

ELECTROMYOGRAPHY-PRINCIPLES AND APPLICATIONS: A REVIEW-I

¹ Dandu Sitarama Raju ¹Principal, Professor and Head
² Laksmayya Naidu D ²Principal, Professor and Head

¹ Department of Orthodontics and Dentofacial Orthopedics, Sree Sai Dental College and Research Institute, Srikakulam, Andhra Pradesh, India
² Department of Orthodontics, KLR Lenora Institute of Dental Sciences , Rajahmundry, Andhra Pradesh, India.

ABSTRACT: Electromyography is the recording and analysis of the electrical potentials of the muscle. Man has always been curious to know about his body and the surroundings. This led the mankind through many path breaking inventions that made human life easy. Much research has been done and documented in the field of bioelectricity which led to the present day electrodiagnostic procedures. .EMG as a diagnostic tool is a boon to the field of medicine. It plays a major and important role in different aspects of clinical medicine and dentistry. Hence an attempt has been made here to review the literature to acquaint the reader with history and invention of EMG and subsequent developments in that field. The literature on EMG in clinical medicine (part 1) and dentistry in general and orthodontics in particular (part 2) has been reviewed analytically.

KEYWORDS: Electromyography, EMG, Clinical medicine , Orthodontics

INTRODUCTION

Quest for knowledge is characteristic of the human mind. Man had always been curious to know about his body and how it functions and had endeavored to know more particularly about his locomotor mechanism. Interposed between bone and bone, across joints, is the source of force to accomplish function - the skeletal muscle. These muscles provide power, under direct control of the Central Nervous System, ready to act at any instant.

Ancient man was thrilled when he realized that certain aquatic animals could give shock when touched. Scientists of the 17th and 18th centuries noted a relationship between muscle contraction and electricity. Many a path finding research followed in this field of " Bio-Electricity " which led to the present day electrodiagnostic procedures of which electromyography (EMG) is one of them.

Electromyography is the recording and analysis of the electrical potentials of the muscle. From the early days when EMG was used as a diagnostic tool, much progress has been made to the present day. Towards the end of the Second World War, it was put to use by orthopedic surgeons, anatomists, kinesiologists and dentists for various purposes of investigation. At present electromyography is a tool used to understand the nature of contractile tissue, viz., the physiologic and pathologic aspects of muscle and as a tool for studying the kinesiology of joints. The electromyographic studies of the muscles of the shoulder (Inman et al, 1944), the wrist (Dempster and Finerty.1947), and the hip (Jahnke, 1949)

were significant landmarks^{1, 2} . Such studies led to the use of electromyography to study the function of masticatory muscles and temporomandibular joint kinesiology.

Robert Moyers(1949), an orthodontist, was first to introduce EMG to dentistry,followed by Carlsoo, Tulley, Pruzansky, Jarabak and Perry³. As in clinical medicine, in dentistry also, EMG is useful to distinguish nerve disease from muscle disease and in differentiating weakness from abnormalities of transmission due to peripheral nerve and muscle disorders. It is an established fact that the oral musculature plays a dynamic role in the establishment and maintenance of occlusion. In the past, orthodontists depended mainly on treatment records in the form of plaster models and lateral head plates for diagnosis and treatment planning. Both plaster models and cephalometric head plates are static records, or at the best, they can be periodic records of the initial morphology and subsequent modifications brought about by different intrinsic and extrinsic factors.

The work of Moyers (1949, 1950), Pruzansky (1952), Carlsoo(1952) and Jarabak (1954) highlighted the dynamic role of musculature and infused new enthusiasm into orthodontic research³. From then on, electromyography gained considerable importance in orthodontics as a diagnostic aid, as a method for treatment assessment and as a research tool since orthodontists moved from a stable to a dynamic functional concept of occlusion.

The present review is aimed to acquaint the reader with a detailed account of history, invention and development of electromyography, its use as a diagnostic procedure in clinical medicine and its applications in orthodontics.

Physiology of Skeletal muscle contraction

Muscle is a highly specialized tissue with contractile properties. It has the ability to transform chemical energy into mechanical energy. The motor properties in this tissue represent, in effect, the division of labor which characterizes multicellular organisms. There are three types of muscle tissue, a. striated or skeletal muscle. b. smooth or visceral muscle. c. cardiac muscle. The difference in physiologic anatomy and physiology of skeletal muscle is comparison to cardiac and smooth muscle^{4,5,6}.

