Clinical neurophysiological examinations

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The presented text was shortened from the original handbook chapter, translated by the Author and supplemented by his own observations from:
Interna Szczeklika, Podręcznik Chorób Wewnętrznych 2013

General abbreviations:

BF- blink reflex
CMAP- compound muscle action potential, during stimulation studies of the nerve efferent fibers a potential recorded from the muscle peripherally, the same as the M-wave
CNAP- compound nerve action potential, a potential recorded from the nerve fibers along their anatomical passage following stimulation of the same nerve
Decrement- a test with the high frequency electrical stimulation applied to the peripheral efferent fibers within nerve, used in diagnostics of disturbances in cases of the neuromuscular junction transmission
EMG- electromyography
ENG- electroneurography
H- H-reflex, examination of H-reflex, similar to the H-wave examination in ENG studies, indicating "closing" the monosynaptic reflex during stimulation studies – both within afferent and efferent fibers
IC-SD- intensity of current *vs.* stimulus duration – a method of investigation both superficial and deep sensory perception threshold with the electrically applied pulses (based on rheobasis and chronaxy phenomena)
MEP- motor evoked potentials – a method based on exciting the motor centers with the magnetic field (mainly overcranially) or efferent fibers of the nerves peripherally with recording of potentials from muscles innervated by them
MU- motor unit
MUAP- motor unit action potential
SCV- sensory conduction velocity – in general, a method of examination the peripheral transmission in sensory fibers when an electrical stimulus (applied during stimulating examinations) excites the receptor and a sensory potential is recorded peripherally along the nerve according to its anatomical passage
SEP- somatosensory evoked potentials – a neurophysiological method of examination the afferent transmission from the electrically stimulated receptor and then via sensory fibers to the spinal cord with recording mainly overcranially the evoked potentials from the contralateral sensory area of the cortex (SCV- in a fact, it is SEP but peripherally recorded only)
SNAP-sensory nerve action potential- a sensory potential recorded from the nerve, a synonym of the sensory evoked potential recorded in SCV examination

Key words: clinical neurophysiological examinations, electromyography (EMG), electroneurography (ENG; M, F – waves, H-reflex), sensory evoked potentials (SCV), somatosensory evoked potentials (SEP), motor evoked potentials (MEP), intensity of current *vs.* stimulus duration curves (IC-SD), blink reflex (BF), myasthenic test (Decrement)

1. General comments on the clinical neurophysiological diagnostic methods

Neurophysiological examinations are usuallly performed to confirm or to exclude the pathological changes in activity of the muscle motor units (**electromyographical examinations, EMG**) or changes in the nerve transmission within motor and sensory nerves (**electroneurographical examinations, ENG**). Diagnostically these studies are the most frequently used in cases of diseases presumed to be present in the systemic changes (degenerative, inflammatory or ischemic) and also coexisting with rheumatoid disorders. In the early diagnostic of many muscles and nerves, the ascertained disturbances may suggest the onset of the rheumatoid disorders.

In **electromyographical examinations** it is possibile to observe two important phenomena: the occasionally existing spontaneous activity at the relaxation state of the muscle and the activity of **motor units (MUs,** originally defined by **Sherrington** awarded with The Nobel Prize in 1932**)** during its stretch (**motor unit action potentials**, **MUAPs**). A functional characteristic is then described in the elementary electromyographic examinations (**needle electromyography recording method**) which allows classifying a disease as the myogenic or neurogenic origin. The **global electromyography** (performed usually before the needle EMG examination) with recordings over the skin from homonymous muscles of both sides (with surface electrodes) lets for the fast examining the extend of disorder in many muscle groups, describes a pathological recordings as symmetrical or asymmetrical, ascertains the pathological changes development suggesting this way the advancement of the disease, estimates a common activity of different muscle groups (for example antagonistic or synergistic) and judges the improvement in bioelectrical activity of the treated muscle groups (for example during a rehabilitation process) or confirms/excludes the presence of the muscle diseases coexisting with the disturbed locomotion. In some cases EMG lets for discovering a reason of the motor dysfunction with an unknown origin or indirectly ascertains the proper muscle tension or helps in explaining the incorrect results of surgical treatment.

The **electroneurographical examinations** describe the activity in nerve fibers by ascertaining their excitability state, the ability of impulses transmitting or their conduction velocity and has a basical meaning in the diagnostic of neuropathies. Results of examinations make possible to find out what kind of fibers are involved by the disease (**motor, efferent – M and F waves studies; sensory, afferent – SCV studies** and **partially with H- reflex studies**), describe a type of changes (axonal, demyelinating, mixed) and a range of the pathological process (mononeuropathy, multiple and multifocal neuropathy of several nerves in different extremities, poliradiculoneuropathy, a general polyneuropathy) or objectively ascertain the influence of therapy or changes in the course of disease (acute or subacute).

The **afferent and efferent transmission** examinations at different levels of peripheral and central nervous systems include the methods of recordings the **somatosensory (SEP) and motor (MEP) evoked potentials** (the latter is induced with the magnetic field). The efficiency in afferent transmission from the level of receptor to the area of the contralateral sensory cortex can be also indirectly characterized in examinations of **sensory excitability curves (IC-SD studies)**. Because many of the demyelinating or rheumatoid diseases evoke changes in transmission of fibers within visual and auditory tracts, methods of examinations with visual and auditory brainstem evoked potentials are of the special interest. Their particular description is however far beyond the aim of this manuscript.

The neurophysiological examinations are performed according to the commonly known standards, however modified from time to time with the reference to the diagnosed diseases. Obtained results are compared with the normal parameters ascertained every five years on the healthy population of volunteers of both sex with different ages. Every neurophysiological labolatory should create its own control parameters because of the population and evolution variability of afferent and efferent electrophysiological parameters and also the evolution of nerve-muscle diseases themselves.

A schedule of choosing the particular methods from neurophysiological examinations depends on the fact if the expected results may help in a diagnosis (by their repeatability in prognosis during the disease course) or in ascertaining the efficiency of applied therapy or to extent the knowledge about the pathogenesis of the nosological entity.

2. EMG examination

Figure 1 A i B shows examples of the normal single motor units action potentials **(MUAPs)** recorded with needle electrodes during the maximal effort of muscles.

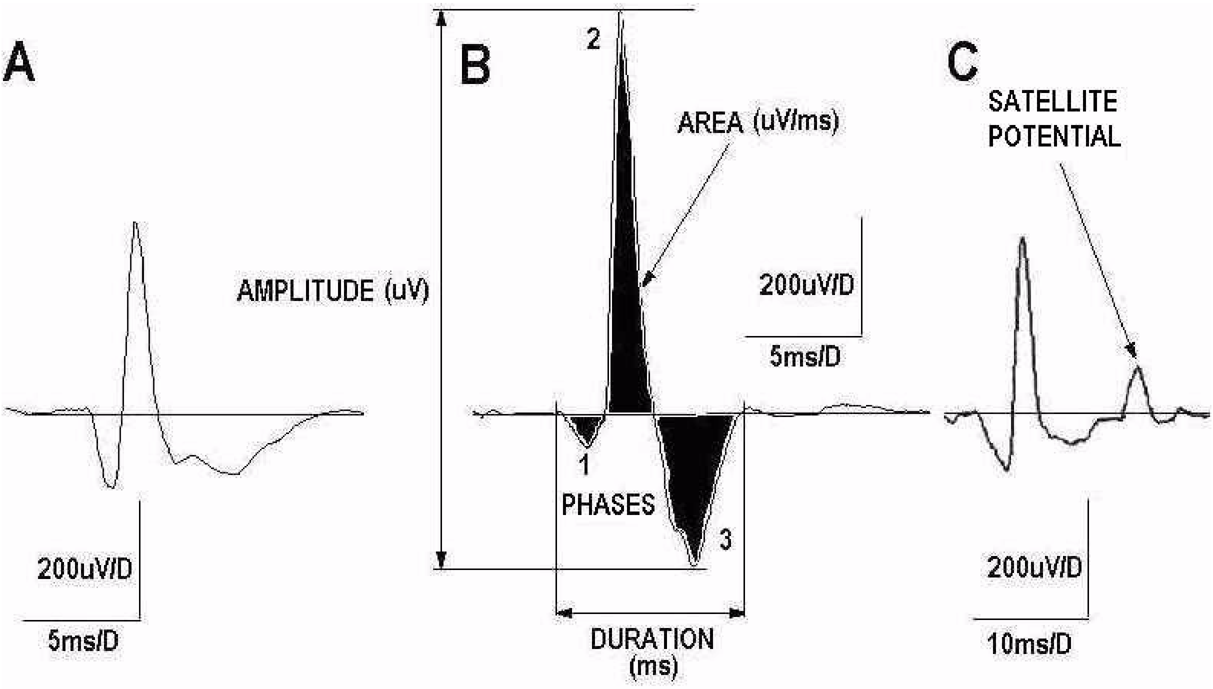


Fig. 1. Samples of recordings with the needle electrodes of muscle potentials (MUAPs, elementary EMG) from the single motor units during the maximal stretch. **A,B**-proper potentials (recorded subsequently from the gastrocnemius muscle and anterior tibial muscle) with marked parameters useful diagnostically (**B**; phases 1 and 3 of the main potential - positive, phase 2 – negative). In **C** it is shown an example of the main potential supplemented with the satellite.

The parameters which are diagnostically useful (during the analysis of usually 20 recoded MUAPs) which help in differentiation between the muscles diseases of neurogenic or myogenic origin are mainly the amplitude, the duration of the potential and its area. At normal conditions these parameters are different with recordings from different muscles, but usually their values are in ranges respectively 300-1000 μV, 8-12 ms and 350-950 μV/ms. A difference for each of these parameters more than 25% in comparison to the normal values can be the indication of pathology in activity of motor units within the examined muscle. The proper potential has got 2-3 phases, it's seldom with four phases. Besides the main potential, it can be recorded a satellite potential, more frequently in muscles covered by the pathological process (Fig. 1 C). A course of changes in all of the mentioned above parameters is decreased in myopathies and increases in neuropathies (Fig. 2 A-C).

