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Electrode Placement in Surface Electromyography (sEMG) "Minimal Crosstalk Area" (MCA)

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Abstract: This paper is an introduction to a workshop on electrodes location and specific exercises. Selectivity of EMG electrodes depends on their interspacing, their conductive area and axis direction with respect to the direction of the underlying muscular fibres. Minimal cross talk area (MCA) helps to limit or avoid crosstalk from neighbouring muscles. We present examples of MCA and typical sEMG patterns during specific exercises.

Keywords: Surface electromyography, muscle, electrodes, minimal cross talk area, location.

This text is the introduction to a workshop on "Electrodes placement and selective tests" hold during the "V course Surface Electromyography. **Società Italiana di Analisi del Movimento in Clinica** (SIAMOC), (**Italian Society of Clinical Movement Analysis)**. February 26-28 2009. Catania, Sicily, Italy.

The challenge in surface Electromyography (sEMG) is to accurately detect the sEMG signal of the targeted muscle or part of it without picking signals diffused from co-active adjacent or inactive muscle(s) [1]. Many technical aspects concur to reach this goal. Two are easily attainable by clinicians -1- selectivity of the electrodes, -2- place the electrodes on zone were the crosstalk is minimal. This implies a high sensitivity combined with a high selectivity of the electrodes.

SELECTIVITY OF sEMG ELECTRODES

Passive Electrodes: Influence of the Size of the Sensitive Part

We cannot know the area and depth of the tissue sensed by electrodes. Surely, the area of the conductive part of the electrodes and the gap between them define the recorded volume. The only assumptions are derived from modelling which do not integrate inhomogeneity of the tissue under the electrodes. From one of these models researchers recommended an inter electrode gap of 2 cm [2].

By default, most EMG devices use disposable ECG electrodes with female snap connectors. Miniatures skin electrodes from Gereonics (USA) http://www.gereonics. com/electrodes.html are attachable to a snap connector by simple "*home made*" adaptation: solder 5 to 7 cm its wire to a female snap connector. Their sensitive part is 2.5 mm but the plastic well has a diameter of 4 mm this means that the overall sensitive area is 12.56 mm^2. The smallest miniature skin electrodes are from TMSI (Holland) http://www.tmsi.com/. Their sensitive area Ag/AgCl and well is 2 mm in diameter. From a sort of brain storming with Andrea Merlo "*How to improve selectivity of pregelled ECG electrodes*" one idea emerged: reduce the sensitive area of disposable ECG electrode by interposing a double side adhesive collar with a hole of 4 mm between the skin and the sensitive part of the ECG electrode. Therefore their sensitive surface is reduced and consequently the sensed volume should be reduced but we do not what are the potential modifications of the sEMG characteristics.

True sensitive surface of different brands of passive electrodes (Fig. **1**) (Table **1**). We have excluded active electrodes because they are too large to fit on small persons, on forearm, hand and leg.

The size of the conductive gel is certainly an important factor of the volume sensed; we tested this hypothesis. Three sets of pairs of electrodes, 15 mm apart, were connected in parallel to a generator, which delivers a sine wave (amplitude 980 µV peak-peak at 60 or 180 Hz). Inter electrode distance = 15 mm. Recording set: PORTI™ TMSI, bandwidth = 10-500 Hz. Sampling rate = 1024 Hz

1. Channel 1: Disposable ECG electrode (Kendall ARBO Ref 31.1245.21), gel diameter 16 mm (see Fig. **1C**), trimmed for a 15 mm inter electrode distance.
2. Channel 2: Disposable ECG electrode (Kendall ARBO Ref 31.1245.21) Modified by interposing a double side adhesive collar with a hole of 4 mm (Fig. **2**) between the skin (SensorMedics ref 650 455), trimmed for a 15 mm inter electrode distance. The collar reduces the pregelled diameter from 16 mm to 4 mm.
3. Channel 3: TMS International (TMSI) skin electrodes (Ref 95-7291- 0015-1-1) attached with a double side adhesive collar with a hole of 4 mm (SensorMedics ref 650 455), 15 mm inter electrode distance.
4. Data are processed with EmgEasyReport Version 4.4 (written by Andrea Merlo).

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Table 1. Difference of Diameter [mm] and Area [mm^2] Between Ag/AgCl Sensitive Part of the Electrode and its Conductive Gel. Easytrode has the Largest Conductive Pregelled Area Though the Ag/AgCl Part is 10 mm Like All the Others ECG Electrode. Easytrodes have a Too Large Pick Up Area for sEMG but Might Be Suitable for TENS. Area of the Conductive Gel, Gap Between Electrodes and Location are Primordial when Choosing Electrodes

Electrode	Ag/AgCl Diameter [mm] & Area [mm^2]	Overall Sensitive of the Gel Diameter [mm] & area [mm^2]	Electrodes Gap [mm]
(A) ECG Pregelled	10 → 78.54	16 → 201.06	Fixed 6.5 mm
(B) ECG Pregelled	10 → 78.54	16 → 201.06	User's decision
(C) ECG Pregelled	10 → 78.54	31.7 x 22.3 →706.9	User's decision
(D) miniature	2.5 → 4.90	4 → 50.27	User's decision
(E) miniature	1.5 → 1.76	2 → 12.57	User's decision

(A) Myotronics/Noromed: *Norotrodes 20,* (B) Tyco Healthcare: *Arbo,* (C) BEAC Biomedical: *Easytrode,* (D) Gereonics: Miniature skin electrodes, (E) TMS International: Miniature electrode with movement artefacts rejection.

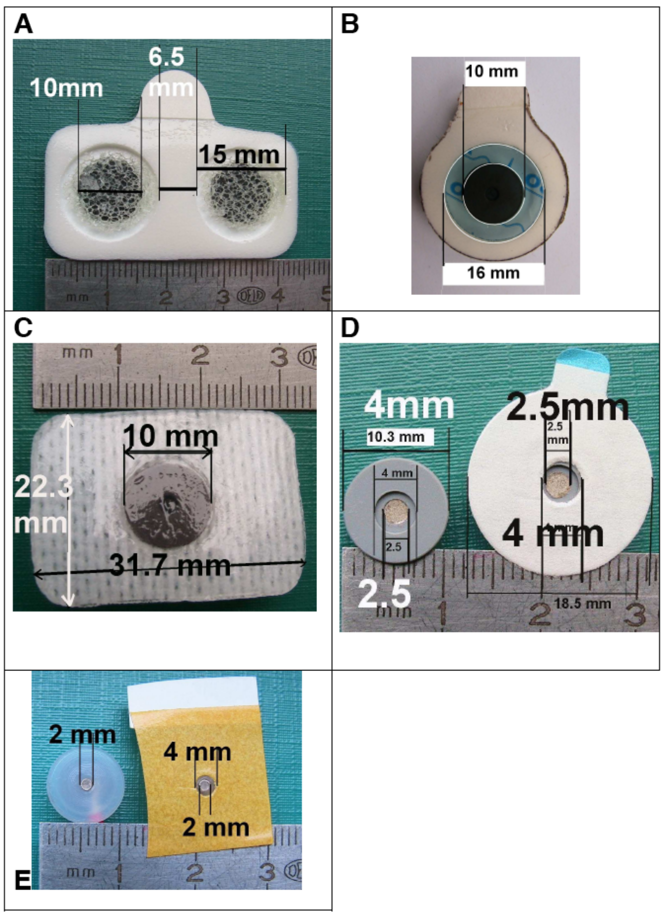


Fig. (1). View of electrodes the limits of the conductive gel is marked:
(**A**) Myotronics/Noromed: Norotrodes 20
(**B**) Tyco Healthcare: Kendall ARBO
(**C**) BEAC Biomedical: Easytrode
(**D**) Gereonics: Miniature skin electrodes
(**E**) TMS International: Miniature electrode with movement artefacts rejection
Electrode **A**: the conductive gel is larger than the Ag/AgCl part. The inter electrode distance is imposed. Stiffness of the support can generate movement artefacts and detachment of the electrodes.
Electrode **B**: Conventional pregelled and disposable ECG sensor wit a snap connector on its back.
Electrode **C**: the conductive gel is adhesive. It covers all the rectangular face of the electrode in contact with the skin. This type of electrode is not suitable for kinesiological EMG because of their lack of selectivity.
Electrodes **D** and **E** are reusable. They are attached to the skin with double side adhesive collar. Their well must be filled with conductive gel. A skin preparation decreasing the skin / electrode gel impedance is mandatory.

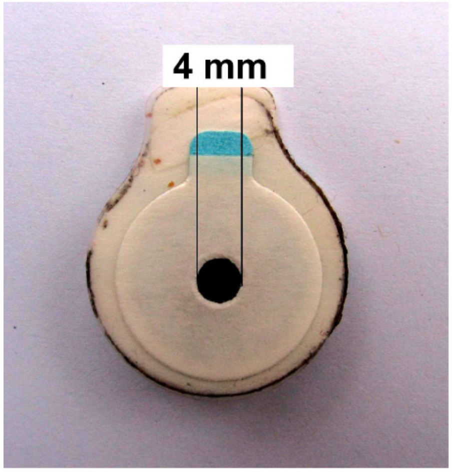


Fig. (2). Reduction of the conductive area of a ECG electrode. Interposition of double side adhesive reduces the original pregelled surface.

Remark: Trimming one side of the support of the electrodes decrease their adhesive surface therefore they are less stable and more prone to generate movement artefact under dynamic testing (wobbling muscles, gait, sports). Making a soft loop of the wire between the electrode and the snap connector minimises this adverse consequence.

With a single sine wave input, there is no difference between the three channels with respect to shape, phase (Fig. **3**), amplitude (Table **2**) and power spectrum of the recorded signals (Fig. **4**).

What would Happen in Real Situation of Recording True sEMG? The Difficulty is to Find a Source of sEMG Common to All Electrodes

On a healthy subject, we placed the same configuration of 3 sets of electrodes on the right rectus femoris because its muscular fibres are very long. The middle set (ECG* + collar 4 mm) was at 50 % of the distance between the Anterior Iliac Spine and the upper border of the patella. We hypothesised that

Table 2. The Output Signals are Identical for the Three Sets of Electrodes when the Electrodes Pick Up a Single Sine Wave

Electrodes	Sine Wave Amplitude [µV]	IEMG [µV]	RMS [µV]	ARV [µV]
ECG* regular	982	307	343	307
ECG* + COLLAR 4 mm	980	307	343	307
TMSI + COLLAR 4 mm	980	307	343	307

ECG* = Kendall ARBO Ref 31.1245.21.
IEMG = Integrated EMG = Envelope area/Duration.
RMS = Root Mean Square.
ARV = Averaged Rectified Value.

