Additionally, ensure that the subject fully understands what will happen during data collection and what is required of them.

Fig. 6 Preparation material for the insertion of the fine wire electrode

1. Sterile Latex Surgical Gloves
2. Delicate Task Wipers, e.g. Kimwipes
3. Skin prepping Gel, e.g. Nuprep
4. Alcohol and Iodine pads
5. Dual surface electrodes
6. Ground Surface Electrode
7. Tape
8. Razor
9. Fine wire electrode
10. Cotton Swab, e.g. Q-Tip

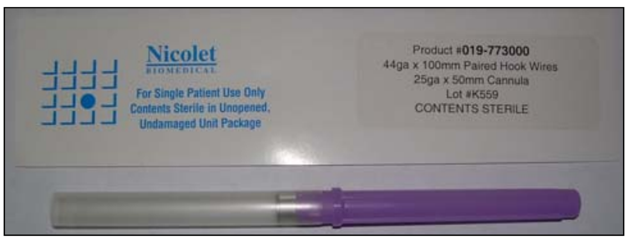


Fig. 7 Fine wire electrode.
44ga × 100 mm Paired Hook Wires
in a 25ga × 50 mm Cannula.

Subject Preparation

Have the subject seated comfortably and perform all experimental set-up prior to electrode insertion

- Prepare the area by shaving and cleaning with an alcohol swab and iodine
- Put on the medical latex gloves
- Explain to the subject that there may be a slight stinging sensation from the alcohol as the hypodermic needle is inserted, but the procedure should not be painful. Instruct the subject not to hesitate in expressing any discomfort during the procedure.

Electrode Insertion

WARNING:

IF THE SUBJECT COMPLAINS OF DISCOMFORT OR PAIN AT ANY TIME DURING THE PROCEDURE, REMOVE THE ELECTRODES IMMEDIATELY AND TERMINATE THE SESSION.

The insertion site should be determined using established procedures e.g. the Anatomic guide for the electromyographers (Delagi et al., 1994 - Springfield Ill: Charles C. Thomas.) One factor that influences an EMG recording is electrode placement. This involves both the distance between the electrodes and the location of the electrodes relative to the neuromuscular junctions (Farina et al., 2002; Merletti et al., 2001). The neuromuscular junctions are located in the middle of the muscle fibers and span an area known as the innervation zone. Each fiber is activated at the neuromuscular junction, which results in the propagation of action potentials in each direction toward the ends of the fiber. The preferred location for an electrode is the area halfway between the center of the innervation zone and the distal tendon. The books by Enoka (2008) and Merletti & Parker (2005) provide a full discussion of the electrophysiological importance of electrode placement in addition to interelectrode distance and electrode placement for various muscles (Freriks et al., 1999; Rainoldi et al., 2004).

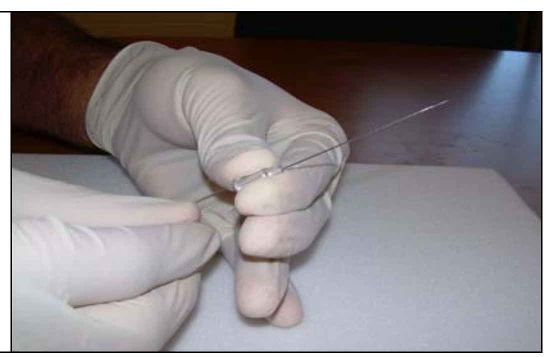
Illustrated step by step scheme for electrode attachment

After skin preparation, if the experiment requires surface and intramuscular recording, apply the surface electrodes parallel to the muscle fibers direction and a surface electrode near the muscle as the ground electrode.

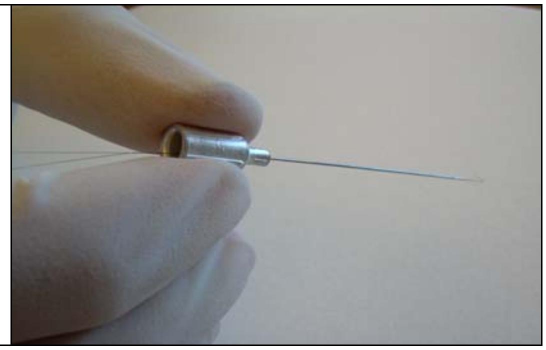
After identification of the area of interest for the electrode insertion, the insertion site will be marked with a non-permanent marker.

After marking the site, clean and disinfect the insertion site with alcohol and iodine.

With medical gloves on, grasp the fine wire electrode by the connection end of the fine wires and hold the plastic portion of the hypodermic needle. Orient the needle so the distal opening faces upward. Check that the fine wires move freely in the needle.



Hold the needle between the thumb and index finger.



Place the end of the needle against the subject's skin over the muscle of interest. With the opposite hand, spread the skin over the muscle with the index finger and thumb. Using firm and steady pressure insert the needle at an angle of approximately 30 degrees until the needle has pierced the skin.

Talk to the subject during the procedure and ensure that any discomfort is minimized. Once the needle has pierced the skin, continue with gentle pressure until the desired depth is reached.

When the appropriate depth has been reached, apply pressure with the hand on the skin while gently removing the needle. This will prevent the wires from being pulled out. Carefully pull the needle over the fine wires and immediately place it into a biohazard sharps container.

Have the subject perform a light isometric contraction ensuring that there is no discomfort. Check the insertion site for any complications (see below) throughout the procedure.

Secure the fine wire electrode with tape.

Two models of fine wire pre amplifiers:

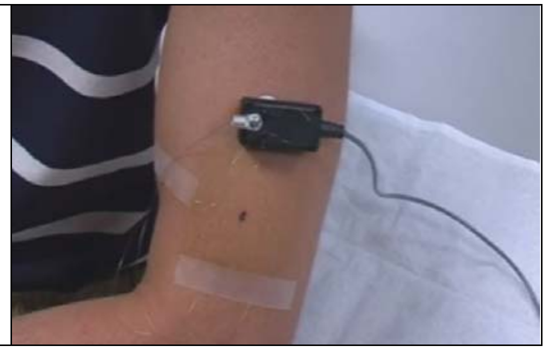
- Screw connectors (left)
- Spring connectors (right)

Alternative spring adapter for regular SEMG preamplifier leads with snap connection

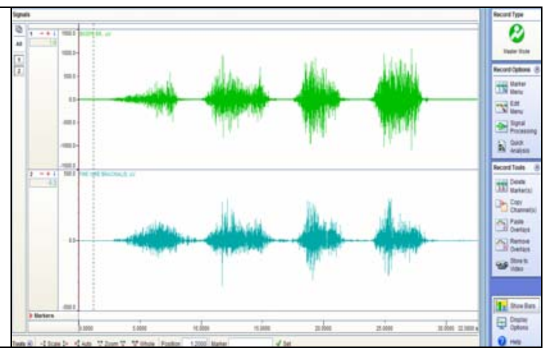
- floating spring adapter
- anchored spring adapter

Attach the wires to the connectors of the pre-amplifier.

Secure the pre-amplifier with tape. Ask the subject to perform some submaximal isometric contractions with his or her muscle followed by dynamic contractions.



Check the quality of the EMG signals on the recording computer. This picture shows the surface EMG signal of the short head of the biceps brachii (top trace) and the intramuscular EMG signal of the brachialis muscle (bottom trace).



Electrode Removal

While wearing medical gloves, grasp the wire(s) with the thumb and index finger on one hand.

- Remove wire(s) with a firm but gentle continuous pull. Once the wire(s) are removed, apply firm pressure with an alcohol swab to the insertion site to minimize bruising. Clean the site with an additional alcohol swab if necessary.
- Place electrode wire(s) in biohazard sharps disposal container.
- Dispose of all other waste in the biohazard waste bin or bag.

Potential Complications

Inflammation

Symptom – Signs will include redness, swelling, pain or tenderness. Inflammation can be caused by bacteria due to non-sterile procedures or by mechanical deformation from excessive movement of the electrode.
Response – Immediately remove the electrode and then compress and elevate the affected limb and apply ice to the affected region.
May require referral to a medical professional.

Hematoma

Symptom – Signs will include swelling and possible bleeding if a blood vessel has been pierced.
Response – Immediately remove the electrode and then compress and elevate the affected limb and apply ice to the affected region.
May require referral to a medical professional.

Vaso-vagal episode

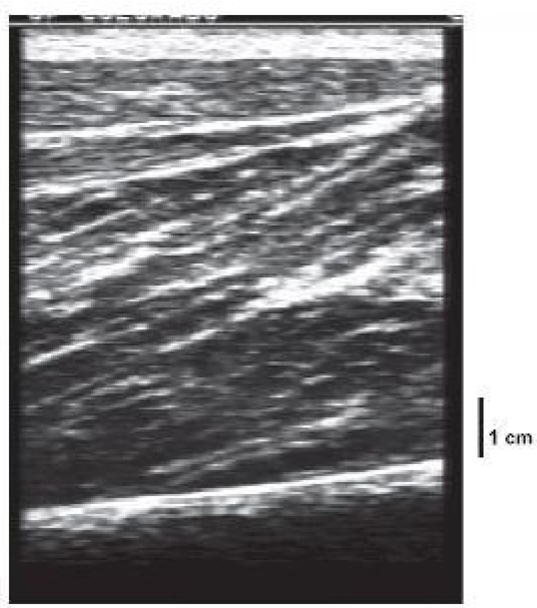
Symptom – Fainting
Response – Obtain assistance from another member of the laboratory. Assure the subject is free of any laboratory equipment and slowly lower them to a supine position on the floor.
When the subject responds, raise the legs by 20 – 30 cm and leave the person on the floor.
If the person is unconscious, loosen any restrictive clothing at the waist or neck. Loosen any restrictive clothing at the waist or neck. Do not give subject anything to eat or drink. Monitor the condition of the subject by checking the strength and regularity of the pulse. Allow the subject to remain on the ground as long as necessary and allow the person to gradually rise to a seated position and then to a standing position.
It may be necessary to escort the person home or to refer them to a medical professional.

In the event of a needle stick injury, report the incident immediately to your supervisor and to a medical professional who will determine what actions may be required.

Verification of electrode location

It is strongly recommended to verify the electrode location. In case of the fine wire technique, electromyographers can use functional tests, ultrasound images and stimulation through the implanted wires to verify electrode location. An appropriate specific muscle test can be used to ensure that the electrode is inserted into the correct muscle (e.g. external shoulder rotation for infraspinatus, leg extension for quadriceps muscles). Perform the contraction and watch for activity in the recording computer. If a more objective method to test electrode location is needed, the investigator may use ultrasonography.

A study by Rudroff et al., 2008 compared changes in intramuscular and surface recording of EMG amplitude in parallel with ultrasound measures of muscle architecture of the elbow flexor muscles during a submaximal contraction. A B-mode ultrasonographic apparatus (Sonolayer SSH0140A, Toshiba) with a 7.5-MHz linear-array probe (38-mm scanning length) was positioned on the skin to measure selected features of the muscle architecture: the thickness of the long head of the biceps brachii, brachialis, and brachioradialis muscles, and the pennation angle of the fascicles in brachialis (Figure 8). Minimal pressure was applied to the scanner against the skin so that deformation of the tissues was minimized. Landmarks were drawn on the skin overlying the muscles. The thickness of biceps brachii and brachialis was measured by placing the transducer on the anterior aspect of the arm in a sagittal plane and proximal to the crease of the elbow.



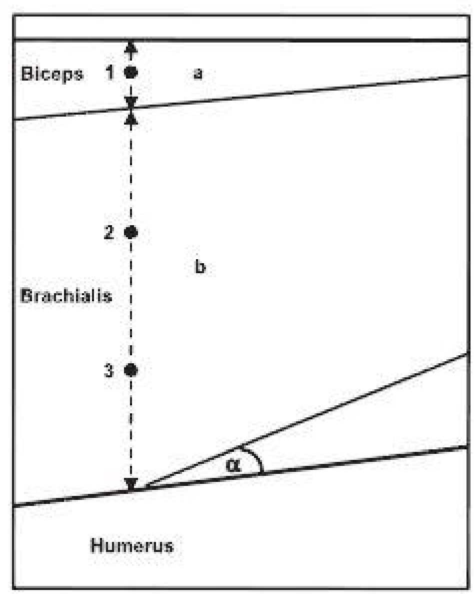


Fig. 8 Representative ultrasonography of intramuscular EMG depth. Ultrasound image (left) of the relaxed long head of biceps brachii and brachialis muscles with the transducer placed on the anterior aspect of the arm in a sagittal plane and proximal to the crease of the elbow. Right shows the parameters measured for each muscle: a:, thickness of the long head of biceps brachii; b, thickness of brachialis; α, pennation angle for fascicles in brachialis muscle.
Depth of the electrodes: 1 = 1/2a, 2 = 1/3b, 3 = 2/3b. Figure from Rudroff et al., 2008.

The transducer was moved slightly in a lateral direction to ensure a clear image of the muscle boundaries and the periosteal reflection from the humerus. Brachioradialis was measured by placing the transducer over the muscle belly just distal to the crease of the elbow joint and parallel to the longitudinal axis of the forearm. Two ultrasound measurements were made for brachialis: the thickness between the superficial border of the muscle and the humeral surface 2 cm from the left-hand edge of the image, and the angle of pennation between the most clearly visualized fascicle and its insertion into the humeral surface. The thickness of the long head of biceps brachii and brachioradialis muscles was determined as the distance between the lower and upper boundaries. The ultrasound analyses were made offline with digitizing software (Scion Image, National Institutes of Health). A disposable 25-gauge hypodermic needle was used to insert two stainless steel wires into the muscle bellies at an angle that was parallel to the ultrasound probe. The needle was removed after the wires reached a depth that was determined by the ultrasound measurements. The depths were 1/2 of the muscle cross-section for biceps brachii, and 1/3 and 2/3 of muscle thickness for brachialis (Figure 8) and brachioradialis. The latter was inserted ~3 cm distal from the elbow crease.

There are recommendations regarding verification of electrode location with ultrasonography for various muscles (Herbert et al., 1995; Hodges et al., 2003; Rudroff et al., 2008; Shi et al., 2006).

Another method to determine the location of the fine wire electrodes is the usage of stimulation through the implanted wires (Basmajian &DeLuca, 1985).

Muscle Maps

Deeper, smaller or overlaid muscles need a fine wire application to be safely and selectively detected and recorded. Most of the important limb and trunk muscles can be measureD by surface EMG electrodes. The following muscle maps show a selection of muscles that typically have been investigated in kinesiological studies.

Frontal View

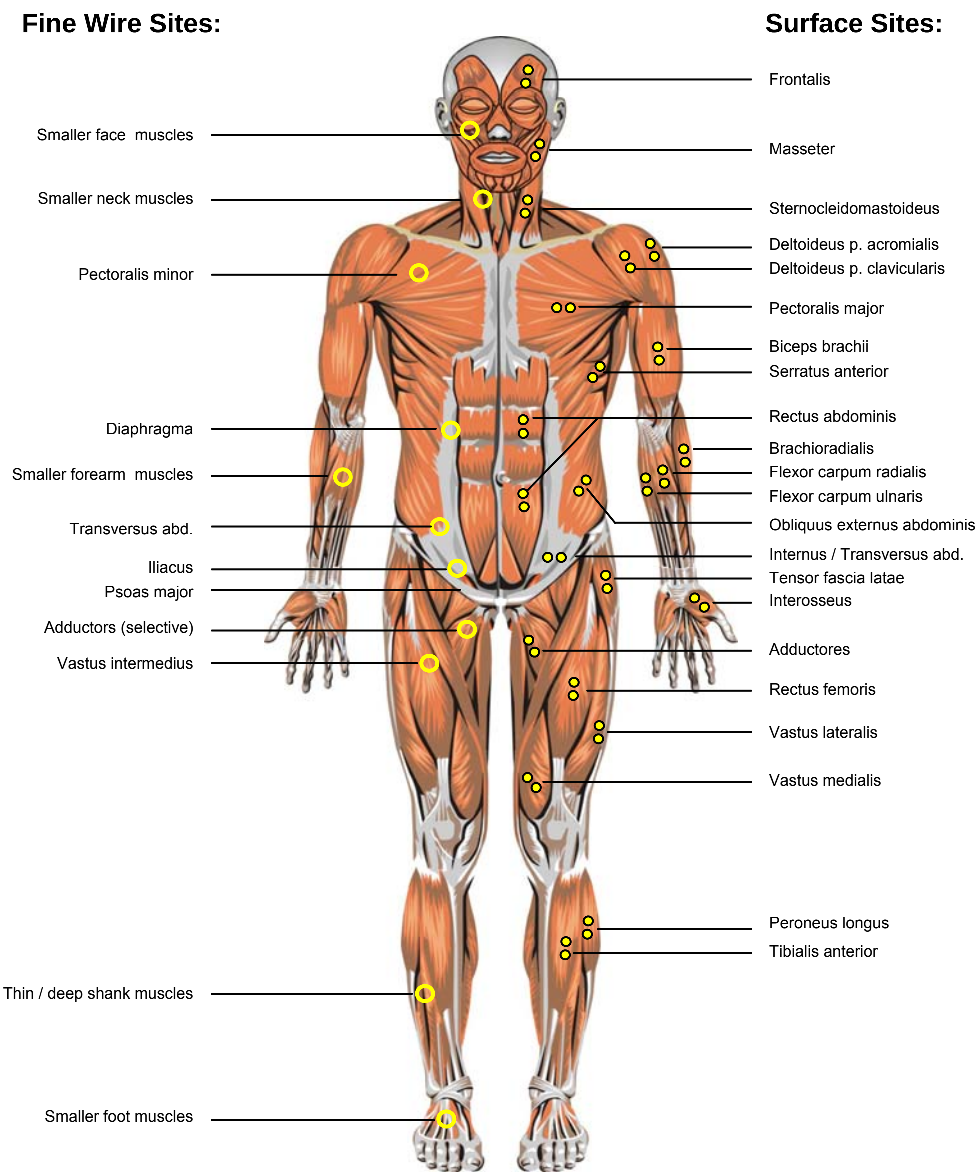


Fig. 9 Anatomical positions of selected electrode sites – frontal view. The left side indicates deep muscles and positions for fine wire electrodes; the right side for surface muscles and placements. *From ABC of EMG*

Dorsal View

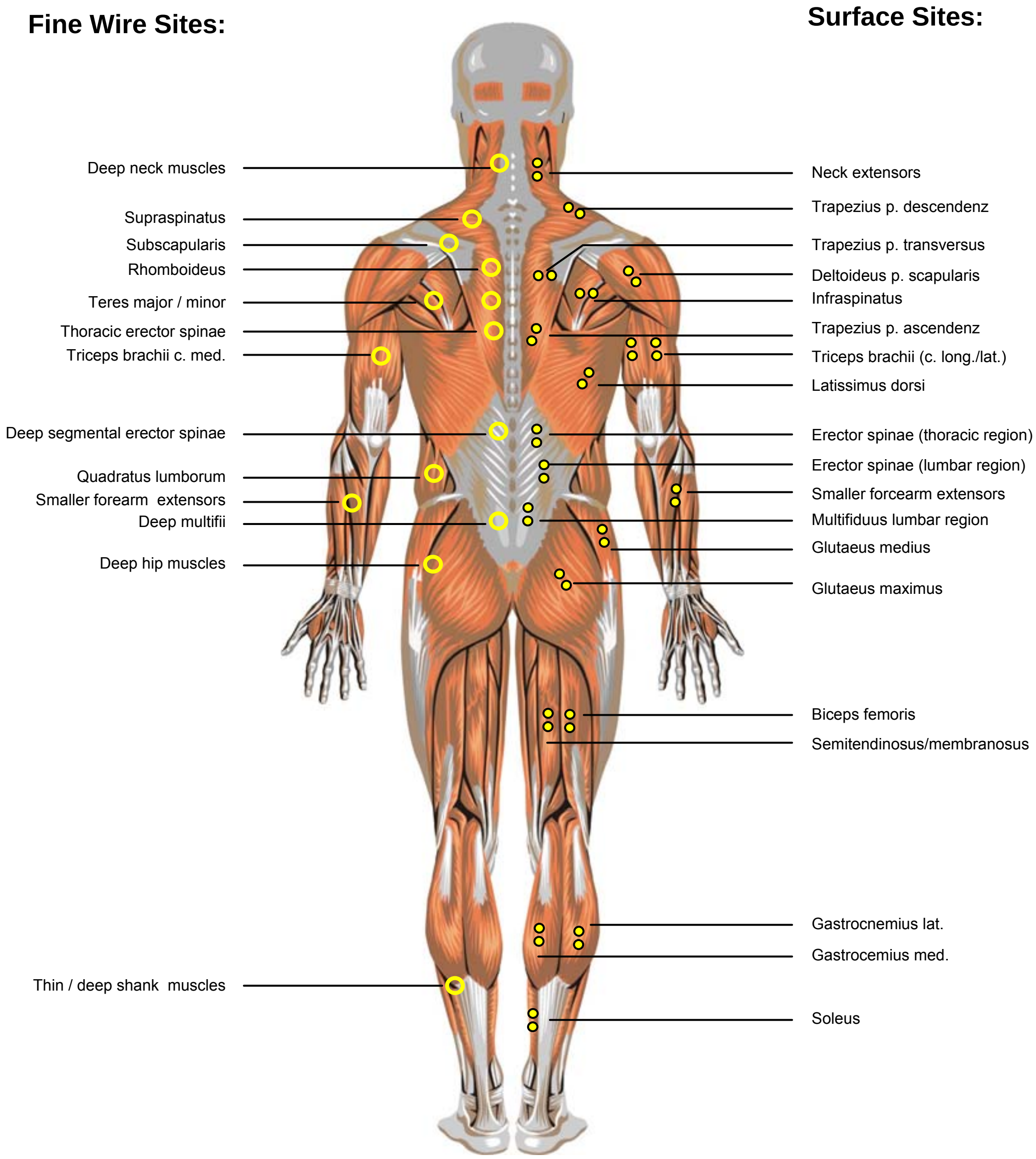


Fig. 10 Anatomical positions of selected electrode sites – dorsal view. The left side indicates deep muscles and positions for fine wire electrodes; the right side for surface muscles and placements. *From ABC of EMG*

Signal Detection problems

50 or 60 Hz Interference

EMG recordings can easily be contaminated by interfering 50 Hz (e.g. Europe) or 60 Hz (e.g.USA) power hum. Fine wire recordings have an increased sensitivity because of the unshielded wire endings. Noise artifacts are caused by leakage current generated from improperly grounded electrical devices, electric motors, power supplies or similar sources. Noise artifacts are conducted by metal frames, certain floor material and may increase if the subject gets too close or in direct contact with the conducting material.