Electromyogram : Technical considerations

The electromyogram is a machine which receives, amplifies and records the electrical potentials at rest and in action in muscle. Muscle potentials picked up by the suitable electrodes are conducted to an amplifier which increases the minute voltages many hundreds of times and transmits them at a proper power level to a recording and / or display system.^{7,8}

Review of literature

Since the topic under consideration has vast literature and in order to have better understanding, the review is divided into two parts:-

Part-I Electromyography as a diagnostic tool in clinical medicine. (its general principles and technical considerations)

Part-II Electromyography in Orthodontics in particular and Dentistry in general.

Electromyography as a diagnostic tool in clinical medicine.

Electricity as a force or even as a name was not described until 1600, when William Gilbert published *De Magnate* and used the Latin adjective *electrica* to label the force excited in *electrum*. In 1666, Francesco Redi⁸ stated that shock given out by some fishes on irritation was muscular in origin. Until the time of invention of the Leyden jar in 1745, frictional electricity was seldom available in quantities shocking to man. But soon after its discovery, the sensation of powerful static electricity became well known to many scientists. Michael Adamson⁸ (1751), a French botanist, while traveling through Africa, came across *Malapterus* and likened its discharge to that of Leyden jar. In 1772, Walsh proved that the Torpedo

discharge was electrical and showed that the back and belly of the fish gave different electrical reactions.

In 1658, Jan Swammerdam⁸ amused his patron of science, the Duke of Tuscany, with twitches of an isolated frog muscle by pinching and cutting its nerve. The experiment described as delightful and useful was questioned by some authors who thought that the muscle contractions were due to electrical stimuli from the metal instruments used. However, an examination of Swammerdam's illustrations failed to reveal any possibility of a closed circuit. In 1700, Duverney⁸, a French anatomist performed an experiment which now is the universally performed experiment in the Physiology class room: muscle nerve preparation.

Towards the middle of the eighteenth century, interest in experimental muscle physiology was aroused by the publication of Haller which established the fundamental principles of peripheral nerve function. In 1745, Katzenstein⁸ first reported purposeful muscle contraction with static electricity. In the following years there were many reports of muscular contraction induced by electricity for the purpose of curing paralysis and other diseases.

In 1758, Beccaria⁸ noted that the contractions arising from electrical stimulation were much stronger than those observed from mechanical stimuli. In 1765, Abbot Fontana⁸, in trying to explain the conduction of a stimulus to the muscle, guessed that "If it be not the electricity, it may be something very analogous to it". In 1784, Cotugno⁸ reported the story of a student who stated that he had received a strong electrical shock when the scalpel with which he was dissecting a mouse touched one of its nerves.

In 1791, Galvani⁸ published his series of observations on muscle contraction in the frog. On the relationship between electricity and muscle contraction, Galvani believed that electricity generated by the body which he called "animal electricity", was not derived from the muscles but from the nervous tissue, especially the brain. He assumed that the nerves were good conductors and that their oily envelopes prevented the dispersion of electricity. He also assumed that the muscles were the receptacles for the animal electricity. Thus, the "frog current" as it came to be known popularly was a nerve current but not of muscular origin. But Volta⁸ (1793) was of opinion that the animal electricity was due to the application of different metals. This was agreed upon by Monro, the famous Edinburgh anatomist and Fowler. However, in 1794, Galvani stimulated muscle by placing the free end of a nerve across a muscle without intervention of metals and proved that electricity could be generated by animal tissue.

By applying electricity to his blistered shoulder, Humbolt⁸ (1795) proved that contraction resulted from direct stimulation with electricity. He also stated that the nerve had to be intact to achieve this response. In his

search for stimulation threshold, Volta⁸ (1799) concluded that the muscle response was a more delicate instrument for measuring minute quantities of electricity than the electrometer. The genius and novelty of Volta's new invention strongly opposed the theory of animal electricity since it was proved that a battery could produce similar effects on the muscle. Practically there was no further research in this subject of animal electricity until 1938.