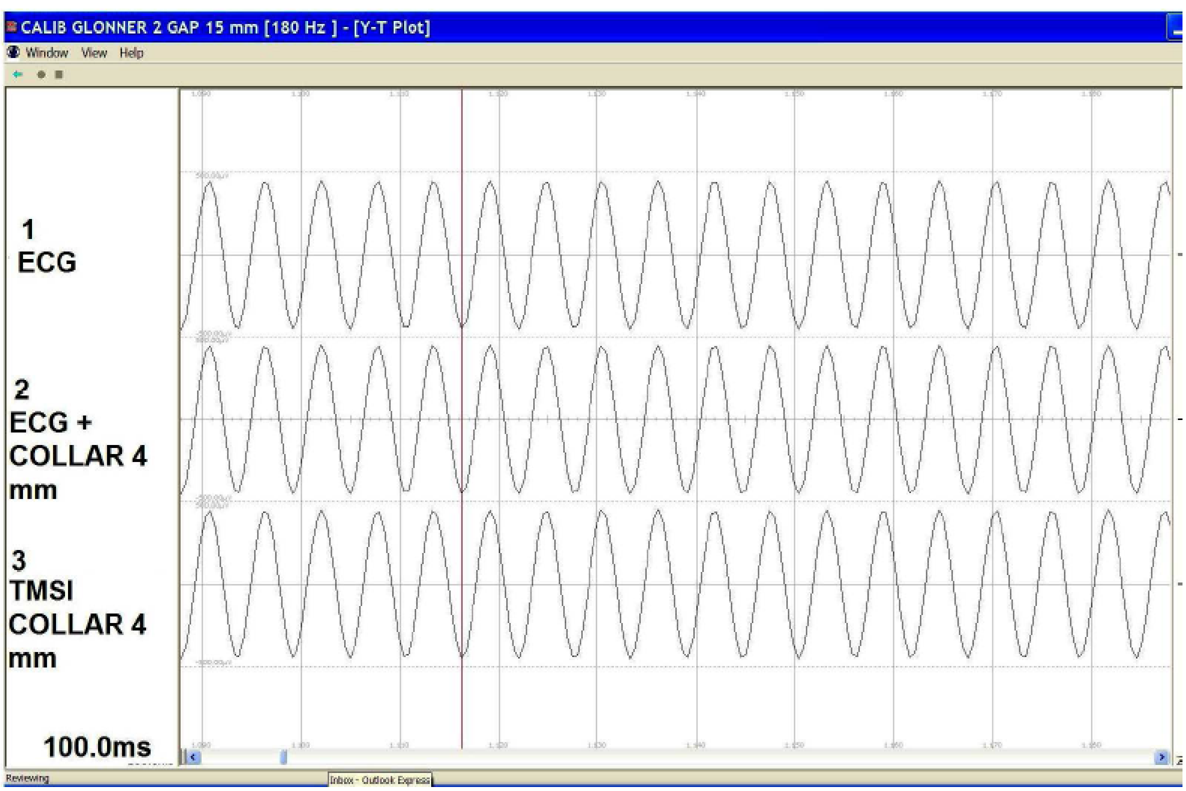


Fig. (3). Same sine wave detected by electrodes pairs of difference size, 15 mm gap between electrodes. No influence of the pick up area in this peculiar context. EmgEasyReport Version 4.4 screen copy.

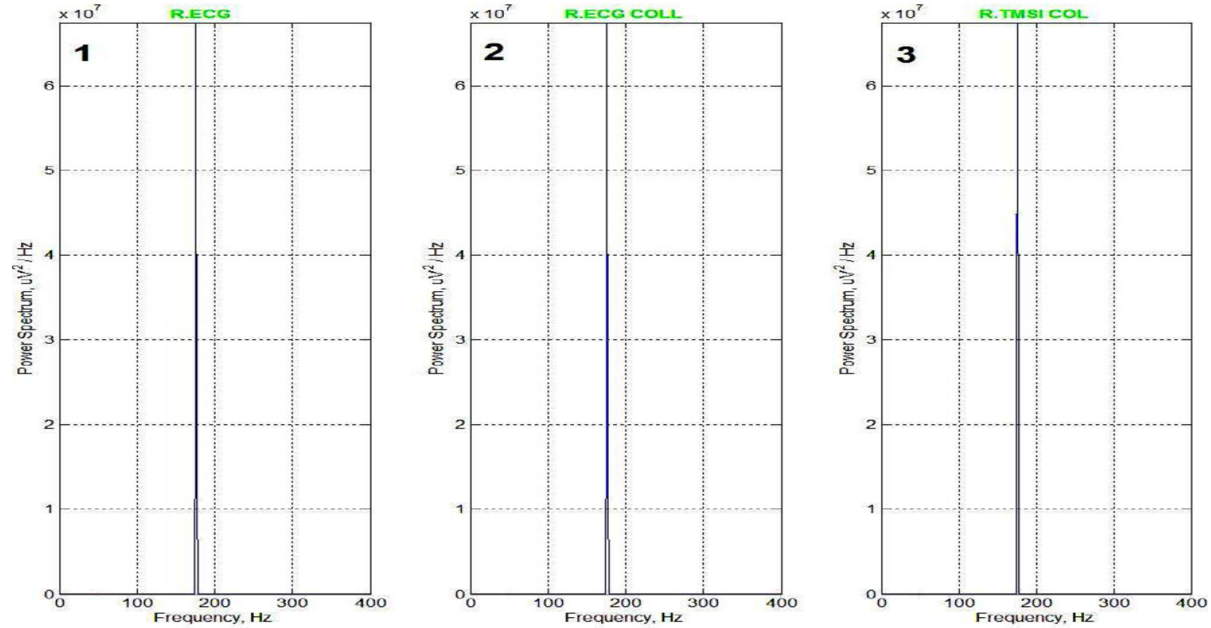


Fig. (4). Power spectrum of the signal of figure 2. No difference in amplitude nor in frequency which the frequency of the generator (160 Hz).

the same contraction should be picked up by the three sets of electrodes. Only the volume sensed by the electrodes would be different because of their different area of conductive gel. Regular ECG = Tyco Healthcare: *Arbo*. ECG collar 4 mm = Tyco Healthcare: *Arbo*.+ SensorMedics ref 650 455 Inter electrode distance = 15 mm. Bandwidth = 10-500 Hz. Sampling rate = 1024 Hz. We recorded:

1. Maximal isometric voluntary contractions of the quadriceps with the knee in full extension.

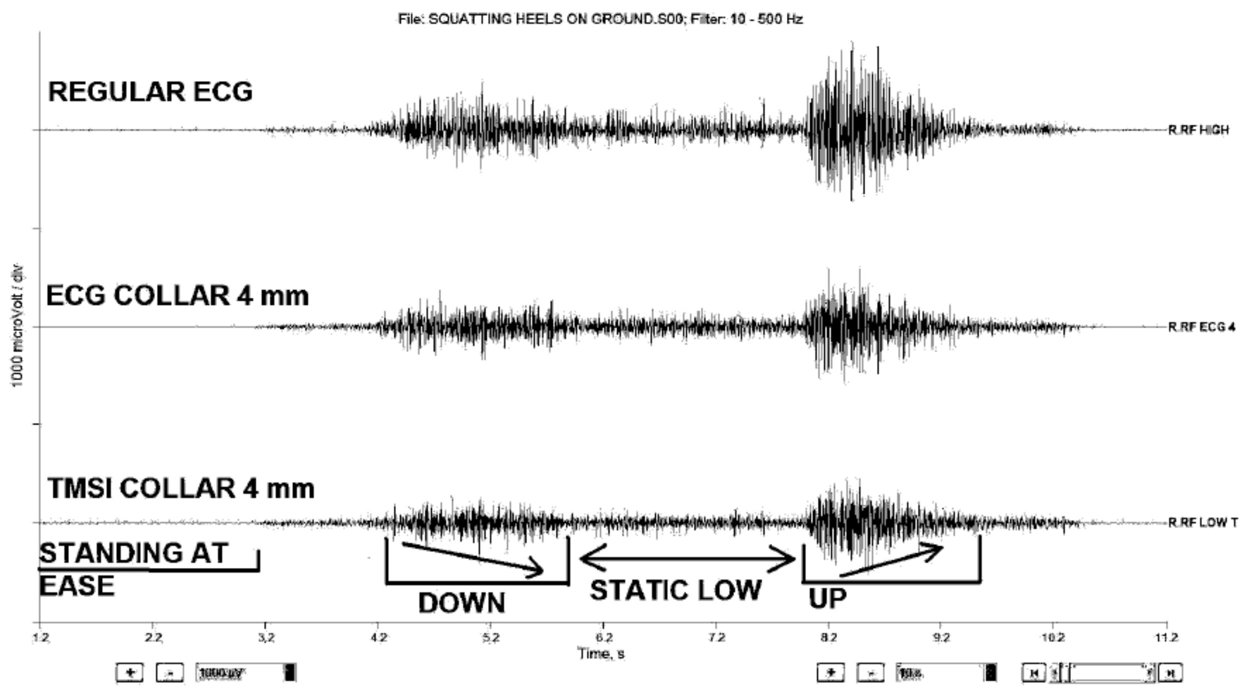


Fig. (5). Example of filtered EMG from 3 spots along the right rectus femoris of one trial when squatting with heels on the ground. ECG COLLAR 4 mm was on MCA of rectus femoris; REGULAR ECG was above, TMSI COLLAR 4mm below. While standing at ease no EMG was detected. From standing to full squat the rectus femoris acts in eccentric contraction while from full squat to standing it is a concentric contraction. Any muscle produce more EMG in concentric than in eccentric contraction. In full squat (knees in full flexion, "static low") the subject tends to lose his balance backward. The activity of the rectus femoris is probably to hold the pelvis. When the vastii are recorded as well, they are inactive in this position. It is obvious that the SEMG amplitude is linked to the pick up area of the electrodes. Reversing sets of electrodes got the same pattern in a reverse order. When pattern and amplitude are different if the heels are OFF the ground. EmgEasyReport Version 4.4 screen copy.

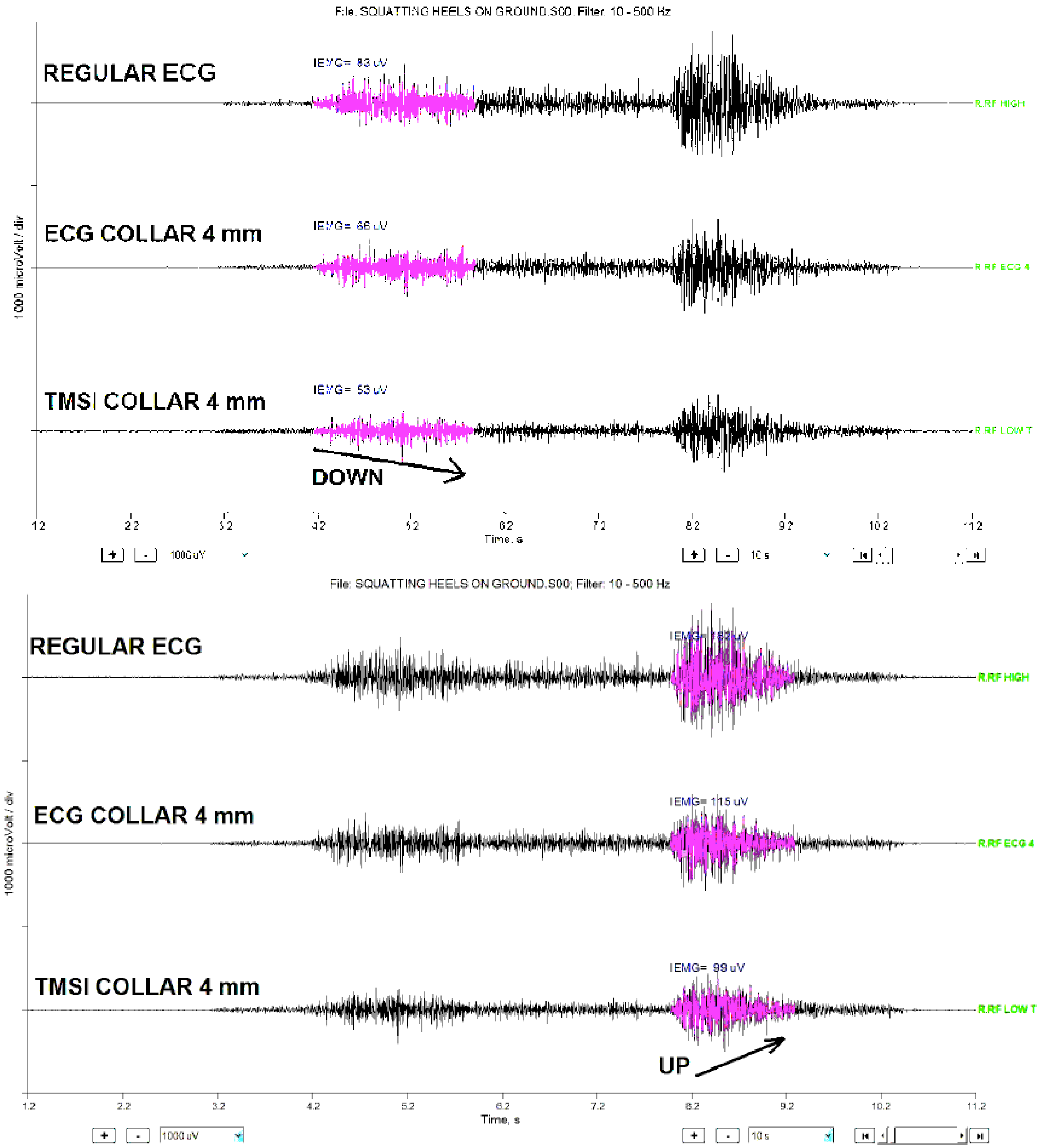


Fig. (6). IEMG computed during the pink periods, some duration for every channel.

