Indications for electromyoneurography

Weiss, Felicitas Catherine Victoria

UNIVERSITY OF SPLIT
SCHOOL OF MEDICINE

Felicitas Cathérine Victoria Weiss

INDICATIONS FOR ELECTROMYONEUROGRAPHY

DIPLOMA THESIS

Academic year:

2021/2022

Mentor:

Ass. Prof. Ivica Bilić, MD, PhD

Split, July 2022

TABLE OF CONTENTS

"Wherever the art of Medicine is loved, there is also a love of Humanity."

- Hippocrates

ACKNOWLEDGMENT

First of all, I would like to thank my mentor Professor Bilić for his expertise, availability, and guidance that have led me to finish this study.

My thanks and appreciations also go to Dinko Martinović, MD for helping and guiding me through the statistical part of this study.

Furthermore, I am very thankful to all my close friends for giving me continuous strength and making six years of medical school so memorable.

Last but not least, I would like to express my deepest gratitude to my family for all the support, encouragement, and love they have given me. This journey would not have been possible if not for them. Therefore, I would like to dedicate this research to them.

LIST OF ABBREVIATIONS

EMNG - Electromyoneurography

EMG - Electromyography

NCS - Nerve conduction studies

ENG - Electroneurography

CNS - Central nervous system

MUP - Motor unit potential

IP - Interference pattern

APs - Action potentials

NMJ- Neuromuscular junction

PSWs - Positive sharp waves

CMAP - Compound muscle action potential

SNAP - Sensory nerve action potential

AANEM - American Association of Neuromuscular and electrodiagnostic medicine

IACD - Implantable automatic cardioverter-defibrillator

1. INTRODUCTION

1.1. Electromyoneurography

Electromyoneurography (EMNG) also known as electrodiagnostic or electromyography (EMG) and nerve conduction studies (NCS) is a diagnostic procedure that combines EMG and Electroneurography (ENG) to identify various neuromuscular disorders (1). EMG looks at the electrical activity that a muscle emits when it is stimulated while ENG measures nerve conduction and velocity of peripheral nerves to determine nerve damage. The combination of the two procedures quickly evaluates the lesion's level and the extent to improve diagnostic capacity (1).

The standard EMNG examination comprises a series of tests that are carried out in order and evaluated as a whole. In general, NCS including sensory and motor NCS is performed first followed by needle EMG (2).

Furthermore, EMNG studies are indicated in patients who have neuromuscular diseases and typical symptoms such as pain, numbness, and muscle weakness. Also, it is the only procedure that can provide information on peripheral nerves when done thoroughly (2). It should be noted, that EMNG should not be seen as a replacement for a thorough patient's history and physical examination but more as an extension (3). It is advisable to reassess a questionable history with no proper findings at a later stage than to simply start with EMNG (4). In today's cost-effective medicine, a diagnostic procedure needs to be sensitive and reliable and give clinically relevant information in making patient care decisions (5). It is vital to have an experienced examiner performing the procedure who knows all the technical and clinical knowledge paired with good patient communication.

1.1.1. Characteristics of Electromyography

EMG measures the electrical activity generated by a skeletal muscle. This electrical activity can be recorded with a skin surface electrode or a needle electrode. The skin surface electrode is non-invasive but is not sensitive nor specific enough and has proven to have no additional benefit in diagnosing or differentiating myopathic from neuropathic neuromuscular diseases (6). Individual motor units can be directly entered with a needle electrode allowing for a more accurate evaluation of the impending action potentials (APs) (7). Therefore, the needle electrode is more commonly used.

There are many different types, shapes, and sizes of needle electrodes. A variety of patient and examiner factors influence needle electrode selection. However, the most common ones used in clinical practice are the monopolar and concentric needle electrodes. The concentric needle consists of a hollow, insulated cannula that serves as the reference electrode. This cannula contains a wire with the active recording electrode at the tip. The electrode has directional recording properties that are determined by the angle and location of the beveled tip (8). Since the electrode cannula serves as a barrier, muscle fibers that are behind it get overshadowed and cannot be measured which in turn means that sharp components will be influenced (9). This is not the case with the monopolar needle.

The monopolar needle uses the Teflon-coated stainless-steel needle with a bare tip as its active recording electrode and requires a second electrode on the skin or subcutaneous tissue as its reference electrode (10). It is cheaper, has a larger tip surface, and has non-directional recording properties. The area of uptake for the sharp components is hemispheric while the slow-wave components are in a circular region (9).

However, concentric needles are preferred because they do not need a surface reference, the signal is clearer, and the inspection may be completed more quickly (11).

The EMG is conducted in three steps: assessing spontaneous electrical activity when the muscle is at rest, analyzing the motor unit potential (MUP) during a modest voluntary muscle contraction, and measuring the interference pattern (IP) at a strong voluntary contraction (9).

1.1.1.1. Spontaneous and Insertional activity

Spontaneous activity may occur spontaneously when the muscle is at rest such as in a noncontracting phase. This is due to either the needle movement that causes irritations to the myofibrils of the muscle (insertional activity) or is completely independent of any muscle stimulus (12).

In an acute muscle injury, the nerve fibers degenerate distally from the injured site while the muscle fibers remain operational for a few days after. During this time, due to acetylcholine receptors not being limited to the neuromuscular junction (NMJ) anymore, they become hypersensitive and a spontaneous activity occurs (13). This spontaneous activity gets picked up as fibrillations by needle EMG.

Single muscle fiber APs that fire spontaneously in the absence of innervation are known as fibrillation potentials (12). They are the most common abnormal spontaneous activity seen on an EMG and are highly suggestive of muscle denervation (14). In extremely acute and chronic denervation, fibrillation potentials may be absent (15). Overall, they can be caused by inflammatory myopathies, direct muscle damage, or any neurological disease that affects the motor axon (16).

Insertional activity arises when needle movement causes irritations to the fibers of the muscle at rest. More specifically, the needle tip causes a mechanical depolarization of the muscle fiber and picks up the spontaneous activity, delineating positive sharp waves (PSWs). PSWs have the same origin and importance as fibrillation and are generated right next to the needle electrode (13). How recent the nerve damage took place can be determined depending on the amplitude of the PSWs. The same applies to fibrillation potentials. Low-amplitude fibrillation potentials signify that denervation took place in the past, while high-amplitude fibrillation potentials indicate that denervation is still continuing (16).

When APs of single muscle fibers stop right after needle movement it is a normal occurrence during a needle EMG. However, decreased discharges of muscle fiber APs can be linked to end-stage neurogenic or myopathic disorders, while an increased discharge of APs is viewed as denervation or muscle membrane instability and is commonly associated with fibrillation potentials (9).

Fasciculation potentials are spontaneous discharges from a single motor unit either partly or entirely which are bigger and a lot more complex than fibrillation potentials (13). They can be found in patients with neuromuscular disorders or healthy people (17). Malignant fasciculations are commonly associated with denervation while benign ones are not (13). In early motor neuron illness, progression of the disease is the most important feature and fasciculation potentials alone are not adequate to suggest an early diagnosis, even though some might suggest otherwise (18). The occurrence of fasciculations may also be found in neuropathy, radiculopathy, peripheral nerve hyperexcitability syndromes, and thyroid diseases (13).

1.1.1.2. Motor unit recruitment

When different motor units get activated to produce an increasing strength of voluntary muscle contraction, this process is known as motor unit recruitment and provides additional information. Low recruitment indicates a motor axonal loss or functional dropout as a result of localized demyelination or conduction blockage (16). Enhanced recruitment may occur in myopathies when a smaller voluntary force is applied (16).

The strength of a muscle contraction can be increased when the central nervous system (CNS) expands the amount of active motor units (spatial recruitment) and when it enhances the firing frequency of individual motor units to maximize the total tension generated (temporal recruitment) (19). Spatial recruitment and temporal recruitment happen at the same time and summed up they form the motor unit potential (MUP).

