

ADVANCES IN ELECTROMYOGRAPHY APPLICATION: EGG AND PAIN ASSESSMENT

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Abstract: In this paper, the author deals with the advances of electromyographic technique. Nowadays, electromyographic measurements are used in several applications to assess specific pathologies. According to the muscle or myoelectric activity to be monitored, different methodologies have been defined such as, for example, electromyography, electrocardiography, electrogastrography, electroencephalography. Although such techniques require different procedures and instrumentation, each one is based on recording myoelectric signals due to muscle or nerve activity. The analysis of such signals allows physician to diagnose a specific pathology depending on arrhythmias and irregularities of the acquired waveform. In the paper, two promising and challenging applications of the electromyographic technique are described: electrogastrography to diagnose gastrointestinal disorders and electromyography for assessing pain in patients with chronic pain. The manuscript aims to call the attention on the still undiscovered potentialities of electromyographic technique and its use in new applications.

Keywords: muscle contraction; nerve stimulus; electromyography; myoelectric signal measurement; electrogastrography; pain assessment.

1. INTRODUCTION

Electromyography (EMG) is a well-known technique widely used in many clinical/biomedical applications. It is based on recording myoelectric signals from muscles or nerves. Myoelectric impulses and stimuli are controlled by the nervous system and are the cause of muscle contraction or sensation. Muscle contraction may be due to voluntary movement or be a consequence of an uncontrolled stimulus. The signal waveform allows physician to get information on anatomical and physiological properties of muscles and nerves. Muscle and nerve electrical activity can be recorded by means of surface or intramuscular electrodes, [1]-[3]. As a consequence, several invasive and non-invasive electromyographic techniques have been developed to assess specific pathologies affecting organs or peripheral nervous system. Electrocardiography, electrogastrography, electroencephalography are some examples of non-invasive electromyography applied to specific organs. By analysing time and intensity of muscle or nerve activation, it is

possible to get electrophysiological information for understanding the behaviour of human body under normal and pathological conditions. In the last years, taking advantages of medical studies on myoelectric activity of muscles and nerves, electromyographic signals are even used for generating stimuli during rehabilitation therapies or for controlling robotic prostheses, [3].

Nevertheless, electromyographic signal records suffer from noise and artefacts, therefore signal processing requires careful analysis and suitable pattern classification algorithm. Moreover, measurement instrumentation and procedures suffer from lack of standardization. As a consequence, classification of electromyographic signals is a complex task.

The aim of this paper is to review the most recent developments and research studies related to two applications of the electromyographic technique: electrogastrography (EGG) and electromyography for pain assessment (EMG-P). They are two promising screening methodologies to diagnose non-invasively pathologies affecting the gastrointestinal system and peripheral nervous system, respectively. In detail, in medical practice today the diagnosis of gastrointestinal disorders is made by using invasive screening techniques such as gastroesophageal scintigraphy and endoscopy (gastrosopy). EGG is a technique known from several years, which has been reconsidered by gastroenterologists as a potential non-invasive screening method, [4]. In detail, digestive function is regulated by rhythmic myoelectric waves, which activate muscles contraction of stomach and bowel. Recent medical studies show a correlation between the occurrence of a gastrointestinal disorder and the manifestation of arrhythmias in the gastric myoelectric record. So abnormal myoelectric activity can be symptomatic of a specific pathology, [5], [6]. Even the *American Gastroenterological Association* (AGA) states the clinical relevance of EGG in demonstrating gastrointestinal disorders. Therefore this non-invasive and painless technique is a promising alternative method for gastrointestinal screening. Nevertheless, this method needs to improve its reliability and evidence. So further advances in the design of measurement instrumentation and definition of processing algorithms are required. In fact, in literature, poor accuracy in the actual diagnostic criteria is highlighted. So additional studies are needed to assess the consistency of this technique. As a

consequence, today EGG is not used in the current practice to diagnose gastrointestinal pathologies.