2. Squatting with heels ON and OFF the ground (Figs. **5**, **6**).

In all situations, the greatest sEMG amplitude is linked to the largest surface of conductive gel in contact with the skin (Table **3**). The output signals have different amplitudes and frequency contents (Fig. **7**). Ag/AgCl site is also determinant when the area of conductive gel is equal. Shift of the power spectrum towards higher frequencies is not obvious with miniature skin electrodes.

Example of different EMG patterns when the subject squats down with both heels on the floor (foot flat) and then with heels off the floor (on fore foot) (Fig. **8**). Keeping heels on the floor creates a posterior imbalance of the trunk thus rectus femoris is active when the subject is steady in full squat. This isometric contraction probably controls the flexion of the pelvis. *(TMSIPortLab2 screen copy).*

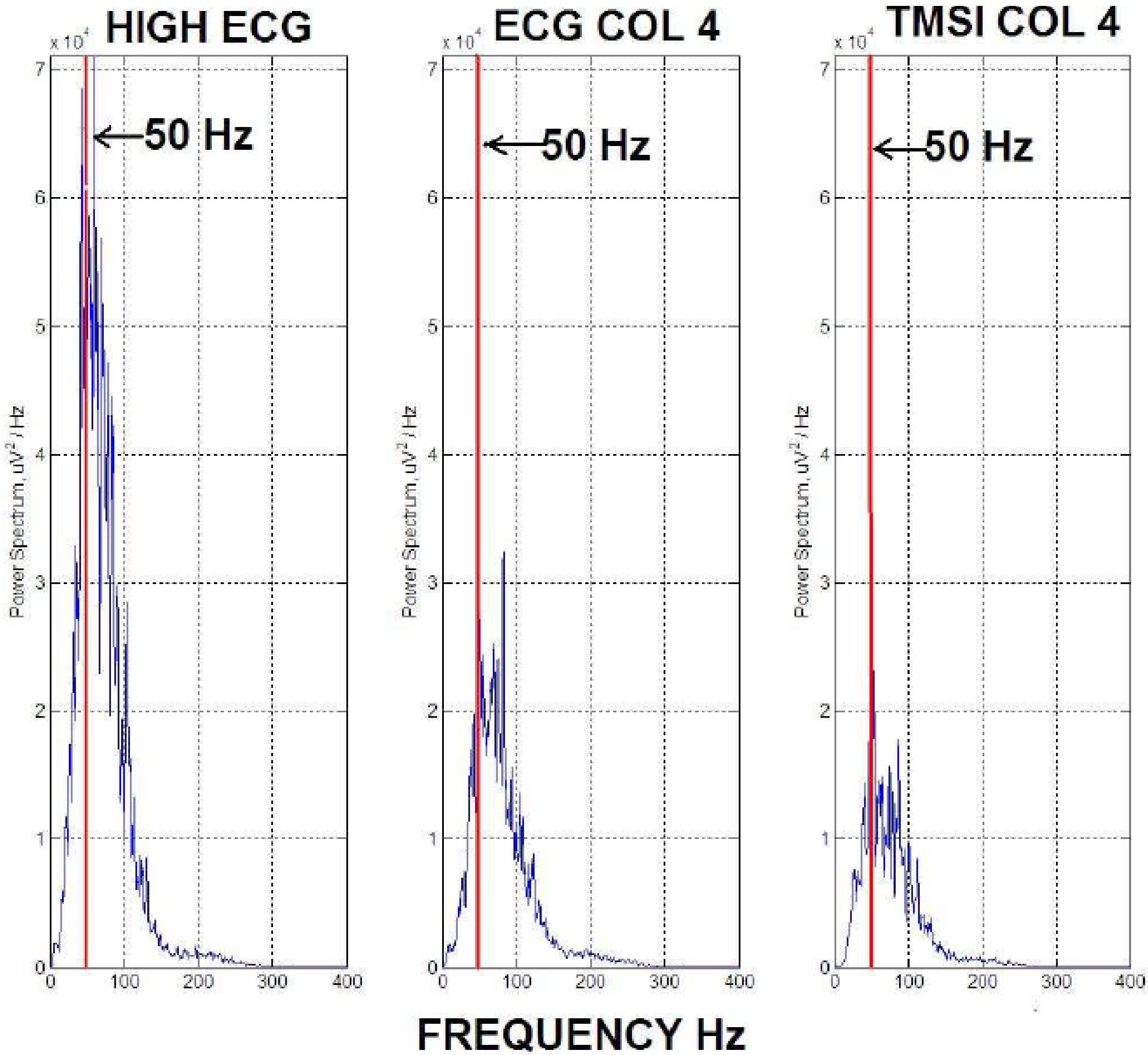


Fig. (7). Frequency analysis: Power spectrum its amplitude depends on the amplitude of the sEMG. The shift toward higher frequency is not obvious may be because the inter electrode gap was the same.

Table 3. Integrated EMG (Same Epoch Duration for All Channels) During Squatting with the Heels on the Ground. The Double Side Adhesive Collar Interposed Between the Electrodes and the Skin Reduces the sEMG Amplitude, which Means that the Volume Recorded is Smaller than the Regular ECG Sensor

Channel	Down IEMG [µV]	Up IEMG [µV]
Regular ECG	83	182
ECG + collar 4 mm	66	115
TMSI + collar 4 mm	53	99

Does a "clean sEMG signal" means an accurate and reliable signal? (Fig. **9**). NO. A "clean sEMG" is a signal free of artefact. An accurate and reliable signal is a signal recorded only from the target muscle.

Where to place the ground or reference electrode? Traditionally, it is recommended to "*place the reference electrode on the skin over a bone which is electrically a neutral zone*". This statement is unverified. The skin over any bone is not electrically neutral it is part of the volume conduction of the muscles in the vicinity (Fig. **10**). A pair of TMSI electrodes stuck on the skin of the medial side of the tibia bone picks up sEMG signals. They are pure crosstalk. They represent a summation of signals from tibialis anterior and plantar flexors. It is possible to recognize the phase of the original signals (Figs. **11**, **12**).

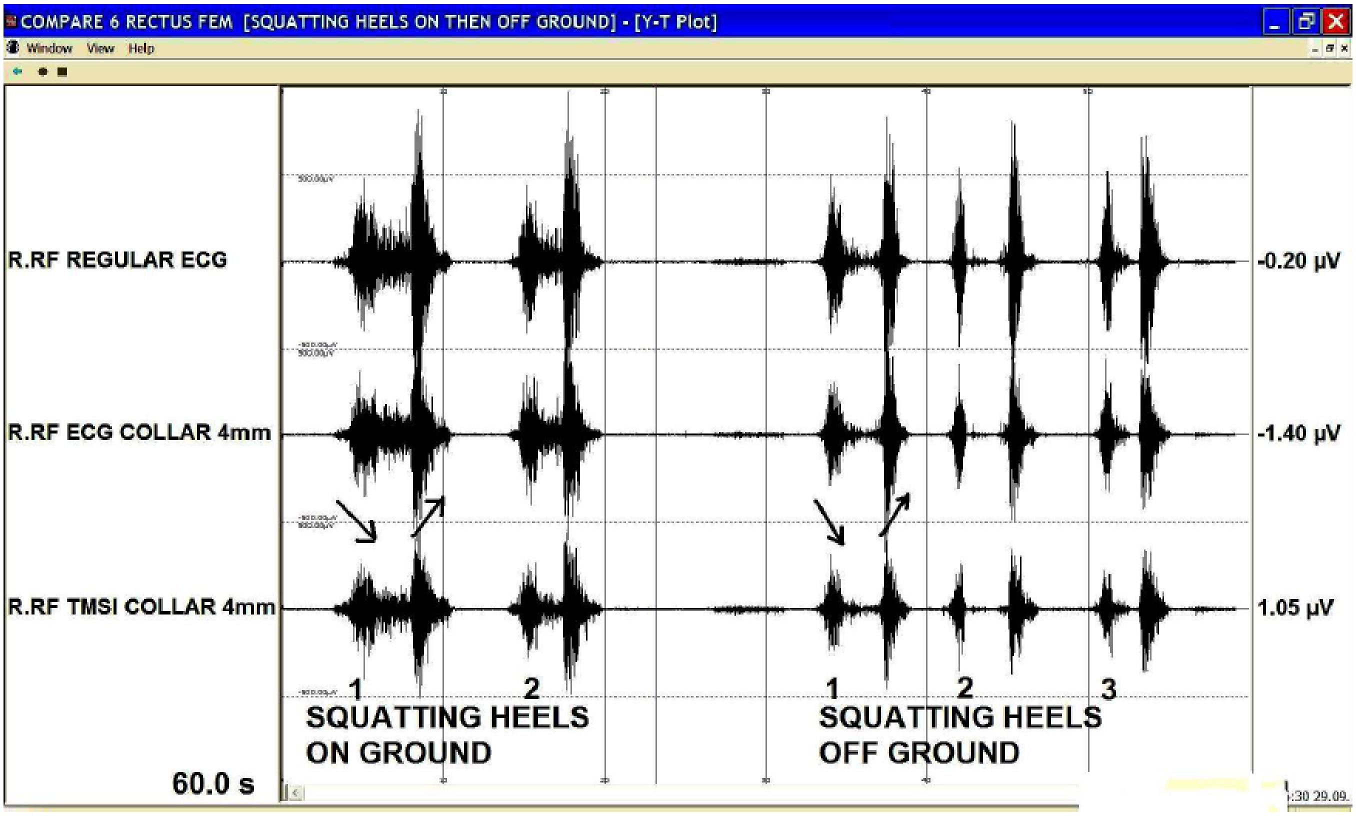


Fig. (8). Full squatting from standing at ease and back. Two first trials with heels on the floor. Three last trial with heels off the floor. The position of the heels induces a different pattern of movement and therefore a different sEMG pattern. In full squat with heels off the rectus femoris exhibits little or no activity.