The age of the patient in analysis of the proper MUAPs should be also considered. In recordings from muscles in children below 13 years there can be observed "immature recordings" (with values lower in comparison to the above mentioned parameters, usually about 1/3) and in adults above 40 years a natural progression of the denervation changes can be observed (increasing the values of analyzed parameters). It should be also remembered about the influence of the temperature factor (22^{o}C is optimal for the diagnostic labolatory), the emotional factor (an information about the painless course of examination) as well as the influence of some pharmaceuticals on EMG recordings which are applied by the patient.

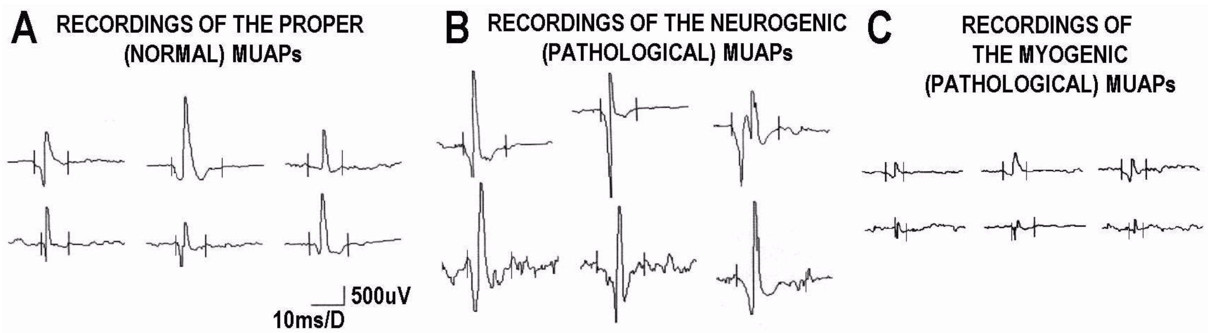


Fig. 2. Samples of the single motor units potential recordings (MUAPs) from muscles: **A**- normal (healthy volunteer), **B**- with neurogenic changes, **C**- with myogenic changes. All recordings were performed from biceps brachii muscle.

A distinction between the proper and pathological muscle activity may by also be performed by EMG recordings at the resting state and by analyzing of the recording frequency during the muscle stretch performed by the patient (from minimal to maximal during a voluntary movement) (Fig. 3).

At normal conditions with the full muscle's relaxation (a resting state recording) when a needle EMG recording is performed (and sometimes with "surface" global EMG recordings) there should not be observed **the spontaneous potentials** (sometimes called "involuntary") (Fig. 3 E and F) with the amplitude greater than 20-30 μV (so called state of "**bioelectrical silence**" or "myoelectrical silence" is recorded) (Fig. 3 D). A presence of potentials with lower values of amplitudes during both methods of recordings can indicate to a certain degree for the proper muscle tension or about the proper state of readiness in muscle motor units to develop the maximal muscle force during its stretch (Fig. 3 A a1-a3, D). A spontaneous activity different from typical potentials observed during insertion of needle electrode to the muscle can be recorded as **fibrillations** (Fig. 3 Ec, with the first phase positive, amplitude 50-1500 μV, duration of potential 2-5 ms, frequency of firing 2-20 Hz, arrhythmic, Fig. B a1,a2) in **neurogenic** processes as a result of muscle fibers denervation and in processeses classified as **myogenic** when **discharges (trains) of fibrillations** are recorded (amplitude 100-300 μV, duration of potential 3 ms, frequency of discharging 20-200 Hz, rhythmical; see also Fig. 10 A a). **Typical neurogenic syndromes** (accompanied also with injury in the central part of motor unit) are characterized with **positive denervation potentials (positive sharp waves)** (Fig. 3 Ed, with the first phase positive, amplitude 50-4000 μV, duration of potential 5-50 ms, frequency 2-50 Hz, arrhythmic ; see also Fig. 10 C a) while **myopathies** – with **myotonic discharges (trains)** (Fig. 3 Eg, amplitude from 500 to 150 μV, duration of potential 1-5 ms, frequency 90-150 Hz, rhythmical, with clear episodes of amplitude „increasing" and „decreasing"; Fig. 3 C a1) or in inflammatory states of muscles **pseudomyotonic discharges (trains)** (amplitude 50-500 μV, potential's duration 2-3 ms, frequency 20-150 Hz, arrhythmic; see also Fig. 10 B a). **Trains of pseudomyotonic discharges** are also observed in cases of the motoneurone diseases (Fig. 3 Eh). In neurogenic syndromes such as the lateral amyotrophic sclerosis there can be observed fasciculations (Fig. 3 Eef) or double sponataneous potentials ("doublets", Fig. 3 Fa). A spontaneous activity which is recorded in muscle as a result of improper impulsation at the supraspinal centres can appear as **mono- or polyphasic series of potentials** (Fig. 3 Eij).

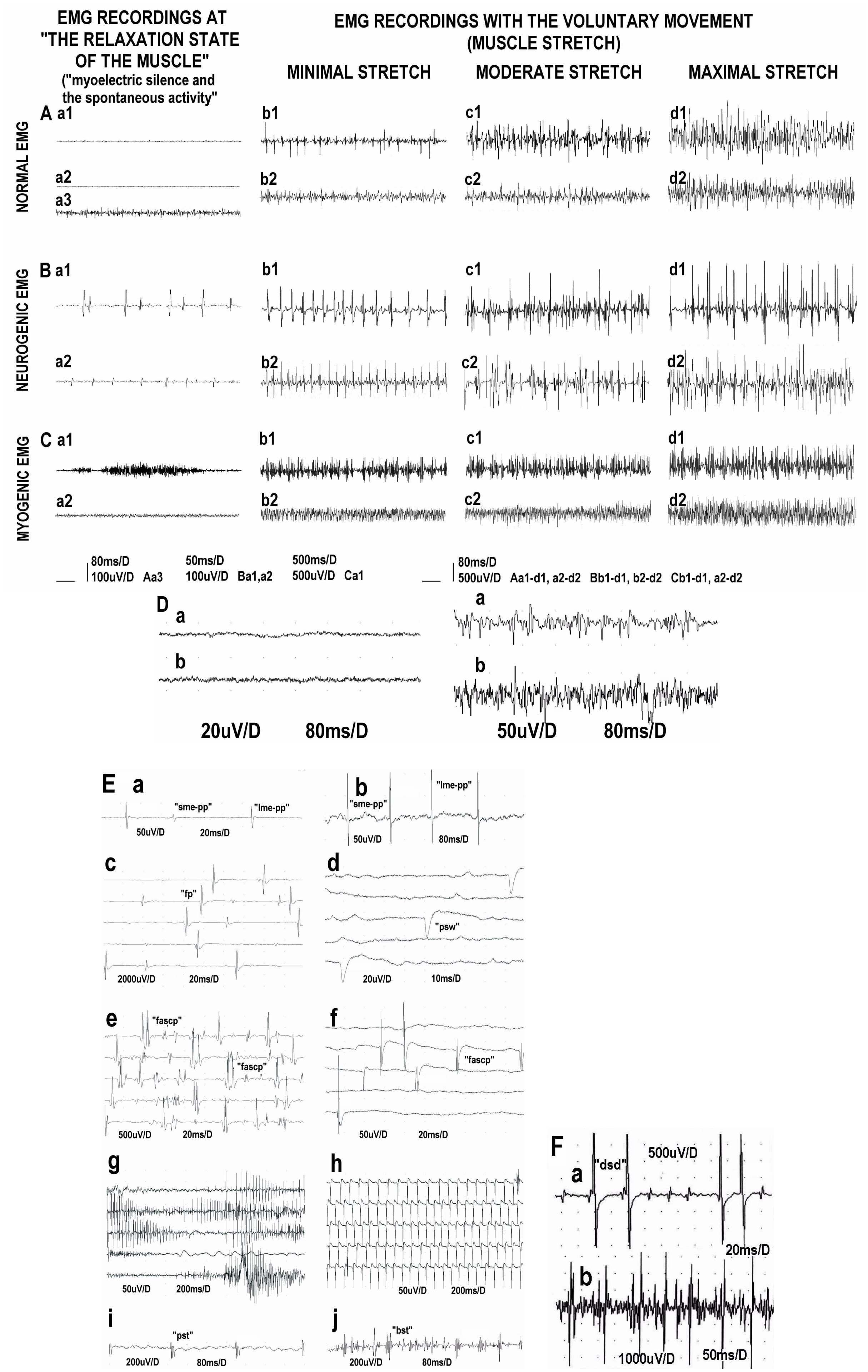

EMG RECORDINGS AT "THE RELAXATION STATE OF THE MUSCLE"
("myoelectric silence and the spontaneous activity"
EMG RECORDINGS WITH THE VOLUNTARY MOVEMENT (MUSCLE STRETCH)
MINIMAL STRETCH
MODERATE STRETCH
MAXIMAL STRETCH
NORMAL EMG
NEUROGENIC EMG
MYOGENIC EMG
A a1 a2 a3 b1 b2 c1 c2 d1 d2
B a1 a2 b1 b2 c1 c2 d1 d2
C a1 a2 b1 b2 c1 c2 d1 d2
80ms/D 100uV/D Aa3
50ms/D 100uV/D Ba1,a2
500ms/D 500uV/D Ca1
80ms/D 500uV/D Aa1-d1, a2-d2 Bb1-d1, b2-d2 Cb1-d1, a2-d2
D a b
20uV/D 80ms/D
a b
50uV/D 80ms/D
E a "sme-pp" "lme-pp" 50uV/D 20ms/D
b "sme-pp" "lme-pp" 50uV/D 80ms/D
c "fp" 2000uV/D 20ms/D
d "psw" 20uV/D 10ms/D
e "fascp" "fascp" 500uV/D 20ms/D
f "fascp" 50uV/D 20ms/D
g 50uV/D 200ms/D
h 50uV/D 200ms/D
i "pst" 200uV/D 80ms/D
j "bst" 200uV/D 80ms/D
F a "dsd" 500uV/D 20ms/D
b 1000uV/D 50ms/D