For every MUP the amplitude, rise time, duration, and the number of changes in direction are being evaluated. These characteristics can be influenced by physiological, technical, and pathological parameters. Physiological factors that influence the appearance of MUP may be age, gender, temperature, muscle type, and strength related (12,20). Technical factors include the type of the needle electrode, the needle proximity to the recorded muscle, and the settings of filters (12). All these parameters are important to diagnose a neuromuscular disorder.

1.1.1.3. Interference Pattern

With a stronger voluntary contraction, a lot more motor units are activated. The EMG gets denser and the maximum peaks have a larger amplitude. At maximal contraction, MUPs start to overlap and interfere with one another leading to the so-called interference pattern (IP) (13). It is normal to not be able to distinguish clearly between a single MUP as the baseline is completely obscured by many activated motor units (19,21). Incomplete IPs with reduced recruitment may indicate that there are neurogenic lesions. Though in advanced stages of myopathic diseases the same can be seen because of too many lost muscle fibers, milder cases generally show a complete IP (9). In milder myopathic diseases the few lost muscle fibers can be compensated by more motor unit recruitment to generate the same voluntary effort causing early recruitment. In other words, it's possible to witness many short-duration low-amplitude motor units even when exerting a moderate voluntary effort (2).

1.1.2. Characteristics of Electroneurography

ENG also known as nerve conduction studies is a procedure that measures nerve conduction and impulse propagation along peripheral nerves. It is crucial in the diagnosis of both localized and diffuse neuropathies (9). A set of surface electrodes are positioned at various points along a particular peripheral nerve. To discover if the nerve is properly transmitting electrical impulses, it is stimulated at one location and recorded at another (16).

Electroneurography encompasses motor nerve conduction, sensory nerve conduction, and mixed nerve conduction (22). The latter assesses the motor- and sensory nerve conduction simultaneously. In all these studies it is wise to compare abnormal findings with the contralateral side.

Specific characteristics, such as onset latency, conduction velocity, and amplitude, are examined in sensory and motor nerve conduction investigations. Distal motor latency is the amount of time required for the impulse to reach the muscle and motor conduction velocity can be easily calculated by dividing the distance between the two electrodes by the latency (23). A factor that influences conduction velocity is the degree of myelination. In trauma, demyelinating polyneuropathies, or recurrent nerve compressions (conduction block) a reduced conduction velocity can be recorded (16). The amplitude measures the number of activated nerve or muscle cells and when reduced is suggestive of axonal damage.

When results from the ENG are being evaluated in combination with the findings from needle EMG, the existence of a neuromuscular disease may be detected more easily.

1.1.2.1. Motor nerve conduction studies

Motor nerve conduction studies (NCS) examine the motor nerves by recording muscle responses to a nerve stimulus. A surface electrode is placed on the belly of the muscle and a stimulus is given at two separate distal points along the nerve that is innervating the muscle. The sum of every single muscle fiber action potential is called compound muscle action potential (CMAP) (2). It can be influenced by mechanisms that impair the cell body of the anterior horn in the spinal cord, muscle cells, Schwann cells, or the neuromuscular junction (2,16). The size and morphology of the CMAP are examined to evaluate the degree of myelination, the status of functional muscle fibers, and neuromuscular junction (16).

Motor NCS measures the distal and proximal nerve segments. Distal nerve segments are easier to reach and can be immediately recorded, whereas proximal nerve segments can only be analyzed indirectly with mechanisms of late responses. Late responses include F-waves, A- waves, and H-reflex (Hoffman's Reflex) (24).

F- waves are tiny CMAPs generated from single or multiple motor units after supramaximal stimulation that are evoked by opposite direction action potentials traveling along the motor fiber reaching the anterior horn cell at a certain time for depolarization (24). Then the response travels back along the nerve causing a slight contraction of the muscle. In radiculopathies F- waves tend to be less sensitive but are more helpful in evaluating polyneuropathies (16). They are best seen in upper and lower extremities and differ in latency and morphology. F- waves have a lower amplitude compared to the directly stimulated CMAPs because only a few motor units are being activated in an antidromic fashion with supramaximal stimulation (25). Therefore, it takes many supramaximal stimulations for F- waves to be seen.

A-waves, also known as axonal reflexes are impulses that enter a proximal axon branch and may increase or decrease in frequency as the stimulus intensity changes (24). The latency decreases when stimulation occurs more proximally and with repeated stimulation, the morphology stays the same unlike F-waves (25). Finally, they are usually linked to reinnervation after axonal loss lesions, though they can also be found in demyelinating neuropathies (26).

The H-reflex is an electrically triggered reflex that activates the Ia afferent muscle spindles (27). By applying a mild submaximal stimulation with a prolonged pulse to a nerve it is feasible to trigger the Ia muscle spindles fairly selectively (26). It can be used to diagnose and differentiate C7 and S1 from L5 radiculopathies, respectively and assess peripheral or proximal neuropathies by looking at proximal nerve segments (24). H-reflexes are widely prevalent in the motor nerves of newborns and diminish after a certain age when they can only be induced by tibial nerve stimulation (26). Therefore, studies are mostly done on the tibial nerve in the popliteal fossa while recording the gastrocnemius or soleus muscle.

1.1.2.2. Sensory nerve conduction studies

Sensory nerve conduction studies are used to evaluate the performance of a sensory nerve fiber. They record the amplitude and conduction velocity of sensory nerve action potentials (SNAPs) and can be performed in an orthodromic or antidromic fashion (28). In orthodromic stimulation, the sensory fibers are tested by stimulating them distally and recording SNAPs over the proximal nerve. Antidromic stimulation occurs when the electrodes are swapped with each other (22).

Abnormal SNAPs have low or absent amplitude and indicate peripheral neuropathy. In diseases affecting the muscle and neuromuscular junction, SNAPs are supposed to be normal besides related diseases such as diabetic peripheral neuropathy (2). In general, by using peripheral sensory nerves a lesion can be localized in regards to the dorsal root ganglion allowing for differentiation of pre-and postganglionic disorders (16).

Same as motor NCS, the onset latency, amplitude, and conduction velocities are measured. The main characteristic of axonal degeneration neuropathies is a significantly decreased amplitude while conduction velocity shows a slight reduction because the biggest axons have been destroyed (28).

1.3. Procedure

It all starts with the patient getting sent by his or her referring physician. Usually, patients get referred to an EMNG examination by neurologists and physiotherapists but also by general practitioners, internists, orthopedists, neurosurgeons, and others (29). Before ordering an EMNG the referring physician should know the quality and level available for this procedure to avoid repeat testing (4). It should be noted, that EMNG is done in addition to a thorough patient’s history and physical examination and by no means should they be replaced. If physicians decide that the EMNG examination is neither necessary nor helpful, they should reject the study (30).

The examiners' knowledge and skills also play a major role. If the procedure is necessary and done correctly in the first place with a correct diagnosis the patient will not have to come back unless it is to monitor the course of the disease. This means that the patient does not have to undergo another uncomfortable examination caused by needle pricking, the examiner's time and skills can be made available for other patients in need and finally, the costs may be reduced significantly (31). Performance and interpretation of an EMNG examination

should not be done by non-physicians such as chiropractors, physical therapists, or technicians as they lack the appropriate training and knowledge (32).

1.3.1. Electroneurography

Generally, ENG including sensory and motor nerve conduction is performed first on a patient followed by needle EMG with studies done on muscle at rest and voluntary forced contraction. This is because ENG usually takes a little more time and is non-invasive which makes the patient more at ease. The exams are safe and generally well endured causing just mild discomfort and having no long-term consequences. A majority of patients report sensations of a tap and tingle (33).

