EMG
Application Note

SystemPlus EVOLUTION

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ELECTROMYOGRAPHY

Electromyography (EMG) is a technique for evaluating and recording the activation signal of muscles. An electromyography machine detects the electrical potential generated by muscle cells when these cells are mechanically active, and also when the cells are at rest. The electrical source is the muscle membrane potential of about -90mV. Measured EMG potentials range between less than 50 µV and up to 20 to 30 mV, depending on the muscle under observation. Typical repetition rate of muscle unit firing is about 7–20 Hz, depending on the size of the muscle (eye muscles versus seat (gluteal) muscles), previous axonal damage and other factors.

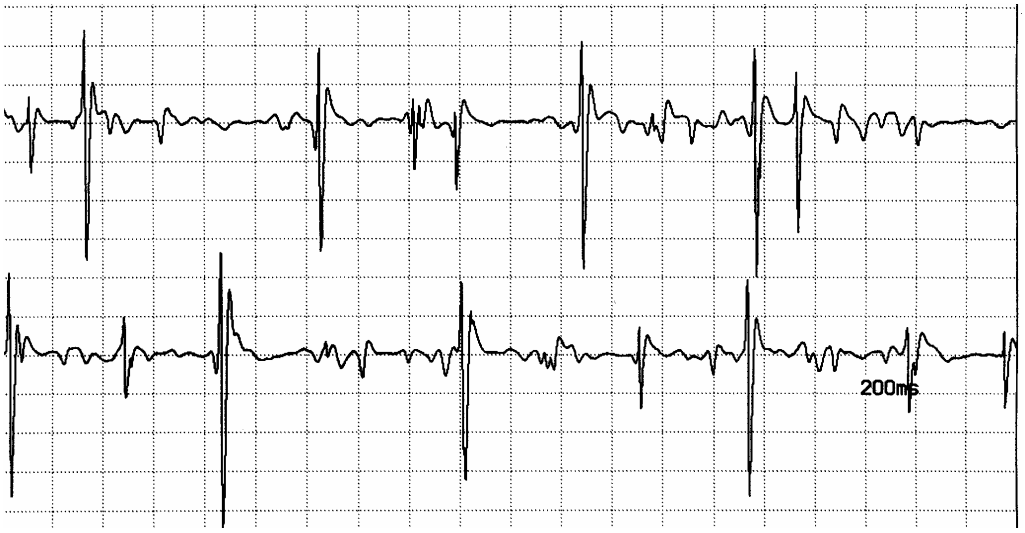
The first documented experiments dealing with EMG started with Francesco Redi's works in 1666. Redi discovered a highly specialized muscle of the electric ray fish (Electric Eel) generated electricity. By 1773, Walsh had been able to demonstrate that the Eel fish's muscle tissue could generate a spark of electricity. In 1792, a publication entitled "De Viribus Electricitatis in Motu Musculari Commentarius" appeared, written by Luigi Galvani, in which the author demonstrated that electricity could initiate muscle contractions. Six decades later, in 1849, Dubios-Raymond discovered that it was also possible to record electrical activity during a voluntary muscle contraction. The first actual recording of this activity was made by Marey in 1890, who also introduced the term electromyography. In 1922, Gasser and Erlanger used an oscilloscope to show the electrical signals from muscles. Because of the stochastic nature of the myoelectric signal, only rough information could be obtained from its observation. The capability of detecting electromyographic signals improved steadily from the 1930s through the 1950s and researchers began to use improved electrodes more widely for the study of muscles. Clinical use of surface EMG (sEMG) for the treatment of more specific disorders began in the 1960s. Hardyck and his researchers were the first (1966) practitioners to use sEMG. In the early 1980s, Cram and Steger introduced a clinical method for scanning a variety of muscles using an EMG sensing device.

It is not until the middle of the 1980s that integration techniques in electrodes had sufficiently advanced to allow batch production of the required small and lightweight instrumentation and amplifiers. At present a number of suitable amplifiers are commercially available. During the past 15 years, research has resulted in a better understanding of the properties of surface EMG recording. In recent years, surface electromyography is increasingly used for recording from superficial muscles in clinical protocols, where intramuscular electrodes are used for deep muscle only.

There are many applications for the use of EMG. EMG is used clinically for the diagnosis of neurological and neuromuscular problems. It is used diagnostically by gait laboratories and by clinicians trained in the use of biofeedback or ergonomic assessment. EMG is also used in many types of research laboratories, including those involved in biomechanics, motor control, neuromuscular physiology, movement disorders, postural control, and physical therapy

INTRAMUSCULAR (NEEDLE) EMG

To perform intramuscular EMG, a needle electrode is inserted through the skin into the muscle tissue. A trained professional (most often a physiatrist, neurologist, physical therapist, or chiropractor) observes the electrical activity while inserting the electrode. The insertional activity provides valuable information about the state of the muscle and its innervating nerve. The signal collected by the amplifier is then displayed into the screen and, in the same time, it is sent to the computer speakers.
Normal muscles at rest make certain, normal electrical sounds when the needle is inserted into them. Then the electrical activity when the muscle is at rest is studied. In normal subjects, we should not find electrical activity in this condition; abnormal spontaneous activity might indicate some nerve and/or muscle damage.
Then the patient is asked to contract the muscle smoothly (voluntary activity). The shape, size and frequency of the resulting motor unit potentials is judged. The step between electric silence and maximum electrical activity should result gradual in normal subjects.
Patient may further be asked to perform a maximum effort in order to study the interference pattern generated by the overlapping of the various motor unit action potentials.
Then the electrode is retracted a few millimeters, and again the activity is analyzed until at least 10-20 units have been collected.
Each electrode track gives only a very local picture of the activity of the whole muscle. Because skeletal muscles differ in the inner structure, the electrode has to be placed at various locations to obtain an accurate study.
As normal practice during the recording, the doctor add comments to the report describing the characteristic of the collected EMG signal (e.g. fibrillation and fasciculation level).



Voluntary activity recorded from triceps muscle and represented at 1mV/Div in 10ms/div

Acquisition parameters for spontaneous activity

Channel numbers:	1-2
Low filter:	16 Hz
High filter:	5000 Hz
Base Time:	100 msec -10 sec
Signal Max:	3.2 mV
Gain/Div:	50-100 µV/div

Acquisition Parameters for voluntary activity

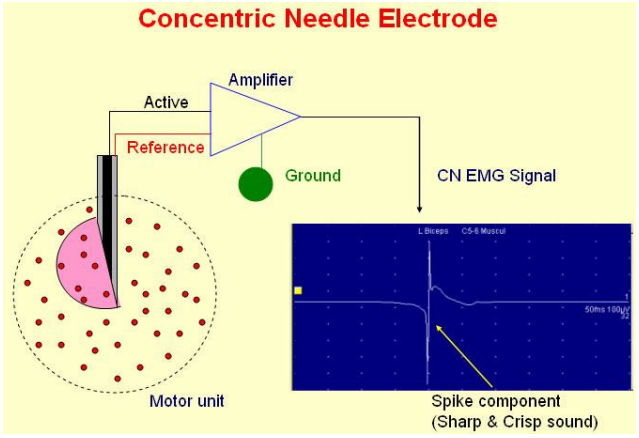
Channel numbers:	1-2
High Pass filter:	16 Hz
Low Pass filter:	5000 Hz
Base Time:	100 msec – 10 sec
Signal Max:	25.6mV
Gain/Div:	1-5 mV/div

Acquisition Parameters for maximum effort activity

Channel numbers:	1-2
High Pass filter:	16 Hz
Low Pass filter:	5000 Hz
Base Time:	100 msec – 10 sec
Signal Max:	25.6mV
Gain/Div:	1-5 mV/div

Working modality

The intramuscular EMG is performed by means of concentric needle electrodes; the external cannula of such electrodes is the derivation point and the internal thread is the active electrode.



The electrode point have an oval surface, the circumference constituted by the external cannulae and internal thread. The recording zone depends by the size of this surface; it is very restricted and limited at few motor units. This is very a important specification because if the needle is not correctly inserted into the muscle, you would not be able to obtain a correct acquisition of muscle activity.
In addition to the needle electrode, the ground electrode has to be placed as well (normally using a surface or belt electrode). It is s important the impedance between the skin and the ground tape/electrode to be as lower as possible, especially when recording spontaneous activity with needle

electrode. Due to the threat and cannulae high impedance, needle is one of the most sensitive electrodes.
Voluntary muscle activity can also be recorded by using surface electrode, positioned in precise areas above the muscle. In this case we record the electrical activity of a large part of the muscle but this is reduced in amplitude and filtered by the distance between the source of signal (muscular cells) and recording area (surface electrode).

MUAP ANALYSIS

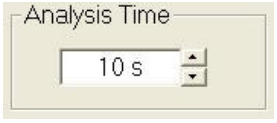
A motor unit is defined as one motor neuron and all of the muscle fibers it innervates. When a motor unit fires, the impulse (called an action potential) is carried down the motor neuron to the muscle. The area where the nerve contacts the muscle is called the neuromuscular junction, or the motor end plate. After the action potential is transmitted across the neuromuscular junction, an action potential is elicited in all of the innervated muscle fibres of that particular motor unit. The sum of all this electrical activity is known as a *Motor Unit Action Potential* (MUAP). This electrophysiologic activity from multiple motor units is the signal typically evaluated during an EMG. The composition of the motor unit, the number of muscle fibres per motor unit, the metabolic type of muscle fibres and many other factors affect the shape of the motor unit potentials in the myogram.
MUAP analysis is performed by means of intramuscular (needle) EMG.