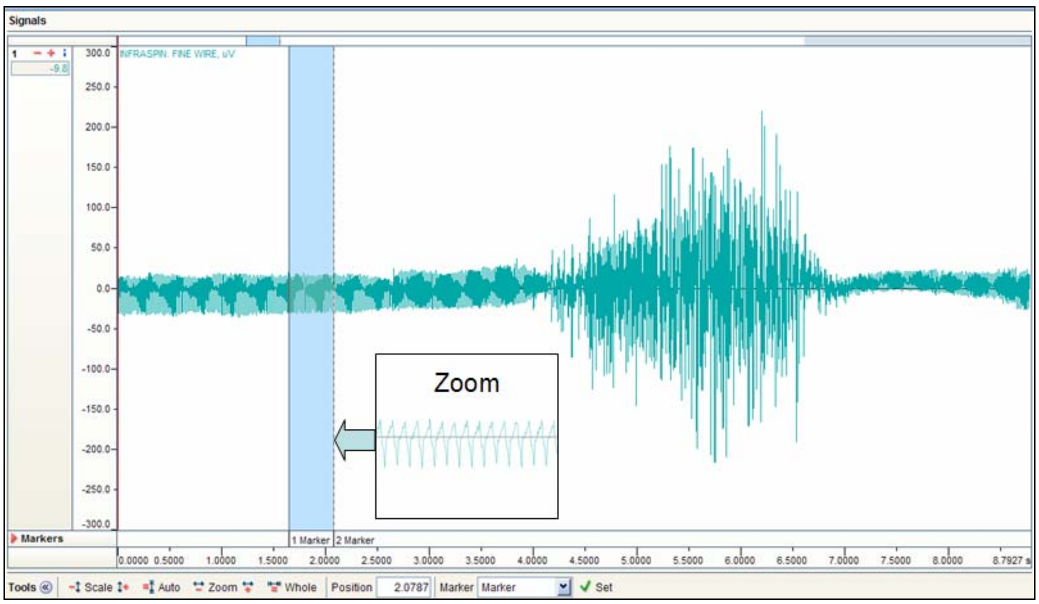


Fig. 11 60 Hz power hum artifact caused by an external “noisy” ultra-sound sonograph. The baseline noise level exceeds 15 to 20 uV

50/60 Hz noise can be visually identified by zooming in on the affected baseline and checking the repetitive sinoidal signal shape (see Zoom box in Fig. 11). A more objective verification is to apply a Fast Fourier Transformation to generate a Total Power Spectrum:

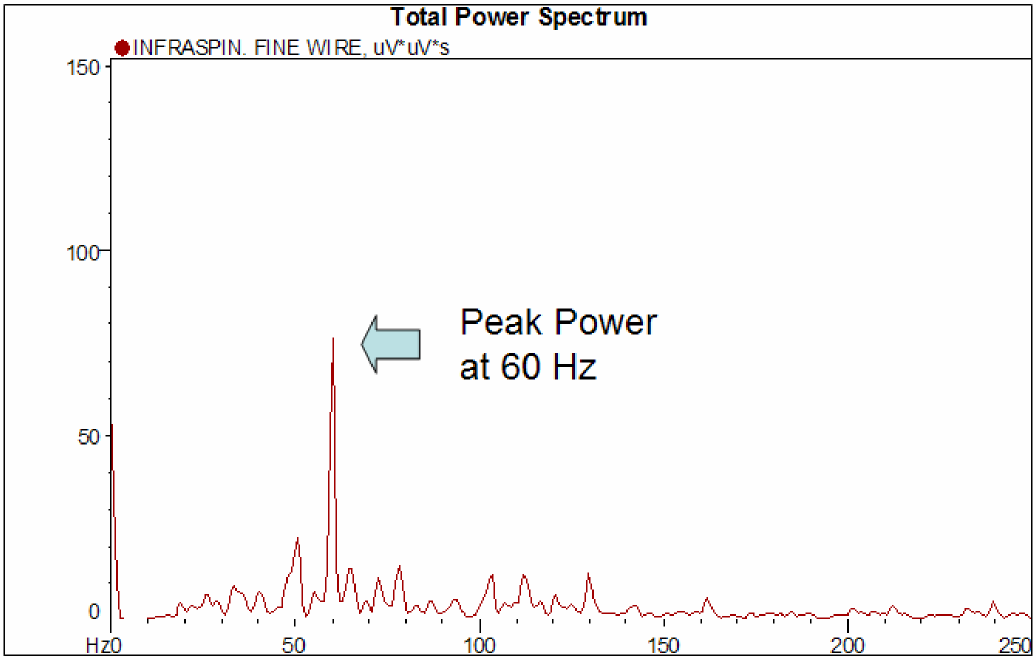


Fig. 12 Power spectrum of the zoomed area in the fine wire EMG trace shown in Fig. 8. Note the dominant sharp spike at 60 Hz

When this source of noise is present a sharp power peak can be seen at 50 or 60 Hz within the Total Power Spectrum.

Troubleshooting schemes for power hum interferences

When power hum is present, the first step is to find the source of the noise. It is generally recommended to avoid cable drums or power strip for all devices involved in the EMG recording. In many buildings, wall-outlets differ by their noise level. Outlets mounted directly to the wall are preferred. All unnecessary electrical devices should be turned off. The first preparatory step of any EMG recording is to verify the electronic noise is below the level that will interfere with the recording. Telemetry systems are much less sensitive to ground and leakage noise because they are battery operated and thus not directly connected to wall powered devices. Walking around the room to find “noisy” areas is one strategy. One can also touch all the devices nearby and check if the noise level increases. A common source of noise can be computer power supplies. Heavy machines like treadmills and/or devices with strong electric motors may interfere and should be checked as well. Often the problem with a given noisy device can be solved by adding a ground using copper wires. If the source of power leakage hum cannot be identified try to move away from noisy areas or consider recording in another location.

Faulty connections between fine wires and amplifier cables

The connection between the fine wire and adapter of the preamplifier is the most sensitive point, so must be carefully arranged. It is typically the first connection to troubleshoot. Special attention should be given to make sure the electrical connection is well arranged. A faulty connection may show an increased noise level, slow wave baseline deviations or no signals at all.

Gently pull the wire to check that it has stable connection with the adapter. Check that the conductive insulated ending of the wire has contact with the preamplifier. Any loose endings should not touch each other to avoid electrical shorts. A repositioning of wires may help with a persistent problem.

Cable or motion artifacts

In dynamic studies motion artifacts caused by wire or muscle belly shaking are an ongoing concern. They can cause sharp amplitude spikes or slow wave baseline shifts.

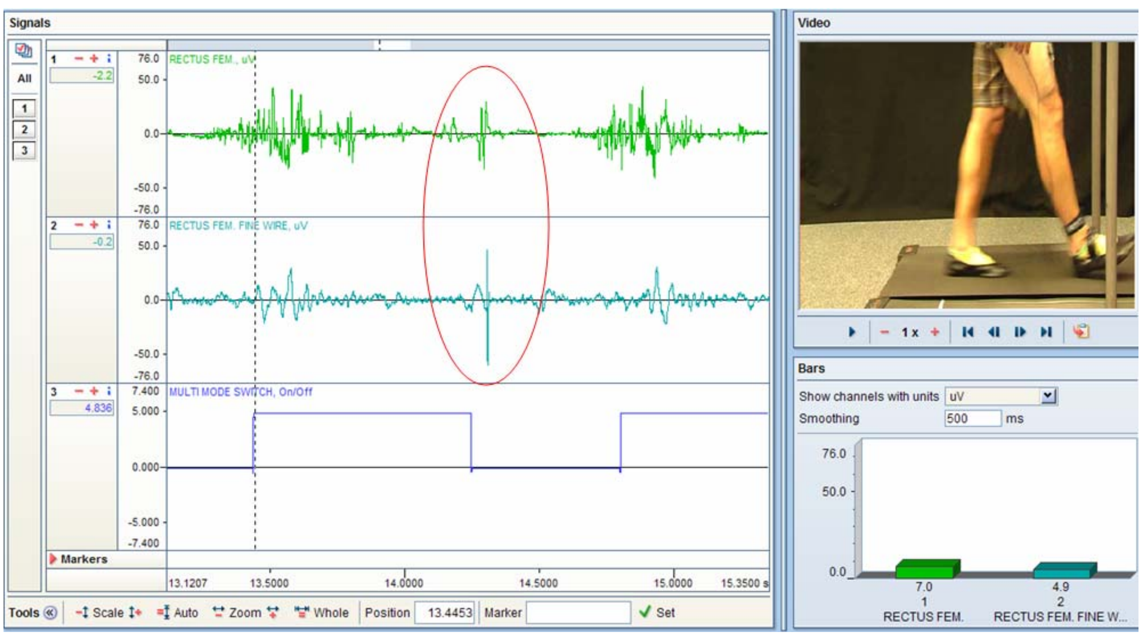


Fig. 13 Cable motion artifact in a walking trial (ch.1=SEMG Rectus Fem., ch. 2= fine wire EMG Rectus Fem., ch. 3= foot switch signal). The artifact appears right after heel strike and is visible both in surface and fine wire recording

Sharp spike artifacts have a repetitive nature related to the subjects motion cycle and are typically caused by wire shaking or changes in pressure near the electrode.

Fig. 14 Fine wire recording of Rectus Fem. (upper channel) in a treadmill walking trial. The cable motion artifact has repetitive nature directly related to the gait event (see foot switch signal – lower channel).

In many cases, the problem can be minimized by securing the patient cables tighter or using another method to attach them. Taping or repositioning the preamps can also help.

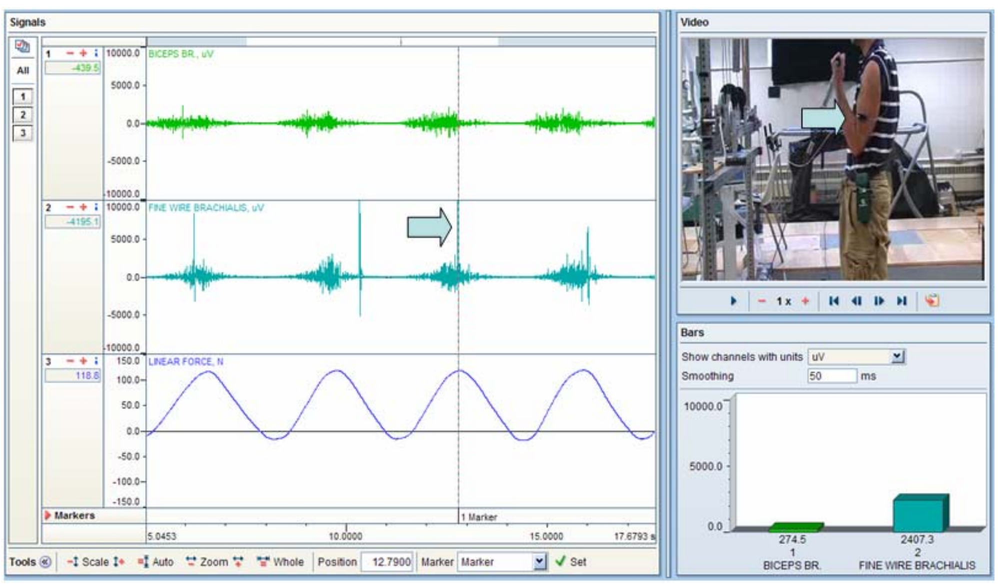


Fig. 15 Motion artifact due to cabling shaking on channel #2: The analysis of the time synchronized video recording (upper right image) reveals that in the end flexion the muscle belly touches the wires and causes an artifact spike on the fine wire Brachialis recording in ch. 2

Muscles can show considerable wobbling in dynamic activities. Changes in temporary volume conduction and geometrical wire ending arrangement cannot be avoided. These interfering temporary changes in local detection geometry are typically producing slow wave baseline shifts. The contraction process itself can temporarily change the position of the wires against each other, even in static contractions.

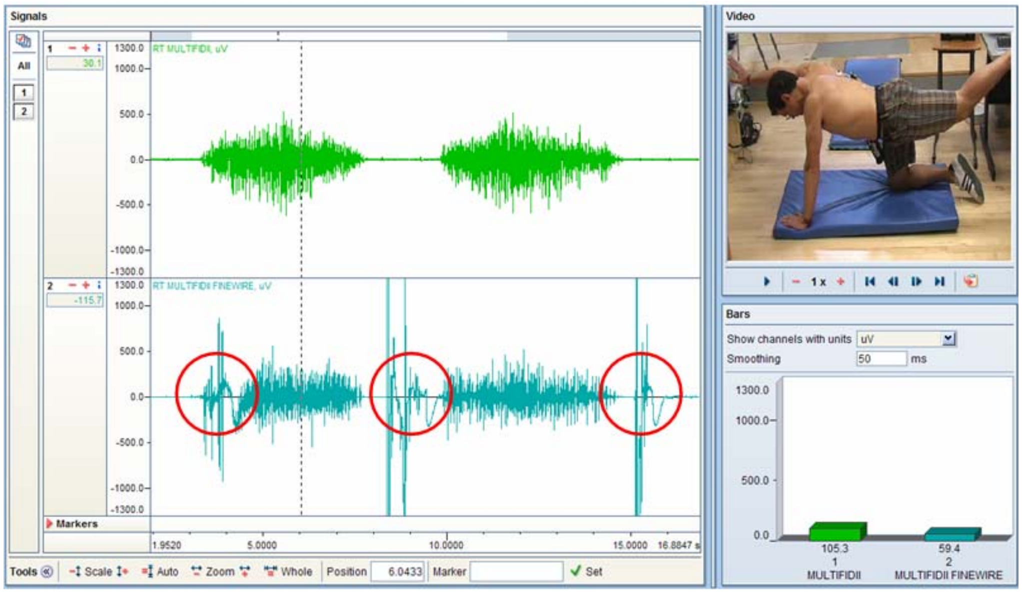


Fig. 16 Slow wave artifacts produced by internal motion/muscle tissue migration in semi static contraction in fine wire recording of multifidus (ch. 2). The parallel surface recording at the insertion position is not affected (ch. 1).The subject is performing a diagonal shoulder-hip extension/flexion cycle in quadruple position

In addition to carefully securing the wires, a temporary static maximal contraction or pulling the wires gently may help to minimize this problem:

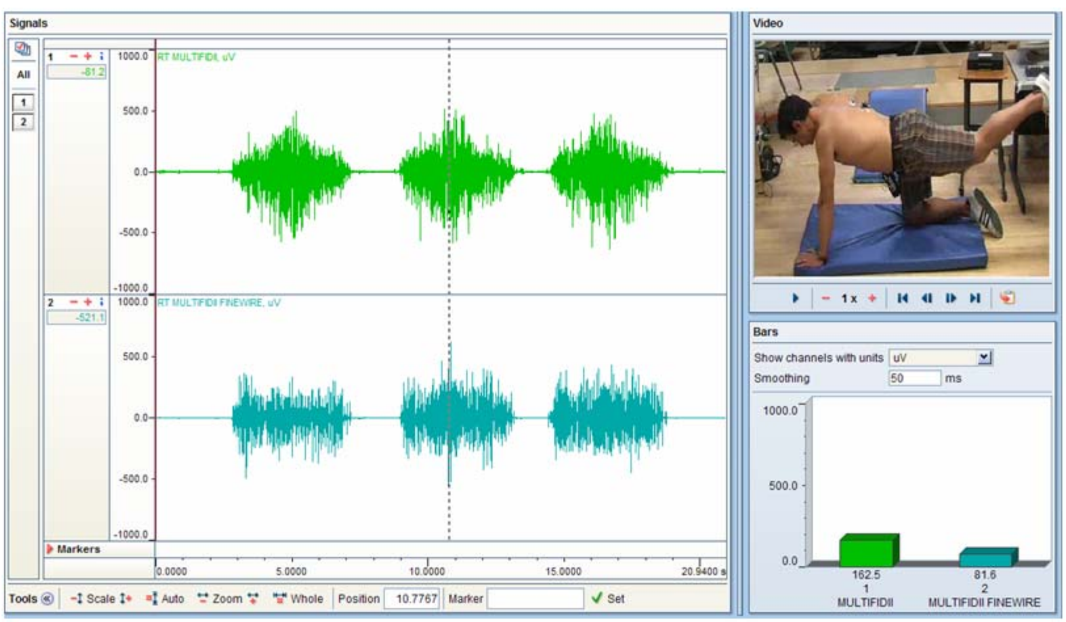


Fig. 17 Same exercise/recording as figure 13 but with rearranged wire positioning.

Shorted wire endings

The hooked wired endings of commercial fine wire electrodes are arranged so that a short direct contact between non-insulated wire endings rarely happens, but it cannot be completely avoided. This is a problem particularly over the course of a dynamic contraction series. In a situation where the contact between the wires and preamp adapter is checked and okay, a flat line signal may be caused by an electrical short between the wire endings in the muscle tissue.

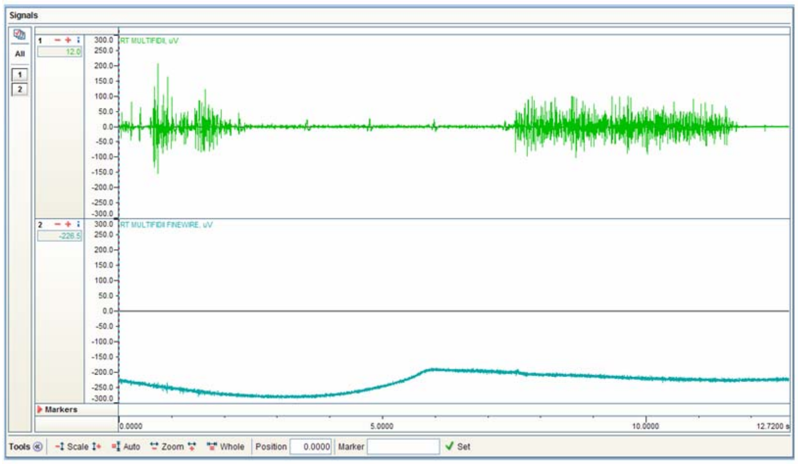


Fig. 18 An example of an electrical short during a fine wire recording (lower trace) of the multifidus during a static test contraction. The baseline is drifting away from zero and no amplitude innervation spikes are visible (Drifting Baseline.).

