INTRODUCTION

Didactic lectures can be made more interesting by incorporating different teaching aids during the classroom session. The electromyogram (EMG) can be easily demonstrated in a practical session (4, 5). However, in this paper, we describe the use of the EMG as a tool during a lecture series to demonstrate and explain various aspects of skeletal muscle physiology. The aim of this exercise was to make the learning of skeletal muscle physiology more interesting by using the EMG to demonstrate the various aspects of muscle physiology.

Recording Apparatus

The recording setup was designed such that the following parameters could be demonstrated to the students:
1. Time of stimulus (tendon tap)
2. Surface EMG (sEMG)
3. Angular displacement of the knee
4. Force of contraction

This was achieved using the following equipment:
1. Custom-designed sEMG sensors
2. Electronic goniometer (custom designed)
3. Electronic tendon hammer (custom designed)
4. Data acquisition system (CMCdaq) with bundled software
5. Elbow splint with a force transducer
6. Recording computer

A tomahawk tendon hammer was modified to include an accelerometer embedded in the head of the hammer (Fig. 1), oriented such that the axis of recording was along the axis of the strike of the hammer. The signal from the accelerometer recorded the swing of the hammer, and, from this reading, the exact time of contact of the hammer could be identified (Fig. 2, point a).

To record the angular displacement of the knee, a custom-designed goniometer was used. This was fabricated using a variable potentiometer centered at the knee. The potentiometer was fixed in such a manner such that, when the two arms of the goniometer were moved, the knob of the potentiometer was rotated.

Demonstration of the Experiment

A sEMG was demonstrated to a group of 100 medical undergraduate students during the routine lecture series in skeletal muscle physiology. The students had already been exposed to eight lecture sessions, in which the anatomical structure of muscle and the physiology of muscle contraction had been discussed. The demonstration was incorporated into the teaching in the form of three sessions, each lasting for 30 min. Each session required an extra faculty member to help in the demonstration.

During all sessions, the acquisition signals were projected on a screen to enable live viewing. The recorded data were processed offline and were also projected to the students. The steps of analysis were explained.

Session 1: Myotatic reflex. The first session recorded the myotatic reflex. This session was designed to discuss the following concepts:
1. The neuronal action potential
2. Transmission of the action potential across the neuromuscular junction
3. Generation of the muscle action potential, leading to mechanical contraction of the muscle

A sEMG sensor was placed on the rectus femoris, and the electronic goniometer was strapped to the limb centered around the knee joint, as shown in Fig. 1. The patellar tendon tap was performed using the electronic tendon hammer. In this configuration, the tendon hammer strike, the sEMG, and the angular displacement of the knee were recorded in three channels.

Fig. 1. Setup is shown for recording the myotatic reflex (session 1) using surface electromyogram (sEMG), including a modified tomahawk tendon hammer, custom-built goniometer, and data acquisition system.
Striking the patellar tendon with the tendon hammer produced a reflex contraction of the rectus femoris, resulting in extension at the knee joint.

From the tendon hammer recording (Fig. 2, point a), the point of contact of the hammer with the patellar tendon can be identified. (The point of first maximal change in acceleration indicates the hammer is contacting the skin over the tendon.) The hammer strike is the stretch stimulus for the myotatic reflex.

This stretch is picked up by the muscle spindle, whose structure and function were explained at this time. The function of the muscle spindle as a sensor for length and velocity was highlighted. The activation of the muscle spindle with tendon stretch causes firing of the Ia afferents that travel to the spinal cord through the dorsal root ganglion. The Ia afferents synapse directly with the α-motoneurons supplying the rectus femoris (3). The impulse from the α-motoneuron crosses the neuromuscular junction and results in an end-plate potential that travels along the sarcolemma as the muscle action potential that is recorded by the sEMG (Fig. 2, point b). This electrical activity of the muscle sets off the sequence of biochemical events of the excitation-contraction coupling, which finally results in the extension of the leg, which is seen in the recording from the electronic goniometer (Fig. 2, point c).