Acquisition Parameters

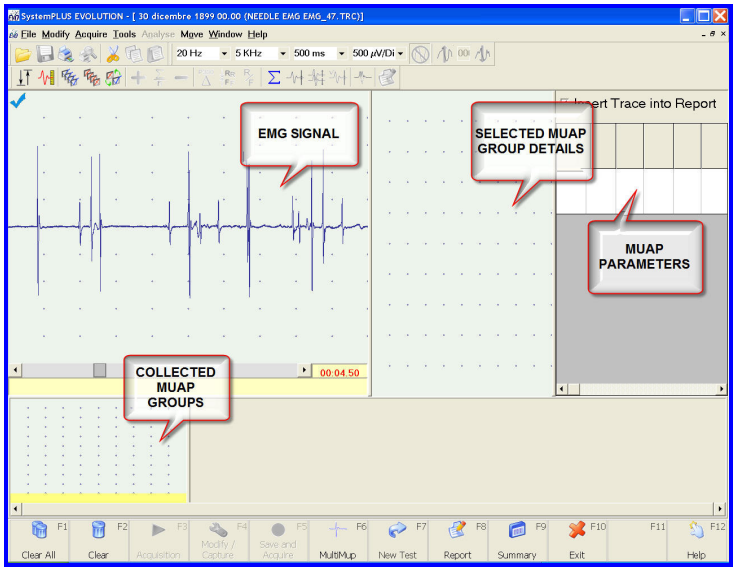
Channel numbers:	1
High Pass filter:	5 Hz
Low Pass filter:	5000 Hz
Base Time:	200 msec
Signal Max:	Auto
Gain/Div:	150 µV/div

Manual MUAP working modality

This function allows user to manually trigger all the motor unit to analyze. During needle EMG examination, click on MUAP button or start MUAP directly by means of the dedicated protocol.
Then select the side and the muscle to record, finally click on **Manual MUP** analysis key.
Analysis Time frame allow the user to select the length of trace epoch to analyze.

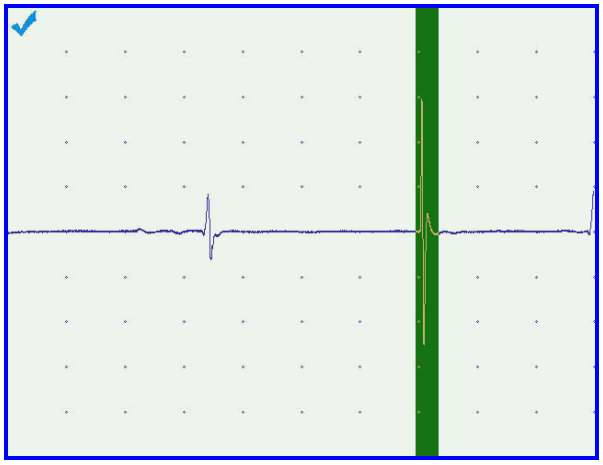


To start recording, press space bar (or acquisition button on the keypad); when the epoch is acquired, the acquisition automatically stops and begins the analysis process. The resulting window should look similar to the following:

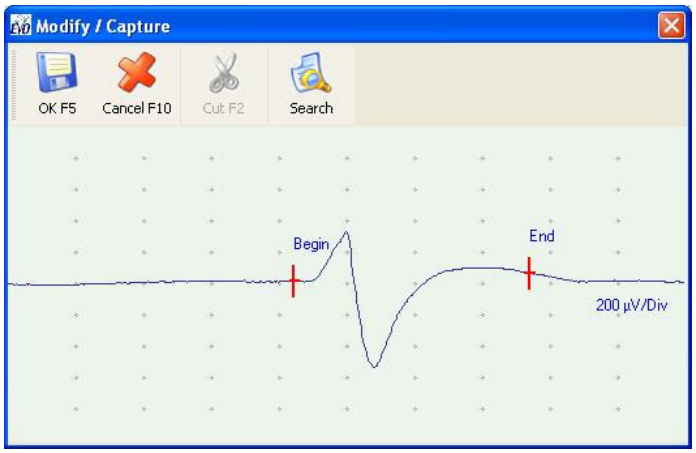


To select the MUAP template, activate the measure cursor by clicking on the dedicated icon

a green band identify the portion of trace you want to analyze, position it to the MUAP template by moving left and right borders (click on the border and drag),



Now by pressing Modify/Capture (F4) button, a new window button you will open a new window zooming onto the selected MAUP. From this window you are allowed to modify begin and end markers.



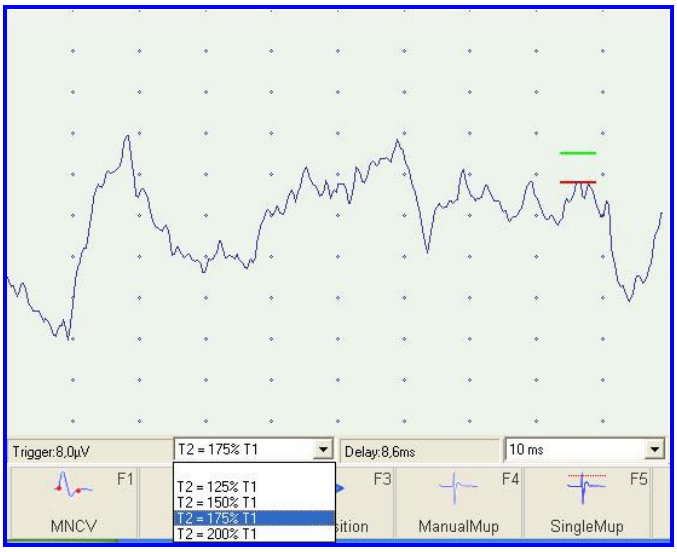
Users have then three different options

- **Search**: for automatically looking for all similar action potentials present in the EMG trace and collect them in the same group,
- **Cut**: for deleting the selected potential,
- **Ok**: for save only the selected potential.

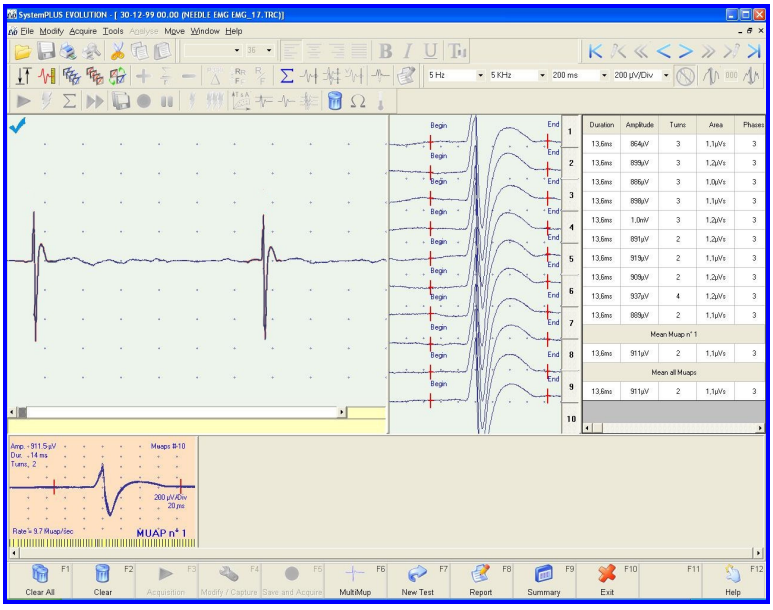
Single MUAP working modality

From the Needle EMG acquisition window, click on Single MUAP button:

and SystemPlus will show the potential upper and lower triggering thresholds. You can manually move the threshold level by dragging and dropping the trigger line. You can further modify the level difference between upper and lower thresholds by using the appropriate combobox, as shown in the picture below:



Clicking onto the spacebar key (or acquisition button on the keypad) will start 10 MUAP collection. MUAPs will be collected in the same group:



To return back to the acquisition window in order to perform a new capture, press F5 (Save) button and repeat the same procedure for all potential you want to acquire.

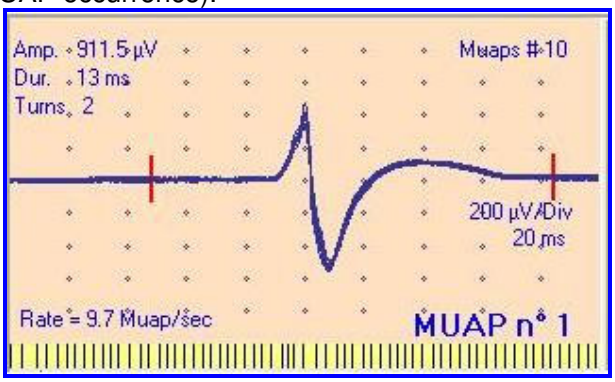
MULTIMUP working modality

From the Needle EMG acquisition window, click on Multi MUAP button:

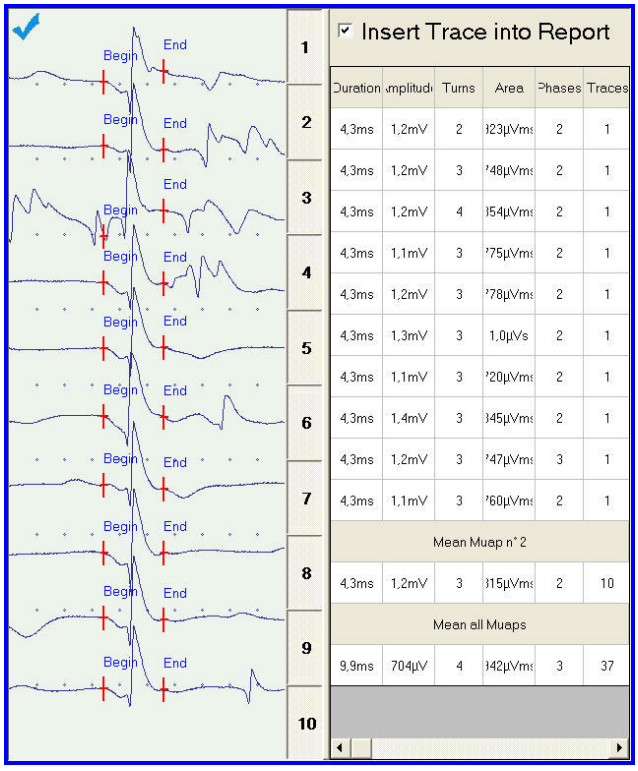
System automatically detects, select and group all MUAP in 5 second EMG trace. User can further add or remove MUAP by using the same process of Manual MUAP selection.

