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Sensors to monitor the muscular activity- a survey

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Abstract:

Muscles play a vital role in maintaining one's good health. They are a key aspect in movement, postures, and internal bodily functions and also help to keep the joints in good shape. The skeletal muscles, one of three main muscles found in the human body, aid with body movement by contraction and relaxation. Therefore, their neglection would directly affect the normal body motion. Wearable technology can be considered as a boon to the healthcare industry. Now, one can keep track of one's heart rate, glucose levels and distance walked throughout during the day. This wearable technology has been extended to developing sensors for remote Electromyography (EMG) and Mechanomyography (MME) monitoring for muscle strain, spasm and fatigue. This review article summarizes current research being done to develop potential sensors for measuring muscle activity, products already available in the market and obstacles to overcome for future scope.

Keywords: Muscles, skeletal muscles, wearable technology, sensors, electromyography (EMG), mechanomyography (MMG).

Introduction

A muscle is a soft tissue made up of muscle cells that contain protein filaments called actin and myosin that slip over each other, resulting in contractions that change both the muscle cell length and shape. In the human body there are three types of muscles-skeletal, vascular and smooth muscles. The hip muscles belong to the category of skeletal muscles and are divided into four categories based on the orientation around the hip joint – gluteal, adductor, lateral rotator and iliopsoas [1-4].

The gluteal muscles shape the buttocks and consist of the maximus gluteus, the minimus gluteus and the medius gluteus as shown in Figure.1. Such muscles derive from the ilium, the largest and uppermost portion of the hip bone and sacrum, a triangular bone, and are incorporated into the bone of the femur or of the thigh. The functions include external & internal movement, hip joint displacement and extension [5]. They also help to stabilize the knee joint.

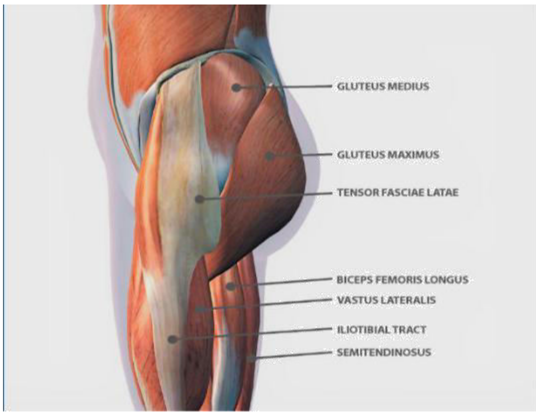

Figure.1. Hip muscle anatomy.

The lateral rotator consists of six small muscles that rotate the femur – piriformis, obturator internus, gemellus inferior, quadratus femoris, gemellus superior and obturator externus as shown in Figure.2.

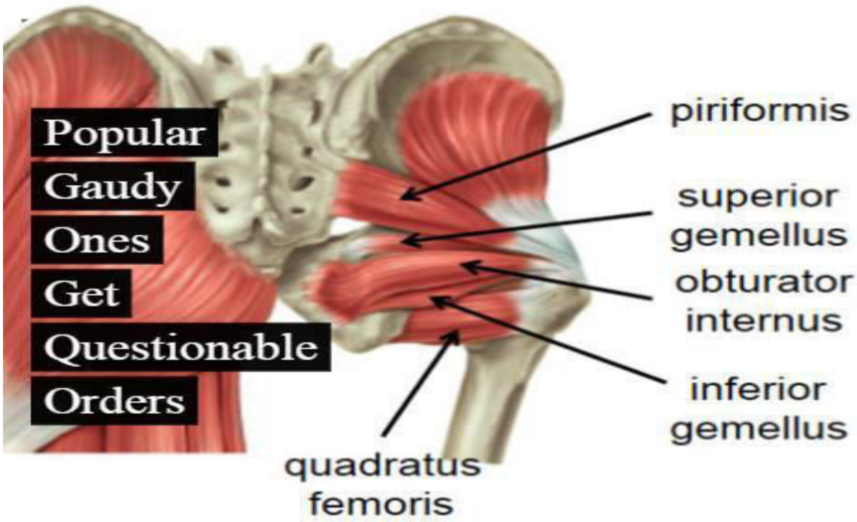

Figure.2. Lateral and Medial Hip rotors.