Fig. 3. Examples of the elementary (marked with **1**) and global (marked with **2**) electromyogramms recorded in healthy muscle (**A**), with properties of the neurogenic changes (**B**) and with properties of the myogenic changes (**C**). Recordings were performed during the relaxation state (**a**) and in three stages of the stretch (**b-d**) from tibialis anterior muscle (**A, B**) or biceps brachii muscle (**C**).
D. Examples of recordings from the same anterior tibial muscle during its maximal relaxation using the needle (**a**) and the surface electrodes (**b**) in a healthy volunteer (left part of the figure, the average amplitude parameter was less than 20μV) and in a patient treated because of the fibromyalgia (recordings from trapezius muscle, right part of the figure, the average amplitude parameter was more than 30μV). The increased parameter of the amplitude in the resting potential may indicate the increasing in the muscle tension under this examination.
E. Examples of elementary EMG recordings from muscles during their relaxation state: **a** and **b**- normal recordings (abductor digiti minimi muscle) with presence of „muscle end-plate potentials", **c**- denervation potentials (abductor digiti minimi muscle) – „fibrillation potentials", **d**- positive denervation potentials, "positive sharp waves" (biceps brachii muscle), **e** and **f**- „fasciculation potentials" recorded respectively from abductor digiti minimi muscle and tongue muscle in one of patients treated because of the lateral amyotrophic sclerosis, **g**- myotonic discharges recorded from first dorsal interosseus muscle in a patient with Thomsen myotonia, **h**- pseudomyotonic discharges called also „bizzare high frequency discharges" recorded from biceps brachii muscle with the clinically recognized spinal muscle atrophy, **i**- series of positive potentials recorded (anterior tibial muscle) in a patient with injury at the brain stem level, generated probably by the tonic activity of the reticular formation neurones, **j**- series of potentials (anterior tibial muscle) recorded in a patient treated because of the ischemic stroke with episodes of epilepsy documented also in EEG examinations ("myoclonic trains").
Abbreviations: „lme-pp"- „large motor end-plate potentials", „sme-pp"- "small motor end-plate potentials", „fp"- „fibrillation potentials", „fascp"- „fasciculation potentials", „psw"- „positive sharp waves", „pst"- „positive spontaneous trains", „bst"- „biphasic spontaneous trains".
F. Examples of elementary EMG recordings (anterior tibial muscle) at the resting state of muscle (**a**) and during its maximal stretch (**b**) in a patient with the lateral amyotrophic sclerosis. Double spontaneous discharges (doublets, „dsd") which are characteristic for the motor unit injury can be clearly seen in **a.**

In the normal EMG recording performed during voluntary movement at the minimal muscle stretch there can be observed single potentials with small amplitudes and low frequency (so called **„simple"** or **"poor"** EMG pattern with frequency of 5-30 Hz; Fig. 3 A b1,b2). With the moderate stretch of the muscle a recruitment of motor units is increased and increasing of the amplitude and frequency parameters in a recording can be observed (so called **„intermediate pattern"** of EMG recording with frequency of 35-60 Hz; Fig. 3 A c1, c2). At the further maximal stretch of the muscle there is observed so called **"interference"** pattern of EMG recording when single potentials are imposssible to be distinguished and summary potentials are collected what is a result of superimposing the activity from many MUs (a recording with frequency of 70-95 Hz; Fig. 3 A d1, d2).

When symptoms of the neurogenic origin disease are suspected to be present in the examined muscle, peculiarities of EMG recording (Fig. 3 B b1-d1, b2-d2) there can be similarly observed low-frequency and high-amplitude potentials in three graded phases of the muscle stretch (from minimal to maximal) resembling "poor" EMG pattern. On the other hand, recordings of the muscle fibers activity with symptoms of changes within the membranes of myocytes or disturbances in their metabolism themselves (myogenic, Fig. 3 C b1-d1, b2-d2) are characterized with the very low amplitude of recorded potentials observed with the excessively high frequency (105-150 Hz) comparing with normal recordings, both at the minimal and maximal stretches.

The elementary EMG as a method is much more sensitive than global EMG. Needle EMG is used when even the discrete signs of pathology in muscle motor units are suspected and it is necessary to precise their etiology and an advancement. The positive sides of the global electromyography application are its non-invasive properties and a short duration of the test when a general functional state of the whole muscle is estimated because of recording the summary myoelectrical activity of many MUs (Fig. 4).

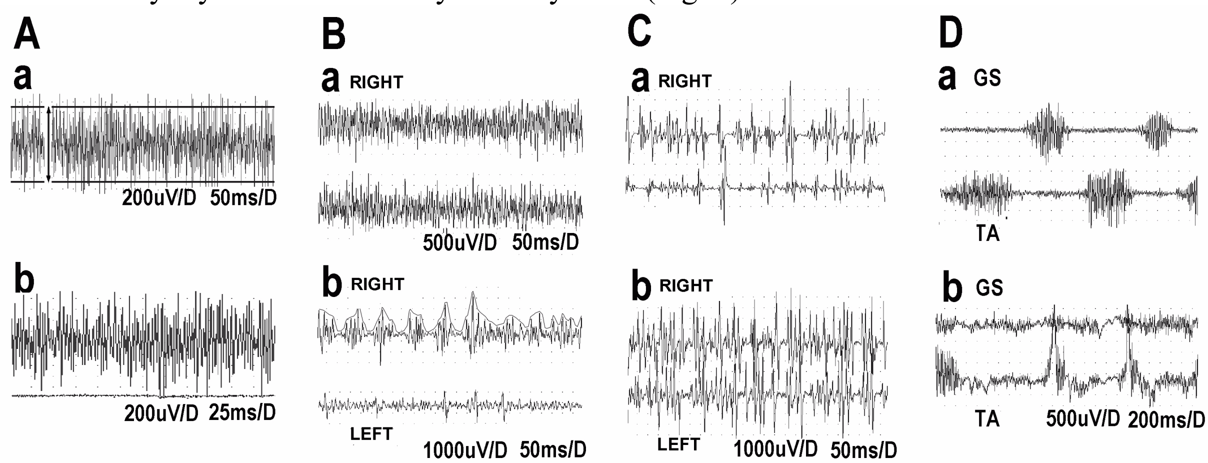


Fig. 4. Examples of global EMG recordings during the maximal stretches of examined muscles.

A- normal electromyogramm recorded from the anterior tibial muscle. Part **a** of the picture shows a fashion of the mean amplitude value measurement (a range between two horizontal lines, in this case it is about 1300μV) while **b** part shows a fashion of the mean frequency value measurement (each single discharge is marked with a dot below the recording, in this case it is about 95 Hz).

B- comparison of normal (**a**) and pathological (**b** – a case of a patient with the ventral root conflict at the lumbosacral level of spine, it can be observed a characteristic modulation pattern of the "intermediate" type recording) electromyogramms recorded bilaterally from extensor digiti muscles.

C- comparison of bilateral EMG recordings from extensor digiti muscles in a patient with the rheumatoid inflammation of joints before (**a**) and half a year after treating (**b**).

D- examination of activity in muscles acting antagonistically at the same ankle joint (GS-gastrocnemius and soleus muscles, TA-anterior tibial muscle). Activity recorded in a healthy volunteer is shown in **a** while in **b** the activity of muscles recorded in a patient treated because of the cortical hemorrhagic stroke is presented.

Advances in a global EMG recording which comprised mainly the computer acquisition and analysis techniques (Fig. 4 A a, b) are so promising at present that in clinical conditions it starts to be used the same often as the needle EMG. The optional repeatability of global EMG method makes possible to monitor the advancement of treating with the reference to a previously diagnosed disease. This method is used by neurosurgery, neurology and orthopedic basing on a rule of "the somatotopical spinal root innervation" in typical pressure syndromes such as discopathies (Fig. 4 B a, b), in rheumatology for cases of estimation the roots inflammatory syndromes (Fig. 4 C a, b) or in the rehabilitation treatment for a verification of efficiency the applied kinesiotherapeutic and physicotherapeutic procedures like in cases of patients after stroke (Fig. 4 D a, b). In the end, the surface EMG recording over the muscle is also a starting point for the electroneurographical examination (ENG).

Too high or too low temperature influences the conditions for the proper recording of electrical MUs activity (it's provocationally changed in examinations of the myotonic syndromes) that's why recordings should be performed in the EMG labolatory room at about 22^{0}C. Some pharmaceuticals influencing the blood coagulation, psychotropics or pharmaceutical influencing the acethylocholine releasing (used in cases of treating the patients with disturbances at the level of the neuromusclular junction) should be considered with the decision and estimation of EMG examination.