MUAP parameter area

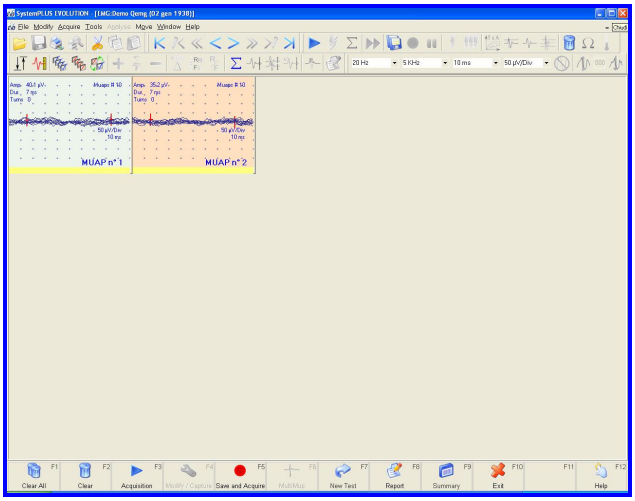
At the bottom of MUAP window, you can find the list of MUAP groups manually or automatically detected. Into every cell (corresponding to every group) you can read group parameters like amplitude, duration, turns. The yellow line at the bottom of the group cell spans the length of the EMG file, and the blue bars in it corresponds to the position of the single detected MUAP within the EMG file (this is useful to calculate frequency of MUAP occurrence).



When selecting a group, the single MUAP composing it are shown into the right part of the window; single parameters of each MUAP occurrence are displayed as well as the average parameters of the whole group.



By clicking on the Summary (F) button, user will access to an overview window showing all MUAP groups referring to the EMG file.



ELECTRONEUROGRAPHY

Electroneurography, or nerve conduction study (NCS) is a test commonly used to evaluate the function, especially the ability of electrical conduction, of the motor and sensory nerves of the human body.
Nerve conduction studies are used mainly for evaluation of paresthesias (numbness, tingling, burning) and/or weakness of the arms and legs. The type of study required is dependent in part by the symptoms presented. A physical exam and thorough history also help to direct the investigation. Some of the common disorders which can be diagnosed by nerve conduction studies are:

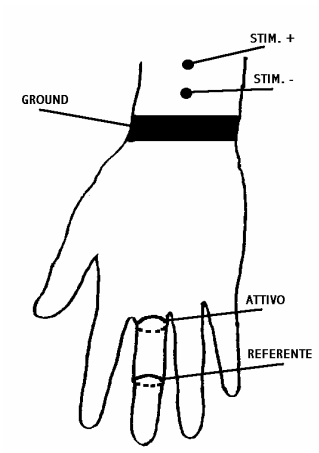
- Peripheral neuropathy,
- Carpal tunnel syndrome,
- Ulnar neuropathy,
- Guillain-Barré syndrome,
- Facioscapulohumeral muscular dystrophy,
- Spinal disc herniation.

The nerve conduction study consists of the following components:

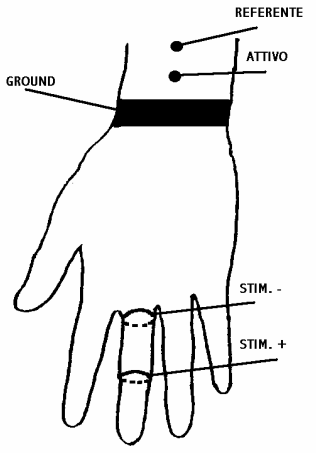
- Sensory NCS,
- Motor NCS,
- F-wave study,
- H-reflex study.

SENSORY NERVE CONDUCTION VELOCITY

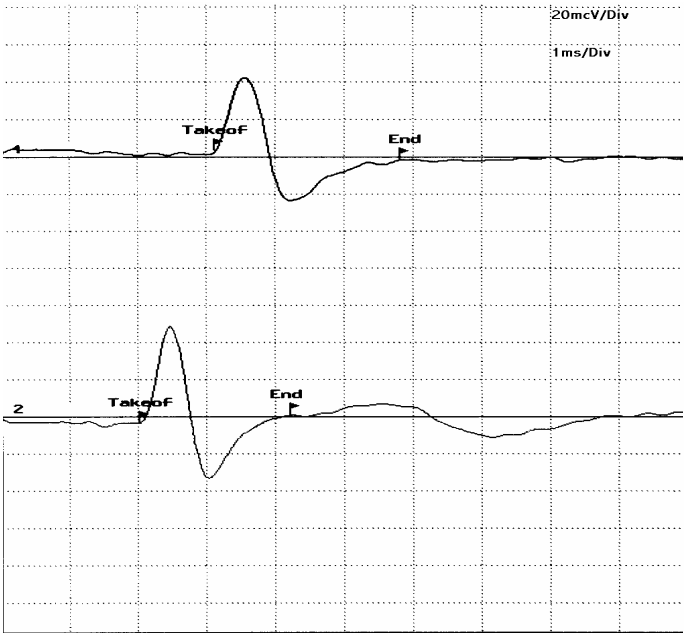
In electromyography chapter an important section is neurography, the most important, and essential aspect is the studying of nerve function with sensory conduction velocity (SCV).
To calculate SCV you need to be able to record electric potentials generated by signal transit through the nerve .
Sensory NCV tests are performed by electrical stimulation of a peripheral nerve and recording from a purely-sensory portion of the nerve, such as on a finger. The nerve is constituted by a lot of filaments (axons), along each filament an electric impulse (Action Potential) can propagate. The action potential has a low voltage and can be recorded only with electrodes directly positioned on the nerve. In order not to damage the nerve using needle electrodes, to record the sensory action potential signal, cup electrodes are used. Stimulating more axons rise up sensory signal and further synchronised average helps obtaining a cleaner response.
Sensory latencies are measured in ms. Sensory amplitudes are measures in microvolts (μV). The sensory NCV is calculated based upon the latency and the distance between the stimulating and recording electrode. This can't be changed. Note: while natural delay between stimulation and start of nerve response does not normally affect velocity calculation, it must be considered in case stimulation and recording electrode distance is very low.
Usually SCV test is performed on short nervous paths (e.g. stimulating on a finger and recording on the wrist) with a distance of about 9-12 cm, and the two stimulation and the two recording electrodes have an inter distance of 2-3 cm. Therefore, it is important to have a standard way to place negative and positive stimulation and recording electrodes. Usually the stimulation electrode is placed closer to the recording cathode (negative) electrode and the first peak on the response, typically biphasic, is referred to the electrode closest to the stimulation area. The distance has to be calculated between cathode and the derivation electrode closest to this one, and the propagation time is measured between the beginning of the trace and the first peak of the sensitive response.



Anti-dromic stimulation



Ortho-dromic stimulation



SCV in the median nerve stimulating on the wrist and recording on the III and I finger. VSC calculated 41.7m/s e 52.1m/s.

Electrode positioning

The S response (sensitive) can be recorded in several nerves. The recording electrodes have to be positioned over the nerve to be analysed.
This response must be studied in an orthodromic sense depending if the stimulation is distal or proximal to the derivation point (see the above pictures). On the orthodromic response you stimulate in a nerve point and you record in a proximal position along the usual direction of sensitive fibres.
It's preferable to place the ground close to the stimulating point, between the stimulating and the recording area, but there can't be a direct connection between this one and the other electrodes. Because of the small distance between the electrodes and the ground, there can be a short circuit caused by the presence of water or conductive gel, generating artefacts.
To have an high signal quality the electrode impedances should be lower than 5 Kohm and balanced between the different electrodes. In order to have a small stimulus artefact it is also important to have a low contact impedance of stimulation electrodes too (using a gel on stimulating electrodes greatly enhance signal quality).

Stimulation

The stimulation intensity is regulated in a way to be felt by the patient without pain, but it cannot be too much low, especially if you have to evaluate the sensory response. So you have to stimulate with an intensity sufficient to have a maximal response without activating other nervous structures different to the nerve under examination.
The stimulus duration can be short (100 µs), but not shortest if you don't want to increase the stimulation intensity. Average intensity of the fingers stimulation are 8-12 mA, for the wrist nerves (median and ulnar) 6-10 mA, for the sural nerve 30-40 mA.

Acquisition parameters

Number channels: 1
High Pass filter: 20 Hz
Low Pass filter: 2000 Hz

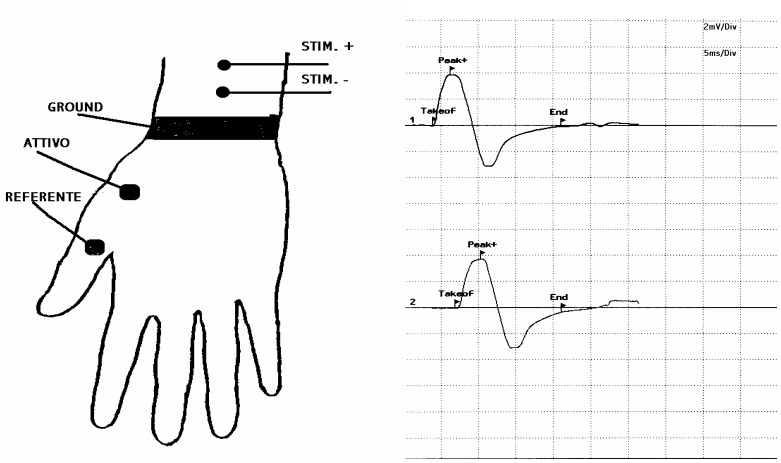
Base Time:	10 - 50 msec
Max Signal	400 µV
Gain/Div	20-100 µV/div
Averaging	20-40 means

Working modality

After electrode application, and after inviting the patient to stay relaxed in order to avoid the generation of electromyographic activity, you have to start stimulation using a low intensity (4-5 mA) increasing the intensity until the impulse is felt by the patient and the sensitive response is clear on the online EMG trace. Then begin the average calculation, until you get a clean signal. Usually 5 to 20 averages are sufficient to obtain a good signal, but more averages may be required for difficult studies. Correct electrode positioning is essential for obtaining a good response.