Their function is lateral rotation of the hip. Certain muscles also provide innervation to other muscles [6,7]. The adductor muscles as shown in Figure.3 are used to bring the thighs together. The group of adductors consists of adductor brevis, adductor magnus, adductor longus, adductor minimus, gracilis, externus obturator and pectineus [8].

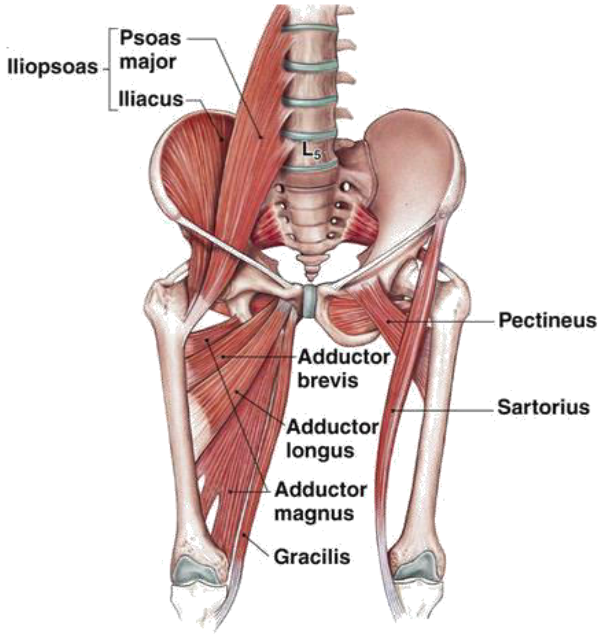

Figure.3. Adductor muscles.

The only adductor muscle that the femoral nerve innerves is pectineus, whereas the obturator nerve innerves all muscles of the adductor [9]. The tibial nerve innervates a small part of the adductor magnus muscles. The iliopsoas consists of the muscles called ilacus and psoas, which separate in the abdomen but fuse in the thigh. The tissue is derived from the lumbar spinal nerves and some segments of the femoral nerve. Iliopsoas, the strongest of the hip flexors, is the primary mover of the hip flexion, the others being sartorius, rectus femoris, and tensor fasciae latae. It is mostly used for functions like standing, walking and running. These muscles perform various actions when the postural changes.

Nerves are bundles of fibers that help in transmission of electrochemical signals called action potentials from different organs to the brain and vice versa. In case of hip muscles, they carry signals from the brain to move the hip and carry signals to the brain about pain, temperature and pressure. The main nerves of the hip muscles are – femoral, obturator and sciatic. The sciatic nerve, in the hip area, is the most known nerve. It is a big nerve that passes to the back of the thigh below the gluteus maximus where it extends to support the leg and foot. Hip dislocations cause adverse injuries to the sciatic nerve.

A spasm is a short-lived and sudden involuntary muscular contraction or convulsive movement that can be caused by muscle fatigue, dehydration, overuse and electrolyte abnormalities. Hip muscle strain may occur when the muscles are strained, pulled or torn leading to injury. Such strain may include muscle spasm as one of the symptoms. Piriformis syndrome is one of the major hip muscle disorders where the piriformis muscle in the buttocks irritates the sciatic nerve and its main symptoms are muscle spasms, buttocks pain and sciatica [10,11].

The meaning of muscle fatigue is a decline in the frequency of the force exerted that a muscle will produce during a duration of continuous operation. Physiologically, tiredness can be characterized as the muscle's inability to exert any more power or force [12,13]. A series of biological events occur during the period of a fatiguing contraction. It may include increase in muscle fiber conduction velocity, improvements in the amount of motor units engaged and a rise in different concentrations of metabolites [14]. The causes for muscle fatigue could be attributed to the loss of glycogen or accumulated glucose or the buildup of lactic acid in the muscle tissue resulting in a decrease in the contractile properties of the muscle [15].

It is a repetitive and inefficient method to monitor the physiological activities in muscle contractions. Nonetheless, surface electromyogram tracking may help detect electrical signals of these incidents. Muscle fatigue can be classified in two according to recent studies: non-fatigue and fatigue. Non-fatigue describes the state of the muscle after contraction and before fatigue begins. Fatigue means the initiation of muscle function loss during a muscle contraction. Other authors [16] identified a third type as well: Transition-to-fatigue. A muscle may exert maximum force in the non-fatigue condition because, when the muscle begins fatigue, new muscle fibers are recruited. This process is the beginning of the transition-to-fatigue cycle and is characterized as a gradual process until the stage of fatigue ends.