Interfering motor unit action potentials

Due to the very small pickup area of fine wires single motor unit action potentials (MUAPs) can be picked up and interfere with the recording:

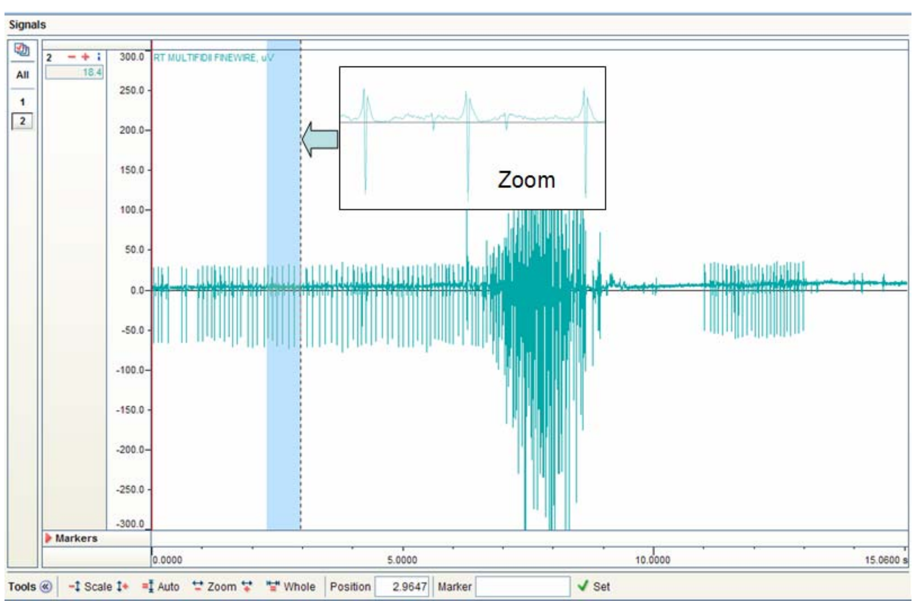


Fig. 19 A fine wire multifidus recording contaminated with MUAPs and shifting baseline during a static contraction.

This problem can be easily detected by zooming in on the raw signal and checking its rhythmic triphasic shape (see Zoom box). The only way to eliminate interfering MUAP recordings is to reposition the wire endings with a static max contraction or gently pulling on the wires.

Generalized troubleshooting scheme for fine wire recordings

- Check and establish the electrical environment in your lab prior to the main experiments
- Use easy muscle setups to test noise sources and conditions
- Find and eliminate 50/60 Hz noise sources and areas of increased current leakage
- Switch off all unnecessary wall powered devices
- Avoid the use of cable drums and faulty power strips
- Check the power supply of all involved devices (e.g. laptop power supply)
- Arrange additional grounding of heavy machines and devices with strong electro-motors
- Carefully check the electrical contact between the fine wires and preamplifier adapter
- Perform a maximum contraction to reposition the wires in the muscle belly
- Gently pull on the wires to reposition them
- If artifact problems persist, consider a new insertion point

Signal Processing of fine wire EMG recordings

To quantify fine wire recordings, it is recommended to apply certain signal processing steps to minimize the effect of artifacts and increase the reliability of the data. The most common steps are summarized in figure 20 and include highpass filtering at 10 or 20 Hz, rectification and smoothing.

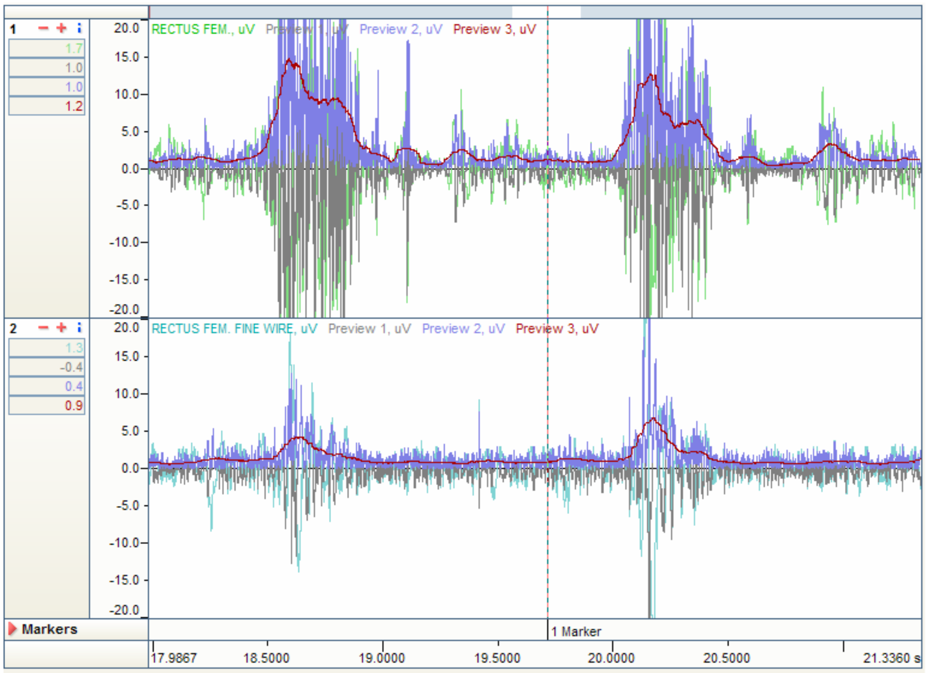


Fig. 20 Bandpass filtered (20Hz high-pass), full wave rectified and smoothed (RMS100) EMG signal (red curve), shown in a processing overlay scheme based on raw data (blue-grey curve).

A short introduction of signal processing methods and strategies are presented in the following chapter. Please also refer to the chapter Signal Processing in the ABC of EMG booklet.

Digital filtering 1: Highpass Filtering

If it is needed, digital filtering is always applied prior to any other signal processing method. Digital filtering should be used with care because it automatically causes loss of signal information. Nevertheless, for dynamic studies involving amplitude analysis it is generally recommended to apply a 10 or 20 Hz highpass filter. This will help to stabilize slow wave baseline shifts and will automatically correct any DC shift of the zero line in raw EMG recordings. Due to the huge benefit of a stable and correctly positioned baseline, the amplitude related signal loss is of minor importance and will only marginally affect the data integrity.

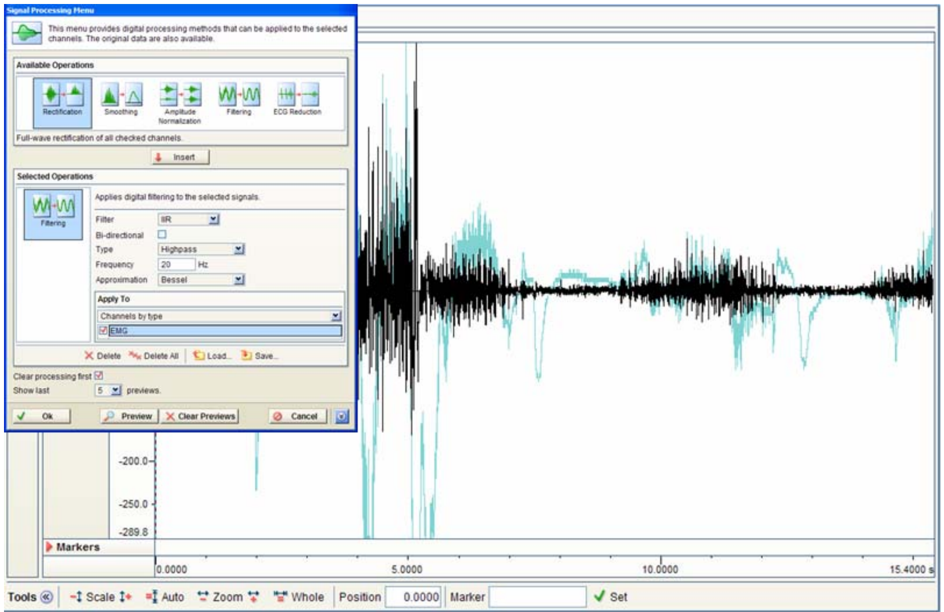


Fig. 21 20 Hz Highpass filtering (black curve) applied to a raw Fine wire recording (blue curve) with heavy baseline shifts in a static multifidus contraction: the IIR Bessel filter corrects any slow wave shift

Digital filtering 2: Notch Filtering

Notch filters cancel out certain frequency contents of the signal, e.g. 50/60 Hz artifact cycles:

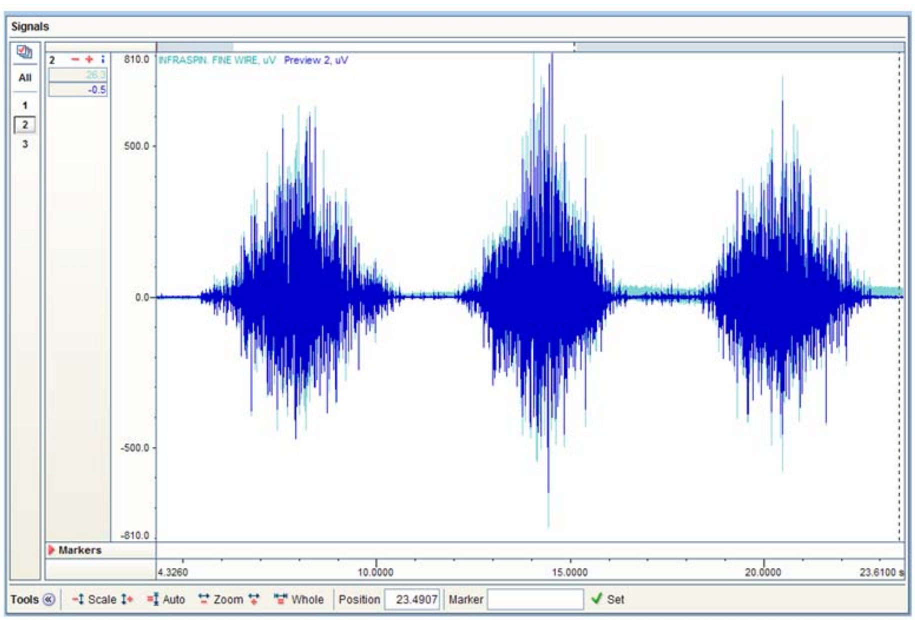


Fig. 22 The original raw curve is shown in green color, the dark blue curve is notch filtered at 60 and 120 Hz. Note the reduction in baseline noise between contractions

The notch filter can help correct records contaminated with power hum. The signal loss is acceptable for amplitude oriented analysis. In general, EMG recordings should have a signal loss due to filtering of less than 10% (see below) of the unfiltered signal magnitude.

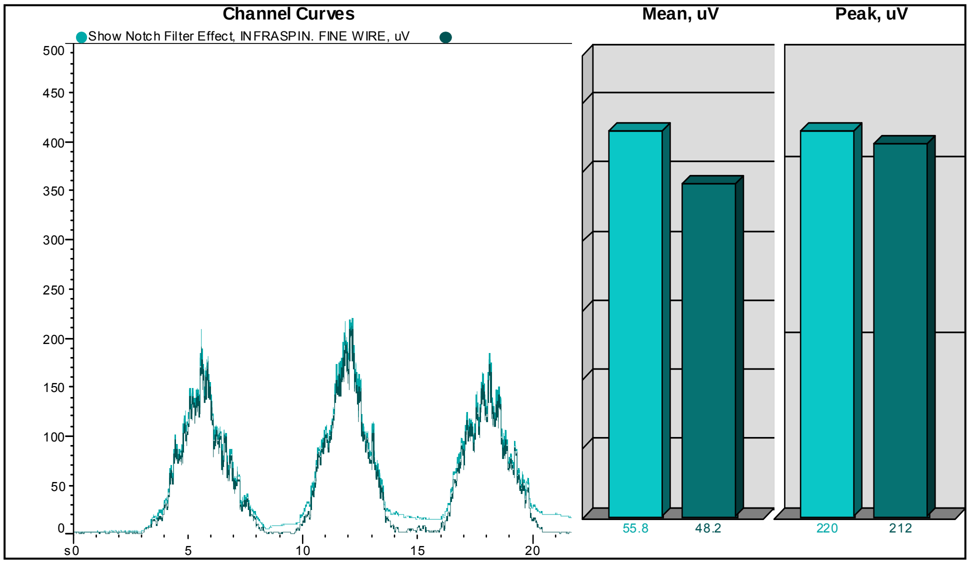


Fig. 23 Highpass filtered and RMS smoothed fine wire EMG recording of infraspinatus contractions as shown in Fig. 22. Dark green is the notch filtered curve, light green is the same signal prior to filtering.

When notch filtering is employed, active EMG bursts will be reduced slightly, but the main effect is to remove the noise from baseline signals. While the amplitude may be slightly reduced, the shape of the rectified smoothed and averaged signal is very close to that of the unfiltered signal.

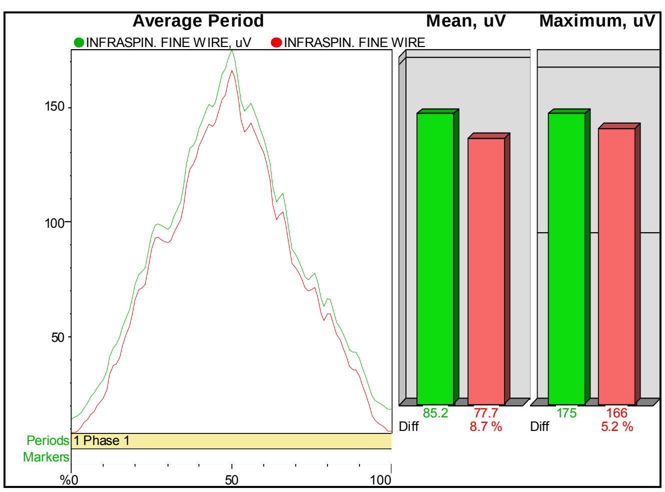


Fig. 24 The three EMG bursts shown in figure 23 are rectified, smoothed and averaged in a time normalized cycle. Green is the un-notched curve, red the notch-filtered curve. Note the similarity between the curves.

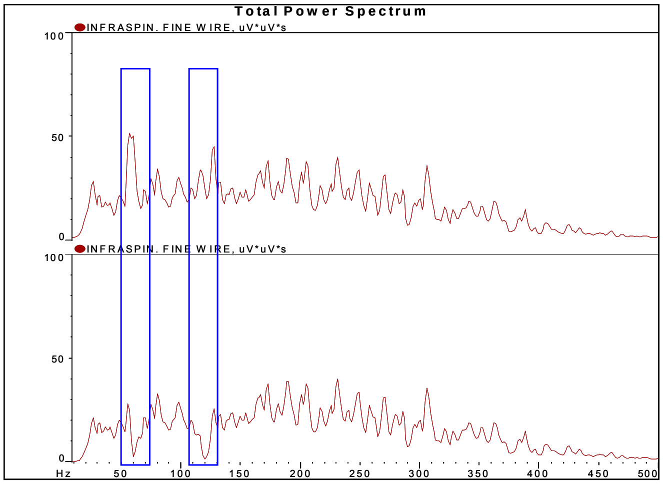


Fig. 25 FFT based power spectrum analysis of the un-notched (upper curve) and notch-filtered curve (lower curve). The blue rectangles indicate the notched frequencies of 60 and 120 Hz. Note the gaps in the notched power spectrums at the notch frequency

For EMG investigations using frequency analysis parameters, notch filtering should not be used because signal energy loss of up to 35% can occur (see Fig. 25).

Because of the increased probability to catch power hum artifacts during fine wire recordings, notch filtering can be used to “save” and fit data, but care should be taken to find the correct ratio between signal fitting and signal distortion. It is strongly recommended to avoid sources of power hum before data collection rather than trying to filter them out of a poor signal. Methods for this were described previously.

Rectification and Smoothing

Rectification and smoothing are standard processes for almost all EMG analysis. Rectification is needed to process standard amplitude values like mean amplitude or area, and smoothing is applied to eliminate the non-reproducible spikes within the EMG signal. Smoothing can be done with mathematical algorithms like moving average or root mean square (RMS). If the latter is applied, the signal is called RMS EMG.

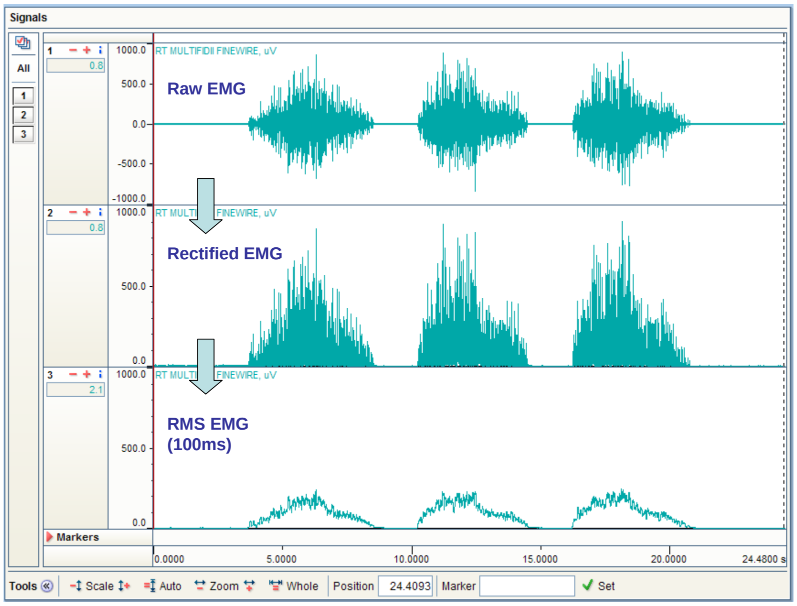


Fig. 26 Based on the raw signal (upper trace) the signal is first full wave rectified (middle trace) and finally smoothed with a RMS algorithm

To some degree, smoothing can eliminate the effects of cable shaking artifacts:

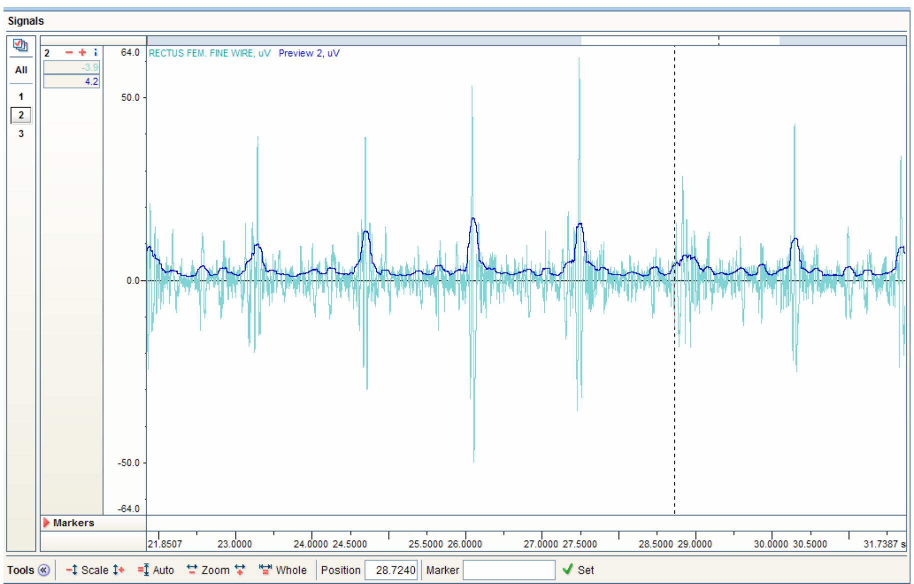


Fig. 27 Smoothed and rectified (RMS 100ms) fine wire EMG signal of the Rectus Fem. during gait analysis. The cable artifact (as described in Fig. 13) is nearly eliminated through the smoothing algorithms, which by its nature only follows the mean innervation trend within the signal

Amplitude Normalization

Any EMG recording is based on a unique detection condition which cannot be precisely reproduced. Therefore, the absolute values obtained cannot be compared across subject or for the same subject across different sessions. One benefit of fine wire recording is that it bypasses the effects of skin and tissue filtering between electrodes and muscles. However, the precise position and distance between the fine wire electrodes can significantly vary and care must be taken to directly compare two raw recordings by means of their absolute microvolt values.