MOTOR NERVE CONDUCTION VELOCITY

Motor NCS are performed by electrical stimulation of a peripheral nerve and recording from a muscle supplied by this nerve. The time it takes for the electrical impulse to travel from the stimulation to the recording site is measured. This value is called the latency and is measured in milliseconds (ms). The size of the response - called the amplitude - is also measured. Motor amplitudes are measured in millivolts (mV).
The response latency depends on two factors: the action potential propagation on the nerve and the signal diffusion from nerve to the muscle. The first one depends to the conduction velocity and to the nerve length, the second one is constant for every nerve-muscle pair. This second delay is about of 3-4 msec depending on the subject, it is therefore impossible to measure the motor speed conduction velocity by stimulating only in one point. Calculations are thus performed using the distance between the different stimulating electrodes and the difference in latencies.
To get the basic motor speed conduction estimation, the nerve must be stimulated in two points. The distance to be measured is between the two stimulation points , while the propagation time is obtained by the latency time difference of the two motor response. The distance-propagation time ratio gives MNCV between two stimulation points in the nerve considered. This operation can be made in further points through the nerve, in a way the entire nervous path can be explored from the spinal marrow to the periphery.
Motor response amplitude and duration can give some indication about the condition of the motor nerve local branches, of the neuromuscular plate, and of the muscle.
MNCV can be calculated recording with needle or cup electrodes. Using surface electrodes, muscular response appears having high voltage and simple morphology (bi or tri-phasic). By using needle electrodes, voltage is lower and morphology is more complex.



MNCV in two points applied on median nerve stimulating on the wrist and on the elbow

Electrode positioning

Motor response can be recorded in several muscles. The recording electrodes have to be positioned in a way the active one is placed on the centre of the muscle and the reference one on a remote area, far from the muscle.
It is better to place the ground electrode close to the stimulating point, between the stimulating and the recording area, but there can't be a direct connection between this one and the other electrodes.
To obtain an high signal quality the electrode impedance should be lower than 5 KOhm and balanced between the different electrodes.

Stimulation

Electrodes have to be positioned on the motor nerve with the negative one placed close to the recording point.
The stimulation intensity has to be supra-maximal (just over the response stabilization level), and the duration has to be short, 100 µs maximum. The intensity values are about 10-15 mA for the wrist nerves (median, ulnar), 40-50 mA for the same nerves on the elbow and on the armpit, 60-70 mA for the nerves on the supraclavear and 20-40 mA for the nerves on the foot and on the poplite (sciatic, internal and external poplite).

Acquisition parameters

Number channels:	1
High Pass filter:	20 Hz
Low Pass filter:	2000 Hz
Base time:	50 msec
Signal max:	25.6 mV
Gain/Div:	1-5 mV/div
Average:	you need a single shock

Working modality

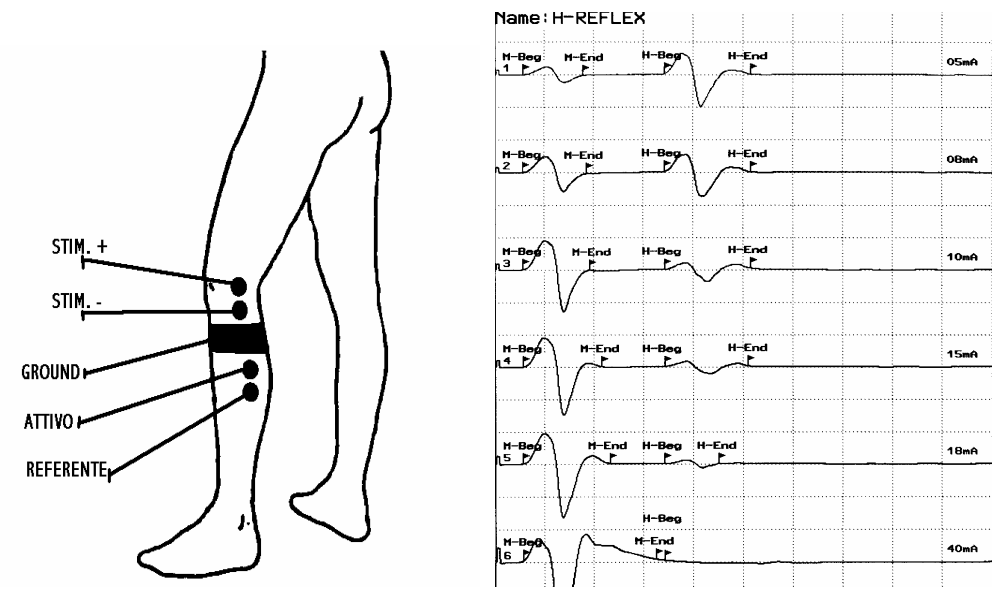
The patient must stay in a relaxed and comfortable position and should be advised that he will not feel a painful shock. Begin stimulating into the closest place to the stimulation point, with a stimulation intensity generating a supra-maximal motor response. You recording a single response (due to the high motor response signal amplitude, it is not necessary to average more responses), then you continue recording into the next point.
The following parameters are calculated for every response:

- Latency: calculated on the deflection point of the base line,
- Amplitude: measured peak to peak, or from positive peak to base line,
- Response area,
- Duration from the initial deflection point to the point of coming back to the base line,
- Morphology, that can be polyphasic in some pathological situations.

In the simplest situation, stimulating the nerve in two different points (wrist and elbow) we will obtain two different latency times. Both values have two components: the conduction time of the signal from the stimulation point to the end of the nerve, and neuromuscular transmission time. The difference between the value of the latency closest to the recording point (proximal) and the latency value of the more distant one (distal) is the time spent by the stimulus to run the nerve path between the two stimulation points. By measuring the distance between the two stimulation points and by dividing it by the latancy time difference, we will find the maximal signal conduction velocity in the analysed path.

H REFLEX

The H-reflex is a reflectory reaction of muscles after electrical stimulation of sensory fibers in their innervating nerves (for example, those located behind the knee). H reflex (Hoffman reflex) has a specific indication for the study of the first sacral root sufferance. The exam consists of a recording of the motor reflex response (H) from soleus or gastrocnemious muscle by stimulating the nerve in the popliteal fossa with short duration and short amplitude. In this muscle the M response appear with a latency of 4-5 msec, as in other muscles when you stimulate the corresponding motor nerve. Then, a further motor response appears after 32-38 msec, as a consequence of the muscle contraction caused by a reflex mechanism. After an initial stimulation of sensitive axons of sciatic nerve, there is an activation of nervous cells and its axons create the motor contingent of sciatic nerve.
The sciatic nerve in the popliteal fossa has both sensitive and motor fibres. Sensitive fibres have a stimulation threshold lower than motor ones. Stimulating this nerve with a low intensity and gradually increasing it, we obtain sensitive fibres only stimulation at the beginning, involving motor fibres as the stimulus increase.
With low stimulation intensity we usually obtain H reflex only, because through the sensitive fibres and their indirect connection with motor cells, we activate the motor axons and the connected muscle. In this case the stimulus path is long and response latency is high: from poplite to back at lumbar level and then again to poplite and sural muscle.
If we stimulate the motor fibres too (too high stimulus intensity), we obtain a rapid response, which is the direct motor response.
Higher stimulations might involve alpha fibres, causing M wave to overlap H reflex, thus compromising the study.
H-reflex is analogous to the mechanically induced spinal stretch reflex (for example, knee jerk reflex) because in both cases muscle-spindle innervating fibres are activated. Although stretch reflex gives just qualitative information about muscle spindles and reflex arch activity; if the purpose of the test to compare performances from different subjects, H-reflex should be used. In that case, in fact, latencies (ms) and amplitudes (mV) of H-wave can be compared.
H-reflex is used to assess fitness of astronauts. H-reflex was the first medical experiment completed on the International Space Station.



H reflex obtained with recording in soleus muscle

Electrode positioning

H-reflex cannot be recorded in every muscle. The easier place to record H-reflex is the soleus muscle. The recording electrodes have to be positioned so that the active one is placed on the centre of the muscle and the reference on a remote area, far from the muscle.
It is better to place the ground electrode close to the stimulating point, between the stimulating and the recording area, but take care not to short the ground to any recording/stimulating electrode.
To obtain a better signal quality, the electrode impedance should be lower than 5 Kohm and balanced between the different electrodes.

Stimulation

The stimulation electrodes must be positioned on the nerve innervating the muscle. On the popliteal fossa you have to find the exact stimulation point of sciatic nerve using the lower possible current intensity. In these condition maintaining the electrode position is crucial: it is sufficient just a little shifting to completely loose the stimulation.