In motor NCS the nerve in question and its innervated muscle have to be located first. Then, a set of recording electrodes is positioned and fixed with tape on the skin overlying the nerve. The active electrode is usually put onto the muscle belly, while the reference electrode is placed over the tendon more distally, also named the belly tendon technique (34). A ground electrode is laid between the two other electrodes to reduce the risk of artifacts. A stimulator held by the examiner's hand consisting of an anode and a cathode is held down onto the previously cleaned skin right over and along the motor nerve. It is important to position the cathode and not the anode in closer proximity to the recording electrode. After that, multiple stimuli are released at an increasing force until a maximal response has been achieved and recorded as CMAPs. When the height of CMAPs is not changing anymore despite higher currents, the force is increased further to confirm supramaximal nerve stimulation. To calculate the velocity, stimulation has to be done on at least two different sites along the nerve to obtain the distance between them (35).

Motor NCS that are done on upper extremities usually involve the ulnar and median nerve stimulated at the elbow and wrist and recorded on the abductor *digiti minimi* and *abductor pollicis brevis*, respectively (36). Meanwhile, tibial and peroneal nerves are stimulated at the knee and ankle on lower extremities and recorded on *abductor hallucis* and *extensor digitorum brevis* (37).

Finally, for each motor nerve the latency, amplitude, and conduction velocity are analyzed and calculated to find any abnormalities.

In contrast to the motor NCS procedure, sensory NCS are mostly done by stimulating just one point along the nerve (38). However, the electrode number, general setup, and method are very similar. The intensity of the stimulation gets augmented gradually to reach a supramaximal stimulation, which is seen in form of waves as SNAP. SNAP is then further analyzed to measure primarily the amplitude, and peak latency and may include others such as onset latency, conduction velocity, and duration.

In most EMNG laboratories, sensory NCS are done on ulnar, median, and superficial radial nerves for the upper extremities. These are stimulated at the wrist and recorded with electrode rings placed on the fifth digit for ulnar nerve recordings, the second digit for the median nerve, and finally, at the base of the thumb on the dorsal aspect of the hand for radial nerve (39). In the lower extremities, the superficial peroneal and the sural sensory nerves are routinely stimulated in the calf area and documented at the foot on the dorsum or ankle (34).

1.3.2. Electromyography

EMG is a minimally invasive procedure where a needle is inserted into the muscle to be studied. As with any diagnostic procedure, an explanation of the exact details of the procedure is very important, even more so when discomfort and pain occur. The needle insertion may cause mild discomfort, however once pierced through the skin there should not be any major pain. If so, the needle has touched the nerve and by slight movement alterations, the pain can be reduced. The procedure is only accurate if the examiner inserts the electromyography needle precisely into the desired muscle (40). After locating the muscle to be examined and placing a ground electrode the skin needs to be wiped with disinfectant. Then, the preferred needle electrode type is chosen and inserted into the muscle belly in a quick and firm motion to reduce hematoma formation or tissue damage. The electrode is then gently moved across different areas of muscle (41).

The spontaneous activity together with the insertional activity is registered in a relaxed state. Some patients might have difficulties relaxing when they are in pain or simply nervous for example. There are several techniques to enhance muscle relaxation such as placing the muscle in a relaxed and neutral spot, manipulating the extremity passively, activating its antagonist, and continuously reassuring the patient (42).

Once the relaxed muscle states are recorded, the patient will be asked to contract his muscle at moderate, and then at full force to record MUP and the IP. The needle electrode is

moved through multiple muscle areas to obtain MUP from different muscle fibers. To have more accurate results 20 to 40 MUPs at different muscle sites with each being 3mm apart should be recorded (43). An audio amplifier is usually used to hear the electrical activity.

The diagnostic evaluation of the needle EMG study occurs as the procedure is being performed. Several approaches may be used to analyze the electrical signals collected during needle EMG including MUP semi-quantitation, recognition of patterns with auditory analysis, and quantitative methods. Since every approach has its benefits and limitations depending on the specific condition and complexity of the results, they can be utilized at different times when needed.

All in all, it requires a skilled examiner to reduce damage and increase diagnostic outcomes. Needle EMG involves understanding the use of tools, the anatomy of muscles, the methods and limits of recordings, and proper patient interaction skills (41).

1.4. Indications

Depending on the country and region indications for EMNG may differ. The ones mentioned here are based on official American guidelines and billing processes from health insurance companies. Since there are so many different reasons and sources available referring physicians may send patients more often to an EMNG examination. Referring physicians' knowledge on EMNG indications should be continuously refreshed so that patients do not simply get sent off to an EMNG examination where it is redundant. For this reason, the American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM) has published referral guidelines that can be found on their website to provide physicians with proper guidance which get updated regularly by a group of experts (44). Embracing good referral practices are crucial in the meaningful use of EMNG studies (45).

EMNG is important in assessing the function and strength of the CNS, peripheral nervous system (PNS), and muscles in general. When the patient is referred to an EMNG it is done to confirm a diagnosis or for follow-ups for an ongoing disease (29). In addition, it can aid with information on prognosis and disease management (33). EMNG testing yields information to help:

1. Establish the type of disease;
2. Identify the location and level of abnormal function;
3. Discover any pathologies revolving around anterior horn cells, plexus, nerve roots, peripheral nerves, and function of NMJ;
4. Determine severity and progression of diseases;
5. Assess the disease course, recovery, and treatment complications;
6. Select different treatment options.

Generally speaking, indications for EMNG examination can be divided into localization, symptoms, and diagnosis. Localization aids in finding the level of injury or dysfunction, symptoms and signs can be assessed using an EMNG, and finally, the diagnosis itself confirms or follows the progress (44). This facilitates the diagnostic approach and may be used as the main grid for referrals to a specialist.

Locations such as seen in Table 1 and symptoms like neck, back, limb pain and weakness, atrophy, paresthesia, and numbness are all indications for an EMNG examination (46).

Table 1. Common examples of diseases that get referred to an EMNG examination (33).

Common Localization		Common disease examples	Common Symptoms
Neuronopathy, motor neuron disease		Amyotrophic lateral sclerosis	Continuous extremity and bulbar weakness, muscle atrophy
Nerve roots		Cervical radiculopathy	Pain in the neck and upper extremity, weakness, and sensory disturbances of the whole upper extremity
		Sciatica	Leg weakness, numbness, tingling, and radiating pain
Polyneuropathies		Diabetic polyneuropathy	Numbness, paresthesia, and pain in hands, legs, and feet. Weakness of the muscles in the feet and hands
Plexuses	Brachial	Brachial neuritis	Severe, one-sided shoulder pain, muscle weakness, atrophy, and sensory disturbances of the upper extremity
	Lumbar	Lumbosacral plexus neuropathy	Pain in the buttock or leg, leg weakness, and sensory loss
	Sacral		
Peripheral nerve entrapment syndromes		Carpal tunnel syndrome	Numbness and pain of hands and fingers, pain also gradually increasing at night
Muscles		Inflammatory myopathies	Myalgias and muscle weakness
Neuromuscular junction		Myasthenia gravis	Weakness of extremities, Drooping of eyelids, Swallowing difficulties

Entrapment neuropathies are a group of individual nerve lesions that occur in the nerves of the upper and lower extremities and are characterized by paresthesia, pain, and tenderness at the location of nerve entrapment (47, 48). Typical ones such as carpal tunnel syndrome and ulnar nerve injuries at the elbow may sometimes be diagnosed clinically. To confirm, localize, grade, and distinguish the lesion and identify other underlying neuropathies an EMNG examination is indicated. Especially so, when comparing the events postoperatively with symptoms persisting (49). AANEM has issued basic recommendations for suggested EMNG examinations in patients with suspected carpal tunnel syndrome and ulnar nerve injury (50, 51). In less common entrapment neuropathies like the ones including the ulnar nerve at the wrist, suprascapular nerve, and posterior interosseous nerve (PIN), the EMNG is irreplaceable as a diagnostic tool (49).