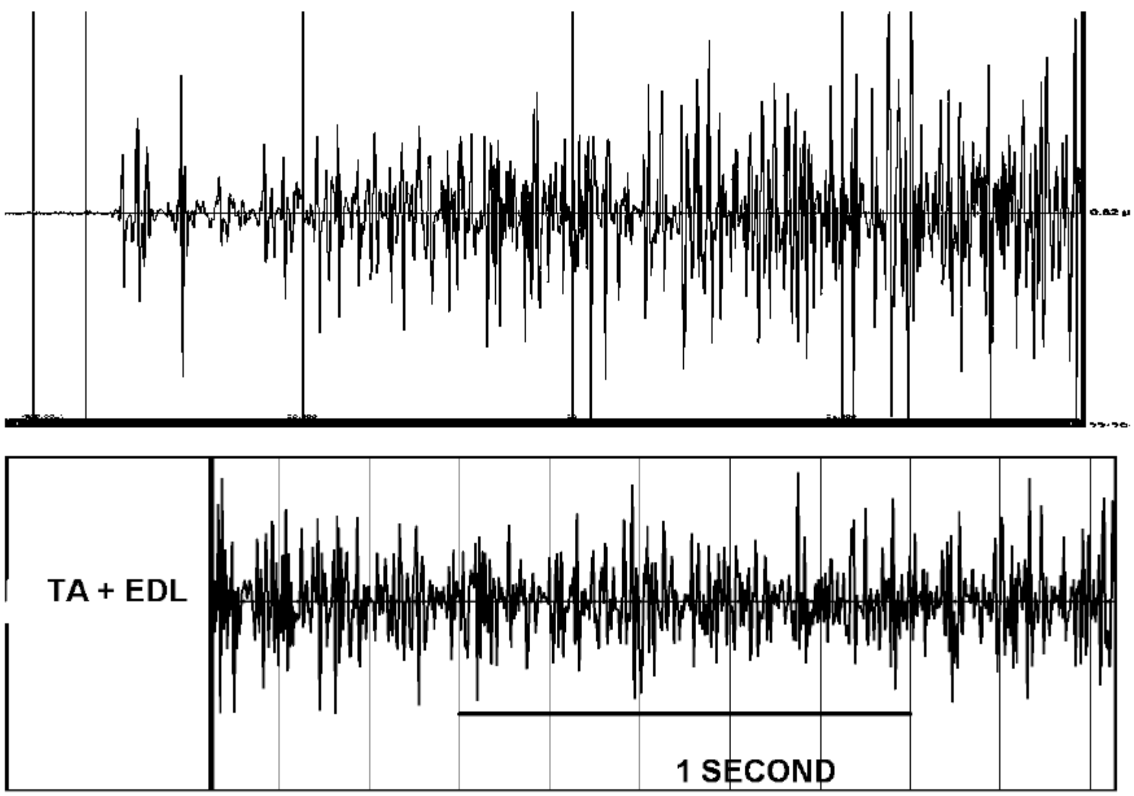


Fig. (9). A "clean sEMG signal" does not mean a reliable signal. These ones are free of artefact but it represents a sum of signals from tibialis anterior and extensor digitorum longus. In gait this error is undetectable because both muscles have a very similar sEMG timing. In this situation SEMG cannot be named "crosstalk" because it is the result of misallocation of the electrodes.

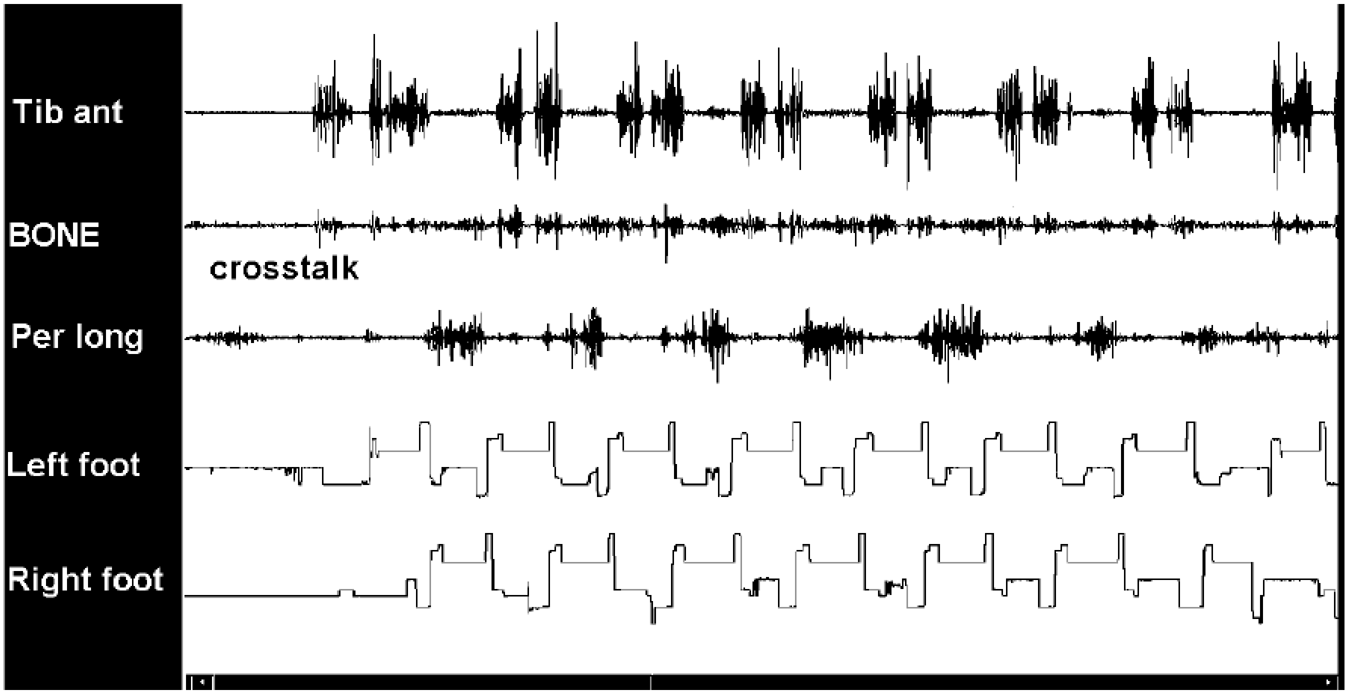


Fig. (10). Subject walking, three channels of EMG and foot switches. Tib ant = tibialis anterior. Bone = skin over the medial face of the tibia. Per long = peroneus longus. The signals recorded over the tibia are true cross talk. The skin over the tibia is not electrically neutral.

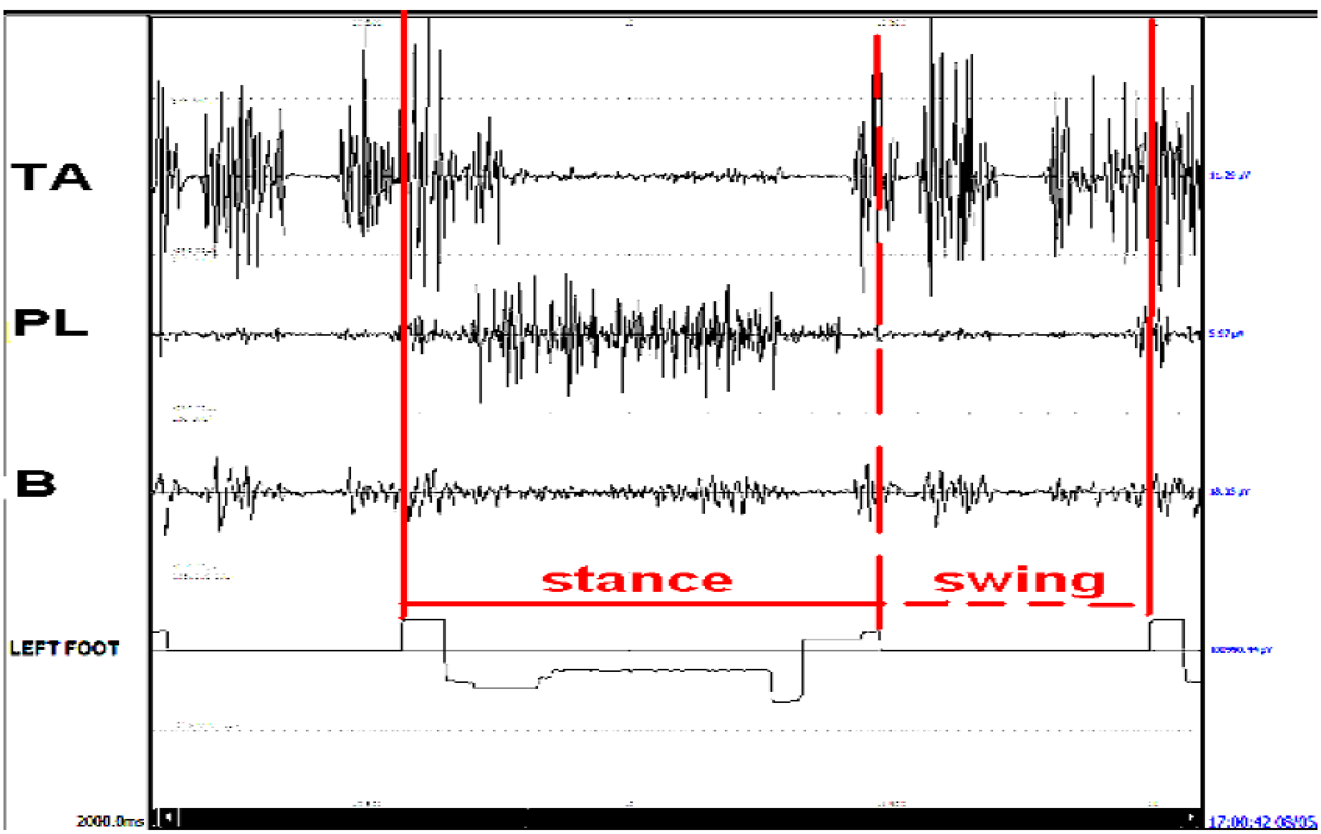


Fig. (11). Same set up as Fig. (**10**). Here "B" means "Bone". It is possible to recognize the burst of the tibialis anterior. The amplitude is decreased because the distance from the source and the filtering effect of the skin and other soft tissue.

Does the Coefficient of Correlation Help to Recognise Crosstalk? We recorded, in parallel, sEMG of tibialis anterior of two subjects standing on their heels with a supination of the fore foot. This movement depends on the tibialis anterior. We computed the coefficient of correlation (CC) between their tibialis anterior. As expected it is very

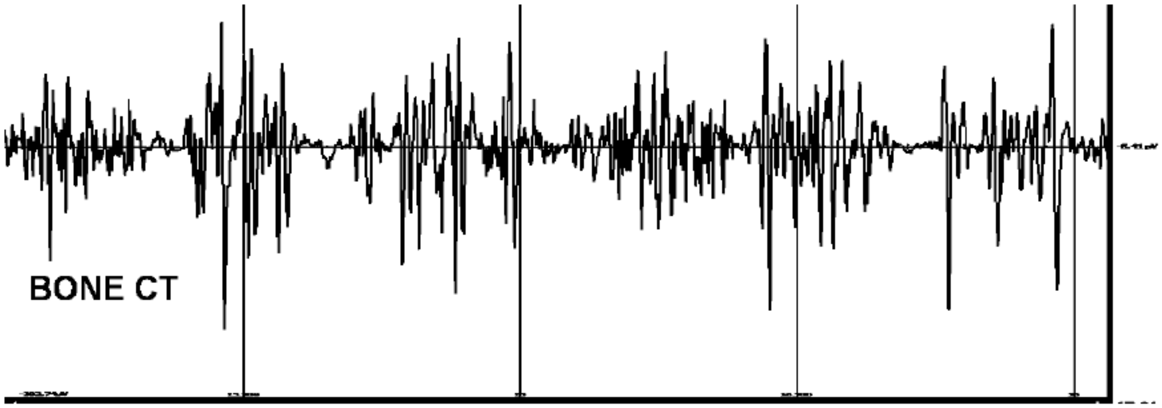


Fig. (12). Phasic cross talk.

low 0.02, this value is interpreted as no relationship between the two muscles (Fig. **13**). This is not surprising but it is a reference to compare other CC. Then from subject 1 the CC was computed between tibialis anterior and its crosstalk on bone. The CC = 0.07 (Fig. **14**). This means that no correlation was detected yet the crosstalk originates from the tibialis anterior. The coefficient of correlation does help to recognise crosstalk [3-5].