Literature survey

Nowadays, wearable technology is gaining immense popularity in the healthcare industry as an activity or fitness tracker in the form of wristbands, straps and rings that monitor the physical and vital signs. Wearable surface Electromyography (sEMG) has recently been introduced for measuring muscle activity in real time and is likely to hit the market soon as shown in Figure.4.

Figure.4. Surface electromyography sensor

Standard electromyography (EMG) makes use of needles or patch electrodes to detect muscle activity and to help differentiate involuntary from voluntary muscle contractions, especially in cases of neurological disorders [17]. Surface EMG (sEMG) has many advantages over standard EMG. It is non-invasive and has a higher patient compliance. Three patch electrodes are located appropriately over the target muscle on the skin with positive and negative electrodes and the third test electrode is mounted well away from it. The main drawback to sEMG is that it is done through wired machines in a health facility. That can present a number of challenges. Firstly, the study time is limited and is restricted to a confined space. Second, due to all the wired connections, motions are restricted, which presents a problem in performing and evaluating experiments involving large changes in body positions [18]. Thirdly, a noise is introduced at 50 Hz which is the most meaningful portion of the EMG spectrum [19,20].

Because of the various drawbacks of conventional wired hardware, portable sEMG systems were introduced, they are in the works and some items are already on the market. Most of these require an external processing unit [21-24] while others are integrated with inertial units for categorizing specific movements. There was also a newly proposed system that allows use of an on-board sEMG signal processing unit and recognizes muscle activity in real time without any outside station. This allows for long-term control and consistent assessment of day-to-day muscle activity.

Muscle fatigue is pretty common in daily life and if not monitored, leads to severe injuries. If such a detection system could be proposed such that it could guide the user during his training and work-out session, by providing accurate and precise fatigue level readings in real-time, it could prevent serious and unnecessary strain and injuries on muscles [15]. Human-computer interface is proving to be a boon, particularly in the healthcare sector. It makes use of bioelectrical signals acting as inputs to provide communication, feedback and situation control between the user and his/her environment. Some of the bio signals used to monitor these assistive and adaptive devices are [25]: electromyography (EMG) [26], electroencephalography (EEG) [27], electrooculography (EOG) [28], and combination of these signals [29]. Several fields make use of this technology: rehabilitation medicine, sports medicine, human-computer interactions, ergonomics [30], neurophysiology, physiotherapy, prosthetics and kinesiology. These EMG signal can be measured and acquired through two methods: invasive (makes use of needle electrodes) and non-invasive (placing of electrodes on the surface of skin). Surface electrodes are usually preferred to prevent users from having safety and comfort issues. Many widely employed non-invasive fatigue identification methods include ultrasound, electromyography, mechanomyography and near-infrared spectroscopy. These methods are used in both isometric as well as non-isometric contractions [15]. Surface electromyography (sEMG) provides valuable insights into localized muscle fatigue through observation of shifts in signal parameters [31-33], such as frequency and time domain parameters, non-linear processes, and discrete wavelet transformations, among others. The sEMG signal constitutes a non-stationary one-dimensional time series which is reported by an electrode set from the muscle [34]. During contractions muscle fibers produce sEMG signals that are registered in a non-invasive manner by the electrodes attached to the skin [35]. In the area of recovery, low-cost sEMG sensors are commonly used to control human motions [36-38]. Nevertheless, sEMG has certain disadvantages, such as inaccurate positioning of electrodes or signal noise. In order to ensure repeatability, some requirements are suggested for proper positioning. The European SENIAM (sEMG for the Non-Invasive Assessment of Muscles) project [39] proposed a standard electrode placement for 27 diff erent muscles as well as guidelines for processing and recording the sEMG signals. This proposal defines an optimal electrode placement for certain muscles in the lower limbs to ensure that the electrodes are located between the tendon and the field of innervation.

EMG does have its limits, though, and there are other ways that assess muscle activity.