Management and treatment of chronic pain is a challenging goal for researchers and clinicians. Several diseases and disorders are cause of chronic pain. The pain treatment is a complex task and the therapy results depend on the specific cause, its location, intensity and frequency. Therefore the response to drug treatment changes from patient-to-patient and even between patients with the same diagnosis. In fact, several factors such as the behaviours, mood, stress level and general health status have influence on patient response. In the present manuscript, attention is paid on gastrointestinal motility disorders which can be cause of pain, [7], [8]. Chronic digestive conditions, Irritable Bowel Syndrome (IBS), diabetic gastroparesis, ulcerative colitis, celiac disease, Crohn's disease, diabetic diarrhea, chronic infections, giardia, and colon cancer are some examples of causes triggering pain reactions. Such pathologies include several dysfunctions of the digestive activity and their symptoms can become strongly debilitating. These diseases are widely spread in population of any age and are cause of a variety of symptoms; nevertheless in the most severe cases, they may be cause of chronic pain. Gastroesophageal scintigraphy and endoscopy (gastroscopy/rectoscopy) are at the moment two invasive techniques extensively used in the practice to diagnose such disorders. Therefore, diagnosis and pain assessment is made by using invasive techniques being cause of several side effects. Since, gastrointestinal disorders and pain are cause of irregular gastrointestinal waves, myoelectric arrhythmias can be observed. Therefore further information on visceral pain can be got by analysing such myoelectric waves, [9]. Consequently, the aim of the manuscript is to investigate the use of the electromyography to provide non-invasive tools to improve the knowledge of the visceral pain mechanism.

In the next Section a general description of the electromyographic technique is provided. In the third Section, an EGG application is described. Potentiality of electromyography for pain assessment is discussed in the fourth Section. In the last Section, conclusions are reported.

2. ELECTROMYOGRAPHIC TECHNIQUE

Electromyography is a technique based on measuring the myoelectric signal generated during the voluntary or involuntary muscle contraction due to nerve activity. Such signals are caused by the electric depolarization of muscular fibers due to nerve stimulus in the neuromuscular synapsis. By acquiring and analysing the myoelectric signal, it is possible to get qualitative and quantitative information on the neuromuscular activity. It allows physician to characterize specific pathologies affecting muscles or peripheral nervous system. Electromyography can be invasive or non-invasive depending on the typology of the used electrodes. In the present paper, attention is focused on the superficial EMG, where skin surface electrodes are used to acquire myoelectric signal in a specific body area, [1], [9]. According to the muscle or myoelectric activity to be monitored, different methodologies have been defined such

as, for example, electromyography, electrocardiography, electrogastrography, electroencephalography, electroretinography. All these techniques are based on recording and analysing myoelectric signals by using superficial Ag/AgCl electrodes. The measurement instrumentation used for electromyographic application has common features, [10]. Therefore, it is possible to define the general architecture of a generic EMG system as in Fig. 1.

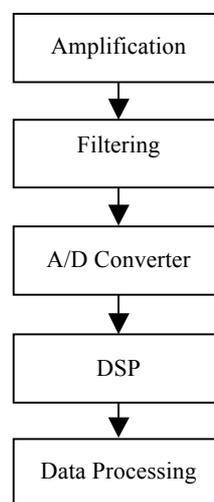


Fig. 1. Block diagram of a generic EMG system.

In detail, electromyographic signals has an amplitude of about 5-20 mV, therefore the acquired signal is amplified before of the processing stage. According to the specific application, different frequency ranges are possible, so a band pass filter is commonly used in order to filter the artefact contributions due to breathing, movements, electrical noise and other myoelectric signals of body. In this way, it is possible to remove baseline drift and to exclude signals from other sources. Such overlapping signals could cause an erroneous estimation of signal amplitude and dominant frequency. So, the design of the filter requires a detailed knowledge on the characteristic features of the monitored signal. The filtered signal is digitalized by an A/D converter. A DSP allows the processing stage to be carried out. Typically, analysis is performed in the time and frequency domains. The aim is to characterize the arrhythmias of the myoelectric signal by comparing the acquired waveform with a reference model. In literature, the standardization of instrumentation and processing algorithms is still a challenging open problem for researchers. So, a lot of processing algorithms, methodologies, classifications methods have been proposed. Nevertheless, each one has specific advantages and disadvantages, so no best practice exists, [2], [3].

All electromyographic techniques suffer from noise and artefact interferences so the data processing represents the most complex task. In particular, the classification of the signal patterns is one of the more interesting aspects of the considered research field. There are different algorithms proposed in literature, they are based on artificial neural network, fuzzy logic, support vector machines, linear discriminant analysis, Markov model. When the number of signal channels and features increase, the complexity of

classification also increases. As a consequence, the pathology diagnosis becomes more difficult.