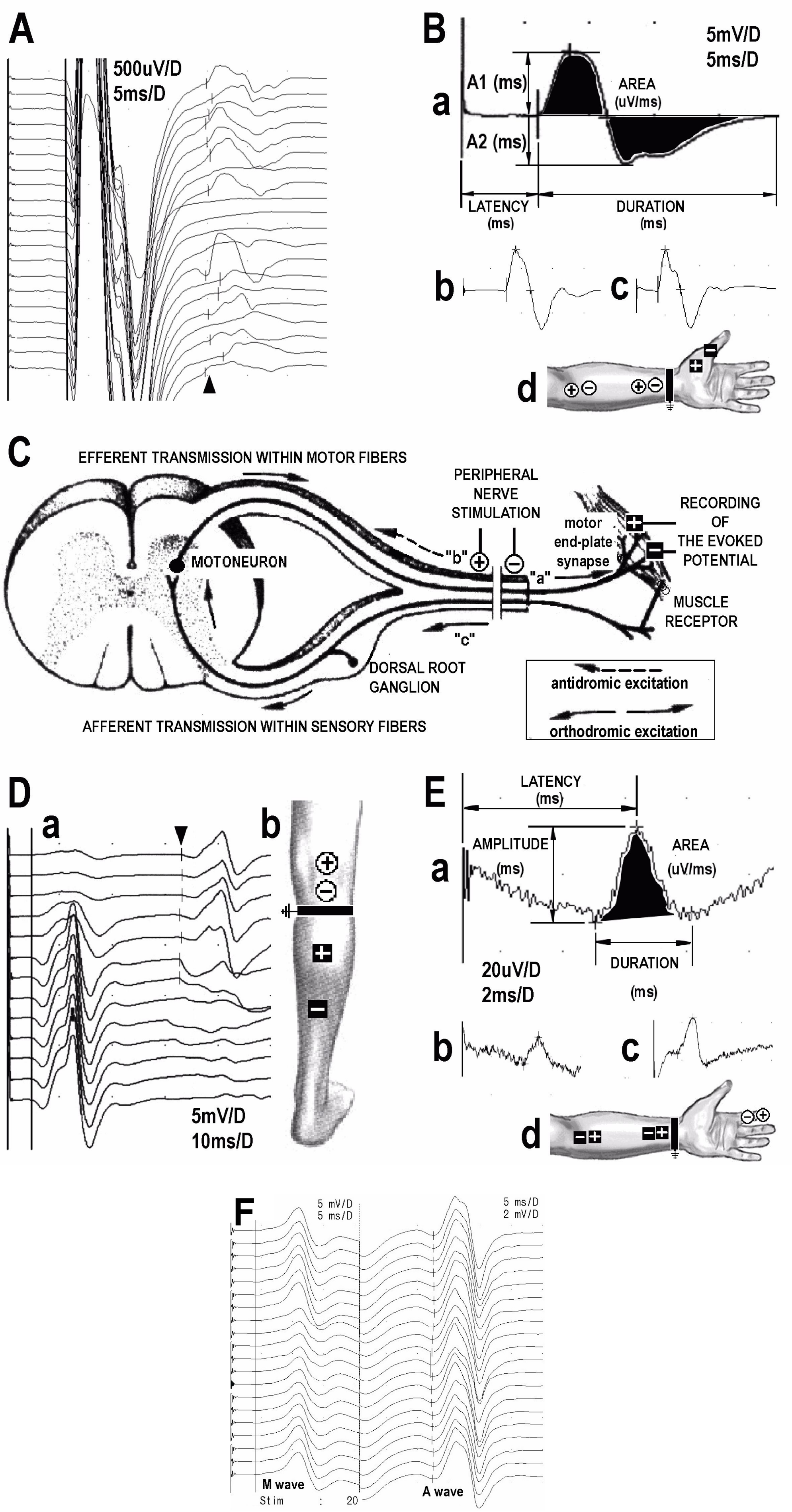
3. ENG examination

The main aim of the electroneurographical examination is to excite the motor or sensory fibers within the nerve with electrical pulses generated by the stimulator and applied via a bipolar electrode (Fig. 5 C). A stimulating electrode is placed over the skin along the anatomical passage of examined nerve. The electrical stimulus is rectangular in a shape, its duration is from 0,1 to 0,5 ms (usually 0,2 ms), intensity from 0 to 100 mA and a frequency usually at 2 Hz.

When a placement of positive and negative poles of the stimulating electrode is in accordance with the **orthodromic** (physiological) direction of efferent transmission, an electrical stimuli evokes the excitation of motor fibers within the examined nerve and consequently also the excitation phenomenon at the level of nerve-muscle synapses (Fig. 5 C „a"). The bipolar recording electrode (a positive pole is placed over the belly of the innervated muscle, a negative pole over its tendon distally, a "ground" electrode is applied between two sets of the stimulating and recording electrodes; Fig. 5 B d) records the **M wave evoked potential** (also called **CMAP potential**, Fig. 5 B a). M wave is a sum of action potentials from all excited muscle fibers following the nerve stimulation. The applied stimulus is supramaximal during examination of the motor potentials, it means that its intensity is increased up to recording a CMAP with the largest stable amplitude. M wave can be evoked following the nerve stimulation in its proximal and distal parts (Fig. 5 B, b and c respectively) during so called "**segmental proximal to distal examination**" (what is important in findings of the local conduction block). Sometimes it its useful to apply the study at very short distances (called „inching"). The amplitude (A1-half from the negative phase or A1+A2- total from both the negative and positive phases of potential), the motor distal latency (it means the time necessary for propagation of excitation, measured from the onset of applied stimulus to the onset of CMAP recording), the duration of main potential (called also "dispersion", it means the whole length of potential described by negative (A1) and positive (A2) components which value is important in the assessment of progressive degenerative changes within nerve fibers), the conduction velocity (calculated from the equation of dividing the corresponding conduction distance value by the latency value) and the potential area (calculated from values of the amplitude and the duration) parameters are assessed in recordings of M wave (Fig. 5 B a). Normal CMAP is usually biphasic, occasionally with three phases. Variants of the superficial nerve stimulation and superficial recording from the nerve itself (over the skin) (**CNAP**) can be also chosen during supplementary conduction studies commonly called "ENG examinations"

Studies of M wave in neuropathies allow for ascertaining a range of the certain injury, describing its type (**axonal-decreasing the amplitude parameter** or **demyelinating-decreasing the conduction velocity parameter**, or the predominance one of changes when they exist together) or describing the dynamic progress in pathological processes.

In most cases of tested nerves under physiological conditions, a total CMAP amplitude should not be smaller than 3000 μV and its value in **segmental examinations** should be the same.



A
500uV/D
5ms/D
B
a
5mV/D
5ms/D
A1 (ms)
A2 (ms)
AREA
(uV/ms)
LATENCY
(ms)
DURATION
(ms)
b
c
d
C
EFFERENT TRANSMISSION WITHIN MOTOR FIBERS
PERIPHERAL
NERVE
STIMULATION
motor
end-plate
synapse
RECORDING
OF
THE EVOKED
POTENTIAL
MOTONEURON
"b"
"a"
"c"
MUSCLE
RECEPTOR
DORSAL ROOT
GANGLION
antidromic excitation
orthodromic excitation
AFFERENT TRANSMISSION WITHIN SENSORY FIBERS
D
a
b
5mV/D
10ms/D
E
LATENCY
(ms)
a
AMPLITUDE
(ms)
AREA
(uV/ms)
DURATION
(ms)
20uV/D
2ms/D
b
c
d
F
5 mV/D
5 ms/D
5 ms/D
2 mV/D
M wave
Stim : 20
A wave

Fig. 5. Sketch of performing the electroneurographical examinations (ENG) and examples of the evoked potentials recorded at normal conditions. **A**-example of F wave potential recording (the arrowhead shows onsets of the recorded potentials with latencies marked with cursors) obtained from the thenar muscle group following the stimulation of median nerve. **B**-examples of M waves recordings (**b** and **c**) from the thenar muscle after stimulation of the median nerve at the cubital fossa and the pre-wrist area respectively (see also a scheme in part **d**). The proper CMAP with parameters useful diagnostically is shown in **a.** **C**-scheme of propagation the antidromic and orthodromic excitations within motor and sensory fibers of the stimulated nerve. White circles symbolize the anode and cathode of stimulating electrodes and black squares the same of recording electrodes. **D**-example of diagnostic in case of H wave recordings. Records shown in **a** (arrowhead indicates onsets of the recorded potentials with latencies marked with cursors) were performed from the gastrocnemius and soleus muscle group following the stimulation of tibial nerve at level of the popliteal fossa (see a scheme in part **b**). **E**-examples of the sensory evoked potentials (**b** and **c**; SCV examination) recorded from the cubital fossa and the pre-wrist area following stimulation of the second finger respectively (see a scheme in part **d**). The normal sensory potential with marked parameters which are diagnostically useful is show in **a.** **F**- examples of M and A waves recordings from the gastrocnemius and soleus muscle group after stimulation of the tibial nerve in a central part of popliteal fossa.

The conduction velocity in motor fibers calculated from the latency of M wave depends on the site of nerve stimulation in its proximal and distal parts what is joined to the progressive diminishing of fibers diameter located more and more peripherally. In the segmental examinations of nerve transmission the mean value of conduction velocity is ascertained, dividing the conduction distance value which is measured between two points of stimulation by a value from difference of latencies proximal (longer) and distal (shorter). In studies of the total transmission, a conduction velocity is calculated by dividing the value of the conduction distance measured from the stimulating point to the recording point in a muscle and the distal latency. The normal conduction velocity value of motor fibers in standard tests of upper extremity nerves (stimulated at the level of cubital fossa) should not be lower than 45 m/s and within nerves of lower extremities (stimulated at the level of popliteal fossa) not less than 40 m/s.

Particular cases of motor fibers neuropathies (such as during neuroboreliosis or Bell's palsy) require a diagnostic of the **facial nerve fibers conduction studies** (Fig. 6 A-C). These motor fibers are sensitive to the injuries almost the same as the sensory fibers of other nerves. In above mentioned pathological syndromes the M wave study is particularly useful, especially in confirming the early symptoms of diseases.

Symptoms of **disturbances at the neuromuscular junction transmission** (such as in cases of myasthenia or Lambert-Eaton syndrome) are the most frequently observed in muscle groups including a large percentage of the fast contracting and the fast fatigue motor units (FF type; for example in muscles of the face, muscles innervated by the upper part of brachial and lumbosacral plexes and distal muscles of the upper extremities). Such diseases can have respectively their origin with disturbances in the acetylcholine releasing or pathological changes in calcium channels at the level of the nerve-muscle synapse. In neurophysiological studies the above mentioned syndromes can be diagnosed with an electrical stimulation test at high frequencies (with recordings of M wave following sequences of stimulations at 3, 10 and 30 Hz) applied to the motor fibers innervating the above mentioned muscle groups. The assessment of the M wave amplitude decreasing phenomenon (so called "**decrement**", fig. 6 D) or its "potentiation" (increasing) with more than 35-50% (when the M wave amplitudes parameters at the first - to the fourth - to the tenth responses are compared) makes possible the supplementation of the clinical diagnosis in differentiation of these two syndromes.