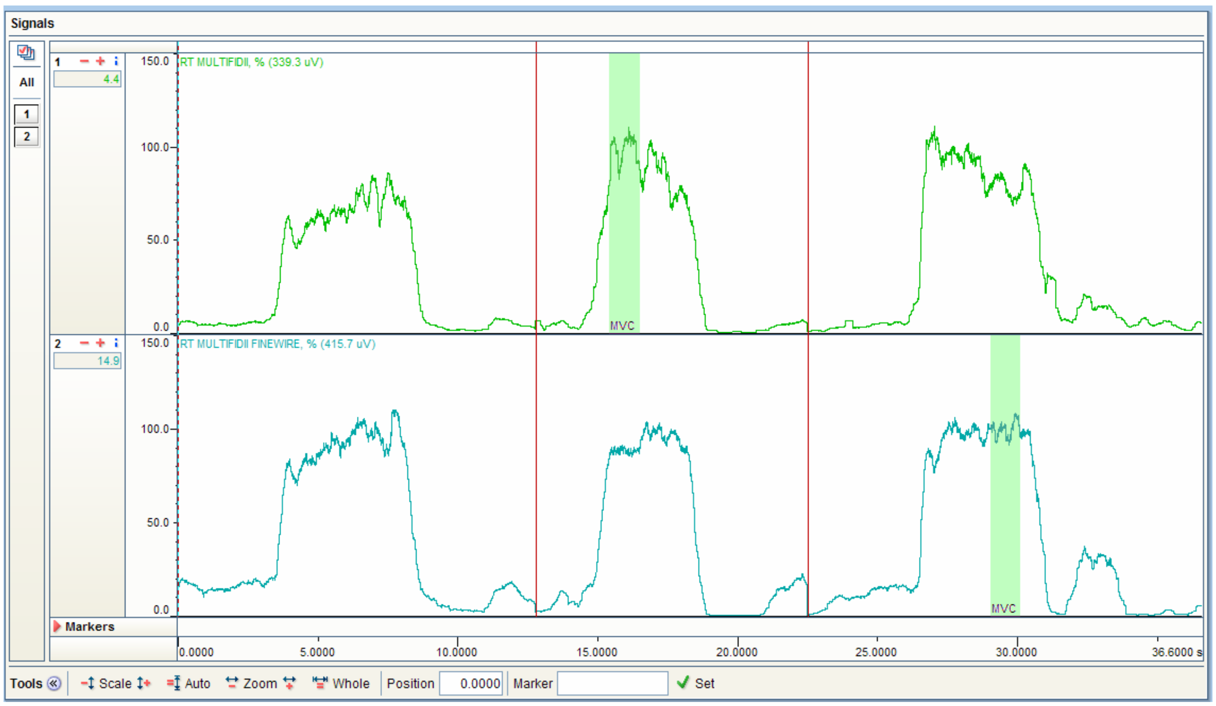


Fig. 28 MVC (Maximal Voluntary Contraction) test for 2 muscles (multifidus SEMG and fine wire) in a static, secured prone lying position. The MVC trial is performed 3 times, with pausing of 30 sec. between trials. The green areas indicate the signal portion of highest EMG level for each channel. The mean value of this interval (500ms) is defined as the MVC reference value.

For healthy subjects, varying anatomical detection conditions can be eliminated by a biological calibration of the microvolt data to reference value. This reference value can be the mean or peak amplitude value of a given trial or the highest activity level for those muscles during a maximal voluntary contraction (MVC). This procedure is typically called MVC-normalization and is measured in separate static tests. The original microvolt data of all trials are expressed as a percentage of the highest innervation level (%MVC). This procedure allows a direct comparison of EMG data between muscle sites and subjects. The other benefit is that MVC data provide information about the neuromuscular fatigue level for those muscles during a particular activity (e.g. “the muscles fire with 35% of its MVC maximum”). MVC normalization requires healthy subjects to perform a true maximum muscular effort in order to obtain representative data. For more information, please refer to the chapter entitled “Normalization” in the ABC of EMG booklet.

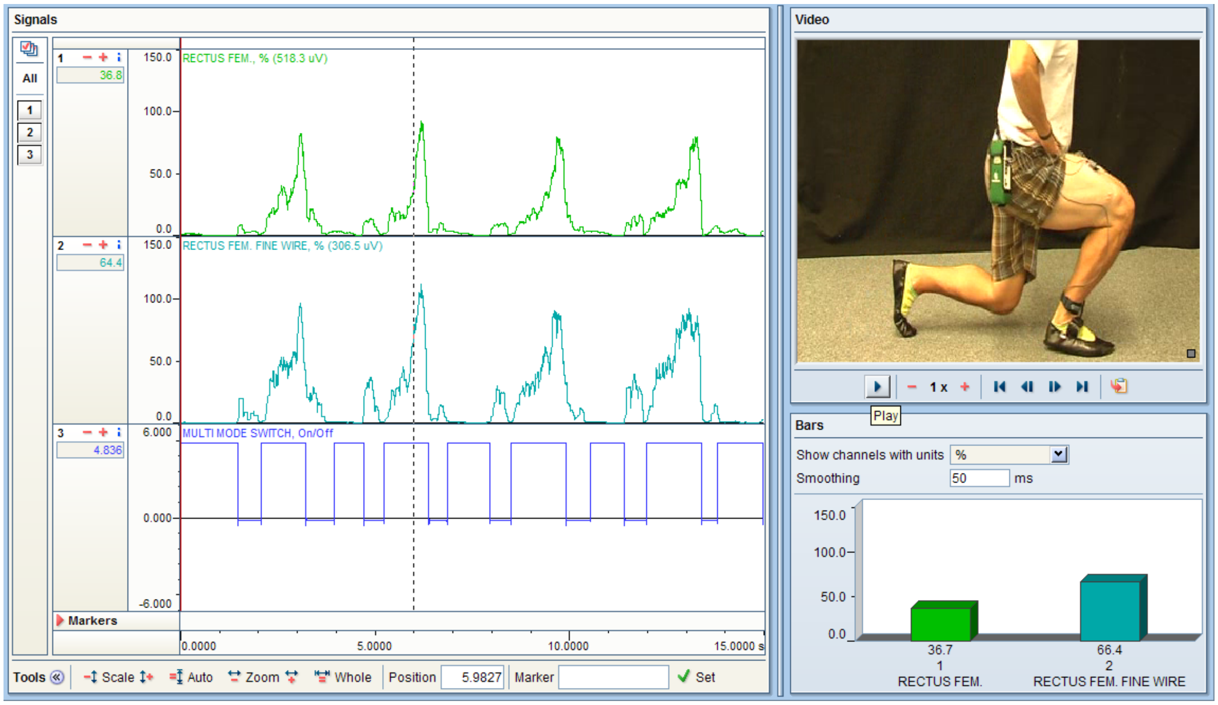


Fig. 29 Example of MVC normalized activity: the subject is stepping back and forth with his right leg. Surface (channel 1) and fine wire recording (channel 2) of the rectus femoris and a foot switch signal (channel 3) were recorded for a sequence of four repetition cycles.

Averaging in time-normalized repetition cycles

Averaging is the preferred method to normalize the unavoidable variability of EMG patterns within repetitive motion cycles (see Fig. 29) Since any repetitive exercise differs in duration between repetitions, time normalization of 100% percent of the motion cycle can be applied. The data are expressed as a vector with a resolution of 100 data points, thus it doesn't matter how long the original repetition lasted. Averaging requires a motion trigger to determine the start and end points, points of return (e.g. flexion to extension) or gait events (heel strike, toe off), which can be accomplished by using foot switches, goniometers, inclinometers or time-synchronized DV video at a minimum of 50 fps.

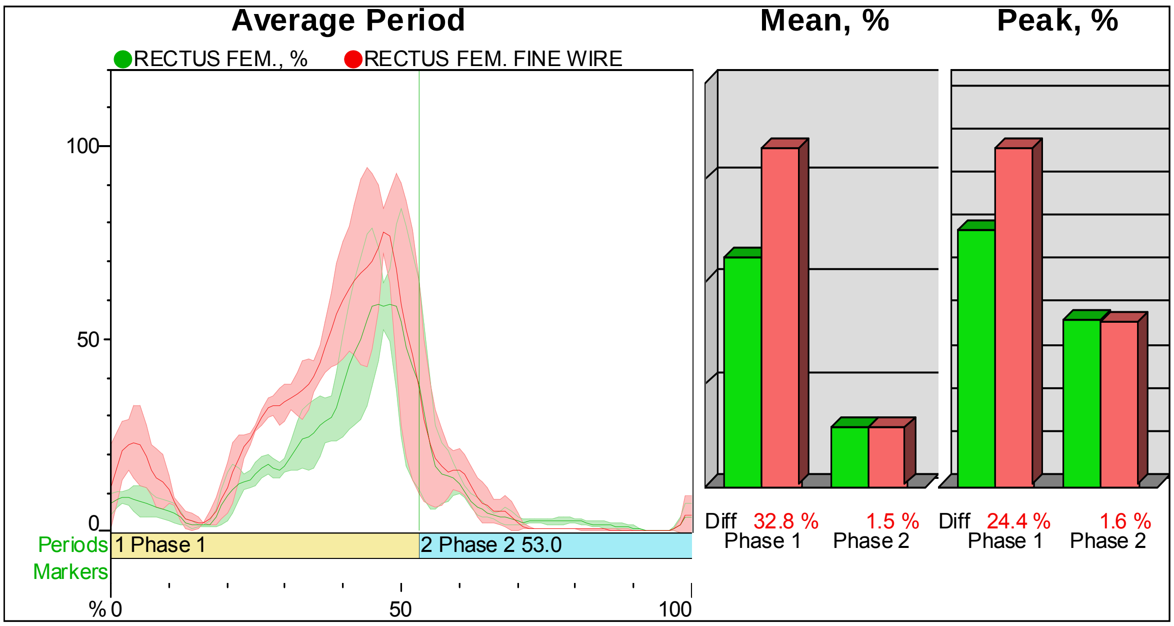


Fig. 30 MVC and time-normalized average activation pattern of the forward-backward step motion. The averaged curves of 4 repetitions +/- 1 standard deviation (shaded area) are shown in the step forward (yellow) and step backwards (blue) phase. The data show a direct comparison of SEMG (green curve) and fine wire (red curve) recording of the Rectus Fem. in the step exercise of fig. 29.

Examples of fine wire EMG recordings

Brachialis

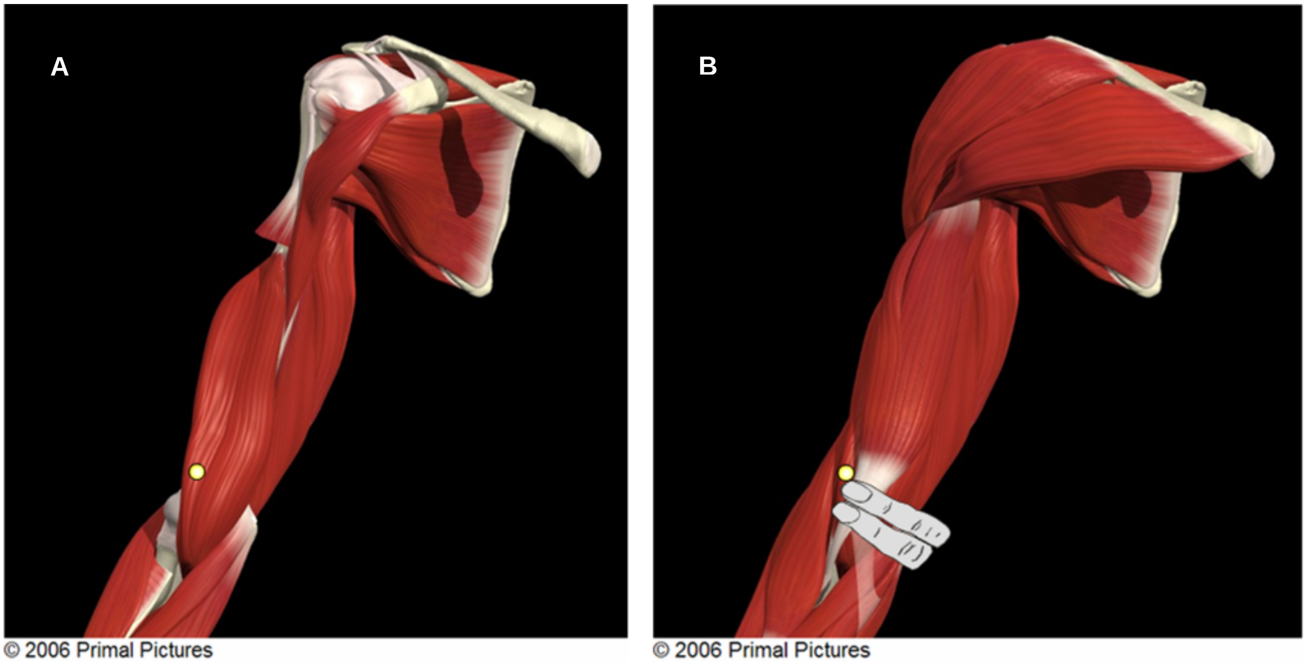


Fig. 31 A. Location of needle insertion into brachialis, **B.** View of brachialis after removal of biceps brachii

The **brachialis** muscle is a muscle in the upper arm that flexes the elbow joint. It lies just below the biceps brachii.

Proximal attachment: Distal half of the anterior aspect of the humerus

Distal attachment: Tuberosity and coronoid process of the ulna.

Innervation: Musculocutaneus nerve (C5, 6)

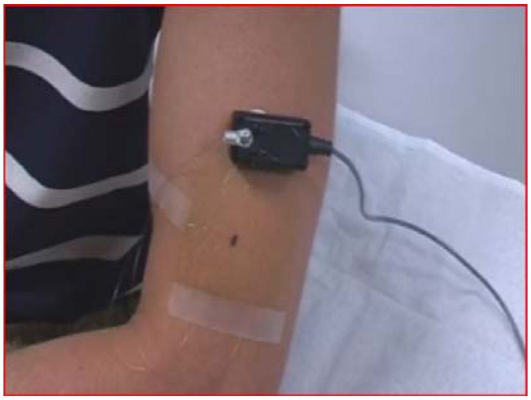
Blood supply: Muscular branches from the brachial artery and the radial recurrent artery from the radial artery.

Action: Flexion of the forearm at the elbow. Agonists: biceps brachii and Brachioradialis; Antagonist: triceps brachii (long, lateral, and medial heads) and anconeus.

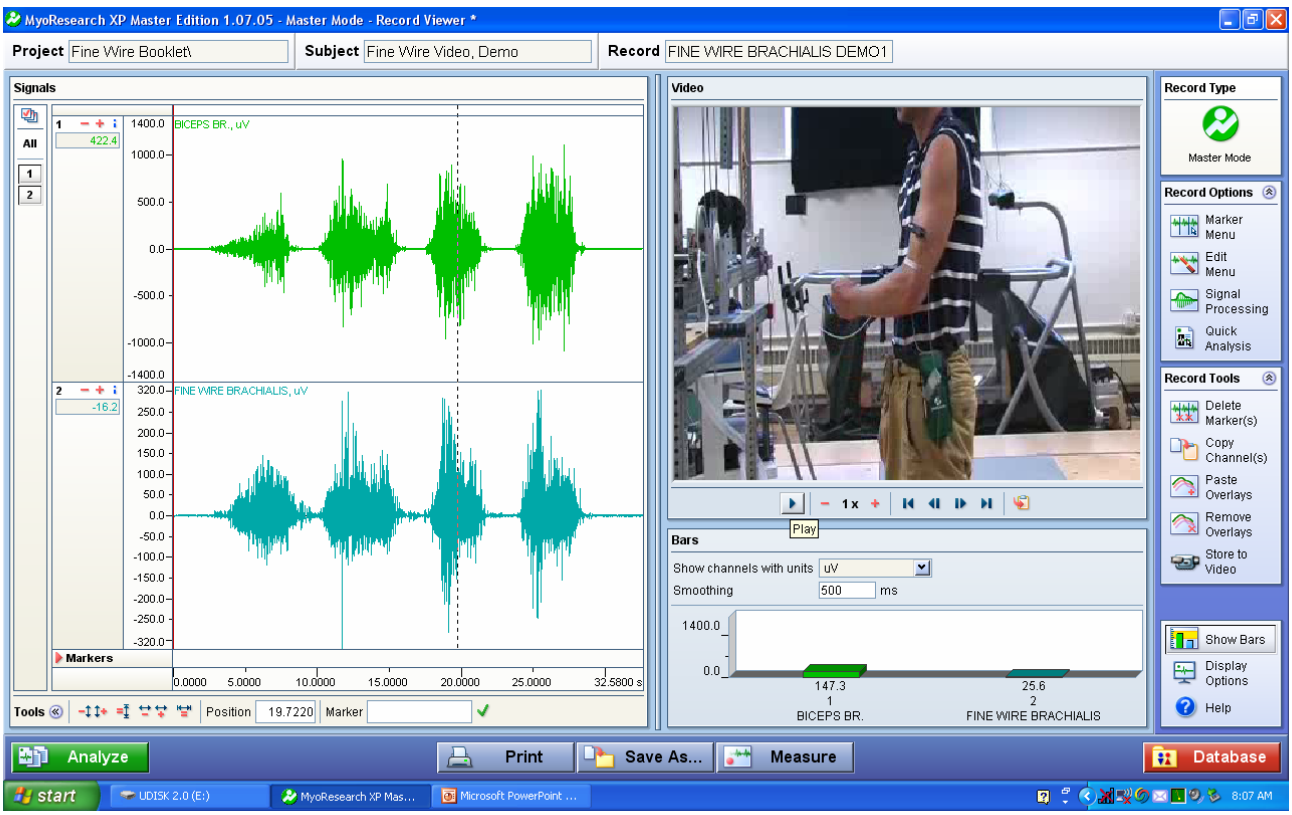
Electrode insertion: Insert electrode two finger widths proximal to elbow groove along and just lateral to the tendon and the bulk of the biceps brachii.

Pitfalls: If the needle electrode is inserted too medially, it will be in the biceps.

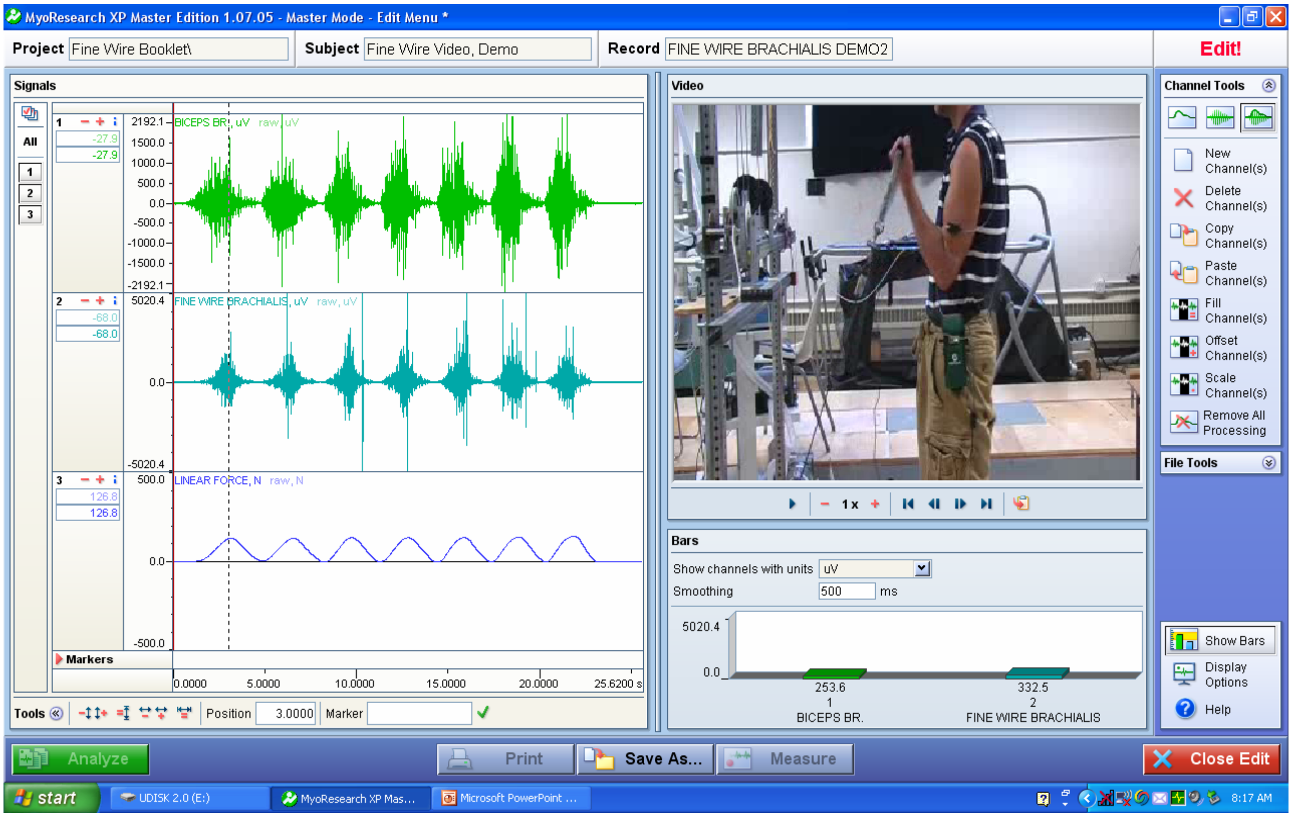
Functional test: Elbow flexion with the forearm pronated.



Subject with fine wires in brachialis muscle (left). Surface EMG electrodes are placed over the short head of the biceps brachii (right).



Subject performs elbow flexion. Channel 1 shows surface EMG activity; Channel 2 fine wire EMG activity. The bars on the lower right indicate the EMG values at each time point of the motion.



Subject performs elbow flexion. Channel 1 shows surface EMG activity; Channel 2 fine wire EMG activity, and the bottom trace the force output measured by a force transducer attached to the cable. The bars on the lower right indicate the EMG values at each time point of the motion.