In conclusion, the sensitivity and specificity of each electromyographic technique depends on several factors, and the research has an active role to overcome the current limitations in order to optimize the effectiveness and the evidence of the electromyographic technique.

3. ELECTROGASTROGRAPHY

EKG is a non-invasive electromyographic technique used to record myoelectric activity of muscles in gastrointestinal area. It has common features with the electrocardiography. However, several issues are still unresolved with reference to the diagnostic criteria and data processing. Therefore, at the moment it is not used as a screening tool, whereas invasive techniques are performed in the medical practice. It is known that electromyographic measurements can provide useful information on the stomach/bowel activity. In fact, recent studies report an undeniable correlation between abnormal gastrointestinal electrical activity and the onset of specific dysfunctions, [11], [12]. Even gastroenterologists have reconsidered EKG as a potential screening tool.

EKG can be used when muscles of the stomach or bowel are not working normally due to gastrointestinal disorders (stomach ulcer, gastritis, esophageal reflux, early satiety, anorexia). Standard EKG signal of healthy individuals shows a periodic trend with a predominant frequency of 3 cycles per minute (*cpm*). Therefore, periodic signals, within specific frequency range, are usual and allow stomach to digest food. Patients with gastrointestinal disorders have irregular myoelectric signals. In [13], the author proposes an EKG measurement system with diagnostic criteria to assess the occurrence of specific pathologies.

By means of cutaneous electrodes displaced in the epigastric area, the gastric myoelectric signal is acquired, see Fig. 1. Three electrodes have been used to record the stomach potentials in the upper region (fundus), the middle region (mid corpus), and the end (pylorus). This configuration allows to reduce the signal-to-noise ratio (SNR).

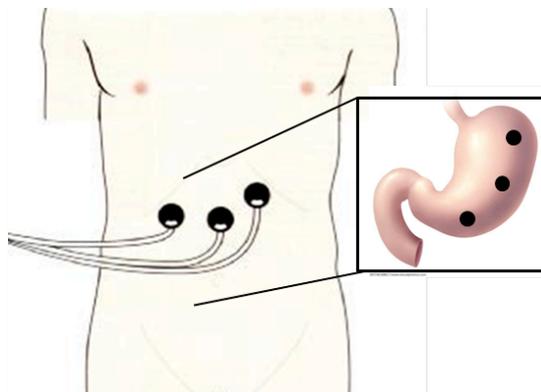


Fig.1. EKG system leads.

A careful study of standard EKG waveforms of healthy persons has allowed to define an innovative diagnostic model so to characterize abnormal gastric activity. The mechanism which regulates the myoelectric impulses has been investigated in order to single out specific parameters in time and frequency domains. To this aim, the behaviour of the stomach during gastric function (digestion) has been analysed.

According to this study, electrogastrographic signal has an amplitude relatively low, about 200-500 μV with a frequency range of [0.016 0.25] Hz ([1 15] *cpm*). Low and high band pass filters at 0.010 and 0.3 Hz, respectively, have been used to filter noise and interference contributions due to breathing, movements or other organs (heart, colon, small intestine). Dominant frequency has to belong to the normal frequency range [2 4] *cpm*. Frequency values lower or equal to 2 *cpm* are index of bradygastria. Frequency values higher or equal to 4 *cpm* are index of tachygastria. During digestion, it is possible to observe an increase of the amplitude of EKG waves because the stomach muscles activity increases, see Fig. 2.



Fig.2. EKG signal trend.

In presence of gastric disorders, the normal frequency of the fundamental component and its intensity change. For example, bradygastria is consequence of a reduced stomach contractile function, so the fundamental frequency decreases. Differently, tachygastria is cause of an increase of fundamental frequency. When a gastric disorder occurs, the gastric emptying is delayed so myoelectric arrhythmias can be recorded. The suggested measurement procedure requires that the patient is in a comfortable position to prevent movement artefacts. A preliminary fasting recording of 30 minutes is performed with empty stomach. In addition, a later postprandial recording of 60 minutes is performed during the digestion of a caloric meal (300 kcal).