„**The blink reflex**" - BF (Fig. 6 Ea-c) is an example of the diagnostic neurophysiological monitoring with the reference to transmission (mainly peripheral) within fibers of both trigeminal and facial nerves, but indirectly proves also "closing" the reflex arc at the level of pons and the lateral part of spinal medulla. Changes in parameters of recorded R1 and R2 waves are clearly seen especially in cases of the trigeminal nerve fibers lesions, Bell's palsy, synkinesis of facial muscles, polyneuropathies, lesions in the brainstem and spinal cord (C2-C3 level) as well as tumors of the ponto-cerebellar angle.

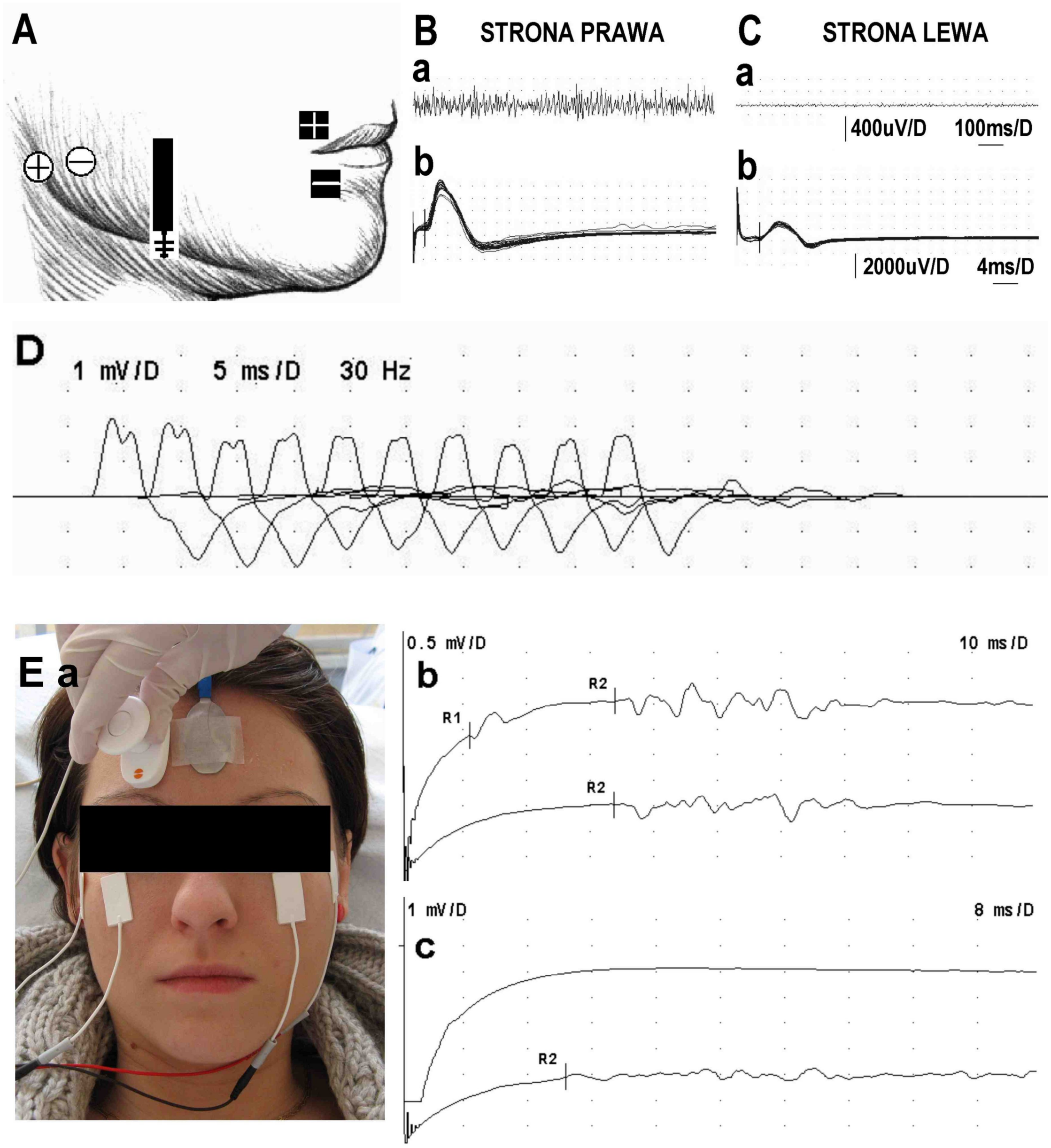


Fig. 6. Scheme of the transmission examination in motor fibers of the facial nerve (**A**) and examples of electromyographical (**a**) and electroneurographical (**b**) recordings performed bilaterally from the orbicularis oris muscles. Normal recordings are shown in **B** while in **C** there are presented recordings performed in one of the patients with an inflammation state comprising the motor fibers of examined nerve.

D. Example of the M wave recorded from abductor digiti minimi muscle following the high-frequency electrical stimulation of motor fibers in the ulnar nerve (at the area of ulnar sulci, with the supramaximal intensity, frequency at 30Hz). This test (called „decrement") is applied to differentiate diseases joined to disturbances at the level of neuromuscular junction.

E. Scheme of „blink reflex” examination (**a**) which is evoked following the electrical stimulation of supraorbital nerve with recordings of early (R1) and late (R2) responses performed from orbicularis oculi muscles (**b** – at normal conditions; upper record – ipsilaterally with the stimulation site, lower record – contralaterally to the stimulation site). Neither R1 nor R2 responses could be recorded on the ipsilateral side in one of diagnosed patients with the right Bell’s palsy as it is presented in **c** (sites of stimulation and recordings are the same as for **b** example).

The transmission in the proximal parts of nerve fibers passing within the roots and plexes can be ascertained with examination of the **F wave** and the **H reflex (wave)**.
When a peripheral placement of positive and negative poles of the stimulating electrode is in accordance with the orthodromic transmission, an electrical stimuli evokes the excitation of motor fibers within the examined nerve which is directed to the effector (Fig. 5 C „a”). A result of this phenomenon is the muscle stretch and M wave potential can be observed in the recording (Fig. 5 A, an onset is indicated with the second vertical line from the left side). Additionally however, a stimulating pulse is able to spread along the motor fiber in the opposite (**antidromic**) direction to the physiological transmission with the electrotonical (electrotonus) rule (Fig. 5 C „b”). Reaching the cell body of the motoneurone exites it, then “rebounds” what evokes the recurrent wave of transmission to the muscle. Since, the F wave evoked potential is possible to be observed (Fig. 5 A, the onset is indicated with the arrowhead) and it appears with the longer latency after M wave in a recording. The amplitude of F wave is much more smaller than CMAP amplitude, at normal conditions it should be not less than 200 μV. A diagnostical value for ascertaining the proper transmission within fibers of ventral root as well as the motoneurone excitability is not mainly the F wave amplitude but its frequency not less than 14 cases with the reference to 20 M wave recordings during a stimulation study (70%). The F wave with a high amplitude (with the value of 1500 μV) can be recorded in patients with lateral amyotrophic sclerosis, neuropathies and in the end myopathies. It is supposed that this phenomenon may reflect the increasing of motor unit area due to the reinnervation process as well as the motoneurone excitability and its axon.

The F wave should not be missed with **A wave** which is observed in neurogenic diseases and the subsequent reinnervation processes. The A wave can be observed after M wave in 20 pulses stimulation studies with much shorter and constant than F wave latency and with the characteristically constant amplitude (Fig. 5 F).

The peripheral electrical stimulation of nerve with the direction of **orthodromic transmission in the sensory fiber** (Fig. 5 C „c”) can evoke the afferent excitation, then a spinal motoneurone excitation and, in the end, H wave potential recorded in the muscle (Fig. 5 D, the onset is indicated with arrowhead). During a successive increasing of the stimulus strength in 20 sstimulation test, H wave is observed earlier than M wave but with the longer latency (comparable to the F wave latency) and then its amplitude decreases whereas the amplitude of M wave increases. It is possible however that the H wave is an equivalent of the monosynaptic reflex. The generation of H wave can be a result of the muscle receptor reaction following the excitation of motor fiber with an electrical stimulus, then the afferent transmission to the spinal center and excitation of motoneurone and consequently, the recording of reflex activity in the muscle (Fig. 5 C, a transmission on the way „a”, „c”, „a”). At normal conditions, the amplitude of H wave reaches from 500 to 5000 μV. H wave with a high amplitude can be observed in examinations of patients with the spinal cord injuries or in patients with the excessive spasticity of different etiology. It is accepted that a proper H wave monitors mainly the afferent transmission within the dorsal root since this method of examination is useful in a diagnosis of the spinal roots conflict syndromes, as well as in cases of radiculopathies and different neuropathies in proximal and distal parts of nerves.

4. SCV examination

Methodologically this test is considered as an equivalent of the segmental transmission examination but with the reference to sensory fibers. A bipolar stimulating electrode is applied over the skin in the area of the longitudinal nerve passage or at the level of the receptor itself. Poles of the electrode are set according to the orthodromic transmission of sensory fibers (Fig. 5 E d). The sensory potentials are recorded proximally or distally at sites of the nerve anatomical passage (Fig. 5 E b, c). Electrical pulses which are released from the stimulator have the same parameters as in cases of CMAP examination, their intensity should be adjusted to excite the whole fraction of fibers, evoking the minimal stretch of the muscle innervated by the motor nerve fibers. Two techniques of examination, ortho- and antidromic are possible. The orthodromic potential (**SNAP**; Fig. 5 E, a) is recorded with a very low amplitude (at normal conditions not less than 10 μV), so in advanced polyneuropathies this method of recording requires the computer averaging process. The amplitude is measured from the negative peak (above the isoelectric line) to the positive peak of potential (below the isoelectric line). The latency, it means the time from the excitation to appearing the response is measured from the onset of the stimulus artifact to the first negative peak. The duration of potential (dispersion, the whole length of the potential) and the conduction velocity calculated from the latency and corresponding conduction velocity are also diagnostically useful parameters. For example, the proper parameters of conduction velocity for sensory fibers are values not les than 48 m/s and 45 m/s in stimulation studies of median and tibial nerves when recordings are performed at the cubital fossa and popliteal fossa respectively.