In peripheral polyneuropathies patients usually present with symptoms such as pain, paresthesia, and weakness in not just one extremity. A thorough anamnesis usually gives away certain risk factors for damage to the peripheral nerve, like metabolic, toxic, medication-related, or hereditary disorders (52). Here, NCS differentiates between motor and sensory fibers and loss of axons, and demyelination (53). In addition, EMG offers prognostic and diagnostic information for peripheral neuropathies (13).

EMNG is possibly the most essential diagnostic for a plexus lesion and is considerably more useful in helping decide on surgical and therapeutic outcomes than any imaging approach (54). It helps identify the extent of denervation changes and offers with studies of the cord, trunk, root, and nerve innervations the exact location of brachial plexus injury (13). They may also be repeated regularly to monitor the recovery following an injury and can be used together with imaging studies to assist in deciding on intervention measures (55). When SNAPs are preserved in a site of sensory loss, NCS can reveal preganglionic nerve root avulsion lesions while EMG may show signs of denervation of the muscle after 3 weeks (56, 57).

1.5. Contraindications and limitations

There are so many indications for an EMNG that one must wonder whether there are as many contraindications and if so, do they out way the benefits. Unfortunately, there are only limited resources on this topic. While no absolute contraindications for an EMG can be found there are a few relative contraindications that still need attention.

Patients with or without bleeding disorders may be at increased risk for bleeding and hematoma formation after needle EMG (58). Even though medically induced coagulopathies may pose some risks they should not be paused for examination (59). In patients with an INR value greater than 3.0, it is up to the electromyographer to decide whether or not to perform an EMG (60). Some modifications such as using the smallest available needle, excluding studies of deep muscles and ones that are close to noncompressible and big vasculature structures, should be done to reduce the risk of bleeding (16, 26). Paraspinal musculature studies are mostly avoided because structures close to the spine may get affected by bleeding (46).

Furthermore, EMG is contraindicated in patients with skin infections and pressure ulcers. In general, infection control is important, since needle EMG is an invasive procedure. Nowadays disposable needle electrodes are widely used and the skin is wiped with alcohol before needle insertion to eliminate the risk of infections (61).

In patients with low pain tolerance needle EMG might pose an issue. Some people may not even recall feeling the needle electrode while others complain of discomfort or even pain. Discomfort and pain may be attributed to needle type, length, and damage to the muscle fibers caused by needle movement. By using a monopolar needle electrode and making smaller movements inside the muscle tissue discomfort and pain may be reduced (62).

Some precautions are needed in patients with cardiac devices depending on the type. Patients with an external cardiac pacemaker where a conductive lead terminates in or near the heart should not undergo NCS due to serious electrical cardiac injury (58, 63). However, patients with cardioverter-defibrillators and implanted cardiac pacemakers can undergo NCS (64). Here, the further the electrodes are from the defibrillator or pacemaker the lesser the chance of device failure (61). Stimulation should not be conducted near the implantable automatic cardioverter-defibrillators (IACDs), and the contralateral limb is the preferred study location (16). In patients with an internal defibrillator or permanent pacemaker, NCS are not carried out when stimulation at the neck or Erb's point is required (46).

During pregnancy, many women complain of swelling which may induce compression and focal nerve entrapments (65). Fortunately, EMNG examinations are not contraindicated during pregnancy (58).

2. OBJECTIVES

2.1. Aim of study

The present study aims to assess the character of referrals that justify electrodiagnostic testing in a sample of patients from Dalmatia County, Croatia, and to identify the specialty of referring physicians.

2.2. Hypothesis

Hypotheses of this study are:

- Too many patients get sent to an EMNG examination without proper indications.
- Most patients get referred to an EMNG by a neurologist compared to other medical specialists.
- The most common diagnosis that justifies an EMNG examination is carpal tunnel syndrome.
- The most common diagnosis that does not justify EMNG testing is a patient with a pacemaker.

3. SUBJECTS AND METHODS

3.1. Study design and Subjects

The present study is a descriptive cross-sectional study involving 100 patients from the outpatient clinic of the Neurology department at the Firule hospital in Split in July 2020. It included patients from Dalmatia County of every gender, age group, and any referral indication in that month who were referred to an EMNG examination by primary care physicians or specialists. Excluded were those who did not make an appearance for the EMNG examination.

3.2. Data collection and Methods

The data were collected simultaneously at the time of patients taking their EMNG examination. For this study, a one-month-long period was followed where every day around five patients from the outpatient clinic were referred to an EMNG examination by general practitioners (GPs) and different specialists. Next to the GPs, the following specialists were involved in this study: neurologist, physiotherapist, orthopedist, neurosurgeon, and rheumatologist.

Patients' initials, gender, date of birth, and diagnosis in form of ICD-10 criteria numbers were recorded. Furthermore, data on whether the patient got referred by a specialist and if so, by which specialist were collected. Additionally, recordings on whether they had a previous EMNG examination and whether they had their results with them were made. These were answered by a simple yes or no depending on the question.

Indications justifying an EMNG examination were based on American guidelines by the AANEM, health insurance companies such as First Coast Service Options, Inc., and centers for Medicare and Medicaid services; an official American government website (29,66,67). Recommendations by AANEM served as the “gold standard” and were carefully studied and compared with results from this study. Even though the billing guidelines contain a list of ICD-10 codes which made it easier to compare them to they were merely used as additional guidance.

3.3. Ethical approval

This research has been approved by the Ethical Committee of the University Hospital Split, Class: 500-03/21-01/142, Number: 2181-147/01/06/M.S.-21-02, Split, 30th September 2021. Patient rights and personal data were protected in line with ethical standards of Croatian laws and the declaration of Helsinki by the world medical association from 1964-2013.

3.4. Statistical analysis

Data were collected and summarized with the computer program Microsoft Excel. All analyses of data were conducted using the computer software MedCalc for Microsoft Windows (MedCalc Software, Ostend, Belgium, version 17.4.1). To estimate the normality of data distribution the Kolmogorov-Smirnov test was employed. Qualitative variables were presented as whole numbers (N) and percentages (%), while quantitative variables were expressed as median and interquartile ranges. The Chi-square test and Fisher's exact test were used for the comparison of qualitative data. The level of statistical significance was set at $p < 0.05$.

4. RESULTS

This study enrolled 100 participants including 63 female subjects and 37 male subjects who got referred to an EMNG examination at the Neurology department at University Hospital Split for one month. Participants' ages varied from 21 to 85 years and the median age of the study population was 59.0 years (52.5-68.0) (Figure 1).

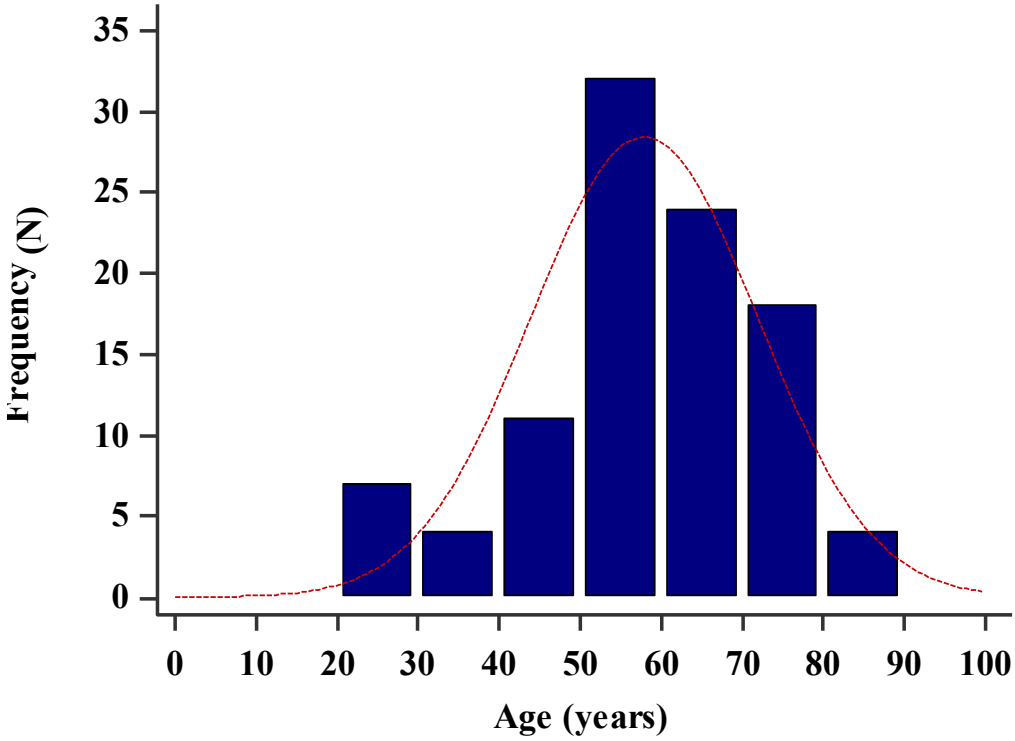

Figure 1. Histogram showing age distribution in the study population (N=100).