One such solution is to track the physiological changes that arise during a contraction in the body. Recent studies have led to a proposal for a novel, simple, non-invasive sensor that will measure muscle activity based on a force-sensitive resistor (FSR). When applied through a rigid dome on the skin, the sensor is able to sense the mechanical force exerted by the basal contracting muscles. Muscle contraction is usually associated with increased regions of cross-sectional area, muscle shortening, mechanical movements, increased tension and stiffness, and other mechanical parameters. Mechanomyography (MMG) can be called Electromyography's mechanical analog as shown in Figure.5 [40,41] and is focused on the recording of muscle vibrations created by active muscles. It is used as an indicator of muscle stiffness, and may also be correlated with exertion of muscle force [42]. Sensor types can also be used to calculate the MMG signal: piezoelectric touch sensors, condenser microphones [41,43,44], accelerometers [41,45-48] and, nowadays, laser distance sensors [41] that are in contact with the skin of the individual.

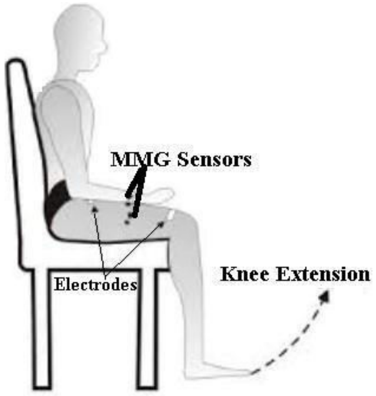

Figure 5. Schematic of Functional electrical simulation with muscular response monitoring using MMG.

Tensiomyography is another new technique which is used to calculate the contractile properties of a muscle by measuring the radial enlargement of the muscle belly [49-51] as shown in Figure.6.

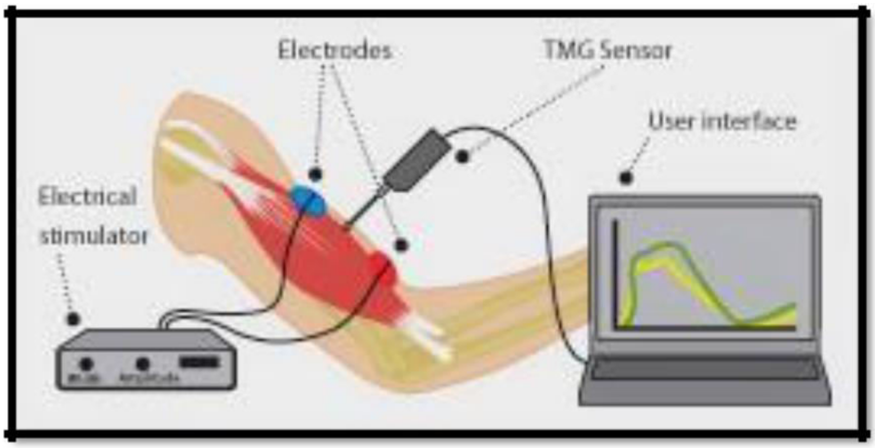

Figure.6. Tensiomyography set up for assessment of muscle contractile.

The contractions can be measured in a number of ways like –

- Pneumatic sensors: Muscle movement identified by shifts in air pressure of the muscle-contacting air bladder;
- Strain gauges: Muscle contractions which trigger sensor stretching;
- A tiny permanent magnet connected to the skin that tracks shifts in the muscle axis, in contrast with the Hall effect-based device;
- Textile, pressure-based sensors incorporated in clothes.
- Differences in electrical muscle impedance: differences in general muscle resistivity due to blood supply in the muscles from a resting state to an active condition.;

- Ultrasonic scanners: Use ultrasonic sensors to test morphological improvements in muscle thickness or displacement;
- Muscle circumference sensor: Muscle contractions are proportional to shifts in the muscle cross-sectional region around which the sensor is placed;
- Resonance-based stiffness sensor for active muscles: Piezoelectric sensors used to calculate muscle rigidity shifts;
- Change in optical properties: Photodiodes and LEDs are used to identify muscle contractions by monitoring light back-scattered from muscle tissues; [52]