Suggested Readings

Herbert RD, Gandevia SC. Changes in pennation with joint angle and muscle torque: in vivo measurements in human brachialis muscle. *J Physiol* 484: 523-532, 1995.

Rudroff T, Staudenmann D, Enoka RM. Electromyographic measures of muscle activation and changes in muscle architecture of human elbow flexors during fatiguing contractions. *J Appl Physiol* 104: 1720-1726, 2008.

Rudroff T, Christou EA, Poston B, Bojsen-Møller J, Enoka RM. Time to failure of a sustained contraction is predicted by target torque and initial electromyographic bursts in elbow flexor muscles. *Muscle Nerve* 35: 657-666, 2007b.

First Dorsal Interosseus (FDI)

Fig. 32 Location of needle insertion into FDI

Proximal attachment: Each by two heads, to the adjacent sides of the metacarpals in each interspace. The first lying between the first and second metacarpals.

Distal attachment: Base of the proximal phalanx and the ipsilateral band of the extensor apparatus. The first dorsal interosseus attaches to the radial side of the thumb.

Innervation: Palmar branch of the ulnar nerve (C8, T1)

Blood supply: Deep palmar arch of the radial artery.

Action: Flexion of the first digit at the metacarpophalangeal joints. Agonists: palmar interossei, lumbricals, flexor digiti minimi, flexor digitorum profundus; Antagonists: extensor digitorum, extensor indicis, and extensor digiti minimi.

Electrode insertion: Insert needle radial to second metacarpal

Pitfalls: If the needle electrode is inserted too deeply it will be in the adductor pollicis.

Functional test: Abduction of the index finger

Suggested Readings

Christou EA, Poston B, Enoka JA, Enoka RM. Different neural adjustments improve endpoint accuracy with practice in young and old adults. *J Neurophysiol* 97: 3340-3350, 2007.

Maluf KS, Shinohara M, Stephenson JL, Enoka RM. Muscle activation and time to task failure differ with load type and contraction intensity for a human hand muscle. *Exp Brain Res* 167: 165-177, 2005.

Poston B, Enoka JA, Enoka RM. Endpoint accuracy for a small and a large hand muscle in young and old adults during rapid, goal-directed isometric contractions. *Exp Brain Res* 187: 373-385, 2008.

Abductor pollicis brevis

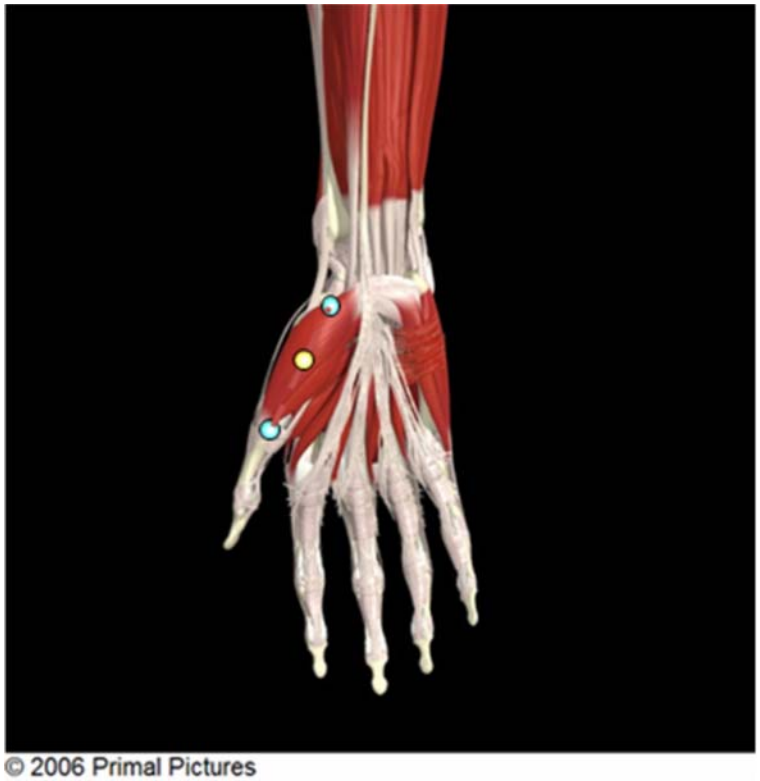


Fig. 33 Location of needle insertion into abductor pollicis brevis

The **abductor pollicis brevis** is a muscle in the hand that functions as an abductor of the thumb.

Proximal attachment: Distal border of the flexor retinaculum.

Distal attachment: Lateral aspect of the base of the proximal phalanx of the thumb and, occasionally, a slip to the extensor apparatus of the thumb.

Innervation: Recurrent branch of the median nerve (C8, T1).

Blood supply: Superficial palmar branches of the radial artery.

Action: Palmar abduction of the thumb at the trapeziometacarpal joint. Agonist: none; Antagonist: adductor pollicis.

Electrode insertion: Midpoint of a line drawn between the volar aspect of the first metacarpophalangeal joint and the carpometacarpal joint. Insert to depth of one-fourth to one-half inch.

Pitfalls: If the needle electrode is inserted too deeply it will be in the opponens pollicis.

Functional test: Palmar abduction of the thumb.

Suggested Readings

Van Oudenaarde E, Oostendorp RA. Functional relationship between the abductor pollicis longus and abductor pollicis brevis muscles: an EMG analysis. J Anat 186, 509-515,1995.

Extensor Carpi Radialis Brevis

Fig. 34 Location of needle insertion into extensor carpi radialis brevis

The **extensor carpi radialis** brevis is shorter and thicker than the longus, which lies beneath.

Proximal attachment: Lateral epicondyle of the humerus via the common extensor tendon and the radial collateral ligament of the elbow.

Distal attachment: Dorsal surface of the base of the third metacarpal.

Innervation: Radial nerve, posterior cord, posterior division, upper and middle trunk (C6, C7).

Blood supply: Radial recurrent artery from the radial artery.

Action: Extension of the wrist. Agonists: extensor carpi radialis longus and extensor carpi ulnaris; Antagonists: flexor carpi radialis, palmaris longus, and flexor carpi ulnaris.

Electrode insertion: Insert two finger widths distal to lateral epicondyle.

Functional test: Wrist extension and radial deviation.

Suggested Readings

Chae J, Knutson J, Hart R, Fang ZP. Selectivity and sensitivity of intramuscular and trancutaneous electromyography electrodes. *Am J Phys Med Rehabil* 80: 374-379, 2001.

Finsen L, Søgaard K, Graven-Nielsen T, Christensen H. Activity patterns of wrist extensor muscles during wrist extensions and deviations. *Muscle Nerve* 31: 242-251, 2005.

Riek S, Carson RG, Wright A. A new technique for the selective recording of extensor carpi radialis longus and brevis EMG. *J Electromyogr Kinesiol* 10: 249-253, 2000.

Flexor Carpi Radialis

Fig. 35 Location of needle insertion into flexor carp radialis

The **flexor carpi radialis** is a muscle of the forearm that acts to flex and abduct the hand.

Proximal attachment: Medial epicondyle of the humerus via the common flexor tendon.

Distal attachment: Base of the second and, occasionally, the third metacarpal.

Innervation: Radial nerve, posterior cord, posterior division, upper and middle trunk (C6, C7).

Blood supply: Muscular branches of the radial artery.

Action: Flexion of the wrist. Agonists: palmares longus and flexor carpi ulnaris; Antagonists: extensor carpi radialis longus, extensor carpi radialis brevis, and extensor carpi ulnaris.

Electrode insertion: Three to four finger widths distal to the midpoint of a line connecting the medial epicindyle and biceps tendon.

Functional test: Flexion of wrist with radial deviation.

Suggested Readings

Alizadehkhaiyat O, Fisher AC, Kemp GJ, Frostik SP. Strength and fatigability of selected muscles in upper limb: Assessing muscle imbalance relevant to tennis elbow. J Elelectromyogr Kinesiol 17: 428-436, 2007.

Calancie C, Bawa P. Voluntary and reflexive recruitment of flexor carpi radialis motor units in humans. J Neurophysiol 53, 1194-1200, 1985.

Infraspinatus

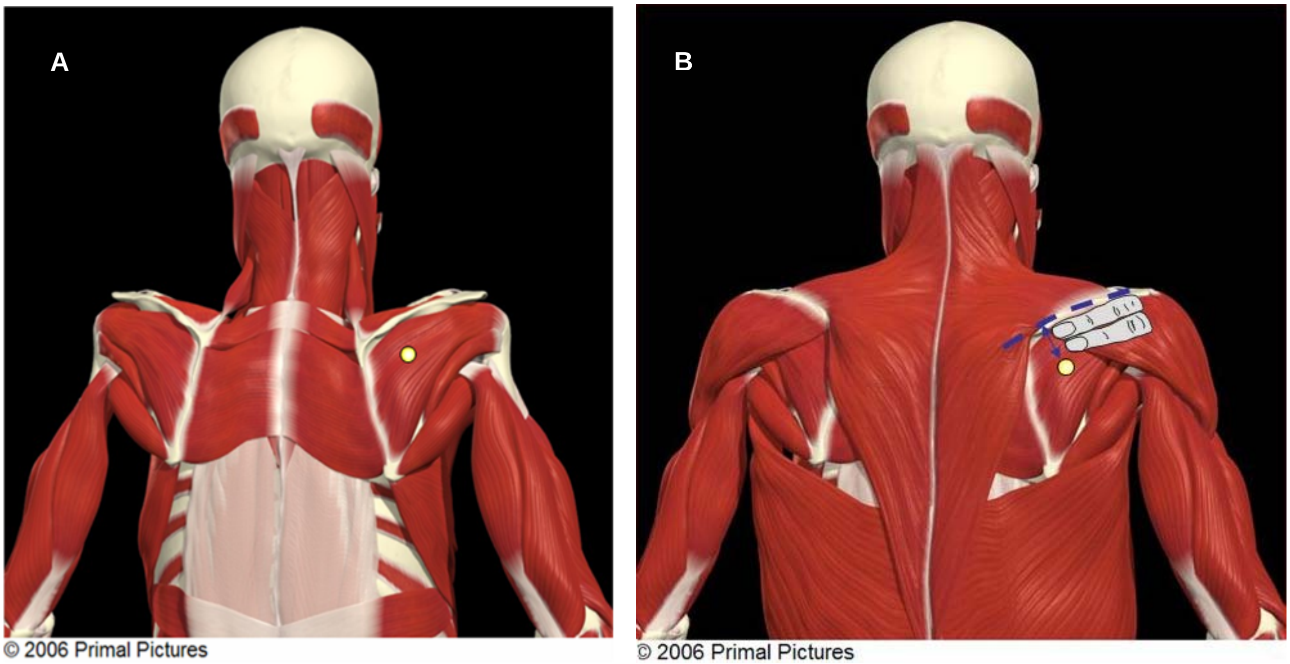


Fig. 36 A. Location of needle insertion into infraspinatus, **B.** View of infraspinatus after removal of trapezius and deltoid muscles

Proximal attachment: Infraspinous fossa of the scapula.

Distal attachment: The middle of the three facets of the greater tubercle of the humerus.

Innervation: Suprascapular nerve (C5, 6)

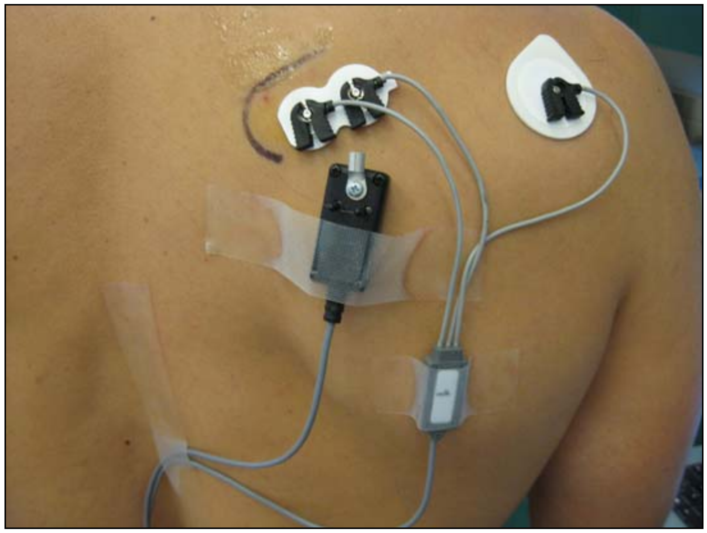
Blood supply: Suprascapular artery from the thyrocervical trunk and humeral circumflex humeral artery from the axillary artery.

Primary action: External rotation of the arm at the shoulder Agonists: teres minor and posterior deltoid Antagonist: subscapularis, anterior deltoid, latissimus dorsi, pectoralis major (sternal head), pectoralis major (clavicular head), and teres major.

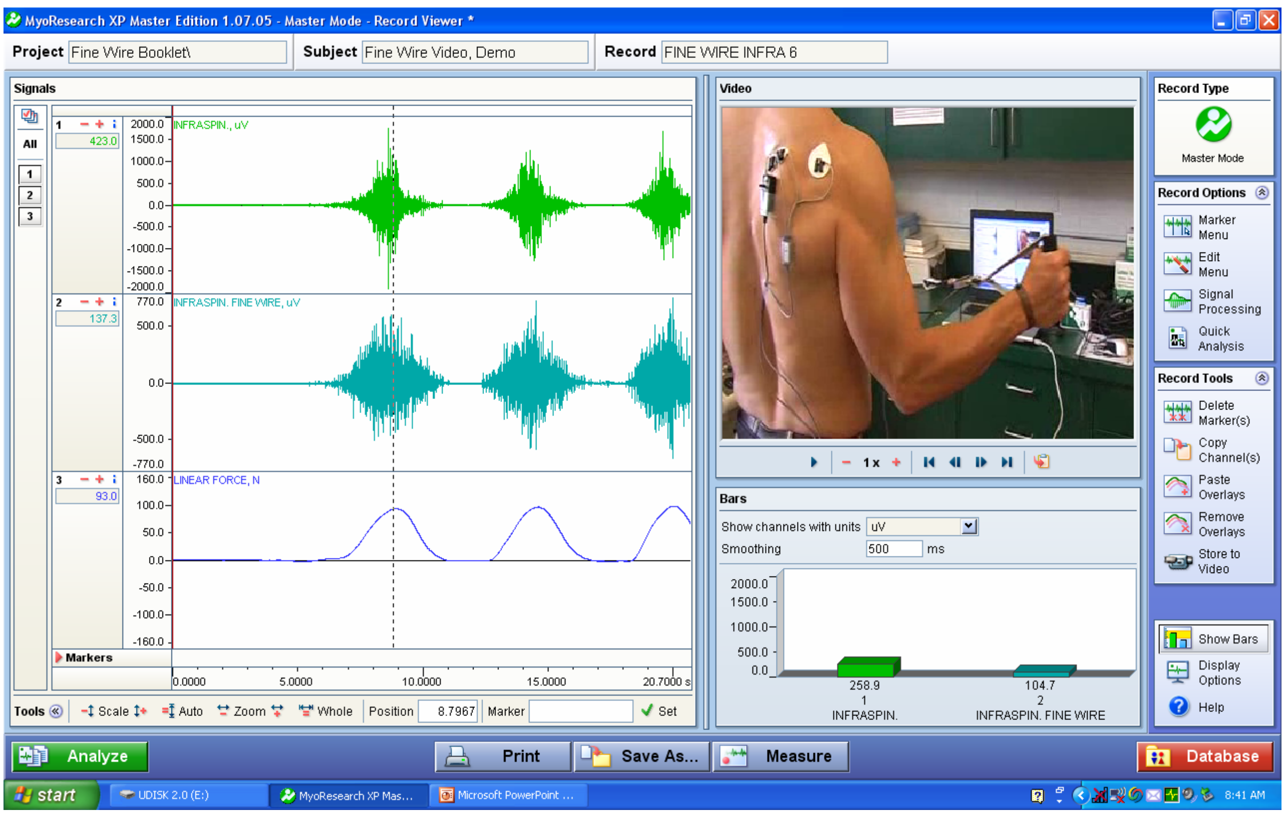
Electrode insertion: Insert needle electrode into infraspinous fossa two finger widths below medial portion of the spine of the scapula.

Pitfalls: If needle electrode is inserted too superficially it will be in the trapezius; if too laterally it will be in posterior deltoid.

Functional test: External shoulder rotation

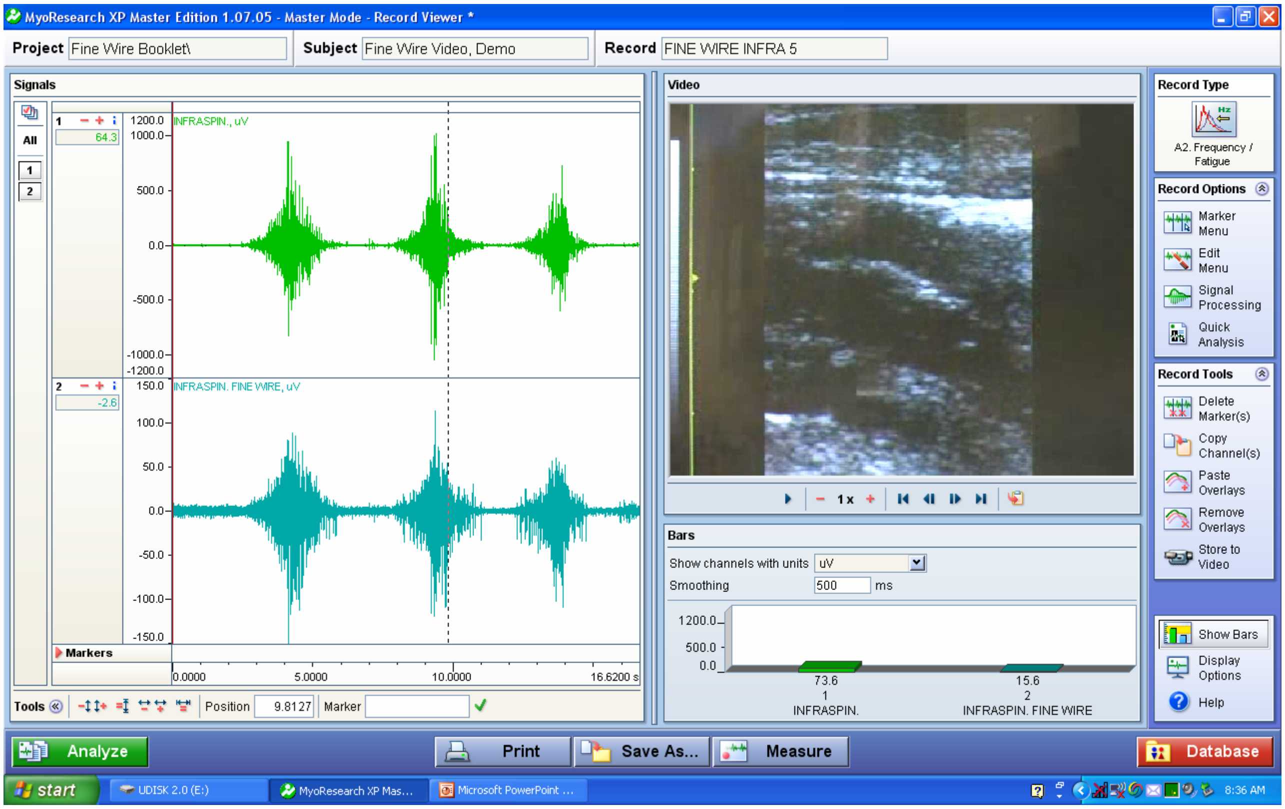


Subject with fine wire electrodes in infraspinatus muscle. Surface electrodes are placed over the muscle.



Subject performs internal and external shoulder rotation. The top trace shows surface EMG activity, middle trace fine wire EMG activity, and the bottom trace the force output measured by a force transducer attached to the cable. The bars on the lower right indicate the EMG and force values during the contraction.

Internal and external shoulder rotation with simultaneous ultrasonography video recording:



Suggested Readings

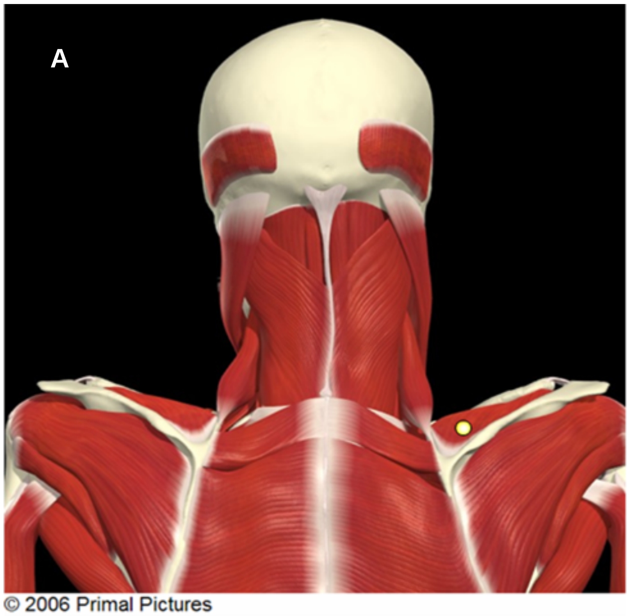
Bitter NL, Clisby EF, Jones MA, Magarey ME, Jaberzadeh, Sandow MJ. Relative contributions of infraspinatus and deltoid during external rotation in healthy shoulders. *J Shoulder Elbow Surg* 16: 563-568, 2007.