Acquisition parameters

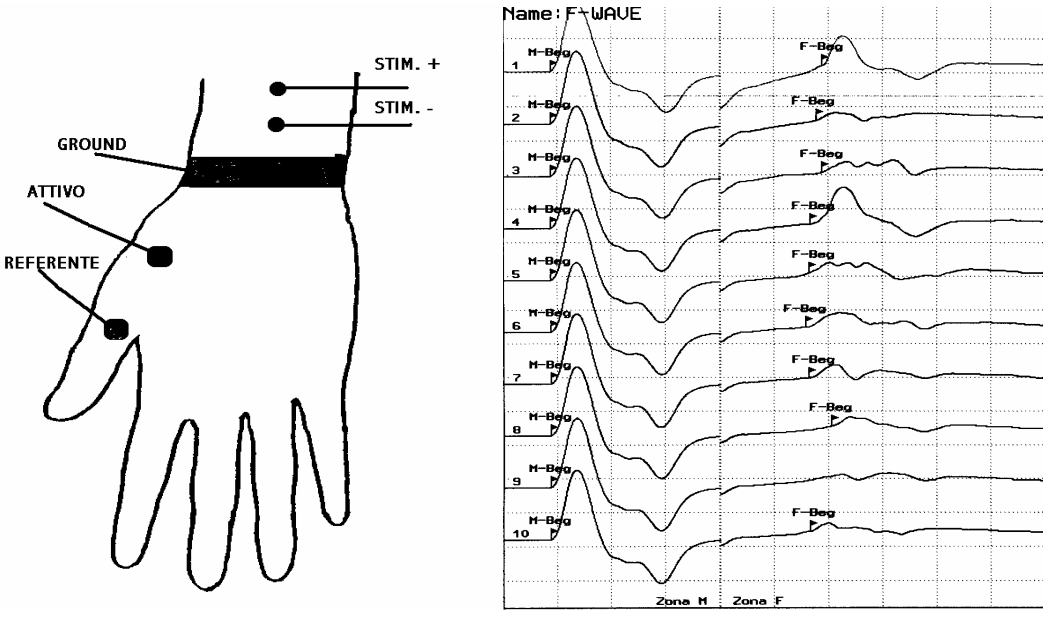
Number channels:	1
High Pass filter:	20 Hz
Low Pass filter:	2000 Hz
Base time:	100 msec
Max Signal:	25.6 mV
Gain/Div:	1 - 5 mV/div

Working modality

Begin with 0 mA stimulation and increase it until the H-reflex disappear, being overlapped by the M wave. At this time, acquire about ten waves fixing a stimulation rate of 0.5 Hz and increasing the stimulation intensity of 1 mA after every response. You should see the M wave increasing and covering H-reflex.
After the acquisition ending it is important to study the variation of H reflex and M wave amplitudes correlated to the variation of stimulation intensity.

F WAVE

F-wave is a motor response (linked to the muscle stimulation) and it is caused by an action potential feedback on the nervous fibre with a mechanism similar to echo. This is not a reflex, per se, in that the action potential travels from the site of the stimulating electrode in the limb to the spinal cord's anterior horn cell and back to the limb in the same nerve that was stimulated. The F-wave latency can be used to derive the conduction velocity of nerve between the limb and spine, whereas the motor and sensory nerve conduction studies evaluate conduction in the segment of the limb.
When stimulating the motor nerve we get two action potential series, one going from stimulation point to the muscle and the other from the stimulation point to the nervous cell positioned in the spinal marrow. The first one generates the M response; the second one terminates in the spinal marrow and does not generate any evident effect. If any action potential directed to the cell succeed in to excite again the motor axon, a new muscle stimulation is generated, having a latency time related to the time spent by the action potential to run the path from stimulation point to the marrow and then to the muscle.
The F-wave absence is not always a pathologic status, while it is important to evaluate F-wave temporal dispersion following successive stimulations. A temporal dispersion or a latency increase of F-wave is the signal of MNCV slowing down. Latency of F-Wave may vary muscle to muscle and patient to patient depending on patient height.
Conduction velocity is derived by measuring the limb length in millimeters from the stimulation site to the corresponding spinal segment (C7 spinous process to wrist crease for median nerve). This is multiplied by 2 as it goes to the cord and returns to the muscle (2D). 2D is divided by the latency difference between mean F and M and 1 millisecond subtracted (F-M-1). The formula is 2D/(F-M-1).



F wave recorded stimulating the median nerve.

Electrode positioning

F wave can be recorded in several muscles. The recording electrodes have to be positioned so that the active one is placed on the centre of the muscle to study and the reference one on a remote area, far from the muscle.
It is better to place the ground electrode close to the stimulating point, between the stimulating and the recording area, but take care not to short the ground to any recording/stimulating electrode.
To obtain a better signal quality, the electrode impedance should be lower than 5 Kohm and balanced between the different electrodes.

Stimulation

Electrodes have to be positioned on the motor nerve with the negative one placed close to the recording point.
The stimulation intensity has to be supra-maximal (just over the response stabilization level), and the duration has to be short, at most 100 µs. The intensity values are about 10-15mA for the wrist nerves (median, ulnar), 40-50 mA for the same nerves on the elbow and on the armpit, 60-70 mA for the nerves on the supra-clavear and 20-40 mA for the nerves on the foot and on the poplite (sciatic, internal and external poplite).

Acquisition parameters

Number channels:	1
High Pass filter:	20 Hz
Low Pass filter:	2000 Hz
Base time:	50 – 100 msec
Max signal:	25.6 mV
Gain/Div	1 - 5 mV/div

Working modality

10 consecutive responses are usually acquired; for every response you have to detect the M and F wave latencies. The F-wave is not always present in all the responses and it is usually 10 times lower than M wave, so the two signals are presented with two different amplifications: one for the M wave zone and another one for the F-wave.

ADVANCED EMG TESTS

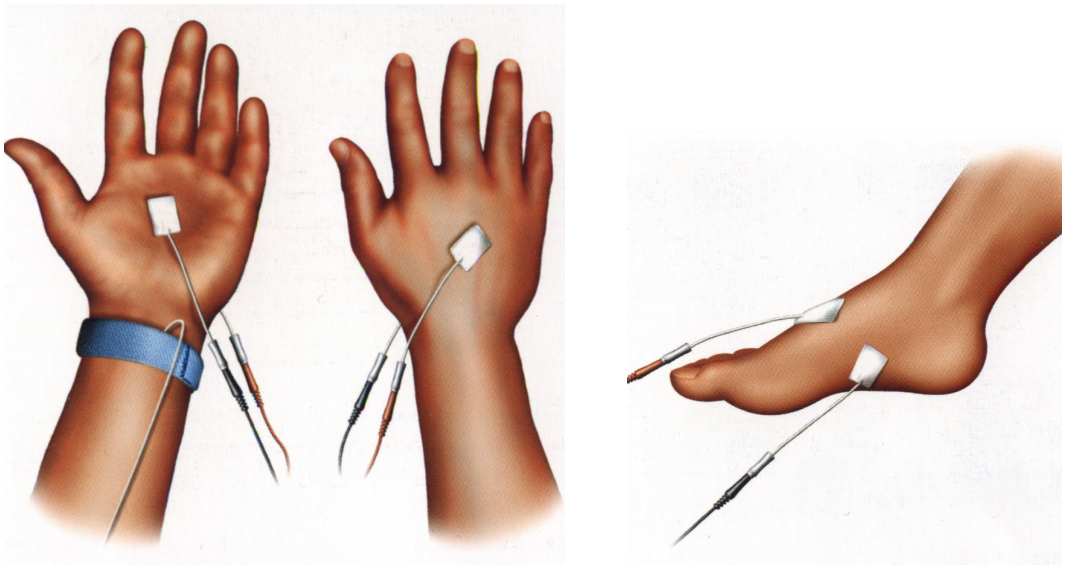
EMG practice also includes less common advanced examinations for particular studies like:

- neurovegetative tests (including sympathetic skin response and R-R interval),
- Single Fibre EMG (SFEMG),
- Motor Unit Number Estimation (MUNE),
- Magnetic Motor Evoked Potentials (MEP).

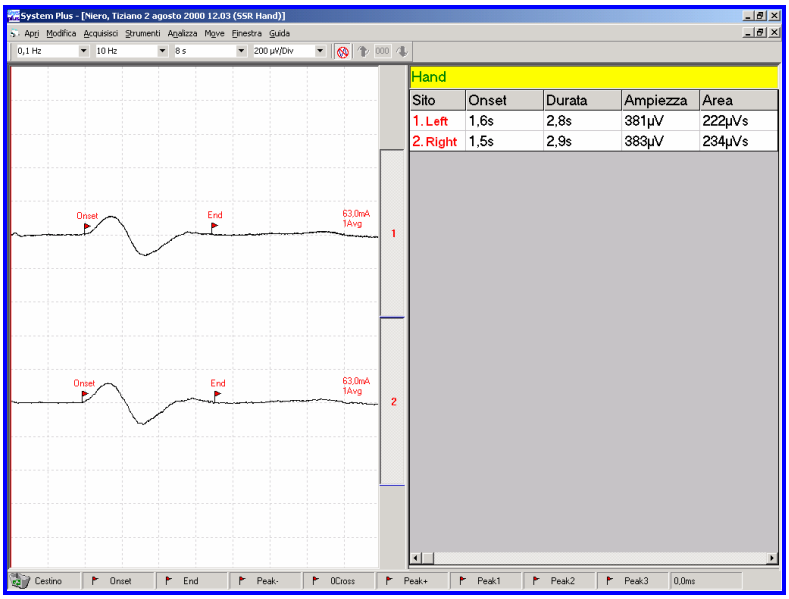
Some of these tests will be described into the present chapter.

SSR - SYMPATHETIC SKIN RESPONSE

SSR is an exam used to examine the conditions of the sympathetic nervous system; it became important about ten years as test for diabetes diagnostics.
The recorded electric response is caused by the variation of contact impedance following fluctuations generated by sweat glands, innervated by sympathetic nerve fibres.



Electrodes positioning for SSR on hand or on foot



SSR traces recorded on the 2 hands

Electrode positioning

Response is recorded at limb extremities:

- When recording on the hands, active electrodes (Negative = Black) are placed on the palm and reference one on the dorsum of the hand,
- When recording on the foots, active electrodes (Negative = Black) era placed on the sole of the foot and referenced against the skin or dorsum of the foot.

In case extremity temperature is below 28°, it is necessary to warm up the hand or foot.
The ground electrode is positioned on the wrist of the hand that is eventually electrically stimulated.

Stimulation

Stimulation can be of different types: electric, acoustic, visual, tactile and thermal. The most commonly used is the electric one, but acoustic is frequent too (just clapping the hands).
It's important the stimulation to be unexpected by the patient in order to create a sort of "fright" and therefore a different condition of sweat cells.