Taking into account their specific structure, the sensory fibers react faster than motor fibers for any considered metabolic changes since the least pathologies observed in SCV examination can be a sensitive indicator of the first syndromes of sensory neuropathies existing in the carpal tunnel syndrome and the lupus erythematosus, a gout, a vasculitis and in collagenoses.

SNAP is often identified with N4 or N7 waves in somatosensory evoked potentials which are recorded at the cubital fossa and popliteal fossa respectively.

5. SEP examination

The averaged **somatosensory evoked potentials (SEP)** make possibile to assess the functional state of **afferent transmission** (Fig. 7) basing on recordings of exitation performed over the skin along its passage at different levels: peripheral (D, C), spinal (B) and supraspinal (A). Parameters of electrical stimuli and placement of stimulating electrodes applied over the nerves passage in distal parts of upper and lower extremities are similar as in cases of SCV examinations. Following the stimulation of sensory nerve fibers, the wave of excitation reaches the contralateral cortex centres located in the postcentral gyrus. Negative (N) and positive (P) components of recordings have their characteristic morphology described by the parameters of amplitude and latency. At normal conditions with the peripheral recording, a value of the potential amplitude (measured from the peak of negative component to the peak of positive component) should not be less than 5μV, and with the central recording (measured from the peak of wave to the peak of isoelectric line) a value less than 2 μV. Latencies (measured from the onset of stimulus to the peak of potential wave) and corresponding conduction distances give a basis for calculation the conduction velocity of the afferent transmission at the certain levels of examined sensory pathway. Proper parameters of the afferent conduction velocity are values not less than 48 m/s i 45 m/s for the stimulation studies with peripheral and central recordings respectively. This examination has got many diagnostic applications for example in the compression syndromes, however in rheumatology it is especially useful in cases of the spinal roots inflammation assessment when parameters of the potentials waves are compared from recordings performed peripherally and oververtebrally.

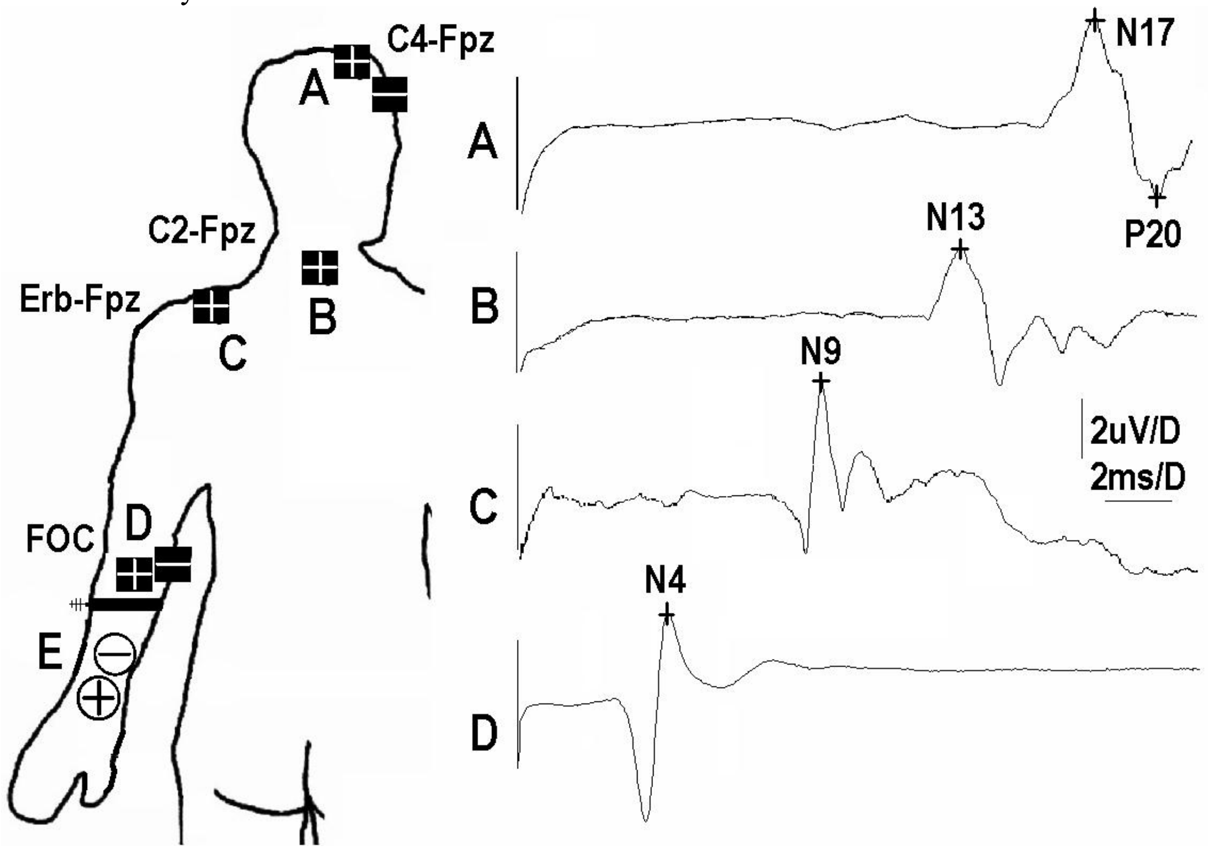


Fig. 7. Examples of the proper somatosensory evoked potentials (SEP) recorded at different levels of afferent transmission following the electrical stimulation of median nerve with pulses applied over skin at the wrist (**E**). **A**-overcranial recording from the contralateral sensory area of cortex (C4-Fz), **B**-oververtebral recording at the cervical level (C2-Fpz), **C**-recording from the sensory fibers of brachial plexus at the Erb's point performed over the skin (Erb-Fpz), **D**-recording from the sensory fibers of median nerve in area of the cubital fossa performed over the skin (FOC).

6. MEP examination

Non-invasive and painless **stimulation with the stream of magnetic field** can be used for excitation the centres or nerve fibers along their passage within central and peripheral nervous systems (Fig. 8). As a result the **generation of motor evoked potential (MEP)** can be obtained and recorded over the skin with bipolar electrodes from nerve at the site of its anatomical passage (CNAP) or directly from the muscle (CMAP). During overcranial stimulation (A) a coil of the magnetic field stream generator is located over the contralateral motor cortex centre with a somatotopical representation for muscle where CMAP is recorded from. When oververtebral stimulation is performed at the cervical (B) or lumbar spinal levels, the area of plexus (C) or peripherally (D), a coil is placed ipsilaterally to the site of recording. Single pulses with the intensity of 40-60% with a reference to maximal are the safest to induce potentials. MEP is characterized by the amplitude (measured from the top of negative to the top of positive deflections in potential) and latency (measured from the onset of stimulus artifact to the onset of potential) parameters. The amplitude of motor potential following the central applied stimulus is about 1600 μV (mean value) after cortical stimulation and with recordings from upper extremity muscle and 2700 μV (mean value) after oververtebral stimulation in cases of recordings the potentials from lower extremity muscles.

Parameters of the motor evoked potentials induced with the magnetic field MEP				
Normal parameters (N=50, 11-28 years, height 140-186 cm) (30-45 years-decreased proportionally with 1/5)				
Range of investigation	Amplitude (uV)	Latency (ms)	Conduction velocity (m/s)	Transmission
Motor cortex stimulation dext. Recording thenar m. sin. (C7)	1050-3100 (1545)	18,9-22,8 (20,9)	59,8-49,7 (54,1)	proper
Motor cortex stimulation sin. Recording thenar m. dext. (C7)	1200-4200 (1780)	18,3-22,6 (20,4)	61,7-50,0 (55,4)	proper
Oververtebral stimulation C7 Recording thenar m. sin. (C7)	1850-4300 (2252)	14,1-17,2 (15,6)	53,9-44,2 (48,7)	proper
Oververtebral stimulation C7 Recording thenar m. dext. (C7)	1950-4200 (2326)	13,9-16,9 (15,1)	54,7-45,0 (50,4)	proper
Motor cortex stimulation dext. Recording tibial.ant. m. sin. (L5)	1100-2800 (1616)	26,2-31,4 (29,0)	59,2-49,4 (53,5)	proper
Motor cortex stimulation sin. Recording tibial.ant m. dext. (L5)	1300-3150 (1698)	25,9-31,5 (28,7)	59,8-49,2 (54,0)	proper
Oververtebral stimulation L5 Recording tibial.ant m. sin. (L5)	2450-3900 (2690)	13,7-17,5 (15,6)	59,8-46,9 (52,6)	proper
Oververtebral stimulation L5 Recording tibial.ant m. dext. (L5)	2600-3800 (2720)	13,2-17,1 (15,4)	62,1-47,9 (53,2)	proper