Crosstalk Between Muscles

"Crosstalk" is an unwanted signal picked up over a non-contracted muscle or added by co-contracted muscle(s). In reality, noise and crosstalk often contaminate more or less the recorded sEMG. Our main aim is to reduce noise and crosstalk to ensure selectivity and consequently fidelity of the sEMG. Reduction of noise is the "easiest" task. Differential amplifiers with a Common Mode Rejection Ratio (CMRR) superior or equal to 110 dB, proper skin preparation, no microphonic effect of the wires between the electrodes and their pre amplifier are major keys to success. Crosstalk is still an unsolved problem. De Luca and Merletti [3] warned us about its effect on interpretation: *"Myolelectric signals are generated by active muscle fibers. Associated with the action potentials carried out by active muscle fibers are action currents which flow throughout the volume conductor. The action currents reflect the presence of an electrical potential field which pervades the volume conductor and which may generate a signal detected by electrodes placed at some distance from the source. Such a signal may be erroneously interpreted as generated by muscle fibers underneath the detection electrode and is usually referred to as crosstalk.*

Crosstalk evaluation is of paramount importance when surface myolectric signals are used to identify the activation of a superficial muscle during static or dynamic contractions. In gait analysis, for example, surface myoelectric signal is often associated to kinematics in order to relate muscle activity to the biomechanical variables that describe the movement. In this case, crosstalk may induce erroneous results, as the signal detected over a particular muscle could be due in part to the activation of another muscle, synergistic or antagonist. It is therefore that data related to co-contraction of different muscles may be corrupted by the presence of crosstalk... ".

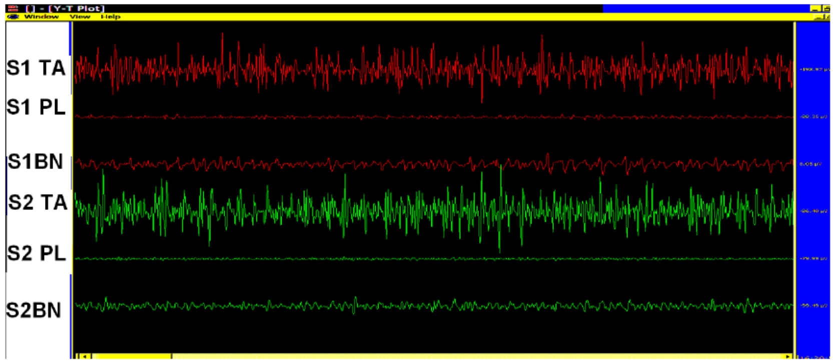
Minimal Crosstalk Area (MCA)

Basmajian & Blumenstein [6, 7] introduced the concept of "Minimal cross talk area". For most superficial muscles, they experimentally defined a surface where crosstalk versus co contraction is minimal. All the described areas have been selected with miniature skin electrodes with an Ag/AgCl sensitive area of 2.5 mm and a double side adhesive collar of 4 mm in diameter. Inter electrodes distance was 15 mm from centre to centre. Their axis was parallel to the direction of the underlying muscle fibres. They are spotted with respect to distance and direction from anatomical landmarks. Only superficial muscles are accurately accessible to sEMG. EMG activity of deeper muscles can interfere with the sEMG of an overlaid muscle and produces crosstalk.

In the early '80s, we have repeated Basmajian & Blumenstein method of experiment including children, teenagers and elderly in the population. An array of electrodes was stuck over the area defined by Basmajian (Fig. **15**). With his method of selective electrical stimulation, Duchenne de Boulogne [8] had determined the various components of movements (specific movement) of most superficial muscles during isolated contraction. His descriptions were the basis of the "specific movement" of each muscle. We added the specific movements (actions) from the different bundles of large muscles i.e. latissimus dorsi, pectoralis major, trapezius, vastii, deltoïdeus, rectus abdominis, calf, etc.

Motor points used by Duchenne de Boulogne or referenced by physiotherapists for muscular electrical stimulation (faradisation) do not correspond to MCA. Not all muscles accessible by trans cutaneous electrical stimulation can be registered with sEMG. For example, tibialis posterior, vastus intermedius contract under conventional faradisation or with electrical currents interferences but we cannot record them with surface EMG, only with implanted electrodes (fine wires).

We recorded the level of electrical noise from each EMG channel with the subject at rest. After teaching and training every subject to perform specific movement for each muscle, we recorded the sEMG during dynamic and isometric contractions with and without maximal manual resistance. We computed Root Mean Square (RMS) for 2 seconds during a maximal isometric voluntary contraction against manual resistance. The pair of electrodes recording -1- the maximal RMS during specific movement of the scrutinised



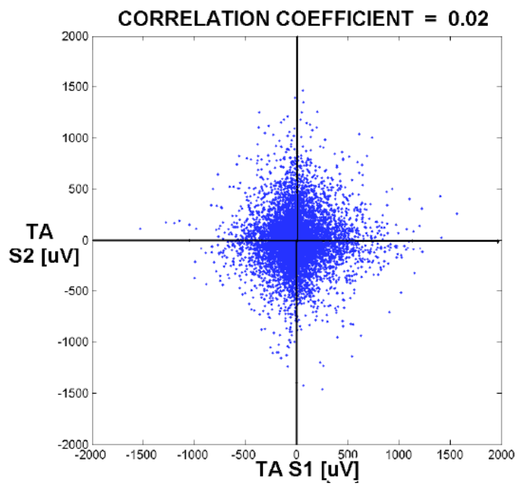
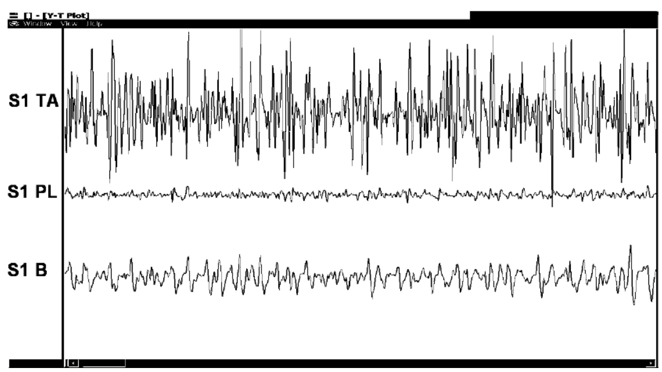


Fig. (13). Red sEMG signals are from subject A, green signals are form subject B. they were recorded in parallel while both subjects were standing on their heels. Coefficient of correlation = 0.02 between tibialis anterior of subject 1 and 2.



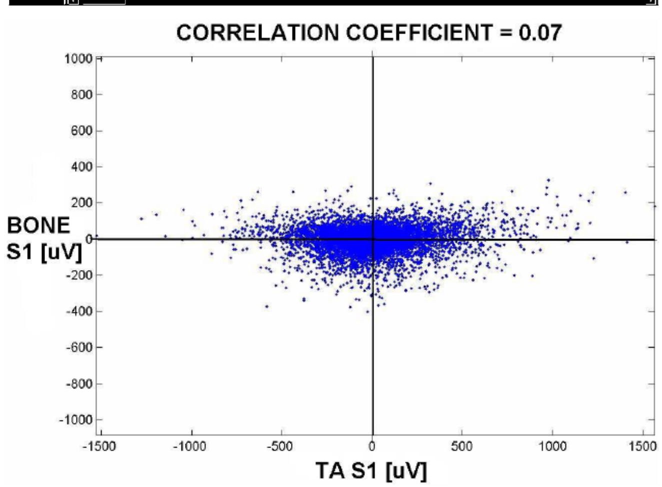


Fig. (14). Subject 1 standing on heels. Coefficient of correlation = 0.07 between c tibialis anterior S1 TA and crosstalk bone S1 B.

muscle and -2- the minimal RMS during antagonist and synergistic movements was considered to be over or the closest the MCA (Figs. **16**, **17**). Then its position was marked with respect to anatomical landmark. Sex, age, morphological characteristics did not modify each location of MCA. From Basmajian [6], extensor digitorum longus (Fig. **18**), biceps femoris long head and soleus were our greatest changes. Examples of typical sEMG patterns and specific movements for muscles of the leg (Figs. **19-23**) and validation with fine wires for peroneus brevis and extensor digitorum longus (Fig. **24**).

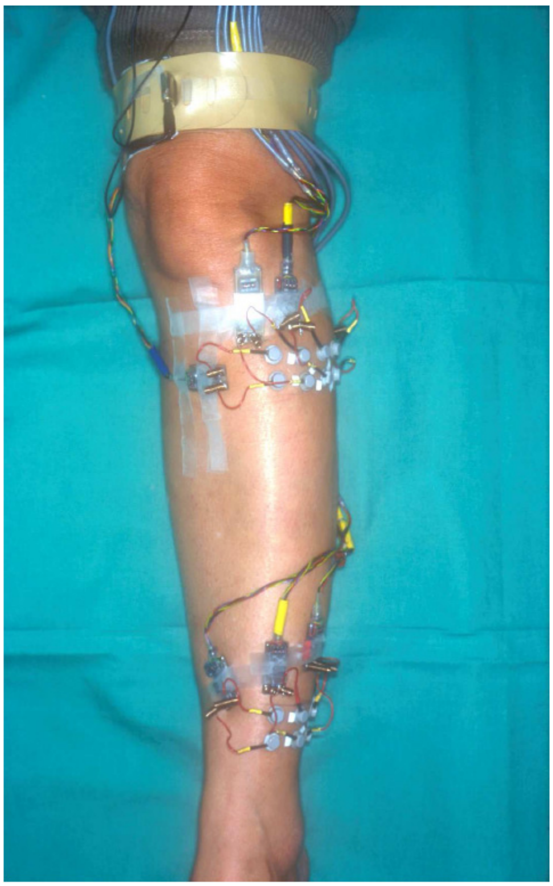


Fig. (15). Overview example of two arrays of electrodes to localise MCA of peroneus longus and peroneus brevis.

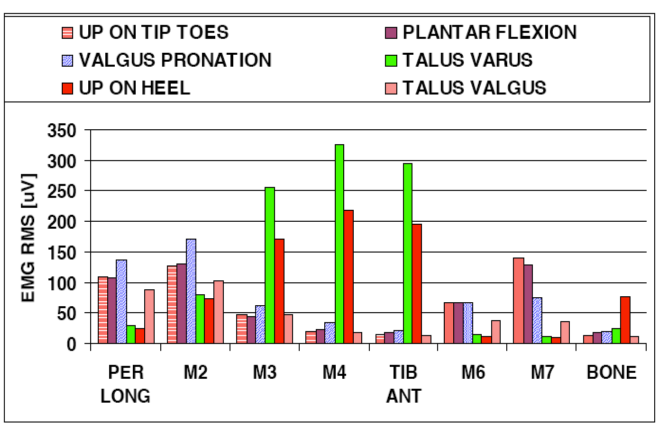


Fig. (16). Histogram of RMS sEMG all exercises tested and electrodes location tibialis anterior versus extensor digitorum longus and peroneus longus. Position M5 was selected as the best position for tibialis anterior.