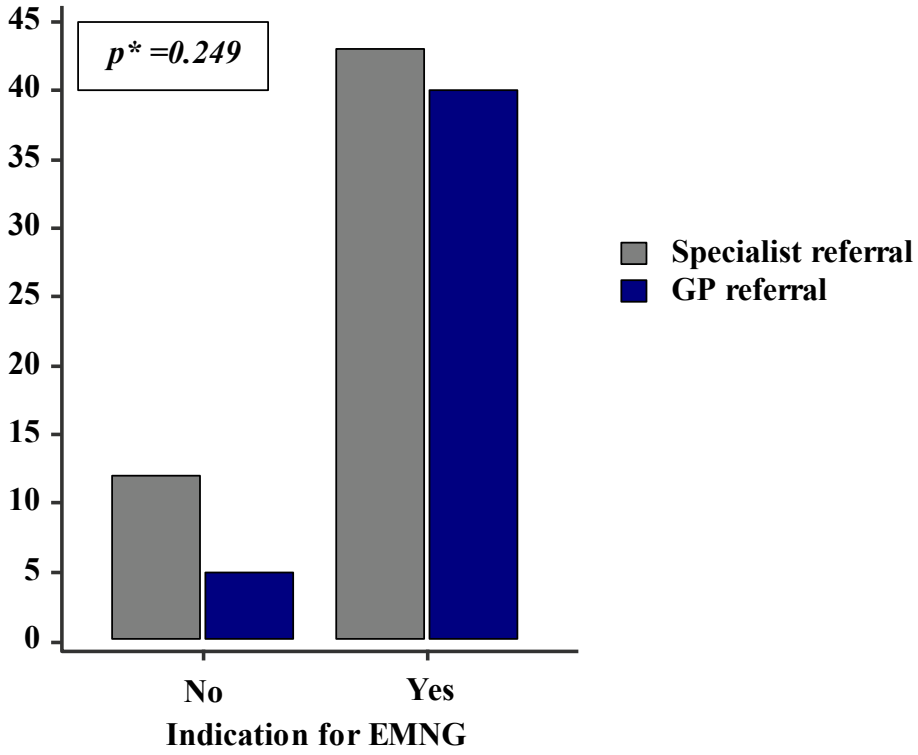

Figure 2. Frequency bar chart showing the rate of diagnosis and indications for EMNG depending on the specialist/GP referral (N=100).

* Chi-square test

There were 45 (45%) referrals to an EMNG by a general practitioner (GP) and 55 (55%) referrals by a specialist. Moreover, there were 83 (83%) referrals to an EMNG with an indication for the patient diagnosis while there were 17 (17%) without an indication for the diagnosis. However, there was no statistically significant difference between the GP and the specialist's referral to an EMNG without an indication for the patient diagnosis (5 (29.4%) vs 12 (71.6%), $p = 0.249$) (Figure 2). Additionally, 19 (19%) patients had a previous EMNG and 3 (15.8%) of those 19 patients had it for a diagnosis without an indication.

Table 1. Comparison of different specialty EMNG referrals depending on the indication for the patient diagnosis.

Specialist	**Referrals N=55**	**Indication for EMNG N=43**	**No indication for EMNG N=12**	***p****
Neurologist	35 (63.6%)	31 (72.1 %)	4 (33.3%)	
Physiotherapist	7 (12.7%)	3 (7.0%)	4 (33.3%)	
Orthopedist	6 (10.9%)	3 (7.0%)	3 (25.0%)	0.032
Neurosurgeon	6 (10.9%)	5 (11.6%)	1 (8.3%)	
Rheumatologist	1 (1.8%)	1 (2.3%)	0 (0%)	

All data are presented as whole numbers (percentage).

* Fisher's exact test

Most specialist referrals were made by a neurologist 35 (63.3%), while the least were made by a rheumatologist 1 (1.8%). There was a statistically significant difference ($p = 0.032$) in comparison between different specialist referrals to an EMNG depending on the indication for the patient diagnosis (Table 1).

Table 2. Patient diagnoses referred to an EMNG (N=100).

Diagnosis	Rate (N)
With an indication for EMNG	
Lumbosacral syndrome	31 (37.3%)
Discopathy	27 (32.5%)
Cervicobrachial syndrome	12 (14.5%)
Polyneuropathy	7 (8.4%)
Mononeuropathy	5 (6.0%)
Myasthenia gravis	1 (1.2%)
Without an indication for EMNG	
Arthropathy/Arthralgia	9 (52.9%)
Joint/muscle trauma	4 (23.5%)
Hypothyroidism	2 (11.8%)
Atrial fibrillation	1 (5.9%)
Cutaneous paresthesia	1 (5.9%)

All data are presented as whole numbers (percentage).

The most frequent diagnosis with an indication justifying an EMNG examination was lumbosacral syndrome with a rate of 31 (37.3%) while the least frequent was myasthenia gravis with a rate of 1 (1.2%) (Table 2). On the other hand, the most frequent diagnosis without an indication for an EMNG was arthropathy/arthralgia 9 (52.9%), while the least frequent were atrial fibrillation 1 (5.9%) and cutaneous paresthesia 1 (5.9%) (Table 2).

5. DISCUSSION

In an era where diagnostic tools are increasingly used, healthcare providers need to be more aware of the cost-effective and also time-consuming aspects before referring patients to diagnostic tests. In regards to electrodiagnostic studies, many electromyographer have complained of more frequent, unnecessary, time-consuming diagnostic testing due to poor referral practice. For this reason, the study examines the efficacy of indications justifying an EMNG examination and looked further into specialists and GP referral practice in a patient sample from Dalmatia County, Croatia. A total of 100 patients were included of which 63 were female and 37 were male. Patients' initials, gender, date of birth, diagnosis in form of ICD-10 criteria numbers, and data on whether the patient got referred by a specialist and if so, by which specialist were collected at the outpatient clinic of University Hospital Split. Determining the appropriateness of referrals to EMNG examination seems to be subjective. Therefore, to find out what referral diagnosis corresponds to a true indication for an EMNG test each diagnosis was carefully compared to American referral guidelines from AANEM, used as a "gold standard", from Medicare and Medicaid services and billing processes from health insurance companies for additional references.

A study done by Bin Ayaz *et al.* at a tertiary care rehabilitation center in Pakistan looking at the quality of referrals to EMNG concluded that inappropriate amounts of referrals without a true indication were done making this study's hypothesis together with the opinion of experienced electromyographers from Croatia more plausible (45). However, here the results show that more than 80% of referrals had a true indication for an EMNG and little less than 20 % did not. Nevertheless, if every country had easily accessible official referral guidelines for EMNG examinations, then results from other studies would be different and complaints about inappropriate referrals would not exist.