The conversion of a mechanical stretch into an electrical impulse, its transfer across the neuronal synapse and neuromuscular junction, generation of the muscle action potential, and the conversion into movement are all encompassed in this recording. This session was, therefore, used to describe concepts such as latency of the reflex, nerve conduction velocity, synaptic delay, neuromuscular junctional transmission, and the time delay between the generation of the muscle action potential and the actual movement of the limb.

Session 2: Voluntary contraction, EMG relationship with force generation. The second session recorded the sEMG, movement of the limb, and force generated by the muscle. This session was designed to discuss the following concepts:

1. The relationship between muscle electrical activity and its translation into movement of the limb
2. The relationship between muscle electrical activity and the subsequent force generated
3. The ability of the muscle to increase and decrease force voluntarily

![Fig. 2. Recording of the myotatic reflex in session 1 of electromyogram (EMG) teaching. a, Point of contact of tendon hammer with tendon; b, onset of skeletal muscle electrical activity; c, onset of movement of limb.](image)

![Fig. 3. A recording is shown of the surface electromyogram (sEMG) of the biceps brachii and the corresponding movement, as recorded with an electronic goniometer. The electrical and mechanical activity of the muscle contraction (point a) and relaxation (point b) is noted.](image)

![Fig. 4. The elbow splint used in session 2 to record force.](image)

![Fig. 5. A: surface electromyogram (sEMG) recording of the biceps brachii muscle with progressively increasing force of contraction (isometric) against resistance. B: goniometer recording showing minimal change in the angle of the elbow joint. C: force generated by the muscle.](image)
An sEMG electrode was placed over the biceps brachii muscle of one arm of a student volunteer. The student was then asked to flex and extend the forearm voluntarily. These voluntary contractions were recorded as electrical activity during flexion and as silence during extension (Fig. 3). The relationship between muscle electrical activity and its translation into movement of the limb due to muscle contraction was explained using this recording.

The forearm was then fixed in an elbow splint (Fig. 4). The splint was constructed such that the elbow of the splint was locked at 90° of flexion. The arm and forearm were fixed to the splint such that all forces of flexion and extension of the elbow were transmitted directly to the force transducer. The student was asked to flex the elbow, thereby creating an isometric contraction. The magnitude of force was progressively increased (voluntarily), and the sEMG was recorded (Fig. 5). The change in magnitude of the sEMG with the increase in force was demonstrated. This recording was used to demonstrate the relationship between force requirement (as measured from the force transducer) and recruitment and frequency of firing (as indicated by the power spectrum of the sEMG) (2).

**Session 3: Isometric, eccentric, concentric contractions.**
This session recorded the sEMG and movement of the limb during an arm-wrestling match between the students. This was designed to discuss the mechanics of various types of muscle contractions.

Two student volunteers were seated opposite each other at a table, and sEMG electrodes were placed on both their biceps brachii muscles. The two students were asked to have an “arm-wrestling” match, during which the sEMG and elbow movement were recorded from each of them. The recording was analyzed, and the segments that showed concentric, eccentric, isotonic, and isometric contractions were displayed and explained to the students (Fig. 6).

The volunteers were chosen such that one volunteer was much stronger than the other. During the match, at the initial phase, when the stronger contestant was able to move the weaker contestant’s arm, an isotonic contraction was recorded. (Fig. 6, point a). For a brief period of time, when the forces generated by the two contestants were equal, an isometric contraction was recorded. (Fig. 6, point b). When the stronger contestant overcame the weaker contestant, an eccentric contraction was recorded from the weaker contestant (Fig. 6, point c).

The power spectrum of various EMG recordings was plotted and used to explain the complex nature of the waveform and the host of frequencies encompassed within. The correlation of the wide spectrum of frequencies that occur as a result of recruitment of multiple motor units and their firing frequencies was explained. Multiple muscle fiber action potentials summing into a motor unit action potential (MUAP) and many MUAPs summing into the voluntary sEMG signal were also explained. A basic explanation of sampling frequency, filtering, rectification, and ensemble averaging of bioelectric signals was necessary and given at this point.

**Feedback**
Anonymous written feedback was obtained from the students to evaluate the usefulness of these sessions. A five-point Likert scale was used, ranging from “very confusing” to “very helpful.” Eighty-three students submitted the feedback form. The feedback received was largely positive: 66.26% of the
students felt that these sessions were helpful, 20.48% found them very helpful, 3.6% reported the sessions confusing, and 9.6% were neutral in their response. None of the students found it very confusing.

