



Muscle Structure and Function

After completing this chapter you should be able to:

- describe the macro and micro structures of skeletal muscle;
- describe muscle contraction and explain the sliding filament theory;
- demonstrate an understanding of nerve–muscle interaction;
- differentiate among types of muscle fibers;
- describe group action of muscles;
- discuss muscle’s adaptation to strength training.



Structure determines function. This is a statement that defines the essence of human anatomy and physiology. Muscle tissue – the contraction specialist – provides a prime example of how the structure of a tissue is well adapted to perform a specific function. With approximately 660 muscles in the adult human body, making up nearly half of our body weight, the importance of muscular activity is obvious. The various structures and types of muscle tissue support numerous life functions, such as ventilation, physical activity and exercise, digestion, and of course, pumping life-sustaining blood throughout the body via specialized cardiac muscle. The focus in this chapter will be on skeletal muscle, which permits voluntary movement and is unique among other types of muscle in other important ways.

We often look at muscle as a single entity, but in so doing, fail to recognize the molecular complexity and hierarchical structure of this tissue. This specialized structure enables muscle to shorten and develop tension, allowing a myriad of human movements to occur. From movements as simple as waving good-bye or picking up a book, to more complex actions such as those required in athletics, the muscular system is vital to our daily functioning. But how does muscle activity integrate with the nervous system to produce movement? And what are the fundamental contractile properties of muscle?

Types of Human Muscle

On the basis of structure, contractile properties, and control mechanisms, there are three types of muscle in the human body: (1) skeletal muscle; (2) smooth muscle; and (3) cardiac muscle.

Most **skeletal muscle** is attached to bone, and its contraction is responsible for supporting and moving the skeleton. The contraction of skeletal muscle is initiated by impulses in the motor neurons to the muscle and is usually under **voluntary** control.

Smooth muscle is under the control of the autonomic nervous system and is called **involuntary**.

Smooth muscle forms the walls of blood vessels and body organs, such as the respiratory tract, the iris of the eye, and the gastrointestinal tract. The contractions of smooth muscle are slow and uniform and are very fatigue resistant. Smooth muscle functions to alter the activity of various body parts to meet the needs of the body at the time.

Cardiac muscle, the muscle of the heart, has characteristics of both skeletal and smooth muscle. Cardiac muscle functions to provide the contractile activity of the heart and has its own intrinsic beat. Like skeletal muscle, the contractile activity of cardiac muscle can be graduated; however, cardiac muscle is very fatigue resistant. Like smooth muscle, the activation of cardiac muscle is involuntary.

Although fitness training can benefit all three types of muscle systems, this chapter will deal primarily with the skeletal muscle.

Skeletal Muscle

Properties

Skeletal muscle refers to a number of muscle fibers bound together by connective tissue and is usually linked to bone by bundles of collagen fibers, known as **tendons**. Tendons are located at each end of the muscle (Figure 4.1 A). During muscle contraction, skeletal muscle shortens, and as a result of the tendinous attachments to bone, functions to move the various parts of the skeleton with respect to one another (joints) to allow changes in position of one skeletal segment in relation to another. Positioning several muscles on each “side” of a joint allows movement in several planes, and through graded activation the speed and smoothness of the movement can be graduated.

Skeletal muscles are capable of rapid contraction and relaxation. Intensive activity causes them to show early signs of fatigue. The assessment of the movement and the sequential pattern of muscle activation acting through joints to move body segments is termed **biomechanics of human movement** (see Chapter 8).



Origin–Insertion

In order for muscles to contract, they must be attached to bones to create movement. This is accomplished by tendons, strong fibrous tissues at the ends of each muscle. The end of the muscle attached to the bone that does not move is called the **origin**, while the point of attachment of the

muscle on the bone that moves is the **insertion** (Figure 4.1 A). The origin tends to be the more proximal attachment (closer to the body), while the insertion is the more distal attachment (further from the body).