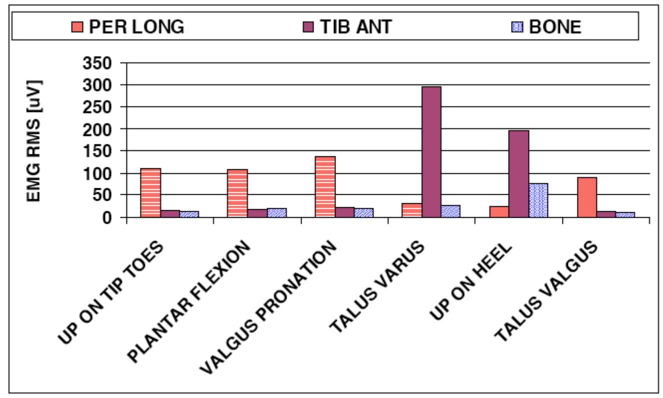


Fig. (17). Talus varus is the most specific movement for tibialis anterior. SEMG of tibialis recorded during the other movements was labelled crosstalk.

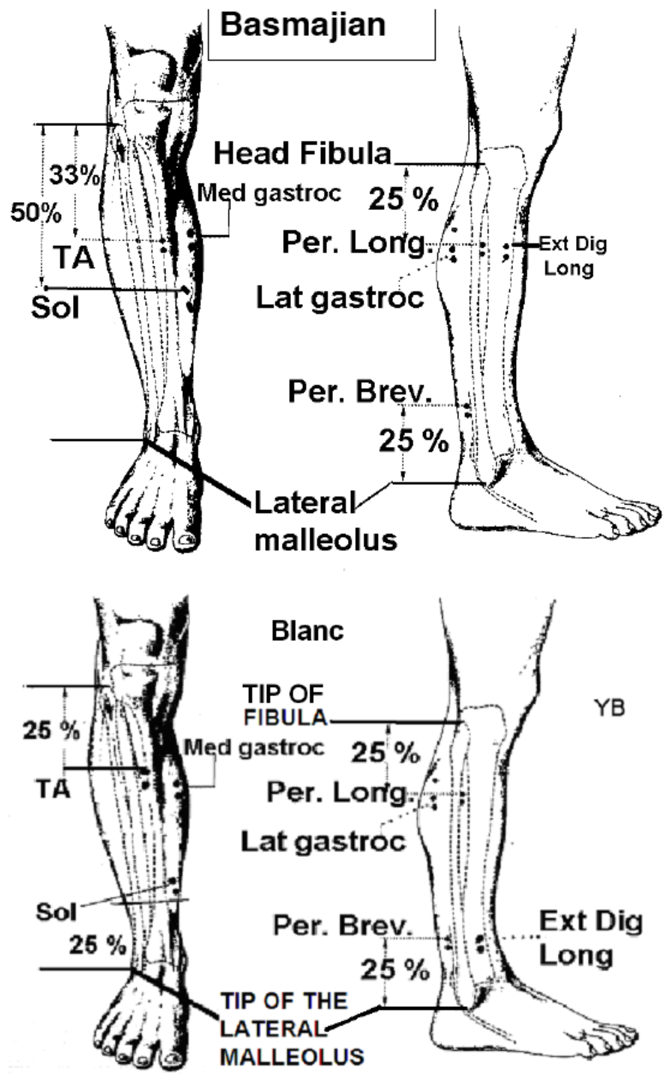


Fig. (18). Basmajian and our MCA for muscle of the leg. Length of fibula is the reference for all muscles.

We introduced the MCA of the vastus medialis horizontal (Fig. **25**). Examples of typical patterns during specific movements showing the selectivity of vastus lateralis, rectus femoris, tensor fascia latae, semi membranosus + semi tendinosus and biceps femoris (Figs. **26-29**).

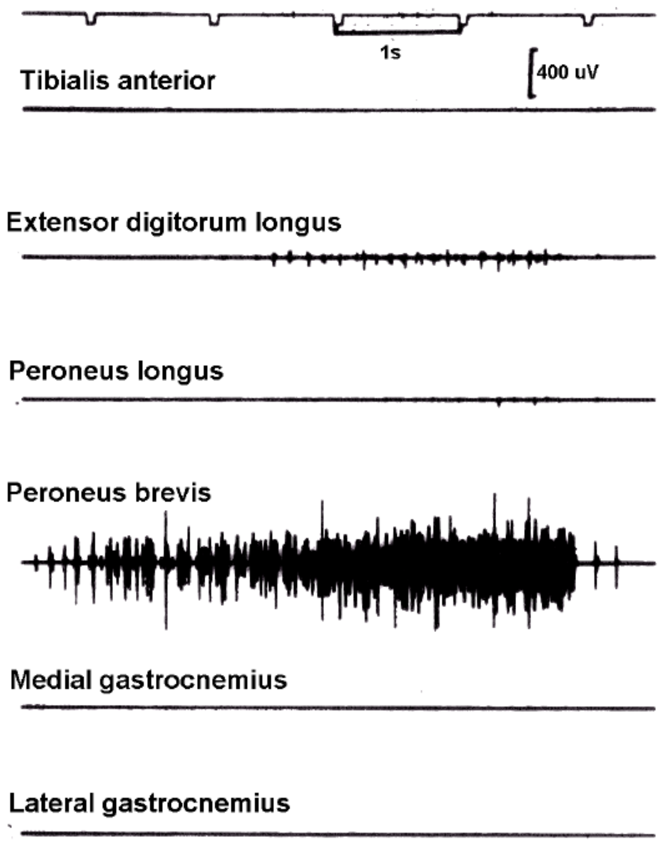


Fig. (19). Typical pattern of sEMG during the specific test for peroneus brevis: foot supported in about 5° of plantar flexion displacement of the fore foot like a windshield wiper without toe extension and pronation of the fore foot.

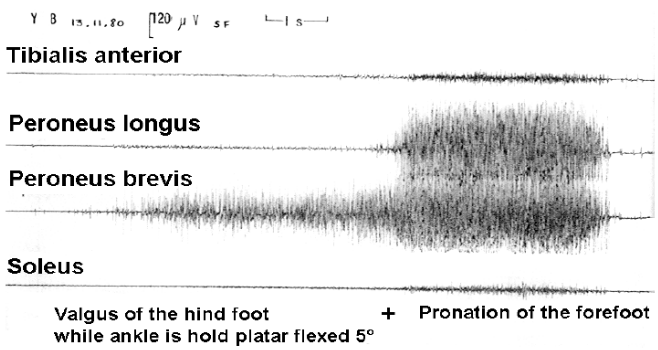


Fig. (20). Difference peroneus brevis - peronus longus.

IMPORTANT: "minimal cross talk areas" ARE NOT VALIDATED for ECG ele minimal cross talk areas ctrodes. Enlarging electrodes diameter and / or gap should increase the volume of muscle tested and consequently the risk of cross talk. Actually there is no index or coefficient, which gives the level of cross talk or the ratio of cross talk versus co-contraction. This valuation is based only on clinician's expertise and the equipment available. These facts are to be kept in mind when one evaluates children, upper extremity, face and in general short individuals.

Directing the axis of electrodes parallel to the general axis of muscles fibres increases selectivity. However there are two exceptions: gluteus medius and upper layer of gluteus maximus where electrodes are perpendicular to the

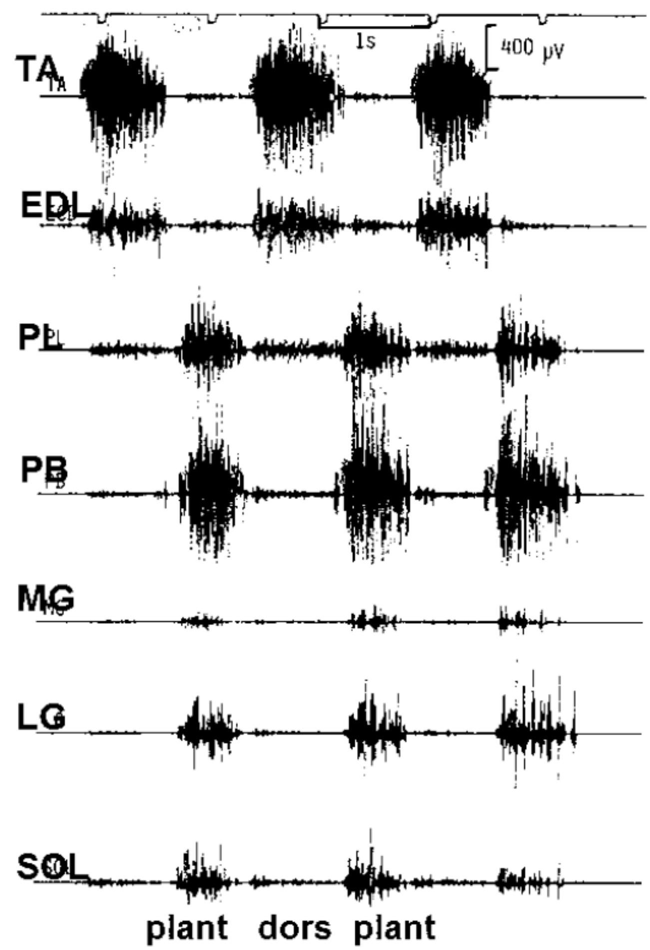


Fig. (21). Alternate dorsi and plantar flexions. sEMG between bursts are crosstalk.

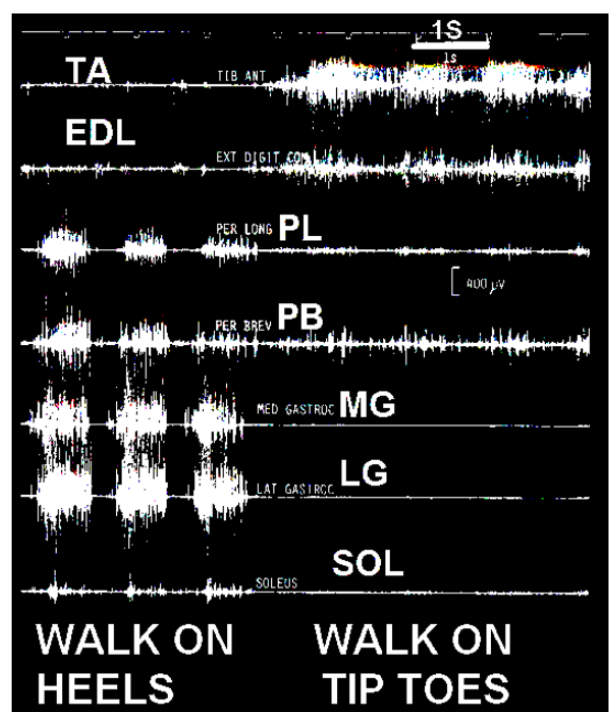


Fig. (22). Typical sEMG pattern of a subject walking on tiptoes then on heels.