EMG only signals electrical muscle contracting results. In addition, EMG characterizes the transmission of potential motor unit motion through muscle fibers, which initiates the mechanical activity of the muscle, accompanied by chemical and mechanical events that occur prior to the muscle activity. The time gap between the initiation of EMG and the triggering of force generation is termed electromechanical delay (abbreviated as EMD). Additionally, inactivity arises between the cessation of the EMG signal and the start of force fading during muscle relaxation, and is classified as electromechanical relaxation delay (abbreviated as r-EMD). However, though relaxation is passive, muscle movement is an active process, and other biomechanical processes (e.g., operation of muscle antagonism and/or other counteracting forces acting externally) must also be studied. Through simultaneous measurement of EMG, MMG, and force (or torque), these electromechanical delays can be precisely measured. [52]

For the wide number of applications, EMG-concise data such as the EMG linear envelope (abbreviated as EMG-LE) is still used, including calculation of muscle relaxation rates (like prosthesis regulation). But the problems associated with EMG selection i.e. electrodes, interferences, motion artefacts, etc., have generated interest in other forms of sensors, such as those prone to muscle mechanical movement, but nothing has proven so effective in offering the EMG-LE a robust replacement for it. Facility to use, comfortable location on the patient, size robustness, reliability wearability, expense, transmitted energy to the patient, electrical connections to the patient, etc. are factors that have impeded its widespread usage. A new muscle contraction sensor, which defeats many of those limitations, is found on replacement. It is installed on a slender force-sensitive resistor placed on a specially designed mechanical connecting device to be operated by another conditioning circuit. The newly developed sensor is capable of recording cross-sectional muscle movements and muscle oscillations, which provide identical feedback to both the EMG-LE and MMG, making it easy and convenient to use.

Applications

1. Electronic muscle stimulation (EMS) [53]

- Electronic muscle stimulation (EMS) is muscle contraction by means of electrical impulses. It is also known as electrical neuromuscular stimulation (NMES) or electromyostimulation.
- In recent years, EMS has gained growing attention because it has the ability to act as: a strength training tool for healthy subjects and athletes; a recovery and prevention tool for partially or fully immobilized patients as a test method for testing in vivo neural and/or muscle function; a post-exercise tool for athletes to recover.

- EMS operates by simulating the natural muscle workout cycle. For example, when you want to move your arm, your brain sends electrical impulses down the spinal cord and through the nerve pathways to reach the right muscles for the job. Such vibrations relax the muscles, allowing them to contract, and the arm swings just like you expected it to. However, with EMS, the impulses come from electrodes over the muscle that are attached to the skin, not your brain. The electrodes give impulses— small electrical shocks, actually— and muscles contract.

2. Transcutaneous electrical nerve stimulation (TENS) [54]

- A Transcutaneous Electrical Nerve Stimulating Device or TENS System is a device that uses electrical current at certain levels to alleviate acute and chronic pain by activating and relaxing the human body's peripheral nervous system by two electrodes that are attached to the body's surface.
- The delivery site of TENS unit electrodes is usually near to the damage site. Delivery outside of the site may also be successful, as TENS may activate the core mechanisms.
- A user should directly monitor a TENS machine. The settings can be changed, without a medical professional being needed. A machine will usually be used, several times a day, for 15-20 minutes per session. With regard to personal use applications, TENS machines are used to reduce pain caused by muscle trauma, joint and nerve algesia, musculoskeletal pain. For these problems they can work better than for stomach, pectoral, or headaches Unlike many treatments a TENS unit has almost no side effects.

Conclusion

A muscle is a soft tissue composed of muscle cells with actin and protein filaments comprising myosin that slip over one another.

Muscle tiredness commonly occurs in everyday life. Unnecessary muscle strain could be avoided and, in effect, accidents could be stopped if a fatigue tracking system could direct a person during their exercises or activities and provide accurate readings of muscle exhaustion rates. Popular bio-signal types used for monitoring assistive devices include: electromyography (EMG), electroencephalography (EEG), electrooculography (EOG), and combinations of these signals. The advantages of recognizing muscle fatigue can be understood in a various fields, including sports medicine and performance, human-computer interactions, ergonomics, rehabilitation medicine, physiotherapy, neurophysiology, kinesiology, and prosthetics. It is possible to acquire the EMG signal in two ways which are by using needle electrodes which is an invasive method and also non-invasively placing electrodes on the skin surface. Mechanomyography (abbreviated as MMG) can be considered the EMG mechanical equivalent and is focused on the recording of muscle activity generated by an activated muscle. The two widely popular devices are Electronic Muscle Stimulation (EMS) and Transcutaneous Electrical Nerve Stimulation (TENS).

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