The initial impetus given to electrophysiology by the work of Galvani decayed because of slow refinements in the methods producing and detecting electricity till the end of 19th century when Nobili improved the galvanometer and Daniell improved the wet cell. Inspired by the work of Carlo Matteucci, great Italian electrophysiologist Dubois-Reymond identified the muscular origin of the current⁸. In 1851, he registered action currents from the arm of a man who contracted his muscle. He used jars of liquid as electrodes. This was virtually the first human electromyography at a time when electrical measuring devices were primitive.

In 1833, Duchenne de Boulogne⁸ became so interested in the procedure of electropuncture that he devoted much of his research to electrical stimulation. He found that muscles could be stimulated electrically without piercing the skin and devised cloth-covered electrodes for percutaneous stimulation, the basic design of a surface electrode still in use.

In 1859, Chauveau⁸, a veterinarian, introduced the monopolar method of muscle stimulation to Physiology before Brenner introduced it to clinical practice in 1882.

In 1801, Halle⁸, a French physician observed that a static current did not elicit muscle contraction in a patient with facial palsy, but a galvanic current did. However, it was not until 1840 that the introduction of electricity into muscles was recommended as a diagnostic aid.

Neumann⁸ (1864) explained a phenomenon which may be the first truly important conclusion in electrodiagnosis that the duration of the current was the deciding factor in eliciting contraction rather than the nature (galvanic or faradic). In 1867, Brucke⁸ showed that nerve and muscle could be excited separately.

Wilhelm Erb⁸ (1883) demonstrated that approximately the same amount of electrical energy was needed to contract symmetrical muscles. Jolly⁸ (1895) applied tetanizing current interruptedly to the orbicularis oculi muscle of a patient with myasthenia gravis and found that the tetanus became less complete with each successive application until it could no longer be elicited.

More precise knowledge of muscle action currents had to await the perfection of an apparatus which could record the small and rapidly fluctuating muscle potentials. Lippmann⁸ (1872) offered the capillary electrometer which continued to be used for recording tissue potentials for more than 30 years. The reflecting coil galvanometer of d'

Arsonval⁸ (1882) was another helpful tool, which Einthoven⁸ (1901) modified by substituting a single straight fibre of silvered quartz for the loop. This enabled the recording of millivolt potentials with speed, accuracy and permanence. The string galvanometer, however, was sensitive only to fluctuation of 2000 per second. Although it could be used for electromyography, it was necessary to find a device in which the writing could be done by a virtually weightless device.

Piper⁸ (1907) recorded the voluntary contractions in the human forearm flexors with string galvanometer and found distinctive rhythm for each muscle. He thought that this rhythm indicated the rate of stimuli received from the Central Nervous System.

Until the third decade of the 20th century, most human electromyograms were made by physiologists attempting to correlate laboratory findings with normal human muscle potentials. Wertheim-Solomonson examined patients with tetany, chorea and hemiplegia, but the first attempt to obtain tracings on peripheral nerve paralysis was that of Proebster (1928) and to him most authors give the credit for beginning clinical electromyography⁸.

Until 1929, human electromyograms showed the potentials developed in relatively large portions of muscle. In the same year, Adrian⁸ made two contributions to the field of electrodiagnosis. With the introduction of the coaxial electrode, he made it possible to pick up the potentials developed by a single muscle fibre. With the use of loud speaker he added the sound record which is a necessary adjunct to electromyography. In the same year, Adrian and Bronk⁸ found that in completely relaxed normal muscle, even at amplifications up to 2×10^6 , there was no spontaneous electrical activity.

One of the major difficulties in recording minute muscle action potentials was the inclusion of extraneous electrical activity. To minimise this confusing effect, screening of the test area was done until Mathews (1934) suggested differential amplification⁸.

Lindsley⁸ (1935) made the first tracings of a patient with myasthenia gravis and noted marked fluctuations in amplitude of motor unit responses to contraction. Denny-Brown and Pennybacker⁸ (1938), using bipolar needle electrodes with tracings on bromide paper, differentiated between fasciculation and fibrillation. Denny-Brown and Nevin⁸ (1941) recorded the characteristic potentials of myotonia. In the same year, Buchthal and Clemmesen⁸ validated the findings of muscle atrophy by clinical electromyography. Hoefer⁸ (1953) obtained rhythmic potentials in rigid muscles at rest in patients with parkinsonism.