Acquisition parameters

Number channels:	1 - 4
High Pass filter:	0.7 Hz
Low Pass filter:	10 Hz
Base time:	8 sec.
Max signal:	25.6 mV
Gain/Div:	1 mV/div

Working modality

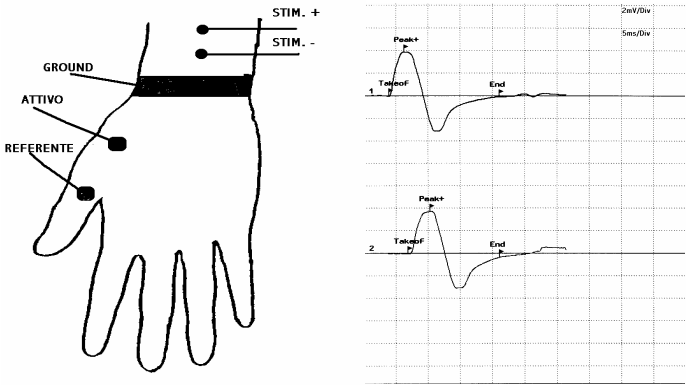
Invite the patient to be relaxed in order to avoid a strong electromyography activity, select 30-40 mA intensity (if you use electric stimulation) and then begin recording stimulating unexpectedly the patient on the wrist.
Response is a slow mono or biphasic variation with a latency time of about 1-2 seconds. Latency, amplitude and area are the most commonly used parameters to detect abnormal responses and therefore problems at sympathetic autonomous nervous system.

MUNE - Motor Unit Number Estimation

A motor unit consists of one alpha motoneuron and all the muscle fibres it innervates. Muscles differ in the number of motor units that they contain, and how many muscle fibres are within each unit (innervation ratio). In a general sense, muscles that require specificity of movement, such as muscles in charge of eye movement, have fewer fibres per unit, while those that are meant for less specific tasks, such as the calf muscles in charge of jumping, have more. MUNE is a non-invasive, electro physiologic method to estimate the number of motor neurons innervating a muscle or group of muscles.
The ability to quantitatively estimate the number of surviving motor neurons is useful in the following areas:

- clinical, for diagnosis of neuromuscular disorders,
- as an end point measure in clinical drug trials for lower motor neuron disorders,
- as a tool, to get an insight about the natural history and pathophysiology of lower motor neuron disorders.

MUNE uses a general formula of: Number of motor units = Compound Muscle Action Potential Size (CMAP size) divided by the mean Surface-detected Motor Unit Action Potential Size
The compound muscle action potential (CMAP) size is found using supramaximal stimulation of the motor nerve to the muscle or muscle group (similar to a nerve conduction study).
The recording is performed by using surface electrodes, this is representative of the sum of the surface detected motor unit action potentials from muscles innervated by that nerve. Surface-detected motor unit action potential (SMUAP) size is the contribution of individual motor units.
There are at least six techniques that are currently in use to estimate motor unit numbers. These include incremental stimulation, multi-point stimulation method, F-response method, spike-triggered averaging method and the statistical method. Incremental stimulation is the most illustrative of the concept, and so will be discussed here.
According to Henneman's size principle, motor unit recruitment is always in the same order from smallest to largest motor unit. Additionally, the motor unit action potential is an all-or-none phenomenon - once the recruitment threshold (the stimulus intensity at which a motor unit begins to fire) is reached, it fires fully. Incremental stimulation starts giving electrical stimulation at a very low stimulus intensity and increases gradually to reach the recruitment threshold of successively larger motor units until the intensity of the CMAP is reached. A 'step' is noted when an increase in stimulus leads to an increase in recorded EMG (i.e. another motor unit's threshold is reached and it is recruited). The CMAP is then divided by the number of steps required to reach the intensity of the CMAP to get a mean SMUAP size. The number of steps does not correlate to the total number of motor units in the muscle. Instead, the CMAP size is then divided by the mean SMUAP size to get an estimation of the number of motor units in the muscle.



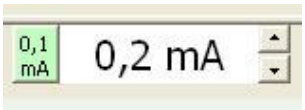
Motor unit number estimation of median nerve

Electrode positioning

M wave can be recorded in several muscles. The recording electrodes have to be positioned so that the active one is placed on the centre of the muscle and the reference on a remote area, far from the muscle.
It is better to place the ground electrode close to the stimulating point, between the stimulating and the recording area, but take care not to short the ground to any recording/stimulating electrode.
To obtain a better signal quality, the electrode impedance should be lower than 5 Kohm and balanced between the different electrodes.

Stimulation

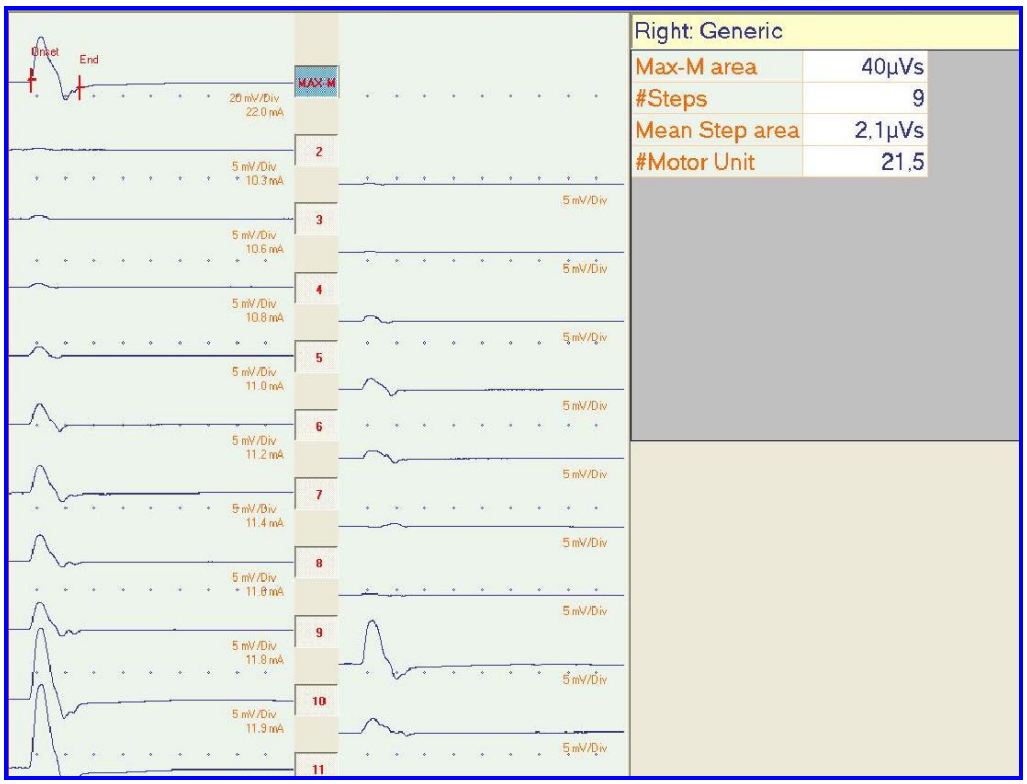
Electrodes have to be positioned on the motor nerve with the negative one placed close to the recording point.
The stimulation intensity has to be supra-maximal (just over the response stabilization level), and the duration has to be short, 100 μs maximum. The intensity values are about 10-15mA for the wrist nerves (median, ulnar), 40-50 mA for the same nerves on the elbow and on the armpit, 60-70 mA for the nerves on the supraclavear and 20-40 mA for the nerves on the foot and on the poplite (sciatic, internal and external poplite).
Action potentials are picked up from a muscle when stimulating its nerve at one site. The operator increases the intensity of the stimulus until a maximal response is obtained and then further increases it in order to assure supramaximal stimulation. This gives the maximal M-wave area, where all muscle fibre conducts. The intensity is reduced to just above threshold and the recording is stored. Increase the intensity until a slight increase in area is obtained (to perform this operation more precisely it is possible to switch the intensity scale from 1 mA step to 0.1 mA step).



The difference from the previous acquired action potential is displayed continuously in the central part of the screen, by turning the intensity down and up slightly, the increase should disappear and appear, here is when the response has to be stored. The estimated number of motor unit is displayed, based upon the max M-wave area and the mean area increase. Continue recording bigger and bigger M-wave until the estimated number of motor units becomes constant.

Acquisition parameters

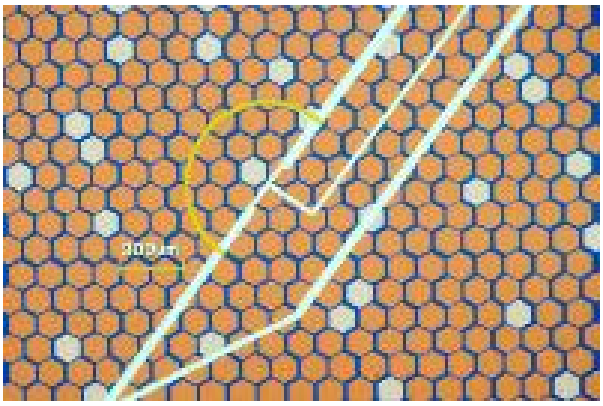
Number channels:	1
High Pass filter:	20 Hz
Low Pass filter:	2000 Hz
Base time:	50 msec
Signal max:	25.6 mV
Gain/Div:	1-5 mV/div
Average:	single shock



MUNE acquisition

SFEMG - SINGLE FIBRE EMG

Single-fibre electromyography (SFEMG) is a selective EMG recording technique that allowing identification of action potentials (APs) from individual muscle fibres.
The selectivity of the technique is mainly given from the small recording surface of the needle electrode (25 µm in diameter), which is exposed by a small port on the side of the electrodes, 3 mm far from the tip. The selectivity of the recording is further heightened by using an high pass filter of 500 Hz



Single fibre EMG needle section

SFEMG allows measurement of 2 characteristics of the motor unit: fibre density and neuromuscular jitter. The amplitude of the recorded APs from an average muscle fibre decreases to 200 µV when the electrode is approximately 300 µm far from the muscle fibre. We can therefore infer that APs greater than 200 µV arise from muscle fibre within 300 µm of the recording surface. By recording from many sites within a muscle, the mean number of time-locked APs having an amplitude higher than 200 µV and rise time lover than 300 µS, make possible to calculate fibre density, which gives an estimation of the local concentration of muscle fibres within the motor unit. SFEMG provides similar information to type grouping in muscle biopsies.
As the patient voluntarily activate the muscle, the electrode is positioned to record with maximum amplitude the APs from one single muscle fibre. APs are recorded in 20 separate sites within a muscle, usually via 3 separate insertion sites. The fibre density (FD) is calculated as the average number of APs, including the triggering AP, counted in these 20 sites. The normal FD is different among different muscles and increases in adults older than 60 years, especially in distal muscles.