Assessing the rate of referrals made by different physicians, 45% got referred to an EMNG by GPs and 55 % were made by specialists. According to a Slovenian study by Podnar *et al*. involving 300 patients, GPs referral rate stood at 64.7%, while a study from Italy including 3,900 subjects showed a referral rate of 25 % made by GPs (45,68,69). This potentiates the importance of educating and keeping both GPs and specialists up to date on indications for EMNG. In the present study, referrals made by specialists included neurologists, physiotherapists, orthopedists, neurosurgeons, and rheumatologists. Neurologists were the ones to make the most specialist referrals with a true indication justifying an EMNG examination implying a greater clinical experience and broader knowledge in this area leading

to a good referral practice. Neurologists referred 72,1% of patients out of all specialist referrals with a true indication for EMNG examination. However, looking at referral numbers with a false indication, neurologists and physiotherapists have both the same high rate at 33,3%. Shockingly, physiotherapists sent more patients without an indication than with. Overall, the results of our study indicated that there was a statistically significant difference between different specialist referrals to an EMNG and its true and false indications from patient diagnosis.

Also of interest to this study was the patient diagnosis with which they got referred to an EMNG examination. Since carpal tunnel syndrome is the most frequently occurring mononeuropathy and due to its typical clinical features, one naturally assumes it to be the most common diagnosis in this study (70). However, the most frequent diagnosis with an indication for an EMNG were plexopathies (51,8%) including lumbosacral syndrome (37.3%) and cervicobrachial syndrome (14,5%), followed by discopathy, polyneuropathy (8.4%), mononeuropathy (6.0%), and myasthenia gravis (1.2%). Interestingly, in other studies the most common diagnoses were in fact mononeuropathies (mostly carpal tunnel syndrome), followed by radiculopathies and polyneuropathies (68, 71).

To abolish the bad referral practice, listing all the diagnoses without an indication for EMNG is of importance. Arthropathy/arthralgia (52.9%) was the most frequent diagnosis followed by joint/muscle trauma (23.5%), hypothyroidism (11.8%), atrial fibrillation (5.9%), and cutaneous paresthesia (5.9%). Some of these are quite obvious referral diagnosis mistakes that should have been prevented.

Some limitations need to be discussed here. The small sample size may have affected the study's results. While the sample of this study has a good age distribution with a median age of 59, the number of participants should have been greater. For this, a longer period of time to collect patient data could have been chosen. Unfortunately, that year the global COVID-19 pandemic also hit Croatia affecting not only the outpatient number making it harder to collect more data but also got physicians to refer with more caution. Unnecessary referrals meant risking further spread and infection with Covid-19 amongst staff and patients. Meanwhile, some patients rather stayed home than risk contracting Covid-19 or other infections leading to a reduced outpatient number.

Some patients get sent to an EMNG examination with mere symptoms as their referral diagnosis. Seeing as this study only included neurological referral diagnosis it could have been extended to symptomatic referral diagnosis, to divide and compare them with each other. Common symptoms such as pain, paresthesia, weakness, and numbness may have been analyzed and listed with the neurological referral diagnosis. Also, the referral diagnosis may have been compared to the final diagnosis made after the EMNG examination to increase the assessment of quality referrals.

6. CONCLUSION

Based on the results of the study the following can be concluded:

- Most patients have an indication justifying an EMNG examination.
- Most patients get referred to an EMNG examination by a neurologist.
- The most common diagnosis that justifies an EMNG examination is lumbosacral syndrome.
- The most common diagnosis that does not justify an EMNG is Arthropathy/Arthralgia.

7. REFERENCES

1. Spiegel MB. Electromyoneurography. Am Fam Physician. 1978 Nov;18(5):119–30.

2. Mansukhani K, Doshi B. Interpretation of electroneuromyographic studies in diseases of neuromuscular junction and myopathies. Neurol India. 2008;56(3).

3. Fuller G. How to get the most out of nerve conduction studies and electromyography. Journal of Neurology, Neurosurgery & Psychiatry. 2005 Jun 1;76(suppl_2).

4. Barboi AC, Barkhaus PE. Electrodiagnostic testing in neuromuscular disorders. Neurologic Clinics. 2004 Aug;22(3).

5. Kothari MJ, Blakeslee MA, Reichwein R, Simmons Z, Logigian EL. Electrodiagnostic studies: Are they useful in clinical practice? Archives of Physical Medicine and Rehabilitation. 1998 Dec;79(12).

6. Meekins GD, So Y, Quan D, Vavricek J. American Association of Neuromuscular & Electrodiagnostic Medicine evidenced-based review: Use of surface electromyography in the diagnosis and study of neuromuscular disorders. Muscle and Nerve. 2008 Oct;38(4):1219–24.

7. Subasi Abdulhamit. Practical Guide for Biomedical Signals Analysis Using Machine Learning Techniques. Elsevier; 2019.

8. Needle Electrode - Laryngeal Electromyograph [Internet]. 2021. Available from: https://lemg.org/equipment/electrodes/needle-electrode/

9. Stålberg E, van Dijk H, Falck B, Kimura J, Neuwirth C, Pitt M, et al. Standards for quantification of EMG and neurography. Vol. 130, Clinical Neurophysiology. Elsevier Ireland Ltd; 2019. p. 1688–729.

10. Chan RC, Hsu TC. Quantitative comparison of motor unit potential parameters between monopolar and concentric needles. Muscle & Nerve. 1991 Oct;14(10).

11. Menkes DL, Pierce R. Needle EMG muscle identification: A systematic approach to needle EMG examination. Clinical Neurophysiology Practice. 2019;4.

12. Rubin DI. Needle Electromyography: Basic Concepts and Patterns of Abnormalities. Neurologic Clinics. 2012 May;30(2).

13. Mills KR. The basics of electromyography. Journal of Neurology, Neurosurgery & Psychiatry. 2005 Jun 1;76(suppl_2).

14. Reed SM, Bayly WM, Sellon DC. Equine Internal Medicine. Elsevier; 2004.

15. Katirji B. Electromyography in Clinical Practice. Elsevier; 2007.

16. Kishner S. Electromyography and Nerve Conduction Studies [Internet]. 2018 [cited 2021 Sep 3]. Available from: https://emedicine.medscape.com/article/2094544-overview#a1

17. Johansson MT, Ellegaard HR, Tankisi H, Fuglsang-Frederiksen A, Qerama E. Fasciculations in nerve and muscle disorders – A prospective study of muscle ultrasound compared to electromyography. Clinical Neurophysiology. 2017 Nov;128(11).

18. Rosenfeld J. Fasciculations without fibrillations: the dilemma of early diagnosis. Amyotrophic Lateral Sclerosis and Other Motor Neuron Disorders. 2000 Mar 10;1(sup1).

19. Sandbrink F. What is motor unit recruitment? [Internet]. 2019 [cited 2021 Sep 4]. Available from: https://www.medscape.com/answers/1141359-194325/what-is-motor-unit-recruitment

20. Bischoff C, Machetanz J, Conrad B. Is there an age-dependent continuous increase in the duration of the motor unit action potential? Electroencephalogr Clin Neurophysiol. 1991 Aug;81(4).