Until 1944, electromyography had been used by few clinicians. The equipment was expensive and custom built, the procedure and identification of diagnostic patterns were not well organized. In 1944,

Weddell, Feinstein and Pattle published a complete report on clinical electromyography which became the working reference for many workers⁸. It discussed and analyzed muscle potentials and all the neuromuscular entities ordinarily encountered. In the same year, Jasper and Notman introduced monopolar needle electrode⁸. With the increasingly useful information offered by electromyography, its use spread with considerable speed. Although Bauwens used electromyography in his clinic in 1941, the procedure was regarded primarily as a research tool until 1950⁸. During that period, only a handful of physical medicine specialists conducted examinations with an electromyograph. However, by 1960, most physical medicine specialists considered EMG a mandatory requirement for a department.

Latif⁹(1957) concluded that placing the reference electrode far away introduces extraneous electrical interference into the records giving wrong results. Hickey et al¹⁰ (1958) empirically approached the problem of the determination of "best" electrode placement for facial muscles and concluded that interpretation of dental electromyographs should recognize the importance of head geometry. They further stated that one of the criteria for selection of EMG apparatus for dental use must be the frequency response. They also recommended that pen recording be supplemented with optical and magnetic records and spectral analysis. In 1975, Vittasalo¹¹ studied the reliability and constancy of recordings of different electromyographic signal characteristics investigated from the measurements taken with miniature size surface electrodes. He suggested that these parameters could be recommended for use in electromyographic studies where recordings were repeated over a period of several days.

Garnick¹² (1975) studied the reproducibility of electromyogram. He used the amplitude, duration and sequence of the onset of muscle bursts in evaluation. Amongst the three, amplitude showed the most variation during the same session, at different intervals and between different sites of the muscle recorded. Onset showed the least variation during the same session. Whereas duration showed the least variation between sites. He started the standardization of the electromyograms in research. Yoshida et al¹³ (1982) discussed the practicability of the clinical application of the miniature surface electrodes which consist of electrically high conductive silver paste, small rubber caps and fine wires.

Ahlgren and Henrikson¹⁴ (1987) compared electromyography recorded parallel and transverse to the fibres of the anterior and posterior temporalis muscle in man. They found that the electrical activity recorded during voluntary clenching was higher when electrodes were placed parallel to the muscle fibres than when placed across the fibres.

Garland et al¹⁵ (1988) stated that their findings were consistent with the view that the reduction in EMG activity was due to reflex inhibition of motor-neurons by afferents from fatigued muscle and that any motor units which could not be recruited in the fatigued muscle were no longer capable of generating tension.

Dorfman L.J.¹⁶ (1990) felt that available methods did not permit meaningful quantitation of regeneration. And that newer methods under development attempted to estimate the number of motor units in a muscle and the number of axons in a nerve.

Palmer.J.B. et al¹⁷ (1991) assessed the utility of clinical electromyography (EMG) for detecting lower motor neuron (LMN) or upper motor neuron (UMN) dysfunction affecting the intrinsic muscles of the larynx and pharynx. They concluded that electromyographic abnormalities were significantly associated with LMN dysfunction, but they were not significantly associated with UMN dysfunction.

Richardson.J.K¹⁸ (1994) et al felt that pain during the performance of electromyography is an important clinical problem because pain distresses the patient and can interfere with diagnostic accuracy. They hypothesized that anxiety and pain perception associated with EMG would decrease if patients received written material describing the EMG before examination. Information before the test significantly decreased pain perception for women during the nerve conduction studies, but not during the needle examination. A similar effect was not identified for the men. Other results indicated that women perceive the test as more painful than do men, older subjects perceive more pain and experience greater anxiety than do younger subjects, and all subjects perceive greater pain during the performance of (concentric, bipolar) needle electromyography than during the nerve conduction studies.

Krivickas et al¹⁹ (1996) felt that Fine wire intramuscular electrodes and spectral analysis had not previously been used to quantify metabolic muscle fatigue in deep muscles not accessible with surface electrodes. They concluded that spectral analysis using fine wire electrodes provides earlier detection of muscle fatigue and can be used in deep muscles, but the reliability must be improved before clinical application.