Morris AD, Kemp GJ, Lees A, Frostic SP. A study of the reproducibility of three different normalisation methods in intramuscular dual fine wire electromyography of the shoulder. *J Elelectromyogr Kinesiol* 8: 317-322, 1998.

Palmerud G, Forsman M, Sporrong H, Herberts P, Kadefors R. Intramuscular pressure of the infra- and supraspinatus muscles in relation to hand load and arm posture. *Eur J Appl Physiol* 83: 223-230, 2000.

Rudroff T, Barry BK, Stone AL, Barry CJ, Enoka RM. Accessory muscle activity contributes to the variation in time to task failure for different arm postures and loads. *J Appl Physiol* 102: 1000-1006, 2007.

Supraspinatus



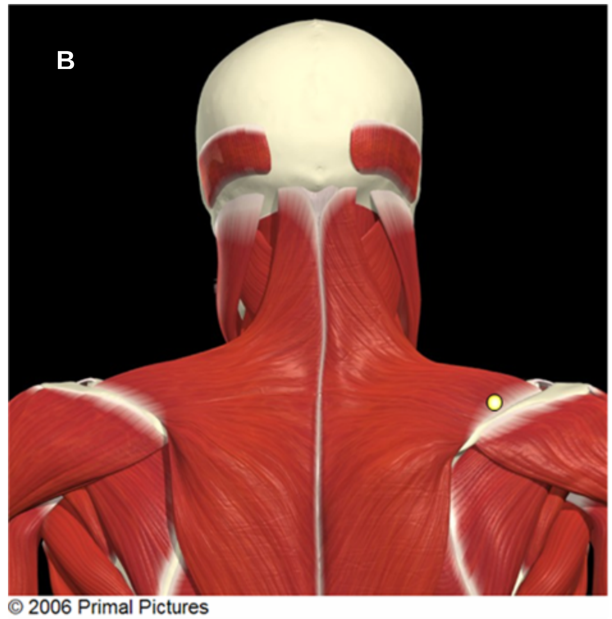


Fig. 37 A. Location of needle insertion into supraspinatus, **B.** View of supraspinatus after removal of trapezius and deltoid muscles

The **supraspinatus** is a relatively small muscle of the upper limb and is one of the four rotator cuff muscles

Proximal attachment: Supraspinous fossa of scapula.

Distal attachment: Superior facet of greater tubercle of humerus.

Innervation: Suprascapular nerve, upper trunk, C5, C6.

Blood supply: Suprascapular artery from the thyrocervical trunk and the dorsal scapular artery.

Action: Abduction of arm and stabilization of humerus. Agonist: middle deltoid; Antagonist: latissimus dorsi, pectoralis major, teres major, and long head of triceps brachii.

Electrode insertion: At the supraspinous fossa just above the spine of the scapula beneath the trapezius. The electrode will travel through the midtrapezius muscle.

Pitfalls: If needle electrode is inserted too superficially it will be in the trapezius.

Functional test: External shoulder rotation.

Suggested Readings: Same as for infraspinatus.

Teres Minor

Fig. 38 Location of needle insertion into teres minor

The teres minor is a narrow, elongated muscle of the rotator cuff.

Proximal attachment: On the dorsal surface of the middle half of the lateral border of the scapula.

Distal attachment: The inferior facet of greater tubercle of humerus

Innervation: Axillary nerve, posterior cord, posterior division, upper trunk, C5, C6.

Blood supply: Scapular circumflex and posterior humeral circumflex arteries.

Action: External rotation of the arm at the shoulder. Agonist: infraspinatus and posterior deltoid; Antagonist: anterior deltoid, subscapularis, pectoralis major (clavicular and sternal heads), teres major, and latissimus dorsi)

Electrode insertion: Insert one-third of the way between acromion and inferior angle of the scapular along lateral border.

Pitfalls: If needle is inserted too cephalad, it will be in the supraspinatus, if inserted too caudally, it will be in the teres major; if inserted too superficially, it will be in the trapezius. If inserted too medially, it will be in the infraspinatus.

Functional test: Externally arm rotation.

Suggested Readings: Same as for infraspinatus.

Multifidus

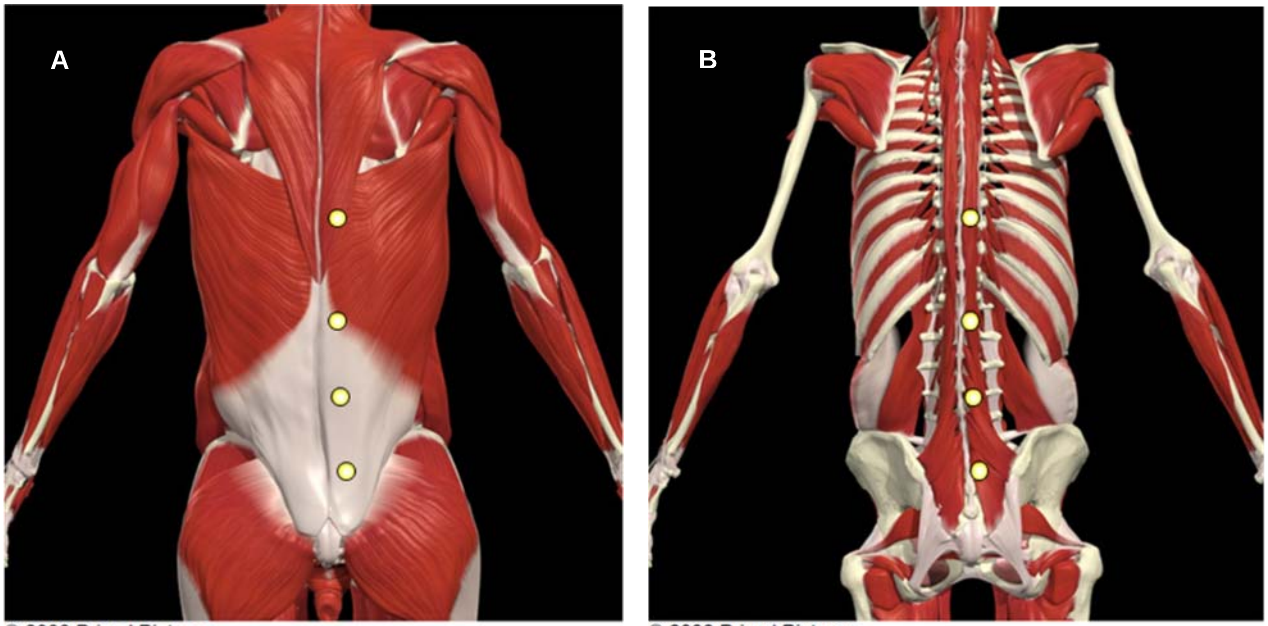


Fig. 39 A. Location of needle insertion into multifidus, **B.** View of multifidus after removal of overlaying muscles.

Multifidus is a series of paired small muscles extending the full length of the spine just superficial to the rotatores and each spanning 2 or 3 intervertebral spaces.

Proximal attachment: Sacral region: dorsal surface of the sacrum as low as the fourth sacral foramen, the aponeurosis of erector spinae, the posterior superior iliac spine, and the dorsal sacro-iliac ligaments.
Lumbar region: all the mamillary processes. Thoracic region: all the transversus processes. Cervical region: the articular processes of C4 to C7.

Distal attachment: arrangement in three layers, attaching to the entire length of the spinous processes of C2 to L5: the deepest layer attaches to the adjacent vertebra; the intermediate layer attaches to the second or third vertebra above; and the superficial layer to the third or fourth vertebra above.

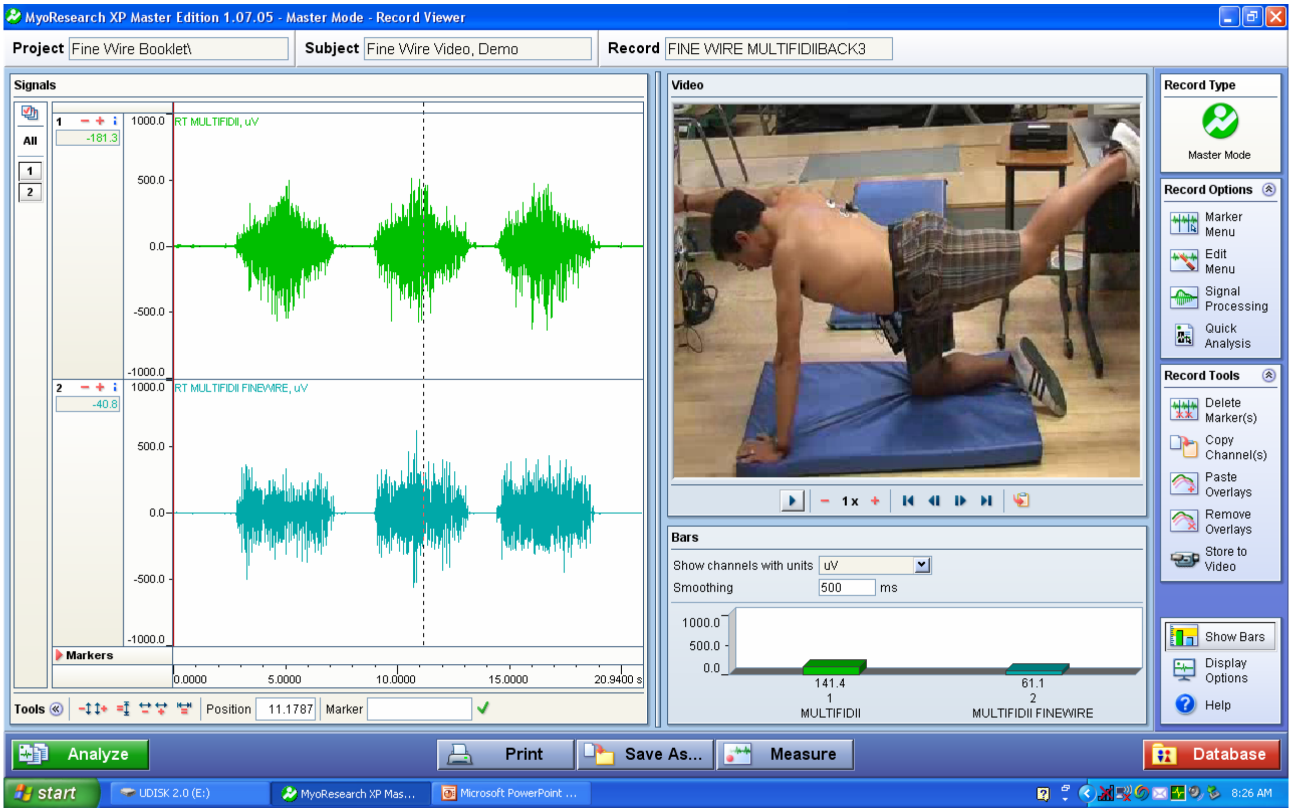
Action: Contralateral rotation of the cervical spine when acting unilaterally. Agonist: semispinalis cervicis; Antagonist: multifidus muscle of the contralateral side.

Innervation: Dorsal primary rami of all spinal nerves.

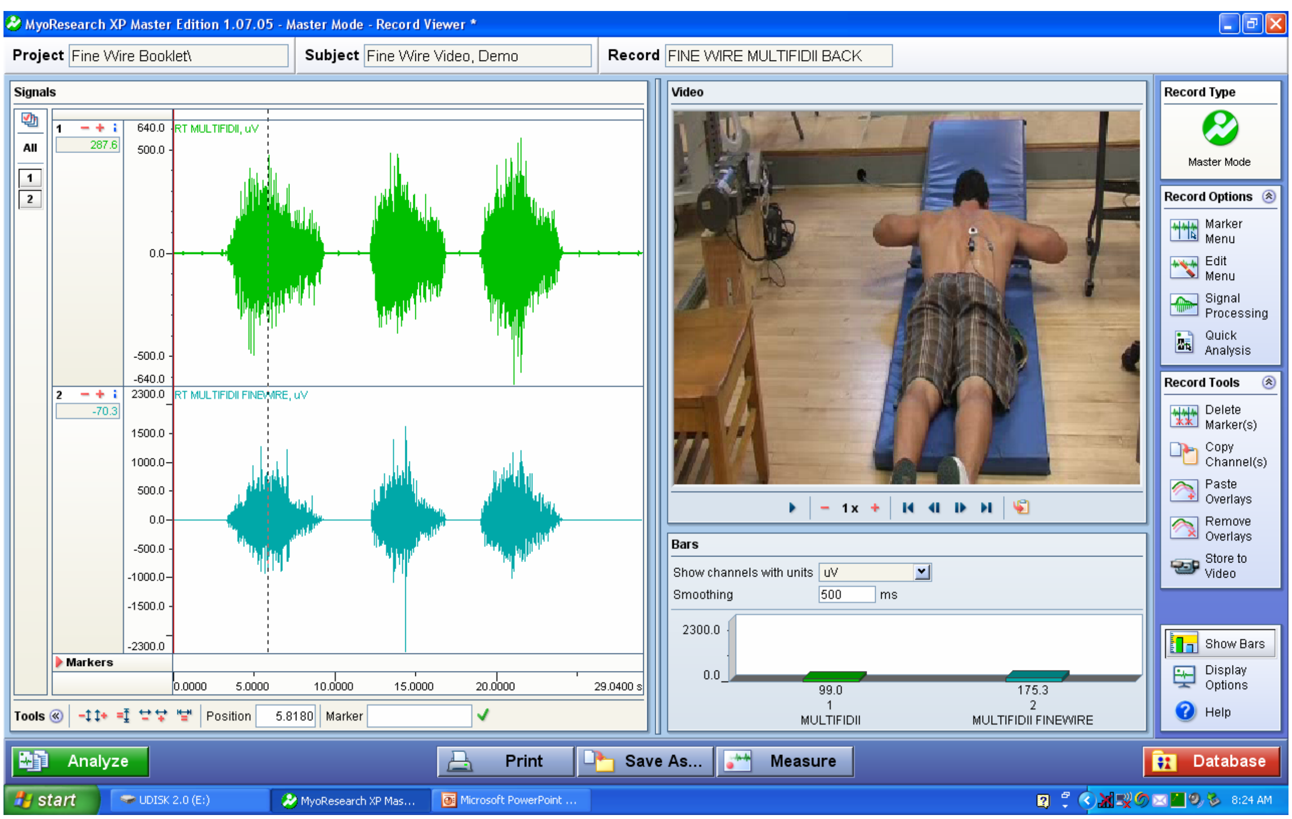
Blood Supply: Dorsal rami of the posterior intercostal arteries, the dorsal branches of the subcostal arteries, and the dorsal branches of the lumbar arteries.

Electrode Insertion: Two finger widths lateral to the spine.

Pitfalls: If the fine wire electrode is inserted too superficially it will be in the erector spinae.



Subject performs a typical exercise (diagonal arm/leg extension in quadruple position) for the back muscles. Left top trace shows surface EMG activity, middle trace fine wire EMG activity of the multifidus. The bars on the lower right indicate the EMG activity during the contraction.



Subject performs another common exercise (prone lying back extension) for the back muscles. Left top trace shows surface EMG activity, middle trace fine wire EMG activity of the multifidus. The bars on the lower right indicate the EMG activity during the contraction.

Suggested Readings

Moseley GL, Hodges PW, Gandevia SC. Deep and superficial fibers of the lumbar multifidus muscle are differentially active during voluntary arm movements. *Spine* 27: 29-36, 2002.

Vasseljen O, Dahl HH, Mork PJ, Torp HG. Muscle activity onset in the lumbar multifidus muscle recorded simultaneously by ultrasound imaging and intramuscular electromyography. *Clin Biomech* 21: 905-913, 2006.

Quadratus Lumborum

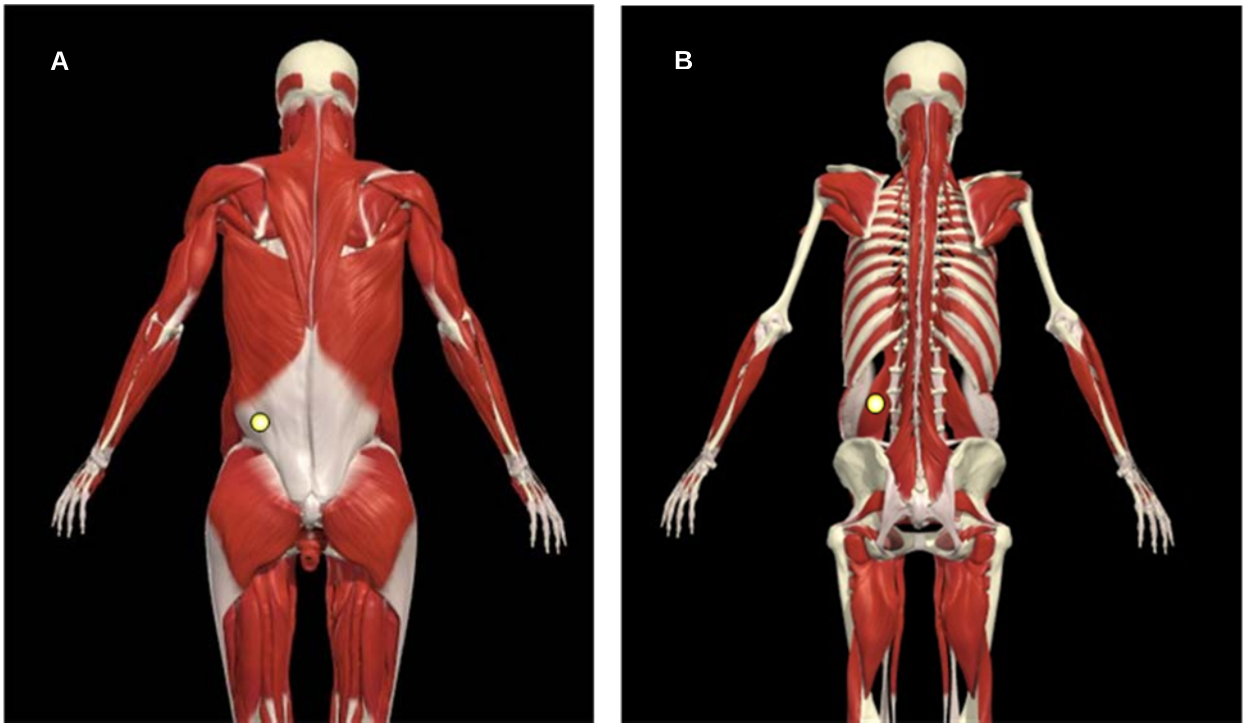


Fig. 40 A. Location of needle insertion into quadratus lumborum, **B.** View of quadratus lumborum after removal of overlaying muscles

The **quadratus lumborum** has an irregular and quadrilateral shape, and is broader at its base.

Proximal attachment: Transverse processes of L1 to L4, the iliolumbar ligament, and the posterior third of the iliac crest.

Distal attachment: Inferior border of the 12th rib

Innervation: Ventral primary rami of T12 to L3

Blood supply: Branches of the lumbar artery

Action: Alone, lateral flexion of vertebral column; Together, depression of thoracic rib cage. Agonists: iliocostalis lumborum, longissimus thoracis, psoas major, external and internal oblique; Antagonist: contralateral quadratus lumborum.

Electrode insertion: Subject starts in a prone position and then is asked to lift the chest off the table to increase the lumbar lordosis. This position will allow the precise identification of the lateral border of the erector spinae muscle. Two insertion areas are available:
(1) One finger width lateral to the erector spine mass and just proximal to the iliac crest: the needle will travel through the latissimus dorsi aponeurosis before entering the quadratus lumborum.
(2) The 2nd lumbar vertebra level is identified and the needle is inserted three fingers breadth lateral to the spinous process. The needle will travel through the latissimus aponeurosis and the erector spinae before entering the muscle. The

needle insertion is easy to feel due to the thickness and toughness of the lumbar aponeurosis, which helps to notice where the tip of the needle may be at any given time.