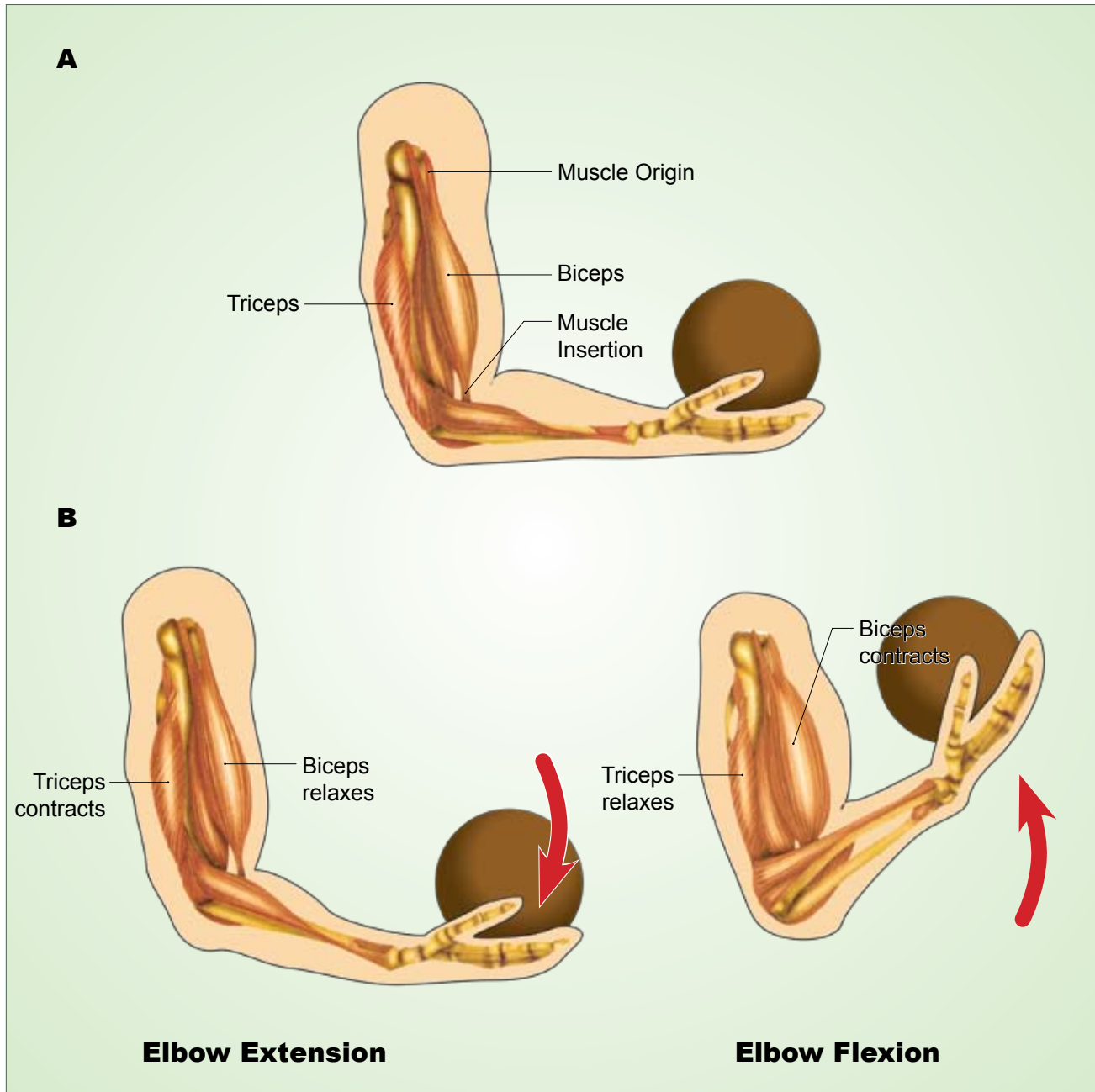


Figure 4.1 Bending or straightening the elbow requires the coordinated interplay of the biceps and triceps muscles.