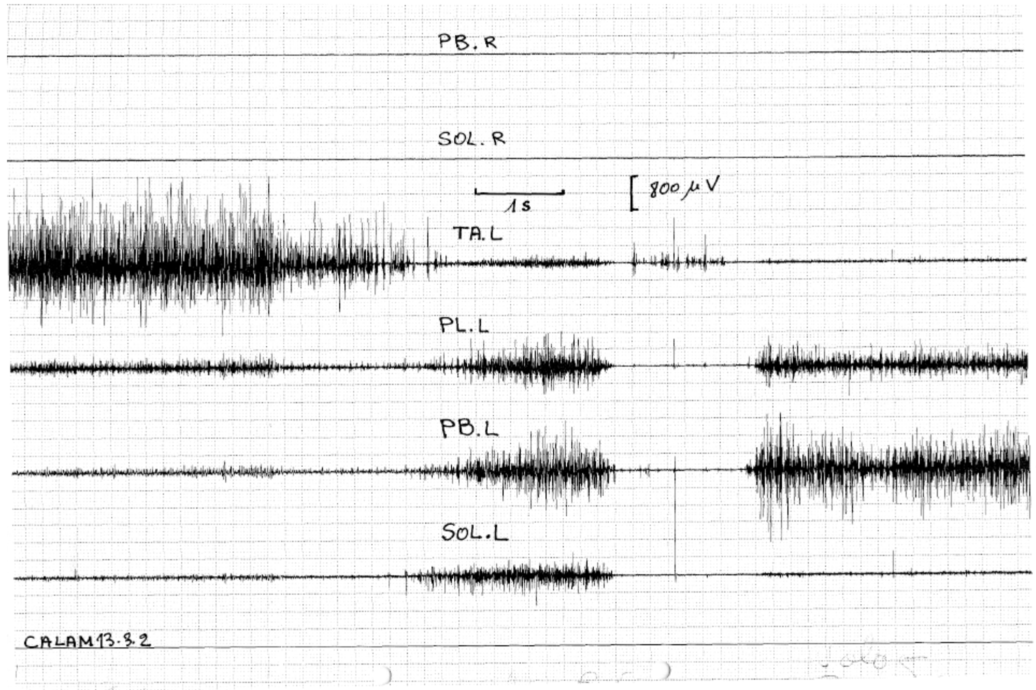


Fig. (23). Difference between tibialis anterior, peroneus longus and brevis, soleus. Tibialis anterior: supination of the fore foot. Peroneus longus and brevis, soleus: plantar flexion. Peroneus longus and brevis: pronation of the fore foot + abduction.

muscle fibres because during gait there is a wave of contraction starting backwards at initial foot contact and moving forward until the end of loading response. When electrodes axis are across the direction of muscular fibres this corresponds to a spatial summation. Therefore, we record a global picture of their sEMG. The side advantage is to use only one recording channel. Campanini *et al.* [9] recorded five muscles of the leg of 10 normal adults walking at their comfortable speed with matrix of ECG electrodes spaced out 2 cm apart. From EMG envelope they concluded "*... the estimate of muscle activation intensity during gait from surface EMG is variable with location of the electrodes while timing of muscle activity is more robust to electrode displacement and can be reliably extracted in those case in which crosstalk is limited.*" Unfortunately, they did not consider crosstalk versus co-activation especially between peroneus longus and the three components of the triceps surae. They confirmed that Basmajian's MCA were the best locations when looking at EMG timing during gait. The time of the peak(s) amplitude within each burst(s) is also extremely important to recognize EMG errors of timing of pathological gait [10].

1- Bony Landmarks

This chapter requires a fair knowledge of surface anatomy to precisely locate, palpate tendons and bony landmarks. Precise location and measurements of distance between two bony landmarks are the keys to find the "minimal cross talk area" of the targeted muscle.

1. Anterior Iliac Spine (A I S)
2. Second sacral vertebra (S2)
3. Greater trochanter
4. Upper border of the patella
5. Gerdy's prominence: bony protuberance on which is inserted the ilio tibial tract of the muscle Tensor Fascia Latae (TFL). It is almost halfway between the head of fibula and the anterior tuberosity of tibia on which the tendon of quadriceps femoris (patellar tendon) attaches.
6. Knee medial joint space: gap between medial condyle of femur and medial condyle of tibia in front of the tibial collateral ligament
7. Apex of the head of fibula, not the most bulky part.
8. Apex of the lateral malleolus, not the most bulky part.

2- Distance Measurements

1. A I S to upper border of the patella
2. A I S to Gerdy prominence
3. A I S to knee medial joint space
4. Apex of head of fibula to apex of lateral malleolus

3- Skin Preparation to Reduce the Skin-to-Electrode Impedance

The following steps are highly recommended even if electrodes larger than miniature skin electrodes are used. Most manufacturers of ECG electrodes do not advice to lower the skin impedance but in dynamic conditions high skin impedance increases the level of noise (especially movement artefacts):

1. If the skin is dry with a thick layer of dead cells (epidermis):
   - ✓ For a few minutes place a piece of tissue soaked with water on MCA of the target muscle

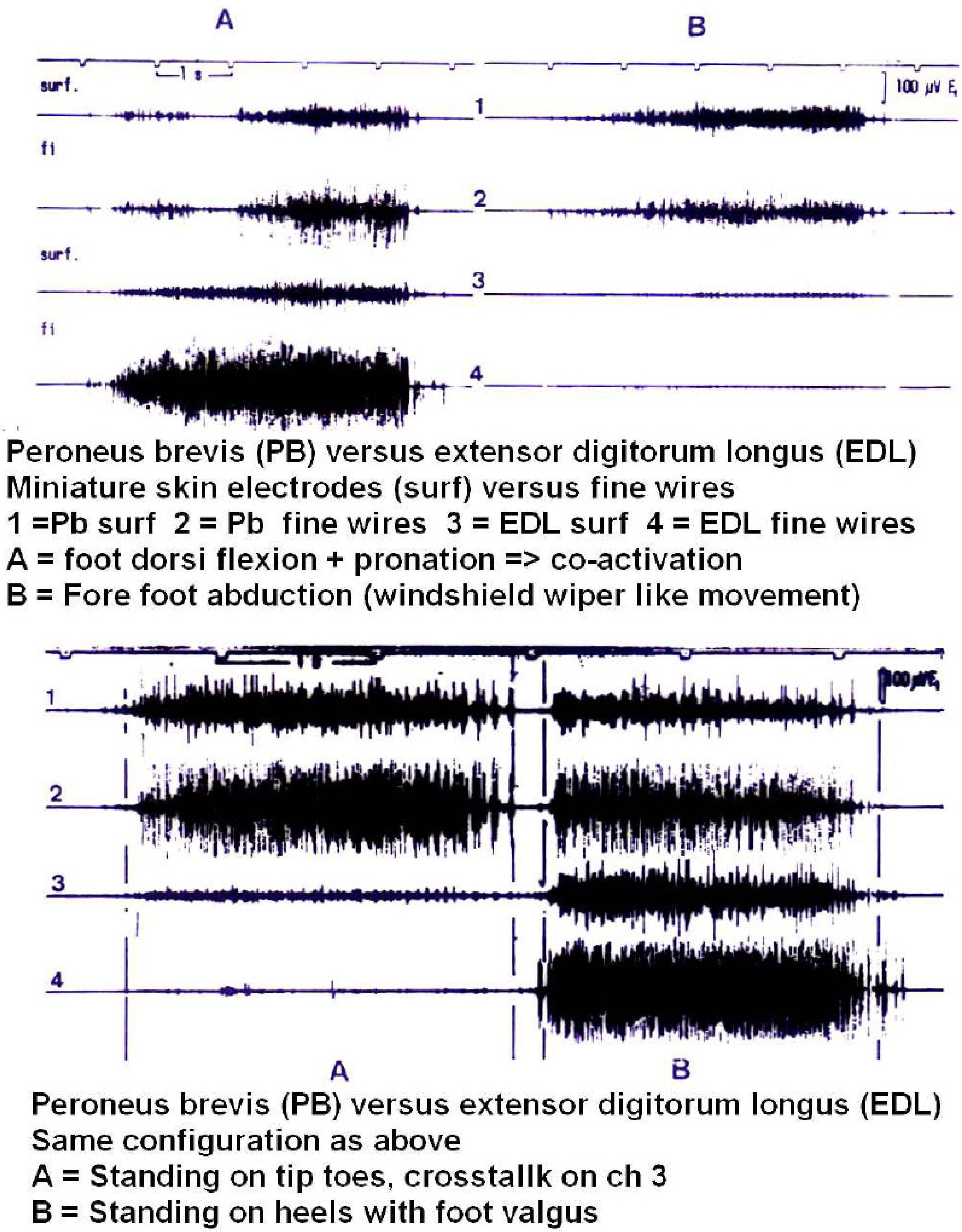


Fig. (24). Validation of MCA of Peroneus brevis (Pb) versus extensor digitorum longus (EDL): comparison of sEMG from miniature skin electrodes and fine wires. Both muscles are involved in many movements of the foot and fore foot. Peroneus brevis is active in plantar flexion of the foot in co-contraction with all the other plantar flexors and in synergy with EDL during fore foot pronation and / or foot valgus.

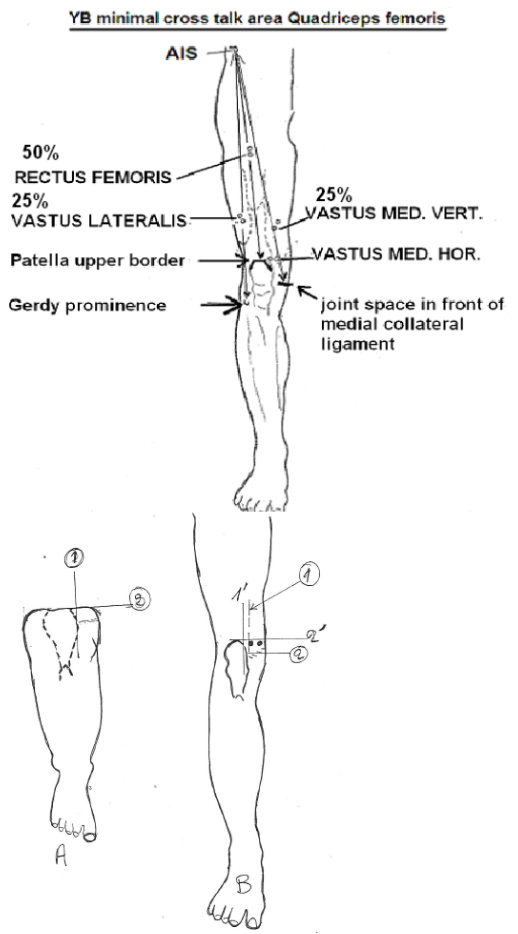


Fig. (25). MCA of the quadriceps femoris. Rectus femoris: landmark 50% of the distance between AIS and upper border of the patella hip 0°, knee 180°. Vastus lateralis lower 25% between AIS and Gerdy prominence. Vastus medialis vertical part: lower 25% between AIS and knee joint space in front of the anterior border of the medial collateral ligament. Vastus medialis horizontal part: a rectangle delimited by tangents to the medial side and the upper border of the patella with the knee in full extension then in flexion 80°.

2. If the skin is oily
   - ✓ Rub it with alcohol
3. Whatever the skin condition keep the skin impedance as low as possible
   - ✓ 1- Rub the skin with a "Q-tip" to remove skin dead cells
   - ✓ 2- With the "Q-tip" rub in some conductive gel
   - ✓ 3- Dry the skin very carefully where you will stick the electrode.

4- Reference Electrode. Conventional Differential Amplifiers

Traditionally we recommend placing the reference electrode (synonym: ground or neutral electrode) on a *"skin area unrelated with the muscle(s) under investigation"*. Many investigators consider that skin over a bone is *"the best place"*. We have already discussed this statement that is not verified due to the*" volume of conduction"* generated by active muscles. The skin over a bone (i.e. tibia, patella, malleolus) is not electrically neutral. Skin electrodes over bones record true crosstalk signals. A rule of thumb for the recommended area of the reference electrode = 10 times the area of detecting electrode.

Recent EMG devices do not need reference electrodes but both electrodes should have the same impedance.

CONCLUSION

Selectivity of electrodes assessed by specific movement for every recorded muscle is mandatory to estimate accuracy and reliability of sEMGs as help in clinical decision-making. sEMG patterns during voluntary tests or reflex movements are the references to estimate crosstalk versus co-contraction. Minimal crosstalk and specific crossed exercises help in deciding if the signal represents co-contraction or is contaminated by crosstalk. We must remember that unrecorded muscles can generate these questioned signals.