The acquired signal is digitalized and processed by a *Discrete Wavelet Transform*. The 3D-diagram showing the frequency vs power trend as function of time is depicted. The spectral analysis of dominant frequency wave has allowed to estimate specific diagnostic parameters as in [14]. Each measured parameter is put in comparison with the reference thresholds of the standard EKG model. Such model has been characterized after a careful study of regular EKG signals. Abnormalities can be characterized by detecting regions of the EKG 3D-diagram with frequency above or below normal range or with several frequency contributions. Starting from the EKG records, the dominant frequency, the time length in which dominant frequency is recorded, the associated amplitude and power distribution are estimated. The fasting and postprandial records are

compared to analyse the difference during the meal digestion. So five patterns have been considered: normal EGG, bradygastria, tachygastria, dysrhythmia, lack of postprandial power increase. According to medical trials, for each pattern, specific conditions for time, frequency and power parameters have been defined.

4. ELECTROMYOGRAPHY FOR PAIN ASSESSMENT

Management and treatment of chronic pain is a complex task. So, new advances in the pain assessment methodologies are a basic challenging goal for researchers working in the field. Several diseases and disorders are cause of chronic pain. To understand the mechanism of chronic pain, it is important to understand how the body experiences pain. Nerve impulses travel from the painful area to the spinal cord. So, such impulses reach various areas of the brain involved in the sensation of pain. One of these areas is strictly concerned with the intensity and location of pain. Chronic visceral pain affects mainly peripheral nervous system, see Fig. 3.

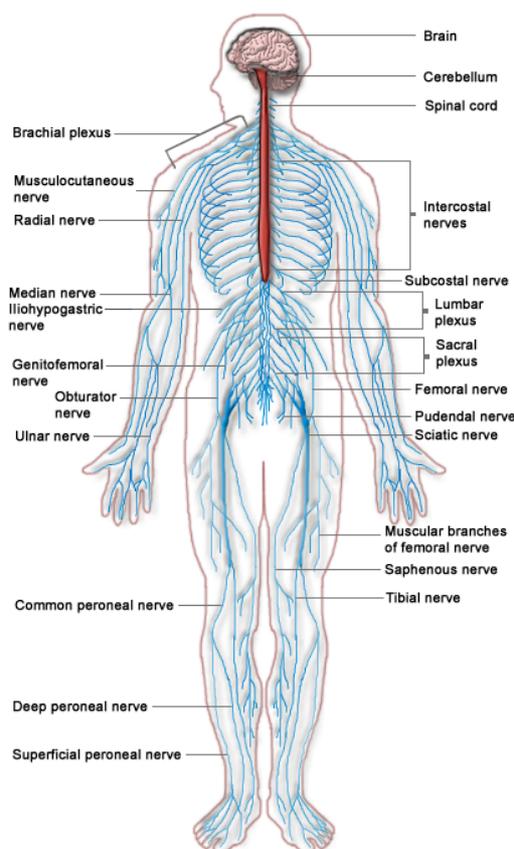


Fig.3. Peripheral nervous system.

As a consequence, dysfunction of the peripheral nerves may provide interesting information on pain perception. So, specific tests can check the integrity of the entire sensory neuraxis in order to localize and quantify visceral pain. In the paper, the author focuses attention on gastrointestinal motility disorders causing chronic visceral pain. Normally

during the digestive function, stomach and bowel muscles contract rhythmically to carry out digestion. As previously described, muscular contraction is regulated by myoelectric signals due to the peripheral nervous system. Each wave is cause of muscle contraction. A standard gastrointestinal wave in healthy individuals has specific characteristics and ranges in time and frequency domains. So, electromyography can be used to assess pain in patients with chronic abdominal pain. Arrhythmias in gastrointestinal waves can be analysed to understand pain mechanism in subjects with specific pathologies being cause of visceral pain. For example, Irritable Bowel Syndrome is a pathology associated with diarrhea, altered motility, altered sensation and/or constipation. In severe cases, it is cause of chronic pain to abdomen. Fig. 4 explains the pain mechanism associated with the Irritable Bowel Syndrome.