21. Sansbrink F. What is the role of interference pattern analysis in motor unit recruitment EMG? [Internet]. 2019 [cited 2021 Sep 4]. Available from: https://www.medscape.com/answers/1141359-194333/what-is-the-role-of-interference-pattern-analysis-in-motor-unit-recruitment-emg

22. Oh SJ. Clinical Electromyography: Nerve Conduction Studies. 3rd ed. 2002.

23. Bischoff C. Electroneurography. In: Encyclopedia of Sciences and Religions. Dordrecht: Springer Netherlands; 2013.

24. THE H-REFLEX AND F-WAVE [Internet]. [cited 2021 Sep 5]. Available from: https://teleemg.com/manual/the-h-reflex-and-f-wave/

25. Daube JR, Rubin DI. CLINICAL NEUROPHYSIOLOGY, 3RD EDITION. 3rd ed. 2009.

26. Preston DC, Shapiro BE. Electromyography and Neuromuscular Disorders. Elsevier; 2013.

27. Robichaud JA. Encyclopedia of Movement Disorders. Kompoliti K, Metman LV, editors. 2010.

28. Hebl JR. Complications in Regional Anesthesia & Pain Medicine. Neal JM, Rathmell JP, editors. 2007.

29. American Association of Neuromuscular & Electrodiagnostic Medicine. Recommended Policy for Electrodiagnostic Medicine American Association of Neuromuscular & Electrodiagnostic Medicine [Internet]. [cited 2021 Sep 8]. Available from: https://www.aanem.org/getmedia/3275d71c-81dc-4b23-96a7-03173ecf8446/Recommended_Policy_EDX_Medicine_062810.pdf

30. Abel NA, de Sousa EA, Govindarajan R, Mayer MP, Simpson DA. Guidelines for ethical behavior relating to clinical practice issues in neuromuscular and electrodiagnostic medicine. Muscle & Nerve. 2015 Dec;52(6).

31. Mallik A. Nerve conduction studies: essentials and pitfalls in practice. Journal of Neurology, Neurosurgery & Psychiatry. 2005 Jun 1;76(suppl_2).

32. American Association of Neuromuscular & Electrodiagnostic Medicine. Model Policy for Needle Electromyography and Nerve Conduction Studies [Internet]. [cited 2021 Sep 16]. Available from: https://www.aanem.org/getmedia/65934187-d91e-4336-9f3c-50522449e565/Model-Policy.pdf

33. Huynh W, Kiernan MC. Nerve conduction studies. Aust Fam Physician. 2011 Sep;40(9).

34. Tavee J. Nerve conduction studies: Basic concepts. In 2019.

35. American Association of Neuromuscular and Electrodiagnostic Medicine. Procedure: Motor Nerve Conduction Studies [Internet]. [cited 2021 Sep 6]. Available from: https://www.aanem.org/getmedia/1d932265-9133-42d3-83ae-59b30b78c0cf/Sample-Lab-proc.pdf

36. Li X, Liu J, Li S, Wang YC, Zhou P. Examination of hand muscle activation and motor unit indices derived from surface EMG in chronic stroke. IEEE Trans Biomed Eng. 2014 Dec;61(12).

37. Wang ZL, Cui L, Liu M, Zhang K, Liu S, Ding Q, et al. Reassessment of Split-Leg Signs in Amyotrophic Lateral Sclerosis: Differential Involvement of the Extensor Digitorum Brevis and Abductor Hallucis Muscles. Front Neurol. 2019;10.

38. Wilbourn AJ. Sensory nerve conduction studies. J Clin Neurophysiol. 1994 Nov;11(6).

39. Alanazy MH. Clinical and electrophysiological evaluation of carpal tunnel syndrome: approach and pitfalls. Neurosciences. 2017 Jul 13;22(3).

40. Haig AJ, Goodmurphy CW, Harris AR, Ruiz AP, Etemad J. The accuracy of needle placement in lower-limb muscles: a blinded study. Arch Phys Med Rehabil. 2003 Jun;84(6).

41. Rubin DI. Needle electromyography: Basic concepts. Handb Clin Neurol. 2019;160.

42. Daube JR, Rubin DI. Needle electromyography. Muscle Nerve. 2009 Feb;39(2).

43. Buchthal F, Rosenfalck P. ACTION POTENTIAL PARAMETERS IN DIFFERENT HUMAN MUSCLES. Acta Psychiatrica Scandinavica. 1955 Jun;30(1–2).

44. American Association of Neuromuscular & Electrodiagnostic Medicine. Referral Indications for Primary Care Providers. 2020.

45. bin Ayaz S, Rahman F, Gill ZA, Rustam Z. Quality of referrals for Nerve conduction studies and Electromyography to a tertiary care rehabilitation center. Rawal Medical Journal . 2013;38(2):113–6.

46. Bridget CT. Chapter 12: EMG and Nerve Conduction Studies. In: Atlas of pain medicine procedures.

47. Pugdahl K, Tankisi H, Fuglsang-Frederiksen A. Electrodiagnostic Testing of Entrapment Neuropathies: A Review of Existing Guidelines. Journal of Clinical Neurophysiology. 2020 Jul;37(4).

48. Scadding JW. Peripheral neuropathies in Handbook of Pain Management. Melzack R, Wall PD, editors. Elsevier; 2003.

49. Hanna AS. Nerve Entrapment Syndromes Guidelines [Internet]. 2017 [cited 2021 Sep 9]. Available from: https://emedicine.medscape.com/article/249784-guidelines

50. Hobson-Webb LD, Juel VC. Common Entrapment Neuropathies. CONTINUUM: Lifelong Learning in Neurology. 2017 Apr;23(2).

51. Thibault MW, Robinson LR, Franklin G, Fulton-Kehoe D. Use of the AAEM Guidelines in Electrodiagnosis of Ulnar Neuropathy at the Elbow. American Journal of Physical Medicine & Rehabilitation. 2005 Apr;84(4).

52. Novello BJ, Pobre T. Electrodiagnostic Evaluation Of Peripheral Neuropathy. 2021.

53. Donofrio PD, Albers JW. AAEM minimonograph #34: Polyneuropathy: Classification by nerve conduction studies and electromyography. Muscle & Nerve. 1990 Oct;13(10).

54. Thatte M, Babhulkar S, Hiremath A. Brachial plexus injury in adults: Diagnosis and surgical treatment strategies. Ann Indian Acad Neurol. 2013;16(1).

55. Antonovich D, Dua A. Electrodiagnostic Evaluation Of Brachial Plexopathies. 2021.

56. Limthongthang R, Bachoura A, Songcharoen P, Osterman AL. Adult Brachial Plexus Injury. Orthopedic Clinics of North America. 2013 Oct;44(4).

57. Harper CM. Preoperative and intraoperative electrophysiologic assessment of brachial plexus injuries. Hand Clinics. 2005 Feb;21(1).

58. American Association of Neuromuscular & Electrodiagnostic Medicine. Risks in Electrodiagnostic Medicine [Internet]. 2020 [cited 2021 Sep 10]. Available from: https://www.aanem.org/Advocacy/Position-Statements/Risks-in-Electrodiagnostic-Medicine

59. Gechev A, Kane NM, Koltzenburg M, Rao DG, van der Star R. Potential risks of iatrogenic complications of nerve conduction studies (NCS) and electromyography (EMG). Clinical Neurophysiology Practice. 2016;1.

60. Gertken JT, Patel AT, Boon AJ. Electromyography and Anticoagulation. PM&R. 2013 May;5.

61. Yoon BN, Ahn SW, Kim JE, Seok JM, Kim KK, Kwon KH, et al. Potential risks of nerve conduction studies and needle electromyography. Annals of Clinical Neurophysiology. 2018;20(2).

62. Campbell WW. Safety considerations in Electrodiagnostic medicine. In: Essentials of Electrodiagnostic Medicine. 2nd ed. 2014.

63. Al-Shekhlee A, Shapiro BE, Preston DC. Iatrogenic complications and risks of nerve conduction studies and needle electromyography. Muscle & Nerve. 2003 May;27(5).

64. Schoeck AP, Mellion ML, Gilchrist JM, Christian F v. Safety of nerve conduction studies in patients with implanted cardiac devices. Muscle & Nerve. 2007 Apr;35(4).