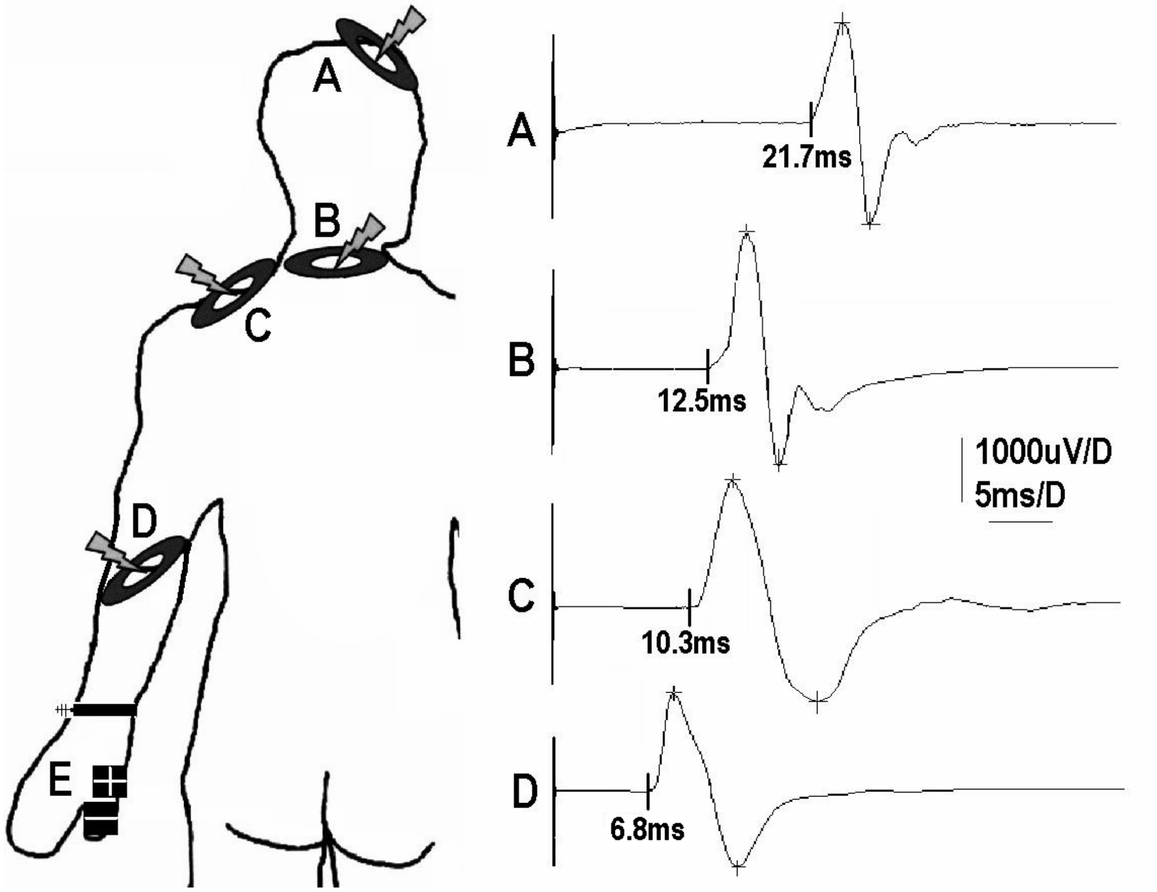


Fig. 8. Examples of the motor evoked potential (MEP) recordings from a thenar muscle (**E**) of the healthy volunteer following stimulation with the stream of magnetic field at different levels of the efferent transmission. **A**-overcranial stimulation at the level of contralateral cortex motor centre, **B**-oververtebral stimulation of the cervical spinal centre stimulation (C5), **C**-stimulation of the brachial plexus motor fibers at the level of Erb's point, **D**-stimulation of the motor fibers in median nerve at the level of cubital fossa.

The lower physiological limit of conduction velocity for efferent impulses (calculated from the conduction distance and the latency value) with the oververtebral stimulation at cervical level it is about 49 m/s and about 53 m/s with the oververtebral stimulation at lumbar level. Principles of the proper MEP parameters shows a table in figure 8. When calculation of the conduction distance from the oververtebral stimulation area to the area of recording electrodes placement in upper and lower extremities is performed, extra 3cm route of transmission should be considered because it cannot be measured directly. This route includes, among others, the anatomical passage of motor fibers within branches of brachial and lumbar plexes. The applications of MEP studies in neurology are similar to those described in previous chapter but with a reference to tests of efferent transmission.

7. IC-SD examination

Examination of the sensory excitability curves (Hoorweg-Weiss curves) is one of the oldest (although still commonly used) tests in clinical neurophysiology. It includes the description of mutual correlation of a **rheobasis (intensity of electrical stimulus)** and a **chronaxy (duration of electrical stimulus)** parameters in a superficial sensory perception of certain areas of the human body according to the rule of somatotopic innervation (Fig. 9).

In this test, a positive pole of stimulating electrode is placed over the skin which is sensory innervated by examined nerve while a negative pole of the stimulating electrode (being the "ground" electrode simultaneously) distally at the distance 5-10 cm. Rectangular pulses from 0,05 ms to 30 ms duration and intensity from 0 to 50 mA are used.

Besides, to the certain degree, a subjectivity from the position of person performing the test and also a patient undergoing the examination, it makes possible for a fast and painless diagnostic as well as motoring the degenerative processes (C, D, E) and the expected advances in regeneration (B; with appearing the "notch" suggesting a dual character of the curve) existing both at the level of receptor, a ganglion cell of dorsal root and in the transmission of sensory fibers themselves. The morphology of curve lets for differentiation of trauma for axonotmesis (C) or neurotmesis (D) type as well as monitoring the progress of treating (B, "staircase" style suggesting the "collateral" regeneration process). Moreover this examination lets for recording from small areas of the body where denervation processes can be presumed, prior to the clinical manifestation of syndrome with a loss of perception or appearing the movement disorders. The normal range of chronaxy reaches from 0,05ms to 0,5ms. A value of chronaxy less than 0,05ms can inform about the analgesia while more than 0,5ms about the hyperaesthiesia. A relatively high value of rheobasis with a typical flat chart of duration suggests the ischemic processes or a state related to polymyositis.

8. Some applications of the neurophysiological examinations with a special reference to rheumatology

The diagnostic of the myopathic disorders, often found (with the general agreement) in the rheumatoid syndromes is difficult in cases of the neurophysiological examinations because of the frequent coexistence of the vasculitis evoking subsequent changes in nerve fibers (degeneration processes) and therefore in the late advancement of the disease – the advancement of the neurogenic changes. The latest of the mentioned may overlap their picture to the primary myogenic changes. In these cases, the neurophysiological studies of the efferent and afferent transmission often reveal the peripheral neuropathies just at the subclinical level (as in cases of patients with the chronic urethral diseases) and these considering such as the diabetes, the systemic diseases such as the generalized amyloidosis, the lupus erythematosus or the systemic vasculitis which may themselves induce the polyneuropathies by the methabolitic system change or the induction of immunological factors.

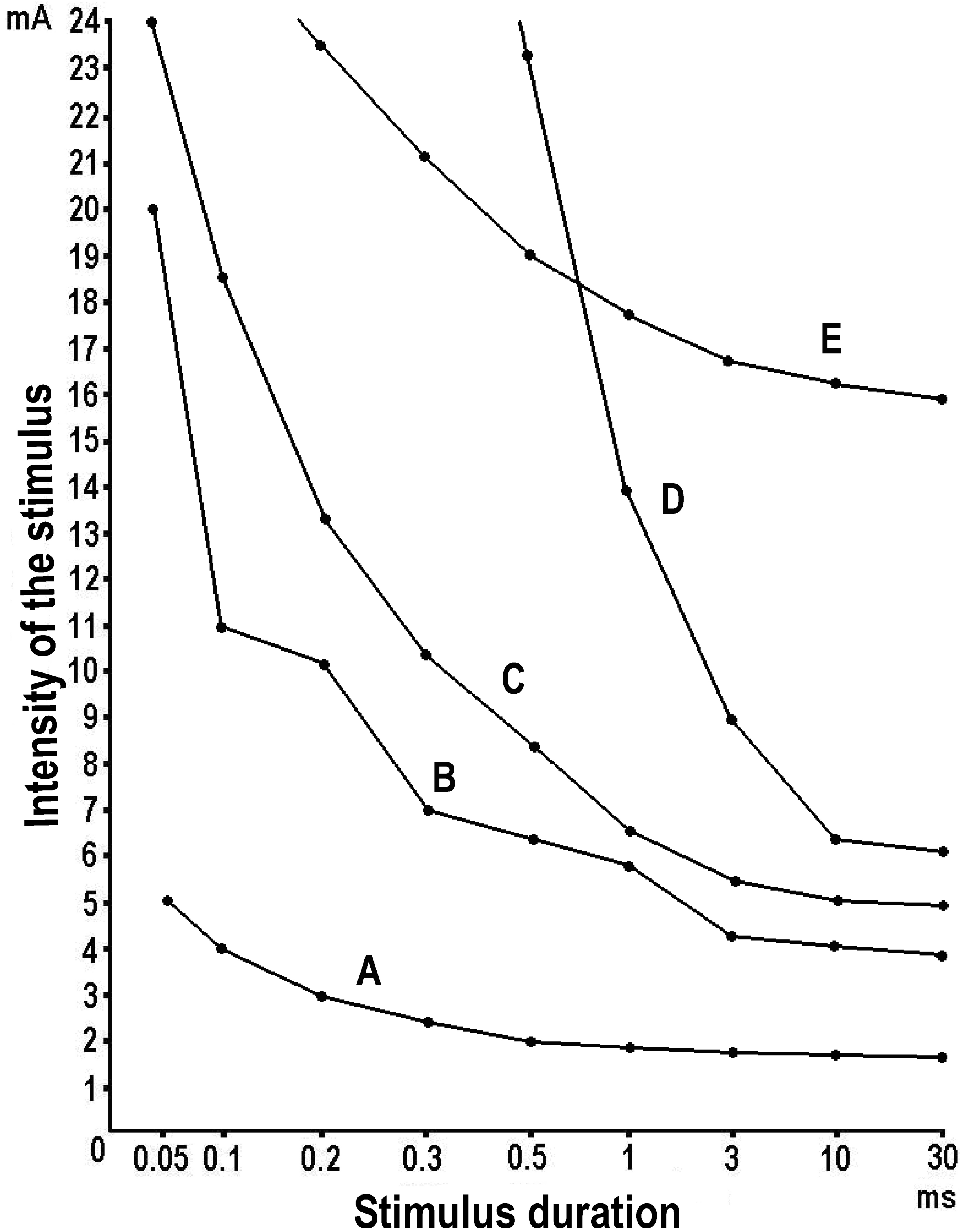


Fig. 9. Parameters of the sensory excitability curves obtained during examination of the peroneal nerve (stimulation of the dorsal aspect of the foot area). **A**-a healthy volunteer, **B**-a patient treated because of diabetes, **C**-a case of axonotmesis, **D**-a case of neurotmesis, **E**-a curve observed in cases of the ischemic changes or a curve in the advanced polymyositis.