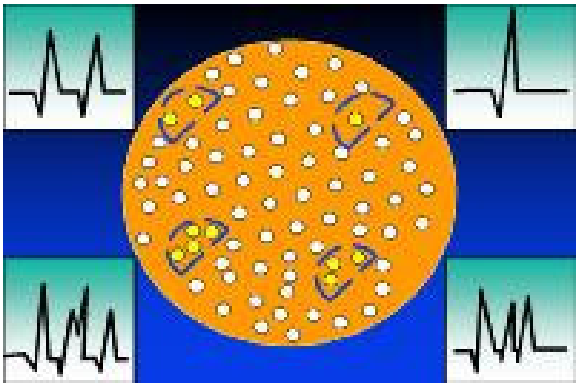
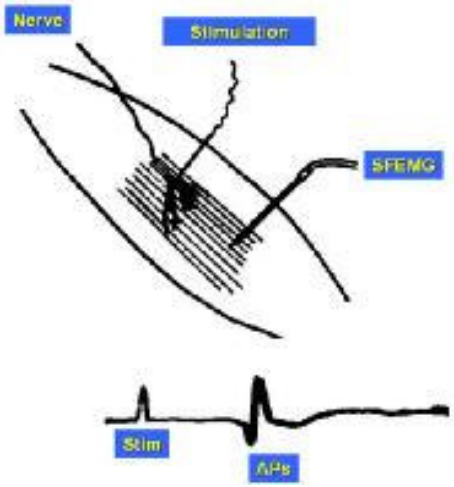


Diagram of single fibre density measurements in single fibre electromyography (SFEMG)

When APs elicited by nerve stimulation are recorded with an SFEMG electrode, the latency from stimulus to response varies. This variation is called neuromuscular jitter, most of which is produced by fluctuations in the time for end plate potentials at the neuromuscular junctions to raech the AP threshold. The stimulating electrode is inserted into the muscle close to an intramuscular nerve fibre, and the recording electrode is inserted distally close to the muscle fibres innervated by this nerve.



Electrode setup for SFEMG during intramuscular axonal stimulation

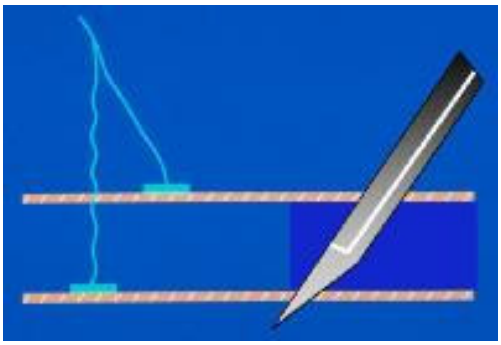
When the SFEMG electrode is positioned to record from 2 or more muscle fibres in one voluntarily activated motor unit, the neuromuscular jitter is seen as variations in the time interval between pairs of APs from these fibres. This paired jitter represents the combined jitter in 2 endplates. Jitter may be measured either as the nerve is stimulated or as voluntarily activates the muscles

AXONAL Stimulation:

The motor nerve may be stimulated proximally to its entry point into the muscle, or individual motor nerve branches may be stimulated within the muscle.
The former technique is ideal for activating facial muscles, since individual branches of the facial nerve can be stimulated with a monopolar needle electrode.
If a surface electrode is used for stimulation, many motor units usually are activated, making identifying the responses of single muscle fibres difficult.
Some artefactual jitter may be introduced by variations in the intensity of the stimulus that reaches the individual motor nerve fibres, especially when surface stimulation is used.

VOUNTARY Activation:

Jitter measurements performed during voluntary activation f the muscle are less subject to technical problems that can lead to misinterpretation of the results. However, this technique requires more patient cooperation than stimulation jitter studies.
As the patient slightly contracts the muscle, the SFEMG electrode is inserted into the muscle near the endplate zone; it is positioned to record 2 or more time-locked APs from the same motor unit. The amplitude of the APs are optimized by slightly adjusting the electrode position; in the best recording position for jitter measurements, all APs of interest should have sharply rising phases and adequate amplitudes.
APs should be measured from 20 potential pairs and recorded from different portions of the muscle, using 3-4 skin insertions.



Recording position of the single-fibre electromyography electrode during jitter analysis with voluntary muscle activation. The electrode is positioned to record action potentials (APs) from 2 muscle fibres that are innervated by the same motor nerve fibre.

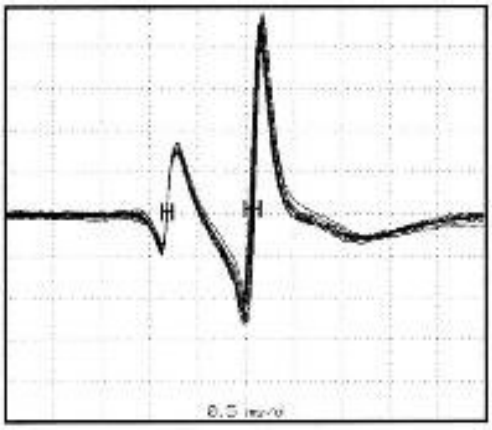
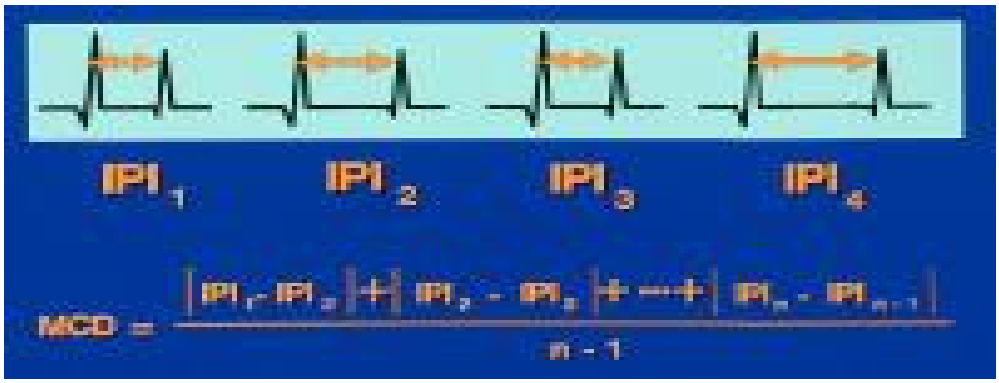


Fig. 5 Single fiber electromyography. Action potentials recorded from 2 muscle fibers with normal jitter during voluntary muscle activation. Ten consecutive discharges are superimposed. The EMG system is triggered by the rising portion of the first potential, witch falls at the same position with each discharge. The second potential falls at slightly varying among successive discharges, demonstrating the neuromuscular jitter.

The jitter is expressed as the average value of consecutive differences of successive interpotential intervals (MCD)



Calculation of the average difference between consecutive discharges (MCD). IPI is the interpotential interval or stimulus-to-response latency during axonal stimulation jitter analysis.

Jitter is increased whenever the ratio between the AP threshold and the endplate potential is greater than normal; thus, it is a sensitive measure of the safety factor of neuromuscular transmission.
The normal mean MCD value varies from 10-50 µs among different muscles.

With more pronounced disturbances, impulses to individual muscle fibres intermittently fail to occur, producing neuromuscular blocking. Only when blocking occurs is clinical weakness or a decrement on repetitive nerve stimulation tests noted. In certain situations the interpotential interval (IPI) may be influenced by the preceding interdischarge interval (IDI), which may introduce an additional variability due to the velocity of AP propagation in the muscle fibres.
This is not a problem with stimulation jitter studies using a constant stimulus rate, if the first 10 intervals of each train are excluded from the jitter calculation.
The effect of preceding depolarizations becomes constant at that point, provided non impulse blocking is present to produce an irregular discharge rate.
The effect of variable firing rates (when jitter is measured during voluntary activation) can be minimized by sorting the IPIs according to the length of the preceding IDI, than calculating the mean of the

consecutive IPI differences in the new sequence. The result is called the mean sorted-data difference (MSD)
If the MCD:MSD ratio exceeds 1.25, then variations in the firing rate have contributed to the jitter; the MSD should be used to represent the neuromuscular jitter. The MCD is used to express the jitter if the MCD:MSD ratio is less than 1.25.

There are three different way to show Jitter analysis

- The mean or median value of the MCD values in all the pairs or endplates that are measured,
- The percentage of paired potentials or endplates in which blocking was seen,
- The percentage of pairs or endplates in witch jitter exceeded the normal limit for that muscle.

The mean MCD may exceed normal limits when a few individual jitter values are extremely high. To avoid this, jitter values greater than 150 µs may be excluded from the mean calculation, or the median MCD may be used to express the central tendency of the data. In normal muscle, the mean and median MCD value are the same.
Reference jitter values have been determined for many muscles. Jitter increases slightly with age in normal subjects A study is abnormal if the mean (or median) jitter exceeds the upper limit for the muscle than 10% of pairs or endplates have increased jitter or blocking.

Jitter lower than 5 µs is seen rarely in voluntarily activated SFEMG studies in normal muscle and more often in myopathies. These low values probably result from recordings that are made from split muscle fibre branches of which are activated by a single neuromuscular junction. These values should not be included in assessments of neuromuscular transmission. The MCD value that is measured during axonal stimulation is less than that measured during activation of the same muscle; the latter cames from only single endplates.