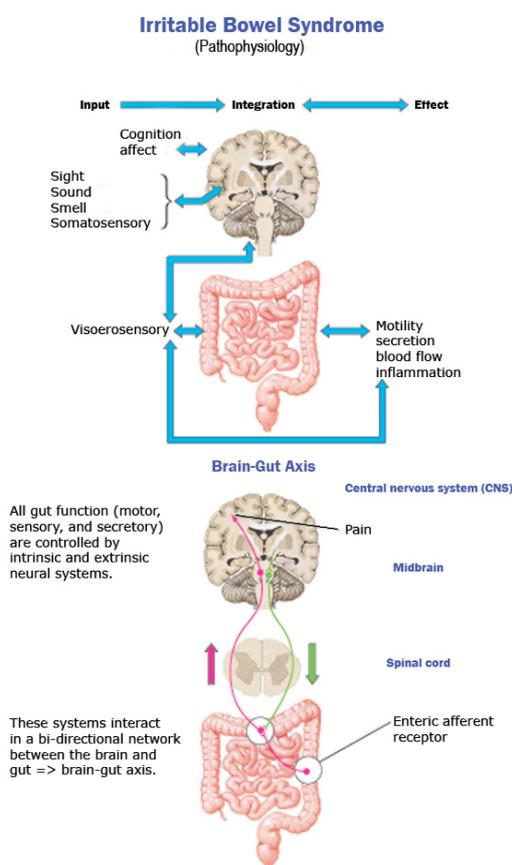


Fig.4. Pain Mechanism [ref.www.puristat.com].

The aetiology of pathology is multi-factorial involving psychological and biological factors. Visceral pain stimulus is regulated by the central nervous system, and by means of peripheral one is transmitted along the brain-gut axis.

The current challenge is to define a new methodology to improve the current knowledge of the pain mechanism. To this aim, electromyographic technique can be used to assess non-invasively chronic pain in the gastrointestinal tract. In this way, it is possible to correlate the pain sensation with arrhythmias of the myoelectric signal.

In detail, the gastrointestinal slow waves can be recorded by using skin surface electrodes placed in epigastric area as

in EMG. In presence of gastric disorders and pain, myoelectric abnormalities can be characterized in the EMG records due to a decreased activity of the muscles and nerves of the stomach and bowel. Generally, the pathogenesis of the gastric myoelectric arrhythmias is due to the delayed stomach emptying in presence of motility disorders causing a reduced digestive activity. In healthy person, the standard EMG record is characterized by regular electrical rhythm such as in the EGG signal. In individuals suffering from pain, electrogastrographic measurements have an irregular rhythm, [15], [16]. Such abnormal myoelectric activity is cause of changes of the fundamental frequency component and of its intensity. By evoking pain, the changes of the myoelectric signal can be measured and analysed. The sensory stimulus can be considered as an objective physical event. Differently the patient response is a subjective report. Factors such as site of stimulation, electrode size, rate and frequency of the stimuli, movements artefacts have influence on sensory threshold measurements. In addition, the environment, patient motivation, as well as age, sex may also influence the test results. The comparison with standard gastrointestinal waves of healthy individuals is basic to define specific diagnostic parameters in time and frequency domains (power, dominant frequency, duration, digestive activity arrhythmias ...). Such parameters are strictly correlated with the pain sensation. This stage is essential in order to define specific diagnostic protocols, sensory threshold values and characteristics of arrhythmias in the gastrointestinal myoelectric signals in presence of chronic visceral pain.

In this sight, the EMG could be a promising technique for non-invasive pain assessment, however further studies have to be still carried out.

5. CONCLUSION

In the manuscript, the author discusses about the current advances of the electromyographic technique. The existing methodology and instrumentation used in the medical practice have been described. The technique has potentialities still undiscovered, so the aim of the paper is to direct the attention on possible new challenging applications. Two specific cases have been investigated with reference to the gastrointestinal disorders.

An electrogastrography system has been described. The system is able to record the gastric myoelectric waves by skin surface electrodes. The electromyographic signals are analysed and processed in order to diagnose the onset of specific gastric pathologies.

In addition, the possible application of electromyography for assessing pain in patients with chronic pain has been discussed. The case study concerns the visceral pain due to gastrointestinal pathologies such as Irritable Bowel Syndrome. The use of the electromyographic technique and its potentialities in pain assessment has been argued.

The author's aim is to describe his experience in the electromyography field calling attention on new challenging and promising applications of a well-known technique, which is widely used in clinical/biomedical practice a long time ago.

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