DISCUSSION

The EMG is a well-established clinical tool in the assessment of neuromuscular physiology. The electrical activity of the muscle, as measured by the EMG, is a good indicator to assess and quantify muscle activity. This can be used to demonstrate and explain the neuromuscular events necessary for movement. Demonstrating the EMG in the teaching of skeletal muscle physiology helps a student appreciate the practical link between skeletal muscle physiology and muscle movement in real life. This also introduces the basics of the EMG, which they would usually come across later in clinical years. The demonstration was also useful to introduce students to the basic concepts of bioelectric signal acquisition, processing, and analysis.

This module was demonstrated using custom-built hardware. However, the lack of an EMG recording apparatus need not limit practical teaching, as low-cost devices have also been described (1). Students found these sessions useful and fun in understanding skeletal muscle physiology.

Conclusion

The EMG is a tool that can easily be used to complement didactic teaching in a classroom setting to make concepts of muscle physiology easier to understand and more interesting.

Authors’ Note

Technical details of the custom-built equipment are available as additional information in the APPENDIX. The corresponding author can be contacted for further details.

This study was reviewed and approved by the Institutional Review Board (IRB), Christian Medical College, Vellore (IRB no. 11139).

APPENDIX: TECHNICAL DETAILS OF CUSTOM-BUILT EQUIPMENT

The following describes the technical aspects of the design and construction of the in-house developed recording equipment. This was used in connection with an in-house data acquisition system (CMCdaq). They can be connected to other data acquisitions systems. Open source analog-to-digital converters like Arduino and Raspberry Pi have shelf sensors that can be used easily for this teaching module.

Electronic goniometer. Ohm’s law [voltage (V) = current (I) × resistance (R)] was used to measure the change in the angle of a joint. A potentiometer-based goniometer (Fig. A1) was constructed using a 10 kΩ rotary multiturn potentiometer (R2). The potentiometer was positioned at the joint of two aluminum strips. The potentiometer was fixed to one strip, and the knob to the other. In this way, as the angle between the strips changed, the knob turned. This potentiometer is one side of Wheatstone’s bridge setup with a similar 10 kΩ potentiometer (R3) on the other side of the bridge used for offset correction. Wheatstones’s bridge needs to be balanced based on the formula $R_1/R_2 = R_4/R_3$.

The output wires were connected to the data acquisition device with adequate amplification. The goniometer was calibrated to display the output in degrees against time. At the beginning of each session, the goniometer was strapped to the limb with the potentiometer (R2) centered at the joint. R3 is used to bring the recording to the baseline.

Electronic tendon hammer. A tomahawk knee hammer (Fig. A2) was instrumented with an analog triaxis accelerometer (ADXL377). The accelerometer was embedded into the rubber of the hammer with the x-axis oriented in the direction of the strike. Only the x-axis was connected to the data acquisition device. The strike of the hammer is read as a positive/negative deflection based on the movement of the tendon hammer.

Elbow splint with a force transducer. A 20-kg load cell (Haris sensors TT-SS 20 kg) was fixed to the end of a wooden strip with screws (Fig. A3). The wooden strip hinged with another wooden
strip and was fixed at a 90° angle. The load cell and wooden strips were fixed to the forearm and arm directly with Velcro straps so that all of the force of elbow flexion or extension was acting directly onto the load cell. The load cell is calibrated in Newtons and is connected to the data acquisition system with adequate preamplification with a DC amplifier.

For further details on the construction of the apparatus, please contact A. J. Mathew at anandijm@gmail.com.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

A.J.M. and V.O. conceived and designed research; A.J.M., M.N., and N.C. performed experiments; A.J.M., M.N., and N.C. analyzed data; A.J.M., M.N., N.C., and V.O. interpreted results of experiments; A.J.M., M.N., N.C., and V.O. prepared figures; A.J.M., M.N., N.C., and V.O. drafted manuscript; A.J.M., M.N., and V.O. edited and revised manuscript; A.J.M., M.N., N.C., and V.O. approved final version of manuscript.

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