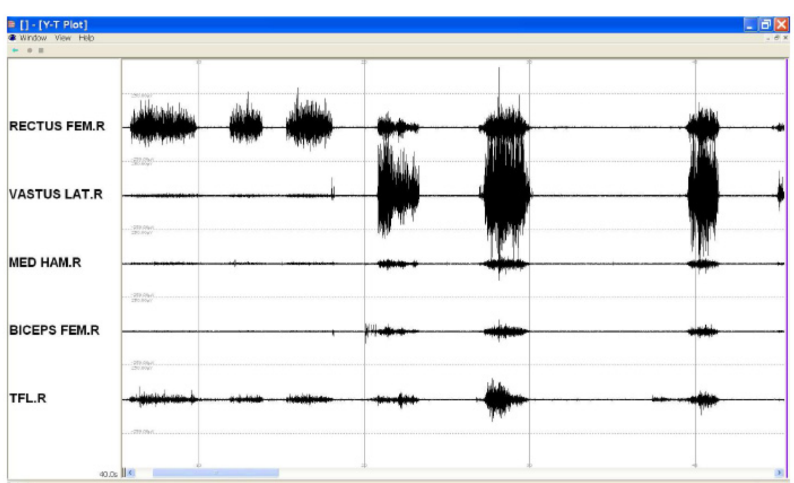


Fig. (26). Hip flexion with knee bent 10 to 15° one of the specific movements to test selectivity of the electrodes over the rectus femoris compare to vastus lateralis and hamstrings. Tensor fascia latae is synergist during hip flexion. Then knee extension 180°: typical pattern of Rectus femoris and Vastus lateralis co-contraction. Cross talk on both hamstrings from vastii.

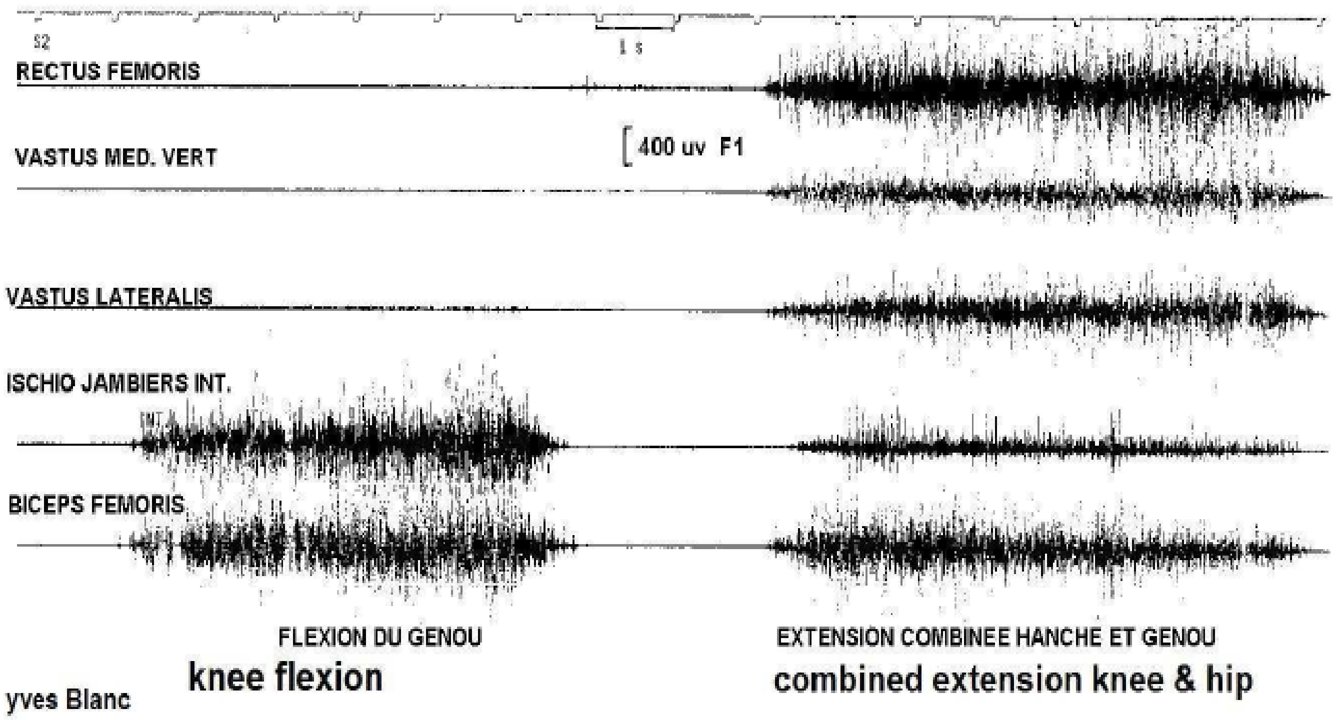


Fig. (27). Knee flexion without hip flexion: co-contraction of semi membranosus + semi tendinosus and biceps femoris then co-contraction of quadriceps and hamstrings.

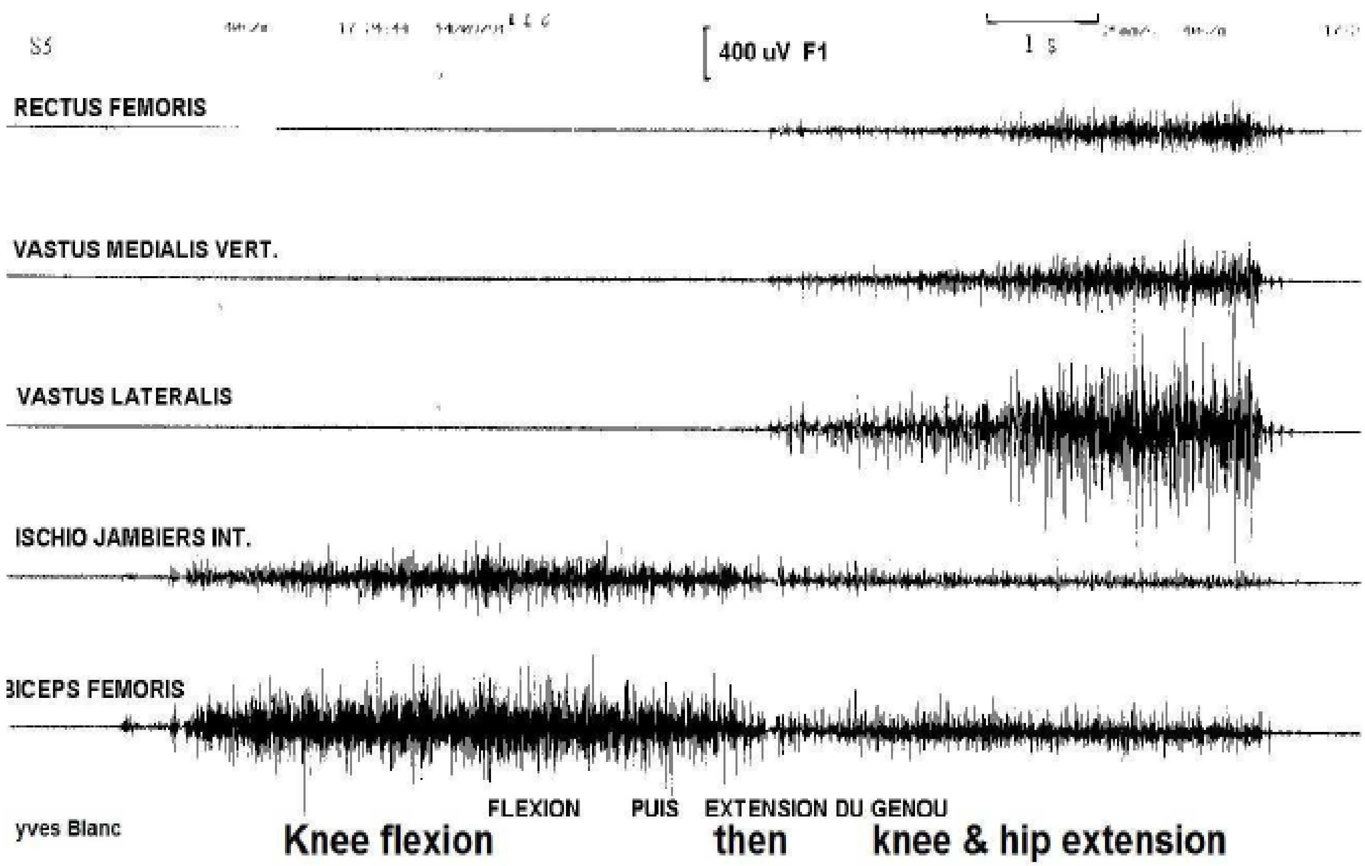


Fig. (28). Knee flexion followed by combined knee and hip extension.

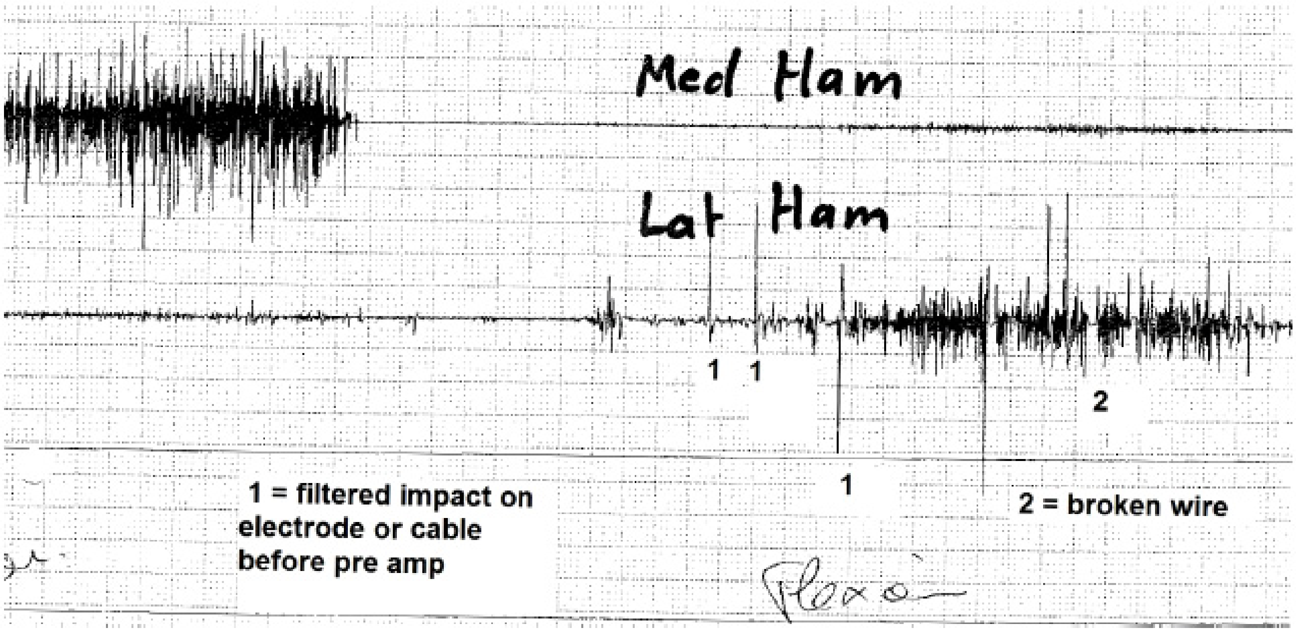


Fig. (29). MCA validation of the different patterns of semi tendinosus + semi membranosus versus biceps femoris. Internal knee rotation of the leg with a knee flexion around 90° triggers medial hamstrings whereas external rotation triggers biceps femoris. Marks 1 and 2 are filtered artefacts.

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