Pitfalls: (1) If the electrode is too superficial it will be in the latissimus dorsi; if too medial it will be in the erector spinae; if too lateral it will be in the internal oblique. If too deep it may enter the abdominal cavity.
(2) If electrode is too superficial it will be in the erector spinae; if too deep it will be either in the medial psoas muscle or in the retroperitoneal renal space. If too medial it will be in the multifidus; if too lateral it will be in the renal space.

Functional test: Subject is asked to laterally bend the body, or to lift the hemipelvis on the ipsilateral side.

Suggested Readings

Andersson EA, Gundstrom H, Thorstensson A (2002). Diverging intramuscular activity patterns in back and abdominal muscles during trunk rotation. *Spine* 15, 152-160.

Andersson EA, Oddsson LI, Gundstrom H, Nilsson J, Thorstensson A (1996). EMG activities of the quadratus lumborum and erector spinae muscles during flexion-relaxation and other motor tasks. *Clin Biomech* 11, 392-400.

McGill S, Juker D, Kropf P. (1996). Quantitative intramuscular myoelectric activity of quadratus lumborum during a wide variety of tasks. *Clin Biomec*h 11, 170-172.

Transversus abdominis

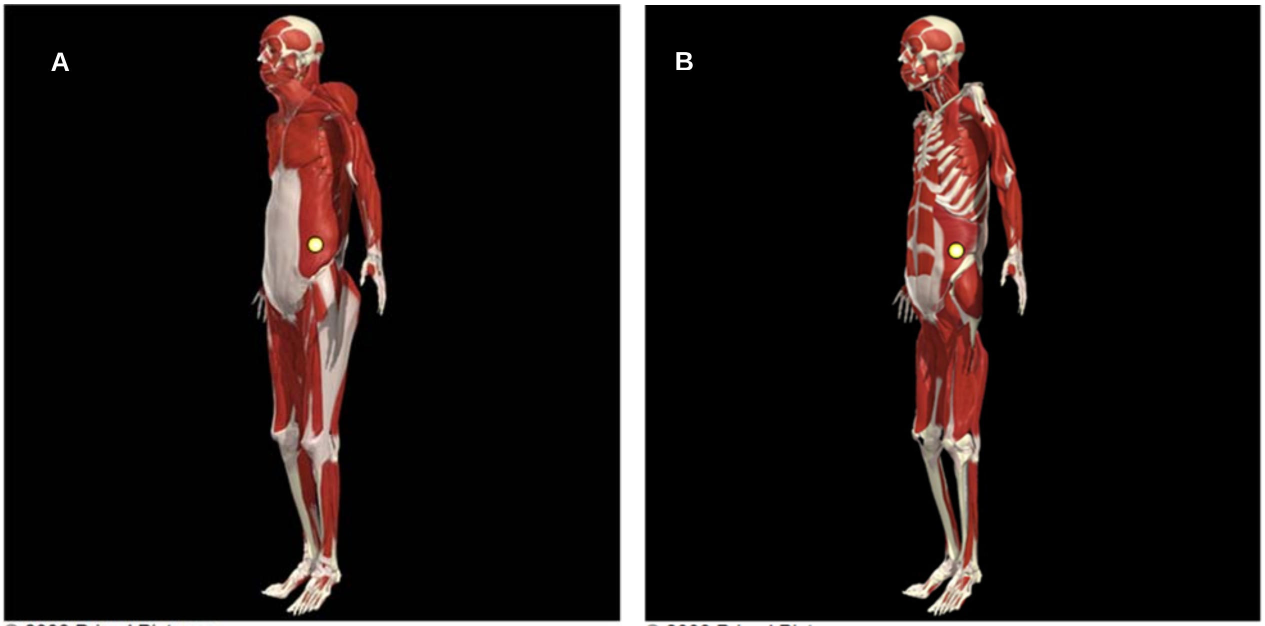


Fig. 41 A. Location of needle insertion into transversus abdominis, **B.** View of transversus abdominis after removal of external and internal oblique

The **transversus abdominis muscle** is a muscle layer of the anterior and lateral abdominal wall which is just below the internal oblique muscle. It is a major muscle of the functional core of the human body.

Proximal attachment: Aponeurosis of the posterior and anterior rectus sheath and the conjoined tendon to the public crest and the pectineal line.

Distal attachment: Costal margin, the lumbar fascia, the anterior two-thirds of iliac crest, and the lateral half of the inguinal ligament.

Innervation: Ventral primary rami of T7 to T12; conjoined tendon is supplied by the ilioinguinal nerve (L1).

Blood supply: Branches from the lower two or three posterior intercostals arteries and the subcostal artery.

Action: (1) Supports the abdominal wall. Agonists: rectus abdominis, pyramidalis, external oblique, and internal oblique; Antagonist: none.
(2) Forced expiration. Agonist: serratus posterior inferior; Antagonist: serratus posterior superior, levatores costarum breves, and levatores costarum longi. Rectus abdominis, external and internal oblique assist with force expiration.

Electrode insertion: Fine wire electrodes are inserted immediately adjacent to the eighth costal cartilage in the upper region of the transversus abdominis, halfway between the iliac crest and lower border of the rib cage in the middle region of transversus abdominis, obliquus internus abdominis and obliquus externus abdominis, and adjacent to the anterior superior iliac spine in the lower region of transversus abdominis and obliquus internus abdominis.

Functional test: Subject is asked to laterally bend the body, or to lift the hemipelvis on the ipsilateral side.

Suggested Readings

Carpenter MG, Tokuno CD, Thorstensson A, Cresswell AG. Differential control of abdominal muscles during multi-directional support-surface translations in man. *Exp Brain Res* 188, 445-455, 2008.

Hodges PW, Gandevia SC, Richardson CA. Contractions of specific abdominal muscles in postural tasks are affected by respiratory maneuvers. *J Appl Physiol* 83: 753-760, 1997.

Hodges PW, Richardson CA. Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. *Exp Brain Res* 114: 362-370, 1997.

Hodges PW, Pengel LHM, Herbert RD, Gandevia SC. Measurement of muscle contraction with ultrasound imaging. *Muscle Nerve* 27, pp. 682-692, 2003.

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Rectus Femoris

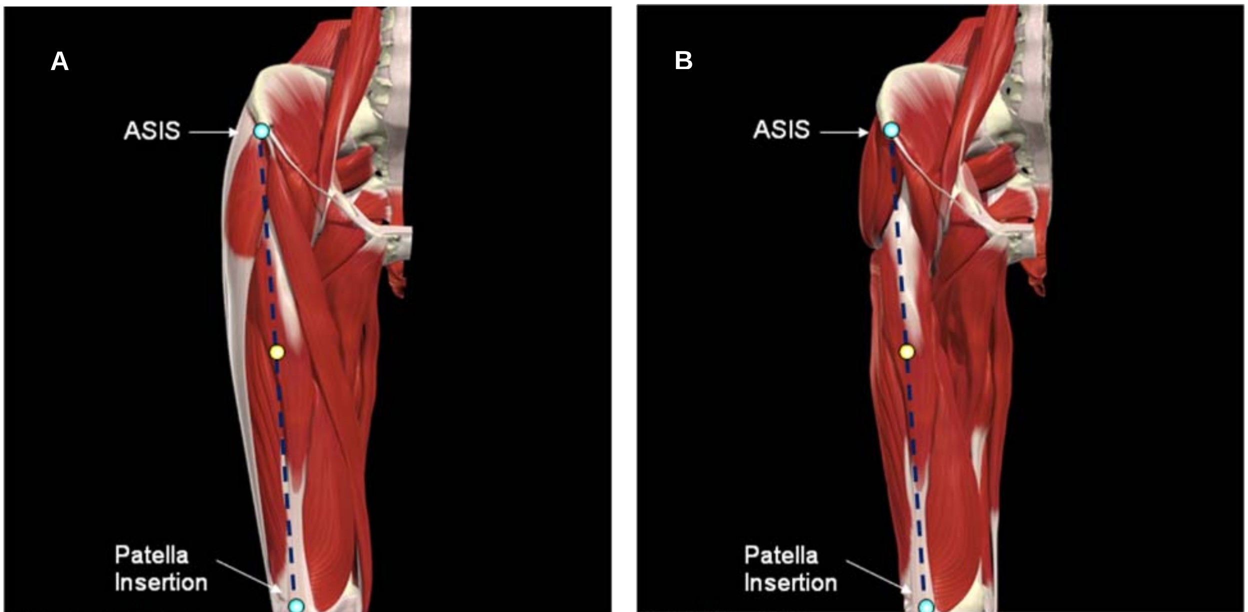


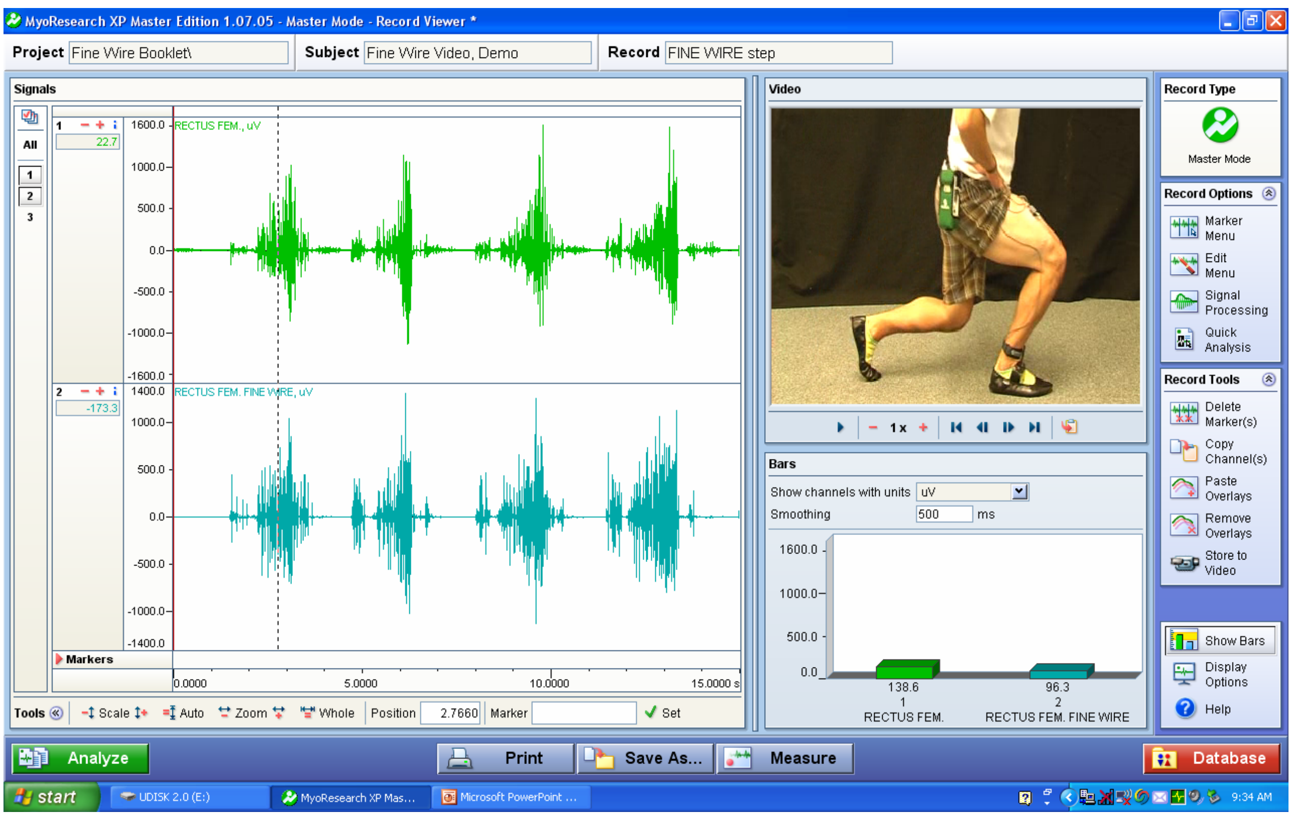
Fig. 42 A. Location of needle insertion into rectus femoris, **B.** View of rectus femoris after removal of sartorius muscle and tensor fascie latae. ASIS = Anterior Superior Iliac Spine

The **rectus femoris** muscle is one of the four quadriceps muscles. The others are vastus medialis, vastus intermedius (deep to the rectus femoris), and the vastus lateralis.

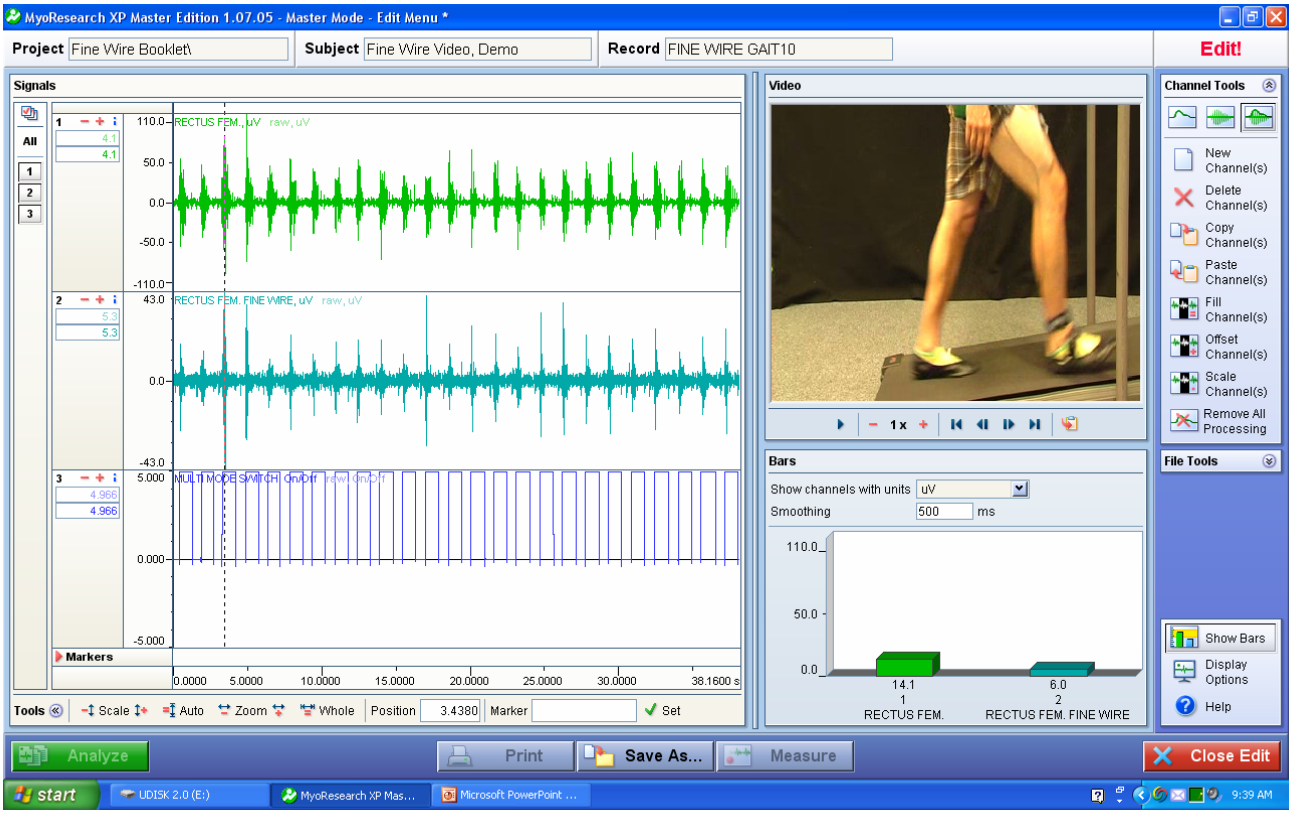
Proximal attachment:	Anterior Inferior Iliac Spine.
Distal attachment:	The quadriceps tendon along with the three vastus muscles, enveloping the patella, then by the patellar ligament into the tibial tuberosity.
Innervation:	Femoral Nerve, Posterior Division Lumbar Plexus, L3, L4.
Blood supply:	Femoral artery and branches from the profunda femoris artery.
Action:	Extension of the leg at the knee. Agonists: vastus lateralis, vastus medialis, and vastus intermedius; Antagonist: biceps femoris (long and short head), semitendinosus, and semimembranosus.
Electrode insertion:	The anterior thigh midway between the anterior superior border of the patella and the anterior superior iliac spine (ASIS).
Pitfalls:	If the electrode is inserted too medially it will be in the vastus intermedius; if inserted too laterally it will be in the vastus lateralis; if inserted too distally and medially it will be in the vastus medialis.
Functional test:	Subject flexes the hip with the knee extended.

Subject with fine wire electrode in rectus femoris muscle.

Surface electrodes are placed over the muscle.



Subject performing forward/backward steps with one leg. Channel 1 shows surface EMG activity, Channel 2 fine wire EMG activity of the rectus femoris. The bars on the lower right indicate the EMG and force values during the contraction.



Subject walking on a treadmill. Channel 1 shows surface EMG activity of the Rectus Femoris; Channel 2 fine wire EMG activity of the rectus femoris; and Channel 3 shows foot switch activities. The bars on the lower right indicate the EMG values during the gait cycle.

Suggested Readings

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Jacobsen WC, Gabel RH, Brand RA. Surface vs. Fine wire electrode ensemble-averaged signals during gait. *J Electromyogr Kinesiol* 5: 37-44, 1955.

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Vastus intermedius

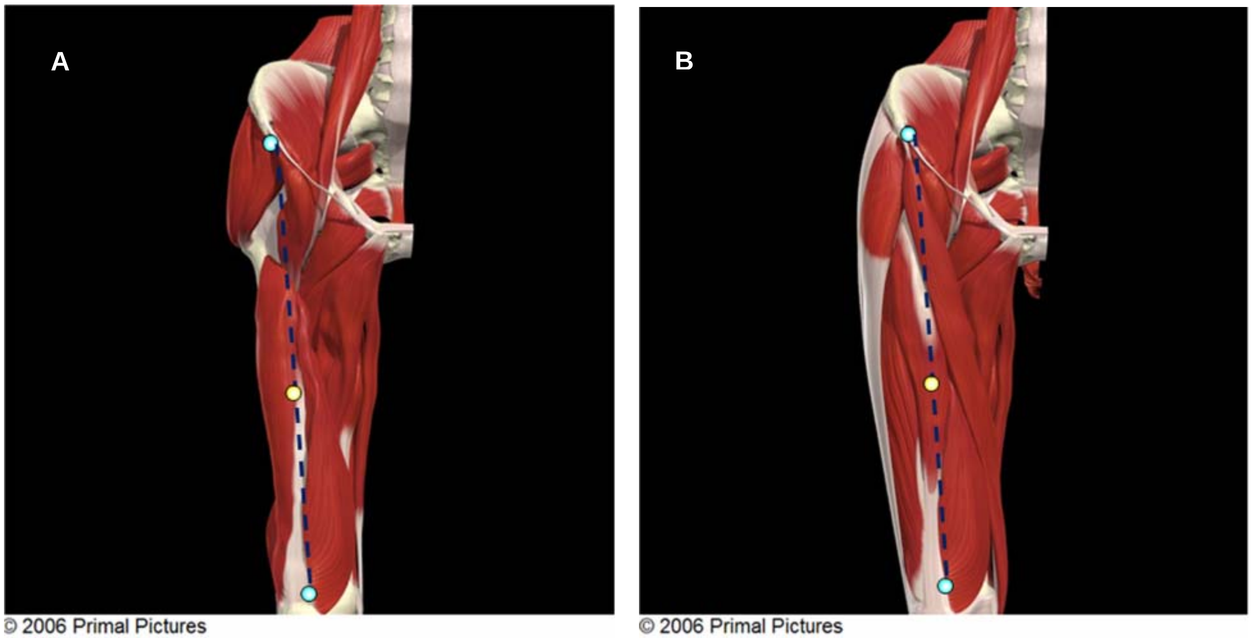

Fig. 43 A. Location of needle insertion into vastus intermedius, **B.** View of vastus intermedius after removal of overlying muscles

The **vastus intermedius** arises from the front and lateral surfaces of the body of the femur in its upper two-thirds and from the lower part of the lateral intermuscular septum. Its fibers end in a superficial aponeurosis, which forms the deep part of the quadriceps tendon.

Proximal attachment: Anterior and lateral aspects of the upper two-thirds of the femoral shaft and the lower part of the lateral intermuscular septum of the femur.

Distal attachment: Into the quadriceps tendon along with rectus femoris and the other vastus muscles, enveloping the patella, then by the patellar ligament into the tibial tuberosity.

Innervation: Femoral nerve, posterior division lumbar plexus, L3, L4.

Blood supply: Femoral artery and branches of the profunda femoris artery.

Action: Extension of the leg at the knee. Agonist: vastus lateralis, vastus medialis, and rectus femoris. Antagonist: biceps femoris (long and short heads), semitendinosus, and semimembranosus.
Tensor fasciae latae assists with extension of the knee through the iliotibial band.

