Efficiency of Arm Movement: A Study of Leverage, ATP Utilization, and Sarcomere Shortening in the Brachium

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A sequence of four experiments have been developed with NSF funds to teach concepts of efficiency of arm movement. They attempt to correlate the chemical energy input with the mechanical energy output to give the student an understanding of the magnitude of energy that is lost in the conversion. The laboratory procedures are organized into the following sections: Prelab Exercises, Learning and Lab Skill Objectives, Background Information, A Problem Case, Methods, and Appendix.

Lab One: Organization of Lever Systems

The first experiment introduces lever systems and how they are organized. Some key concepts taught are:

- characteristics of skeletal muscle
- microscopic anatomy of a skeletal muscle fiber
- organization of skeletal muscle tissue by connective tissue wrappings
- origin, insertion, and action of representative arm muscles
- lever systems
- mechanical advantage

In the prelab the student studies the "Muscular Module" on the Interactive Physiology CD by Benjamin Cummings. The methodology takes the student through a detailed look at the

arm of the human and the cat. Muscles of the forearm necessary for flexion, bones providing arm leverage, and types of lever systems are covered.

Lab Two: Understanding the Sarcomere by Determining its length using a Light Microscope

This experiment assumes the student has gained the knowledge of skeletal muscle tissue and microscopic anatomy of a skeletal muscle fiber from the previous lab. It also contains background on the sliding filament theory of contraction the student will need.

Key concepts addressed are:
- banding patterns within a Sarcomere
- changes in banding patterns during contractions
- length-tension relationship regarding contraction
- the role of adenosine triphosphate (ATP) in contraction

The procedure is designed around the classical rabbit psoas muscle experiment. By adding calcium and ATP to the preserved muscled fibers the contraction can be observed.

A microscope-calibrated ocular micrometer is used to measure the percent shortening that occurs.

Lab Three: Determining the Relationship between Shortening and Use of Chemical Energy (ATP) by developing an ATP Dose-Response Curve

At this point the student should have a firm understanding of the microscopic anatomy of skeletal muscle as well as the sliding filament theory. This experiment will attempt to give the students a means of converting degree of shortening to chemical expenditure using a dose response curve.

Key Concepts are:
- dilution and dilution schemes
- muscle fatigue and the role that ATP plays
- sources of ATP in skeletal muscle
- requisites for shortening to occur
- dose response relationship between ATP concentration and percent shortening

The prelab of this exercise helps the student review the concept of dilution and deal with the development of the ATP dilution doses needed to determine shortening. Procedures used in experiment 2 are applied to this experiment. Calipers are used for measuring the length of the Psoas muscle segment before and after adding ATP. Micropipettes are used to apply ATP solutions to segments in a special slide which restricts curling and twisting of the Intact fiber. Graphing software is used to complete the analysis.

Lab Four: Estimating the Among of ATP Needed for Shortening of an Intact Muscle

Students should bring to this lab a knowledge of arm flexor muscles and results from the dose response curve (Lab Three).

Key concepts covered are:

- Techniques for measuring the volume of the brachium, i.e. volume displacement
- Identification of surface markings on the arm and shoulder used in measuring force and resistance arm length
- Making energy conversions from muscle shortening to ATP consumption
- Determining the efficiency of arm movement

The prelab and background section of this lab introduces the student to mechanical advantage and torque associated with movement of the forearm about the elbow. The student practices determining the force necessary to lift the arm and fixed weights in the hand. The experimental procedure first guides the student through an estimation of the percent shortening of the biceps and brachialis muscles when the arm is move from 180 degrees to 90 degrees. The work done by the arm is then determined using equations of leverage. The next step is to determine the volume of the upper arm using water displacement. The energy used per volume of muscle is estimated by combining results from lab three and the volume estimation. The energy needed for moving the arm 90 degrees is then compared from the leverage results and the ATP results. Efficiency is determined.

Materials needed

The following is a partial list of materials needed for these labs:

- Articulated human skeleton
- 6 microscopes with ocular micrometers
- Preserved cats
- Hemacytometers
- Calipers
- Interactive Physiology CD (Branstrom, M. J., and E. N. Marieb. (1995). Anatomy Review: Skeletal Muscle Tissue. Muscular Module. On *Interactive Physiology* CD. Redwood City, CA, Benjamin Cummings.)
- Preserved Rabbit Psoas Muscle
- Micropipettes
- Glass slides
- ATP
- Pipette washer

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