It should be also remembered that the demyelization changes in nerves can be also associated with the development of the axonal origin disease at its advancement. Examples of the neurophysiological diagnostic in patients with rheumatoid changes are shown in figure 10.

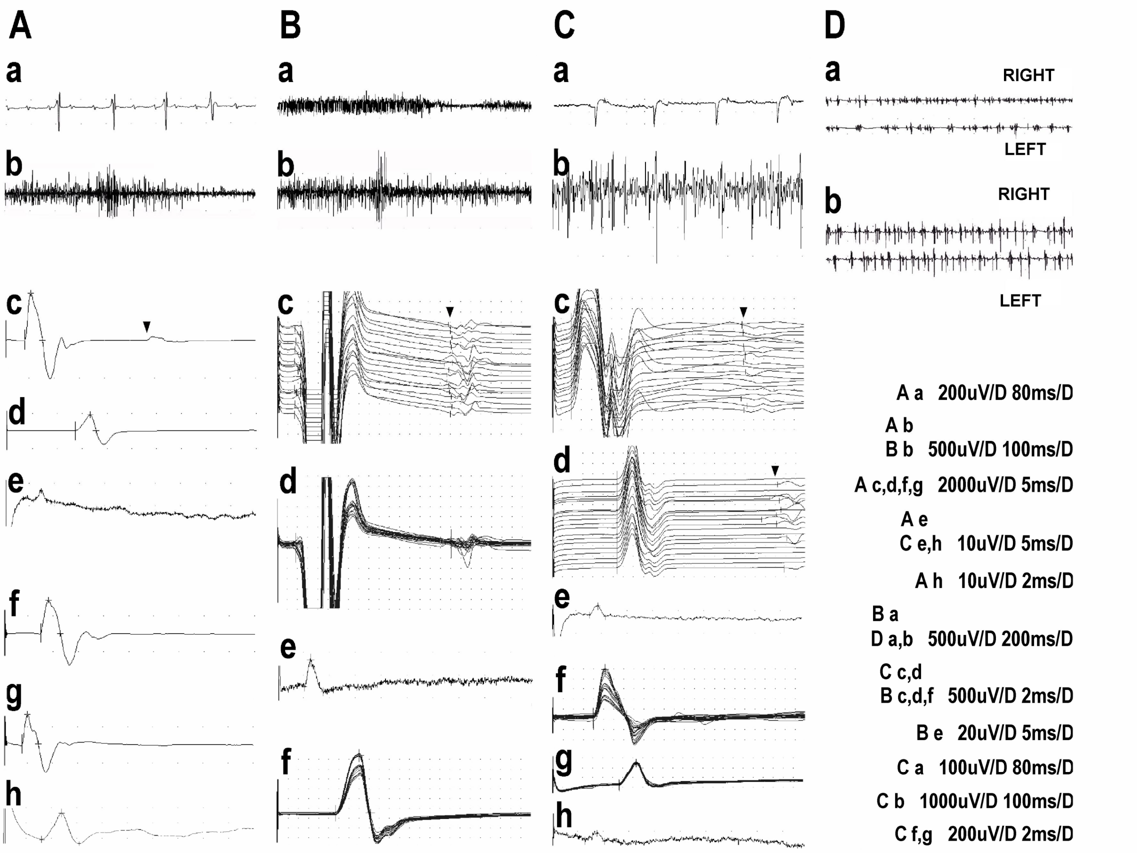


Fig. 10. Elementary (needle) electromyograms recorded from the anterior tibial muscles at their resting states (all **a** in **A-C**) and during muscle stretches (all **b** in **A-C**), as well as examples of the potentials evoked in motor nerve fibers (M-waves) (**A c,d,f,g; B c,d,f; C c,d,f,g**) and sensory fibers of nerves (SCV potentials) (**A e,h; B e; C e,h**) recorded in patients treated because of the polymyositis (**A**), dermatomyositis (**B**) and severe demyelinating inflammatory polyneuropathy (**C**). In part **D** of this figure there are shown the bilateral elementary EMG recordings from trapezius muscles during their "complete relaxation" (**a**) and from supraspinatus muscles (**b**) in one of patients with fibromyalgia symptoms.
A. In the patient with polymyositis there were observed fibryllations during the resting state of examined muscle (**a**), the recording from muscle during its maximal effort was characteristical for the myogenic injury (**b**). M-wave examination following stimulation of the tibial nerve at the level of popliteal fossa showed the slight axonal-demyelinating changes in the distal part of nerve with recording from the abductor hallucis longus muscle (**d**), with proper parameters of the potential recorded from the gastrocnemius muscle (**c**, see also the presence of F-wave which onset is indicated with arrowhead). The slight decreasing of amplitude and increasing in the latency parametr found in SCV examination recorded at the popliteal fossa following stimulation of the tibial nerve in medial part of ankle (**e**) suggest the similar fashion of changes. This patient was found not to have changes in transmission of motor fibers (**f,g**) and sensory fibers (**h**) within proximal and distal parts of median nerves.
B. During EMG recordings at the resting state in the patient with dermatomyositis there was observed a train of pseudomyotonic discharges (**a**), recording during the voluntary stretch was characteristical for myogenic injury of muscle (**b**). Examination of M-wave following the stimulation of tibial nerve at popliteal fossa didn't show significant changes of parameters

with recordings from gastrocnemius muscle (**c** and the same recordings with superposition shown in **d**, see also the proper frequency and parameters of F-wave which onset is shown with the arrowhead) as well as from extensors muscles of foot following the stimulation of peroneal nerve (**f**). There were not also found changes in parameters of sensory potential recorded from the area of popliteal fossa following stimulation of tibial nerve in medial part of ankle (**e**).

C. In a case of patient with the advanced polyneuropathy (Guillain-Barré-Strohl syndrome) the resting muscle EMG recording was full of positive denervation potentials (**a**) and EMG muscle voluntary recording was characteristical for neurogenic injury (**b**). M-wave study following stimulation of tibial nerve showed decreasing the amplitude parametr and slowing down the parametr of conduction velocity of impulses in nerve fibers with recordings from the gastrocnemius muscle (**c**, see also a diminished frequency of F-wave recordings which onset is indicated with arrowhead) as well as from the abductor hallucis longus muscle (**d**). Similarly advanced changes more of demyelinating than axonal origin were observed in recordings of motor nerve evoked potentials from the anterior tibial muscle (**f**) and from extensor muscles of the foot (**g**) following the stimulation of peroneal nerve at level of the popliteal fossa. There were also ascertained changes in parameters of sensory potentials recorded from the area of popliteal fossa following stimulation of tibial nerve (**e**) and at the level of ankle after stimulation of peronal nerve (**h**).

All recordings illustrating the neurophysiological examinations were performed in patients diagnosed in Karol Marcinkowski Medical University Department of Pathophysiology of Locomotor Organs.

Literature

Bolton C. F., Me Keown M.J., Chen R. et al: Subacute uremic and diabetic polyneuropathy. Muscle and Nerve, 1997; 20: 59-64

DeLisa J.A.: Manual of nerve conduction velocity and clinical neurophysiology. New York, Raven Press, 1994

Falck B., Stålberg E., Bischoff C.: Sensory nerve conduction studies with surface electrodes. Meth. Clin. Neurophysiol., 1994; 5: 1

Hausmanowa-Petrusewicz I.: Choroby mięśni. Warszawa, Wydawnictwa Naukowe PWN, 1993

Hubbard D.R., Berkoff G.M.: Myofascial trigger points show spontaneous needle EMG activity. Spine, 1993; 18: 1803-1807

Johnson E.W., Pease W.S.: Practical Electromyography. Baltimore, William & Wilkins, 1997

Kimura J.: Electrodiagnosis in diseases of nerve and muscle, Principles and Practise, Oxford University Press, 2001

Lenmann J.A.R., Ritchie A.E.: Clinical Electromyography. Edinburgh London New York, Churchill Livingstone, 1987

Mauguiére F., Allison T., Babiloni C. et al: Somatosensory evoked potentials. Recommendation for the practice of clinical neurophysiology: guidelines of the International

Federation of Clinical Neurophysiology. Amsterdam, Elseviere, Electroencephalography and Clinical Neurophysiology, 1999; supl. 52: 79-90

Merletti R., Parker P.: Electromyography. Physiology, Engineering and Noninvasive Applications. New Jersey, John Wiley&Sons Inc. Hoboken, 2004

Oh S.J.: Clinical Electromyography. Nerve conduction studies. Philadelphia, Lippincott Williams and Wilkinson, 2003

Okeson J.P.: Orofacial pains. The Clinical Management of Orofacial Pain. Chicago, Quintessence Publishing Co, Inc., 1995

Rothwell J.C., Hallet M., Berardelli A. et al: Magnetic stimulation: motor evoked potentials. Recommendation for the practice of clinical neurophysiology: guidelines of the International Federation of Clinical Neurophysiology. Amsterdam, Elseviere, Electroencephalography and Clinical Neurophysiology, 1999; supl. 52: 97-103

Sanders D.B., Stålberg E.V., Nandedkar S.D.: Analysis of the Electromyographic Interference Pattern. J. Clin. Neurophysiol., 1996; 13: 5, 385-400

Stålberg, E., Falck B.: Clinical Motor Nerve Conduction Studies. Meth. Clin. Neurophysiol., 1993; 4: 3

Stålberg E., Nandekar S.D., Sanders D.B. et al: Quantitative Motor Unit Potential Analysis. J. Clin. Neurophysiol., 1996; 13: 5, 401-422

Wolfe F.: Fibromyalgia. W: Tempomandibular disorders and related pain conditions, Progress in Pain Research and Management. Wyd.: Sessle B.J., Bryant P.S. i Dionne R.A., Seattle, IASP Press, 1995