Chu.J²⁰ (1997) studied the effect of EMG examination at tender points in myofascial pain symptoms related to cervical nerve root irritation. He concluded that EMG at tender points on myofascial bands tends to improve symptoms. Needling these points elicits motor end plate activity and twitches, and induces more relief than when needling random points.

Kothari mj et al²¹ (1998) felt that electrodiagnostic testing [EMG] and nerve conduction studies [NCS]) may result in some patient discomfort and that the justification for such testing should be based on the expectation that

the results will affect patient management. Hence they conducted a study to determine how frequently the results of EMG/NCS change the clinical management of the patient. They concluded that EMG/NCS are useful, informative, and diagnostic in the management of various neurologic disorders.

Dascalu et al²² (1999) felt that standard methods for accurate intraoperative measurement of neuromuscular block are either expensive or inconvenient and are not used widely. Hence, they had evaluated a new method of monitoring neuromuscular block using a low-frequency microphone. The method is based on the phenomenon of low-frequency sound emission by contracting skeletal muscle. Acoustic monitoring with an air-coupled microphone was used to evaluate intraoperative neuromuscular block. They concluded that monitoring intraoperative neuromuscular block by a microphone which transduces low-frequency muscle sounds is clinically feasible.

Laursen .B et al²³(2000) felt that Increasingly, more older people are using computers, while hardware and software are not designed with special consideration of their needs.They concluded that shoulder muscle activity during computer work is affected by age, but only to a minor extent by the type of computer mouse task. The deltoid and the trapezius muscle activities are low during computer mouse use when there is efficient forearm support by the table. Increasing number of people use computers for hours every day. Intensive use of computers increases the risk of development of work-related musculoskeletal symptoms in the shoulder region.

Mc Keown²⁴ (2002) felt that dysphagia is an important consequence of many diseases. As some of the muscles of deglutition tend to be deep to the surface, needle electrodes are typically used, but this limits the number of muscles that can be simultaneously recorded. Since control of swallowing involves central pattern generators (CPGs) which distribute commands to several muscles, monitoring several muscles simultaneously is desirable. Here they described a novel method, based on computing the independent components (ICs) of the simultaneous surface EMG recordings to detect the underlying functional muscle activations during swallowing using only surface EMG electrodes.They concluded that the independent components of the surface EMG provide a non-invasive means to assess the complex muscle sequence activation of deglutition.

Lapatki B.G. et al²⁵ (2003) developed a surface EMG electrode for the simultaneous observation of multiple facial muscles. Lapatki.B.G. et al²⁶ (2004) developed a thin,flexible and non invasive two dimensional multielectrode grid for high density surface EMG. It has inexpensive, universally adaptable and minimally obstructive sensor which allows the principal advantages of high-density surface EMG to be extended to all skeletal muscles accessible from the skin surface.)

Castroflorio T. et al²⁷ (2008) felt that the advantage of surface electromyography (EMG) is it's non-invasive nature. It's disadvantages are lack of reliability and sensitivity giving rise to controversial results, which could be attributed to methodological errors. Despite these problems, several clinical applications of surface EMG in jaw muscles are promising. Moreover, technological advances in signal detection and processing have improved the quality of the information extracted from the surface EMG and furthered our understanding of the anatomy and physiology of the stomatognathic apparatus. Minetto.M.A. et al²⁸ (2011) analyzed the cramp threshold (i.e. the minimum frequency of electrical stimulation capable of inducing a cramp) and the behavior of individual motor units during cramps electrically elicited in the absence (intact condition) and presence (blocked condition) of a peripheral nerve block in eight healthy subjects. The results indicated a spinal involvement at the origin of cramps and during their development.

Boon A.J. et al²⁹(2012) concluded that hematoma formation from standard needle EMG is rare even in high-risk muscles, which have been avoided historically in anticoagulated patients.

(Part-II to be continued in next issue)

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Corresponding Author

Dr. D.S. Raju,
Flat No. S-2, Plot No. 65,
Sandilya Kutir,
Pandurangapuram,
Visakhapatnam – 530003
Andhra Pradesh, India.
Phone- 098481 90611,
0891-2525511, 2501740
E-mail ID- drdsraju@yahoo.com