Electrode insertion: The anterior thigh midway between the anterior superior iliac spine and the patella and under the rectus femoris

Pitfalls: If the fine wire electrode is inserted too superficially it will be in the rectus femoris; if inserted too laterally it will be in the vastus lateralis; if inserted too medially it will be in the vastus medialis or sartorius.

Functional test: Subject in supine posture lifts heel from bench with knee extended.

Suggested Readings

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Iliopsoas

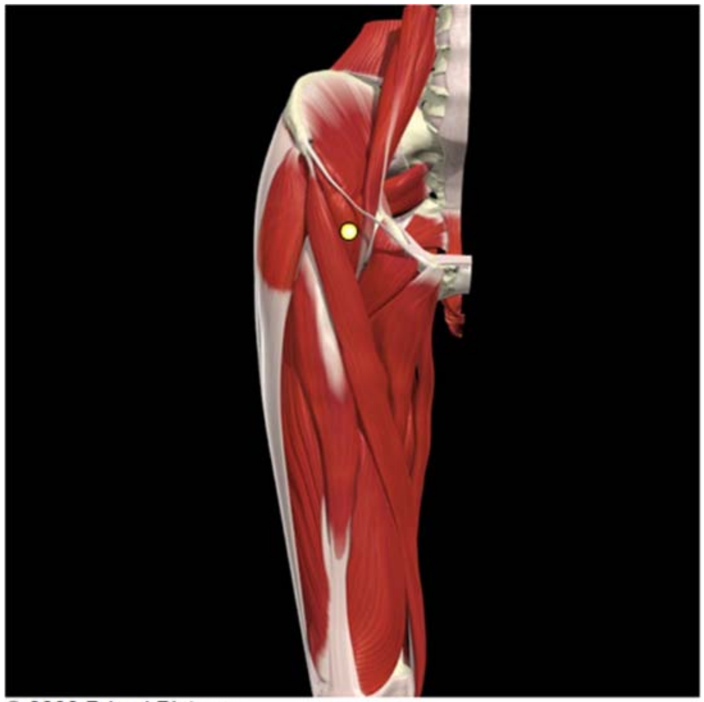

Fig. 44 Location of needle insertion into iliopsoas

The term **iliopsoas** refers to three muscles: psoas major, psoas minor, iliacus.

Origin: Iliac fossa; base of sacrum, and lumbar spine.

Insertion: Lesser trochanter on the shaft of the femur, anteromedially.

Innervation: Femoral Nerve, L1, L2.

Blood supply: Medial femoral circumflex artery, iliolumbar artery.

Action: Flexes and internally rotates thigh.

Electrode insertion: Two finger widths lateral to the femoral artery pulse and one finger width below the inguinal ligament.

Pitfalls: If the needle electrode is inserted too medially it will contact the neurovascular bundle; if inserted too laterally it will be in the sartorius.

Functional test: Subject to flex the thigh with the knee flexed beyond ninety degrees.

Suggested Readings

Juker D, McGill S, Kropf P, Steffen T. Quantitative intramuscular myoelectric activity of lumbar portions of psoas and the abdominal wall during a wide variety of tasks. *Med Sci Sports Exerc* 30 (2), 301-310,1998.

LaBan MM, Raptou AD, Johnson EW. Electromyographic study of function of iliopsoas muscle. *Arch Phys Med Rehabil* 46, 676-679, 1965.

Tibialis Posterior

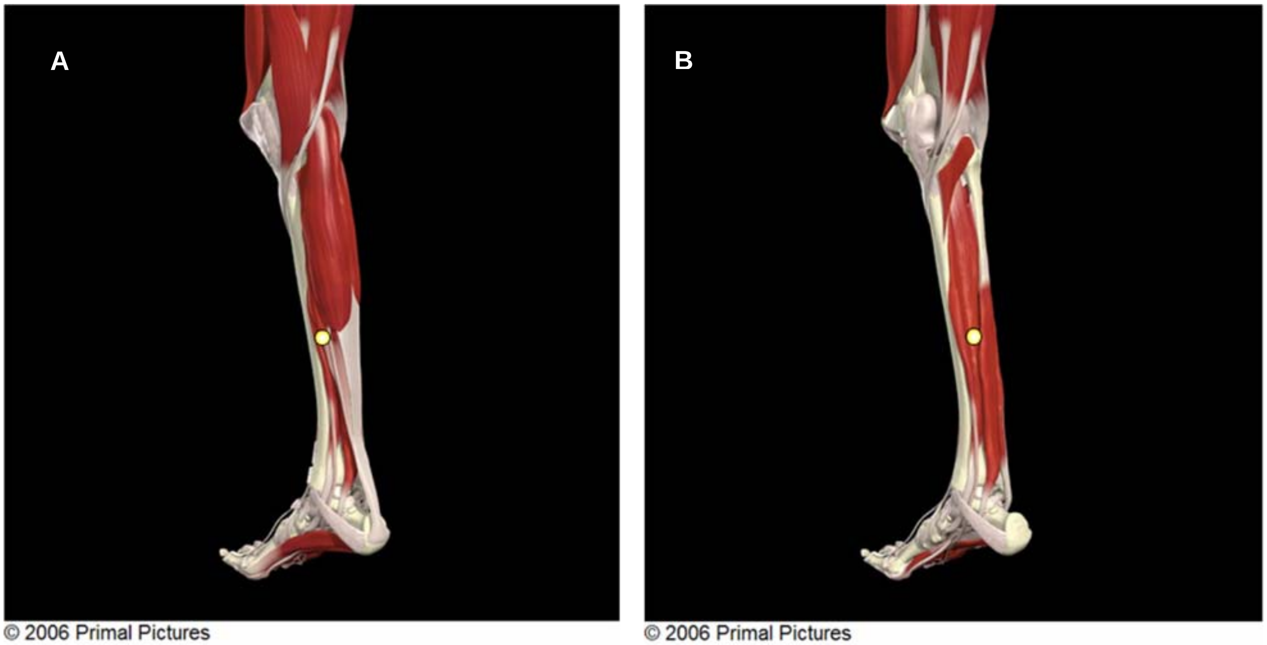

Fig. 45 A. Location of needle insertion into tibialis posterior, **B.** View of tibialis posterior after removal of surface muscles

The **tibialis posterior** is the most central of the lower leg muscles. It is a key stabilizer of the lower leg.

Proximal attachment: Posterior surface of the interosseous membrane and the adjacent sides of the tibia and fibula for the upper two-thirds of the attachment.

Distal attachment: On its way into the foot, on the posterior side of the ankle, the tendon of tibialis posterior makes a groove in the posterior groove in the posterior side of the medial malleolus just anteromedial to the groove made by flexor digitorum longus. In the foot, the tendon divides into two: a larger superficial division and a more tendinous lateral band. The superficial division attaches to the tuberosity of the navicular with fibers continuing to the inferior surface of the medial cuneiform. The deeper lateral division sends attachments to the second cuneiform and the bases of the second, third, and fourth metatarsals.

Innervation: Tibial nerve (L4, L5).

Blood supply: Branches from the anterior and posterior tibial arteries.

Action: Inversion of the foot at the subtalar joint. Agonist: tibialis anterior; Antagonist: Peroneus longus and brevis.

Electrode insertion: 1 cm medial to the margin of the tibia at the junction of the upper two-thirds with the lower third of the shaft; direct the needle obliquely through the soleus and flexor digitorum muscles.

Pitfalls: If the needle electrode is inserted too superficially it will be in the soleus or flexor digitorum longus; if inserted too deeply it will be in the tibialis anterior.

Functional test: Subject to invert foot in plantar flexion.

Suggested Readings

Chapman AR, Vicenzino B, Blanch P, Hodges PW (2008). Patterns of leg muscle recruitment vary between novice and highly trained cyclists. *Journal of Electromyography and Kinesiology* 18, 359-371.

Murley GS, Buldt AK, Trump PJ, Wickham JB (2008). Tibialis posterior EMG activity during barefoot walking in people with neutral foot posture. *Journal of Electromyography* 27, ahead of print.

Peroneus Longus

Fig. 46 A. Location of needle insertion into peroneus longus, **B.** View of tibialis posterior after removal of surface muscles.

The **peroneus longus** is a superficial muscle in the lateral compartment of the leg.

Proximal attachment: Head and proximal two-thirds of the lateral surface of the fibula, and the anterior and posterior intermuscular septa of the leg.

Distal attachment: The tendon of peroneus longus runs obliquely forward across the lateral side of the calcaneus, below the peroneal trochlea and the tendon of peroneaus brevis, and beneath the inferior peroneal retinaculum. The tendon crosses the lateral side of the cuboid and then runs under it in a groove converted into a canal by the long plantar ligament. It continues across the sole of the foot obliquely. The tendon of peroneus longus attaches by two slips to the lateral side of the base of the first metatarsal and the medial cuneiform.

Innervation: Superficial fibular (peroneal) nerve (L5, S1).

Blood supply: Branches from the posterior tibial artery.

Action: Eversion of the foot at the subtalar joint. Agonist: peroneus brevis; Antagonist: tibialis anterior and posterior.

Electrode insertion: Three finger breadths below the fibular head directed toward the lateral aspect of the fibula.

Pitfalls: If the needle electrode is inserted too posteriorly it will be in the soleus; if inserted too anteriorly it will be in the extensor digitorum longus.

Functional test: Subject to plantar flex and evert the foot.

Suggested Readings

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Walmsley RP. Electromyographic study of phasic activity of peroneus longus et brevis. *Arch Phys Med Rehabil* 58, 65-69,1977.

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Finsen L, Søgaard K, Graven-Nielsen T, Christensen H. Activity patterns of wrist extensor muscles during wrist extensions and deviations. *Muscle Nerve* 31: 242-251, 2005.

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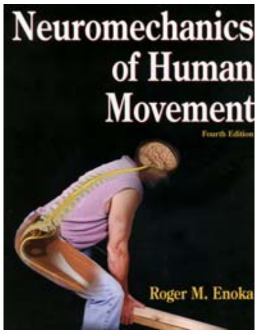
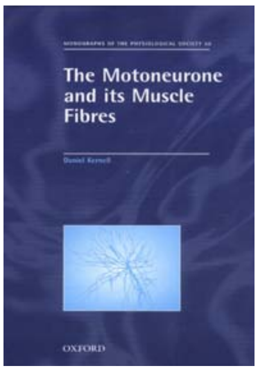


Enoka RM

Neuromechanics of Human Movement.

Human Kinetics
Champaign (2008)



Kernell D

The Motoneurone and its Muscle Fibres.

Oxford, Great Britain:
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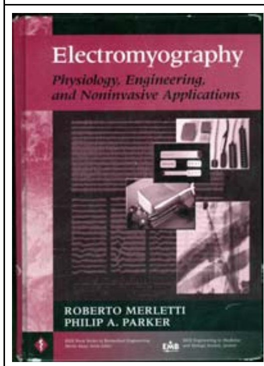

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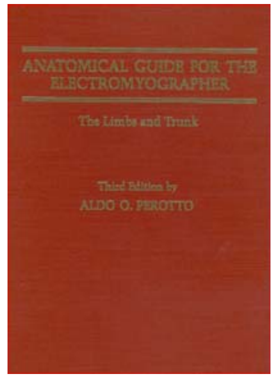
Dr. Peter Konrad

The ABC of EMG
A Practical Introduction to Kinesiological Electromyography

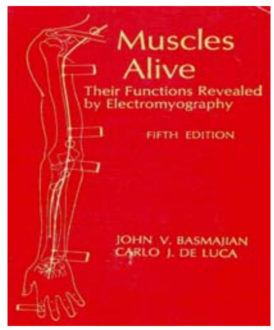
Free download booklet addressing the most important topics and operational steps to plan and perform kinesiological EMG studies.
[Download The ABC of EMG at: www.noraxon.com/emg/emg.php3](http://www.noraxon.com/emg/emg.php3)



Perotto A

Anatomical Guide for the Electrromyopher: limbs and trunk

Thomas Books Illionis (1994)

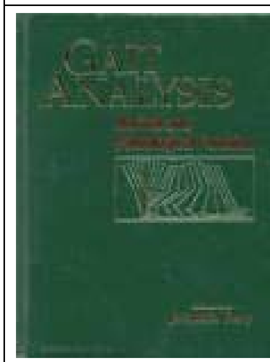


J.V. Basmajian; C.J. De Luca

Muscles Alive

Their Function Revealed by Electromyography.

Williams Wilkins
Baltimore (1985)



8) Perry J

Gait Analysis

Normal and Pathological Function.

Slack Thorofare (1992)

EMG Guidelines, Societies, Search Links

The International Society of Electrophysiology and Kinesiology (ISEK)

Web Link: http://isek.bu.edu/

"The International Society of Electrophysiology and Kinesiology (ISEK) is a multidisciplinary organization composed of members from all over the world in health-related fields and basic science with a common desire to study human movement and the neuromuscular system". The webpage contains important links, journals, congress dates and addresses for electromyographers. The very important "ISEK Standards of Reporting EMG Data" can be found under:
http://isek.bu.edu/publications/standards/emg_standards.html

The European Recommendations for Surface Electromyography (SENIAM)

Web Link: http://www.seniam.org/

The SENIAM project (Surface Electromyography for the Non-Invasive Assessment of Muscles) is a European concerted action in the Biomedical Health and Research Program (BIOMED II) of the European Union. The SENIAM project developed important guidelines for EMG measurements. The results are published under:

Hermens H.J., Freriks B., Merletti R., Hägg G., Stegeman D.F., Blok J., Rau G., Disselhorst-Klug C. (1999) SENIAM 8: European Recommendations for Surface ElectroMyoGraphy, Roessingh Research and Development b.v., ISBN 90-75452-15-2.
Freriks B., Hermens H.J. (1999) SENIAM 9: European Recommendations for Surface ElectroMyoGraphy, results of the SENIAM project, Roessingh Research and Development b.v., 1999, ISBN 90-75452-14-4 (CD-rom).

Pubmed – free access to Medline

Web Link: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi

"PubMed, a service of the National Library of Medicine, includes over 15 million citations for biomedical articles back to the 1950's. These citations are from MEDLINE and additional life science journals. PubMed includes links to many sites providing full text articles and other related resources"

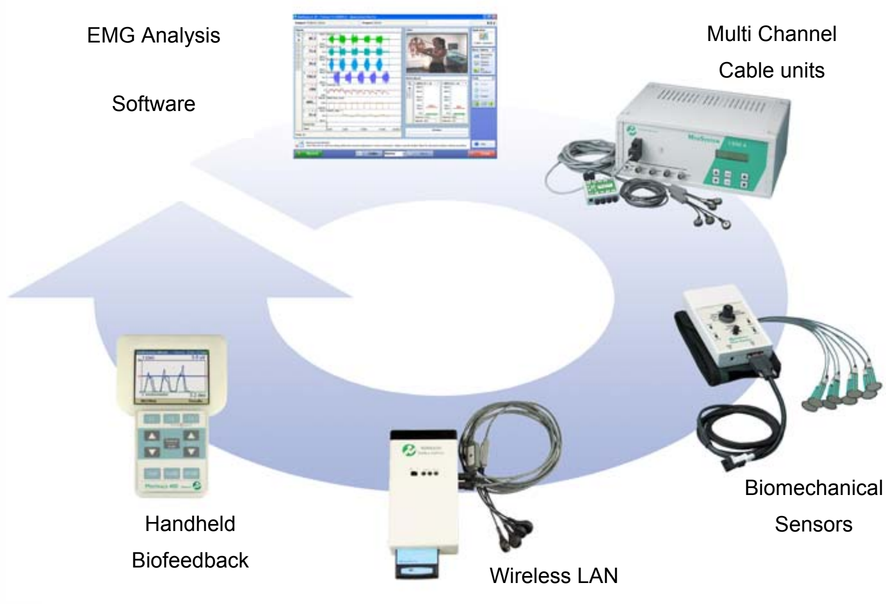
Search engine Scholar Google

Web Link: http://scholar.google.com/

Powerful search engine for (EMG-) articles and publications

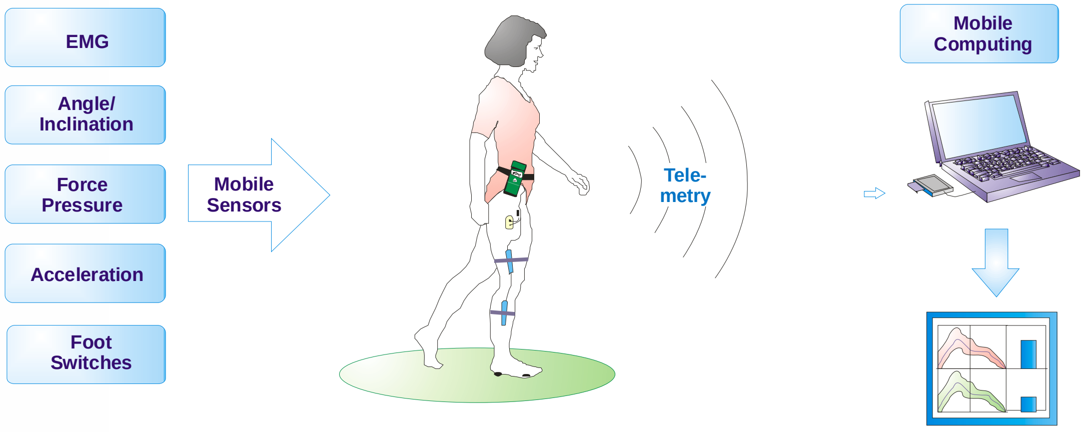
The World of Electromyography

Since 1989, Noraxon has been manufacturing and distributing high-end surface electromyography (SEMG) and biomechanical sensor systems to research, sports medicine, ergonomics and clinical professionals worldwide. Our systems meet the technical requirements of highly acclaimed international research societies, like ISEK and Seniam and are CE and/or FDA approved.



Mobile Monitoring Concept and Connectivity

EMG, force, angle and other types of biomechanical sensors can be connected to a telemetry system. Data is then transmitted from the system directly to a computer or notebook. Hardware interface solutions and software export/import modules ensure complete communication capabilities to other measurement devices, such as movement analysis, isokinetics, force plates, footswitches, goniometers, etc.



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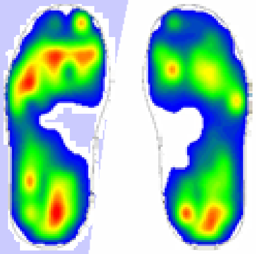
Direct Transmission Technology

Noraxon's latest transmission technology includes Direct Transmission probes (DTS System) which directly transmit telemetric data from the electrodes' site.

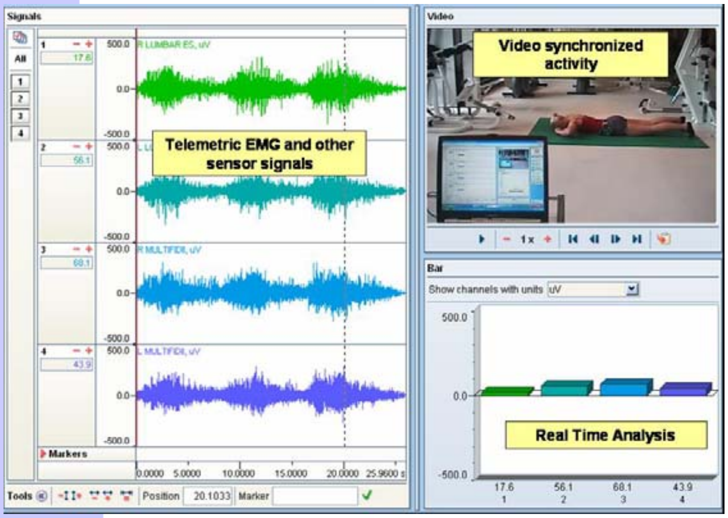
Integration of 3D Kinematics and Pressure Distribution

New!



Pressure distribution telemetry with resulting vertical force curves measured from insoles and 3D kinematics, which are operated by wireless inertial sensors can directly be combined with the EMG/sensor recordings.

Real Time Monitoring of Muscle Activity and Performance



Noraxon's comprehensive data acquiring software features the most commonly used analysis routines of biomechanical, medical, occupational and sport science applications: from MVC Normalization to Wavelet Analysis, Onset Timing to ECG Removal. The option to quickly and easily configure report routines meets the professional need for a highly sophisticated software program. DV Video and ultra-sound imaging can directly be combined with the EMG/sensor recordings.

Numerous Ready-to-go Application Protocols

Noraxon's latest MyoResearch XP software features many protocols, such as Gait Analysis, Incontinence and Isokinetics, which perform immediate analysis with the push of a few buttons! From Postural Analysis to Gait Analysis, from Manual Muscle Function Tests to EMG Isokinetics, Noraxon's unique protocol system automatically guides you to meaningful results.

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