65. Abbas FN, Jabbar B. THE ROLE OF NERVE CONDUCTION STUDY IN PREGNANT LADIES IN BABYLON PROVINCE, IRAQ. 2018 [cited 2021 Sep 10]; Available from: https://www.researchgate.net/publication/328130864_THE_ROLE_OF_NERVE_CONDUCTION_STUDY_IN_PREGNANT_LADIES_IN_BABYLON_PROVINCE_IRAQ

66. Nerve Conduction Studies and Electromyography [Internet]. [cited 2021 Sep 21]. Available from: https://cdn.ymaws.com/www.fapaonline.org/resource/resmgr/docs/EMG%27s.pdf

67. Billing and Coding: Nerve Conduction Studies and Electromyography [Internet]. [cited 2021 Sep 21]. Available from: https://www.cms.gov/medicare-coverage-database/view/article.aspx?articleId=54969&ver=21&LCDId=36524&Date=&DocID=L36524&bc=iAAAAAIAIAAA&

68. Podnar S. Critical reappraisal of referrals to electromyography and nerve conduction studies*. European Journal of Neurology. 2005 Feb;12(2):150–5.

69. Cocito D, Tavella A, Ciaramitaro P, Costa P, Poglio F, Paolasso I, et al. A further critical evaluation of requests for electrodiagnostic examinations. Neurological Sciences. 2006 Feb;26(6):419–22.

70. Hanewinckel R, Ikram MA, van Doorn PA. Peripheral neuropathies. In 2016. p. 263–82.

71. Mondelli M, Giacchi M, Federico A. Requests for electromyography from general practitioners and specialists: critical evaluation. The Italian Journal of Neurological Sciences. 1998 Aug;19(4):195–203.

8. SUMMARY

Objectives: This study aimed to assess the character of referrals that justify electrodiagnostic testing in a sample of patients from Dalmatia County, Croatia, and to identify the specialty of referring physicians.

Methods: This descriptive cross-sectional study involved 100 patients from the outpatient clinic of the Neurology department at the University Hospital Split from July 2020. Patients' initials, gender, date of birth, diagnosis in form of ICD-10 criteria numbers, and data on whether the patient got referred by a specialist and if so, by which specialists were collected. Indications justifying an EMNG examination were based on American guidelines by the AANEM, health insurance companies such as First Coast Service Options, Inc., and centers for Medicare and Medicaid services; an official American government website. The computer software MedCalc for Microsoft Windows was used to conduct data analysis.

Results: Participants' ages varied from 21 to 85 years and the median age of the study population was 59.0 years (52.5-68.0). The gender distribution showed 63 females and 37 males. There were 45 (45%) referrals to an EMNG by a general practitioner and 55 (55%) referrals by a specialist. Moreover, there were 83 (83%) referrals to an EMNG with an indication for the patient diagnosis while there were 17 (17%) without an indication for the diagnosis. However, there was no statistically significant difference between the GP and the specialist's referral to an EMNG without an indication for the patient diagnosis (5 (29.4%) vs 12 (71.6%), $p = 0.249$). Most specialist referrals were made by a neurologist 35 (63.3%), while the least were made by a rheumatologist 1 (1.8%). There was a statistically significant difference ($p = 0.032$) between different specialist referrals to an EMNG depending on the indication for the patient diagnosis. The most frequent diagnosis with an indication justifying an EMNG examination was lumbosacral syndrome with a rate of 31 (37.3%) while the least frequent was myasthenia gravis with a rate of 1 (1.2%). On the other hand, the most frequent diagnosis without an indication for an EMNG was arthropathy/arthralgia 9 (52.9%), while the least frequent were atrial fibrillation 1 (5.9%) and cutaneous paresthesia 1 (5.9%).

Conclusion: This study concludes that most patients have a true indication justifying an EMNG examination with the most common diagnosis being lumbosacral syndrome. Meanwhile, the most common diagnosis that did not justify an EMNG examination was Arthropathy or Arthralgia. Moreover, most specialist referrals were made by a neurologist establishing the good referral practice seen in this study.

9. CROATIAN SUMMARY

Naslov: Indikacije za elektromioneurografiju

Ciljevi: Cilj ovog istraživanja bio je procijeniti karakter uputnica koje opravdavaju elektrodijagnostičko testiranje na uzorku pacijenata s područja Dalmatinske županije, Hrvatska, te identificirati specijalnost liječnika koji su uputili.

Metode: Ova deskriptivna studija presjeka obuhvatila je 100 pacijenata iz ambulante Neurologije KBC- u Split od srpnja 2020. Inicijali pacijenata, spol, datum rođenja, dijagnoza u obliku brojeva kriterija ICD-10 i podaci o tome je li pacijenta uputio specijalist i ako jest, koji je specijalist uputio. Indikacije koje opravdavaju pregled EMNG-a temeljile su se na američkim smjernicama od strane AANEM-a, društava za zdravstveno osiguranje kao što je First Coast Service Options, Inc. i centara za medicare i medicaid usluge; službena web stranica američke vlade. Za analizu podataka korišten je računalni softver MedCalc za Microsoft Windows.

Rezultati: Dob sudionika varirala je od 21 do 85 godina, a srednja dob ispitivane populacije bila je 59,0 godina (52,5-68,0). Spolna distribucija pokazala je 63 žene i 37 muškaraca. Na EMNG je bilo 45 (45%) uputnica liječnika opće prakse i 55 (55%) uputnica specijalista. Štoviše, bilo je 83 (83%) upućenih na EMNG s indikacijom za dijagnozu bolesnika, dok ih je 17 (17%) bez indikacije za dijagnozu. Međutim, nije bilo statistički značajne razlike između upućivanja liječnika opće prakse i specijaliste na EMNG bez indikacije za dijagnozu bolesnika (5 (29,4%) prema 12 (71,6%), p = 0,249). Najviše specijalističkih uputnica uputio je neurolog 35 (63,3%), a najmanje reumatolog 1 (1,8%). Utvrđena je statistički značajna razlika (p=0,032) između različitih specijalističkih uputa na EMNG ovisno o indikaciji za dijagnozu bolesnika. Najčešća dijagnoza s indikacijom koja opravdava EMNG pretragu bila je lumbosakralni sindrom sa stopom od 31 (37,3%), a najrjeđa miastenija gravis sa stopom 1 (1,2%). S druge strane, najčešća dijagnoza bez indikacija za EMNG bila je artropatija/artralgija 9 (52,9%), a najrjeđe fibrilacija atrija 1 (5,9%) i kožna parestezija 1 (5,9%)

Zaključci: Ovo istraživanje zaključuje da većina pacijenata ima pravu indikaciju koja opravdava EMNG pretragu, a najčešća dijagnoza je lumbosakralni sindrom. U međuvremenu, najčešća dijagnoza koja nije opravdavala EMNG pretragu bila je artropatija ili artralgija. Štoviše, većinu specijalističkih uputa dao je neurolog, čime se uspostavlja dobra praksa upućivanja viđena u ovoj studiji.

10. CURRICULUM VITAE

Personal Data:

Name: Felicitas Catherine Victoria Weiss

Date of birth: 05.10.1996

Citizenship: German

Place of birth: Essen

Email: fcvictow@gmail.com

Education:

2015- today	University Split School of Medicine, Split, Croatia
2012- 2014	International Baccalaureate Diploma, Malvern College, Great Malvern, UK
2011- 2012	(I)GCSE/AS/A2, Malvern College, Great Malvern, UK

Work experiences and other experiences:

February 2021	Department of Nephrology and Gastroenterology at University Hospital Essen, Germany
January 2021	Department of General Surgery, at University Hospital Essen, Germany
March 2020	"Annual Interdisciplinary Skills Competition 2020", Split, Croatia
September 2014 - February 2015	Assisting at Infirmary and temporary teacher at Malvern College, Qingdao, China
May 2014	Department of Gastroenterology and Nephrology, University Hospital Essen, Germany
July 2013	Neonatology department, Elisabeth Hospital, Essen, Germany

Linguistic Proficiency:

German, French	Native speaker
English	Fluent
Spanish	Good spoken and written knowledge, GCSE
Croatian	Level A2

Further engagements:

University orchestra- Violine

University Badminton competitions

Member of "Medic Sibling" program