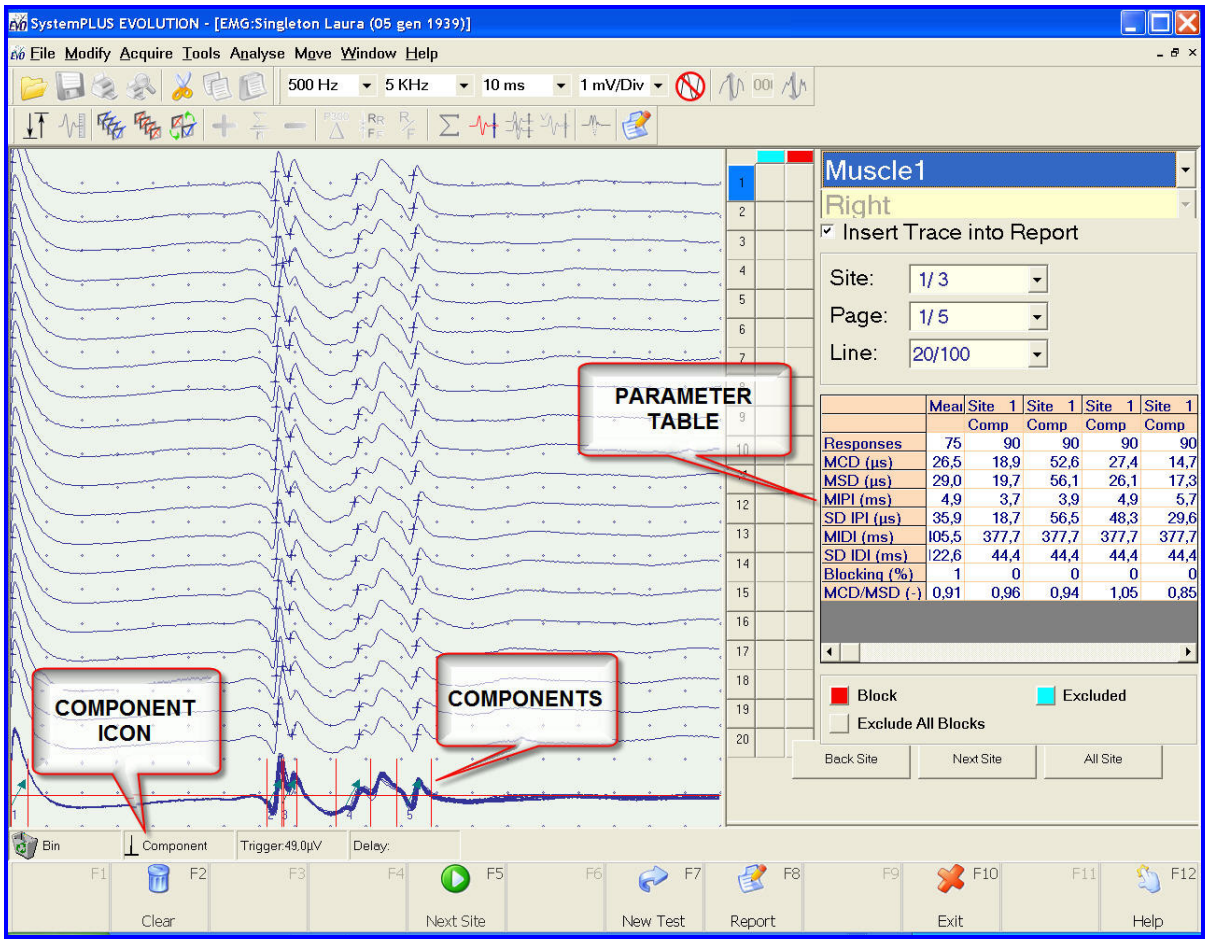
Reference values for jitter during axonal stimulation have been determined for the extensor communis (EDC) and orbicularis oculi muscles. For other muscles, the normative values for stimulation jitter can be obtained by multi values for voluntary activation by a conversion factor 0.8. MCD values less than 5 µs that are obtained during stimulation SFEM occur when the fibre is stimulated directly; these values should not be used for assessing neuromuscular transmission.

The electromyographer must have considerable experience with SFEMG to be able to perform studies on most patients. EMG machines incorporate automated jitter analysis techniques greatly reduce analysis time. Most adult patients can cooperate for adequate SFEMG studies. Patient discomfort rarely limits the use of this test, even when several muscle must be examined. If the patient has a tremor, making adequate recording from distal arm muscle during voluntary activation may be impossible. In such cases recording usually can be made from facial or more proximal arm muscles. Alternatively, recordings of jitter can be made during axonal stimulation.

SFEMG performed using concentric needles
Several recent studies have examined the quantitative evaluation of neuromuscular transmission using disposable concentric needle electrodes (CNE). A larger recording area results in potentials that are easier to acquire and this larger area is more likely to produce recordings with overlapping pairs.
The overlapping pairs, along with contributions from more distant motor units within the recording area, probably results in an underestimation of the true jitter value.
The several studies available suggest that the specificity may be similar to recordings performed with a single-fiber electrode. However, CNE studies are a less sensitive measurements of neuromuscular transmission. No normative exist for this method and CNE studies cannot measure fibre density.
An abnormal CNE-SFEMG is useful in supporting the diagnosis of myasthenia gravis. A normal study result does not adequately reduce or eliminate the possibility of a defect in neuromuscular transmission.

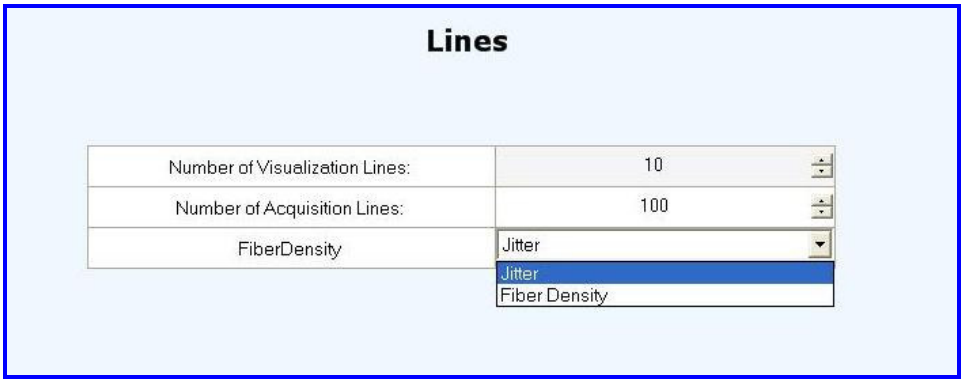
Single-Fibre SystemPLUS Layout and Setup

All parameter and values concerning Single-Fibre examination are displayed into the SFEMG test in SystemPlus. The parameter tab is compiled automatically by the software after defining the components (or triggers) of the signal. In order to add a component, drag and drop it from the component icon at the bottom of acquisition window.



	Mea	Site 1 Comp	Site 1 Comp	Site 1 Comp	Site 1 Comp
Responses	75	90	90	90	90
MCD (µs)	26,5	18,9	52,6	27,4	14,7
MSD (µs)	29,0	19,7	56,1	26,1	17,3
MIPI (ms)	4,9	3,7	3,9	4,9	5,7
SD IPI (µs)	35,9	18,7	56,5	48,3	29,6
MIDI (ms)	105,5	377,7	377,7	377,7	377,7
SD IDI (ms)	22,6	44,4	44,4	44,4	44,4
Blocking (%)	1	0	0	0	0
MCD/MSD (-)	0,91	0,96	0,94	1,05	0,85

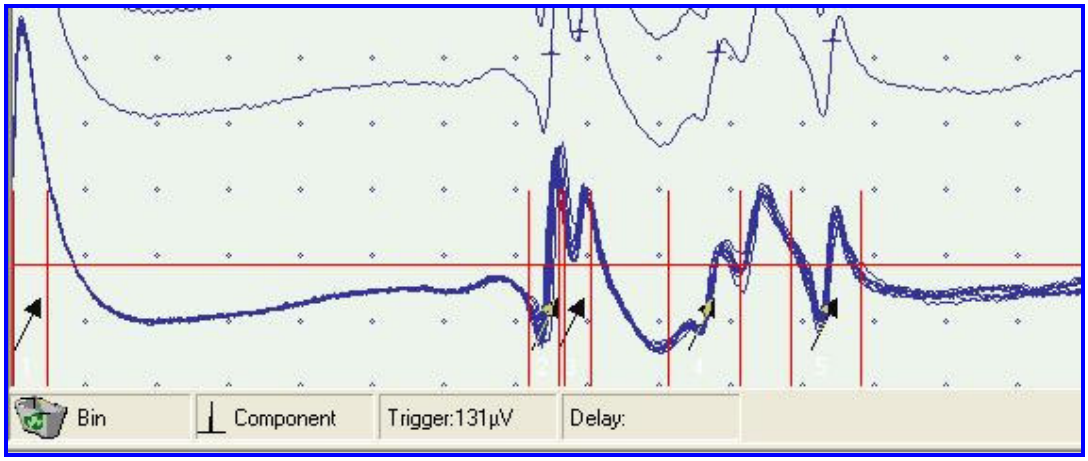
From the single fibre protocol setup, it is possible to select whether you want to investigate Jitter or Fibre Density. Remember you cannot measure fibre density without a single fibre needle.



After choosing the kind of investigation to perform (Jitter or Fibre Density) you can proceed to the signal acquisition. To capture the APs, press spacebar, “save” pedal or “acquire” button into keypad10, and system automatically proceed to capture the potentials compatible with the selected trigger level.

After acquiring 100 APs, acquisition is automatically stopped in a way to allow the user to define further components and blocking rules. It is possible to display 10 to 100 APs into at the same time; at the bottom of the window, all triggered APs are overlapped.

When acquiring stimulated single fibre, you have to activate the stimulator (pressing F4 or Stimulation Button on the keypad). In this case you can easily trigger the APs by the stimulation artifact



Stimulated single Fibre, with stimulation artifact at the right