Striated or Voluntary Muscle

Muscle attached to the skeleton to make it move is known as **skeletal muscle**. It is also known as voluntary or **striated muscle**. Skeletal muscle is considered *striated* because of the alternating light and dark bands (created by the organization of the muscle fibers, or cells) that appear when viewed under a light microscope. Its description as *voluntary* comes from the fact that we can contract skeletal muscle when we want to, voluntarily (e.g., flex the biceps).

Muscle Teamwork

Muscles work in perfect synchrony. When one muscle contracts (draws together) to move a bone, another relaxes, allowing the bone to move. The muscle or group of muscles producing a desired effect is known as the **agonist**, the **prime mover**. A muscle or group of muscles opposing the action is called an **antagonist**.

An agonist–antagonist relationship occurs between the biceps and triceps of the upper arm. When the biceps (agonist) contracts to bend the elbow, the triceps (antagonist) relaxes and allows the bend. When the triceps (agonist) contracts to straighten the arm, the biceps (antagonist) in turn relaxes (Figure 4.1 B).

The cooperation of biceps and triceps is typical of what takes place throughout the body. When entire groups of muscles get involved, the interaction between agonist and antagonist muscles becomes more complex.

The muscles surrounding the joint being moved and supporting it in the action are called **synergists** (complementing the action of a prime mover). Other muscle groups called **fixators** will steady joints closer to the body axis so that the desired action can occur. For example, if you want to climb a rope hand over hand, the muscles holding your shoulder girdle tightly to your rib cage are fixators, enabling you to use the muscles acting over the shoulder, elbow, wrist, and finger joints to perform their job and pull you up the rope.

Structure

Skeletal muscle is made up of numerous cylinder-shaped cells called **muscle fibers**, and each fiber is made up of a number of **myofilaments** (Figure 4.2). The diameter of each fiber varies between 0.05 and 0.10 mm, with the length being dependent mainly on the distance between skeletal attachments (in the case of the biceps, the length of a fiber is approximately 6 inches, or 15 cm). Each cell (fiber) is surrounded by a connective tissue sheath called the **sarcolemma**, and a variable number of fibers are enclosed together by a thicker connective tissue sheath to form a bundle of fibers (Figure 4.2 B). Each fiber contains not only the contractile machinery needed to develop force (Figure 4.3) but also the cell organelles necessary for cellular respiration (see Chapter 6, Energy for Muscular Activity). Also located outside each fiber is a supply of capillaries from which the cell obtains nutrients and eliminates waste.

A large number of individual threadlike fibers known as **myofibrils** run lengthwise and parallel to one another within a muscle fiber. The myofibrils contain contractile units that are responsible for muscle contraction (Figure 4.2 D).

Muscle's Tug of War

In some muscles, the individual fibers extend the entire length of the muscle, but in most the fibers are shorter. The shorter fibers, anchored to the connective-tissue network surrounding the muscle fibers, are placed at an angle to the longitudinal axis of the muscle. When muscle pulls on the bone during the transmission of force, it is like a number of people pulling on a rope, each person corresponding to a single fiber and the rope corresponding to the connective tissue and tendons.





Muscle: The Contractile Machinery

Within each myofibril, a number of contractile units, called **sarcomeres** (Figure 4.3 A), are organized in series (i.e., attached end to end). Each sarcomere consists of two types of protein myofilaments: **myosin**, the so-called thick filament, and **actin**, termed the thin filament. Looking at the filaments in a cross-section (i.e., looking at the myofilaments end-on), we see that each myosin filament is surrounded by actin filaments (Figure 4.3 A). Examining the sarcomere longitudinally (i.e., lengthwise), we see the distinctive banding pattern (striations) characteristic of skeletal, or striated, muscle (Figure 4.4). Projecting out from each of the myosin filaments at an angle of approximately 45 degrees are tiny contractile elements called **myosin bridges**; from this view, these elements look similar to the projections of oars from a rowing shell (Figure 4.3).

The Sliding Filament Theory During the contraction of a muscle, it is the sliding of the thin actin filaments over the thick myosin filaments that causes shortening of the muscle to create movement. This phenomenon is called the **sliding filament theory**. It is far more complex than described

here, but you should still be able to appreciate all the intricate anatomical structures involved with every move we make.

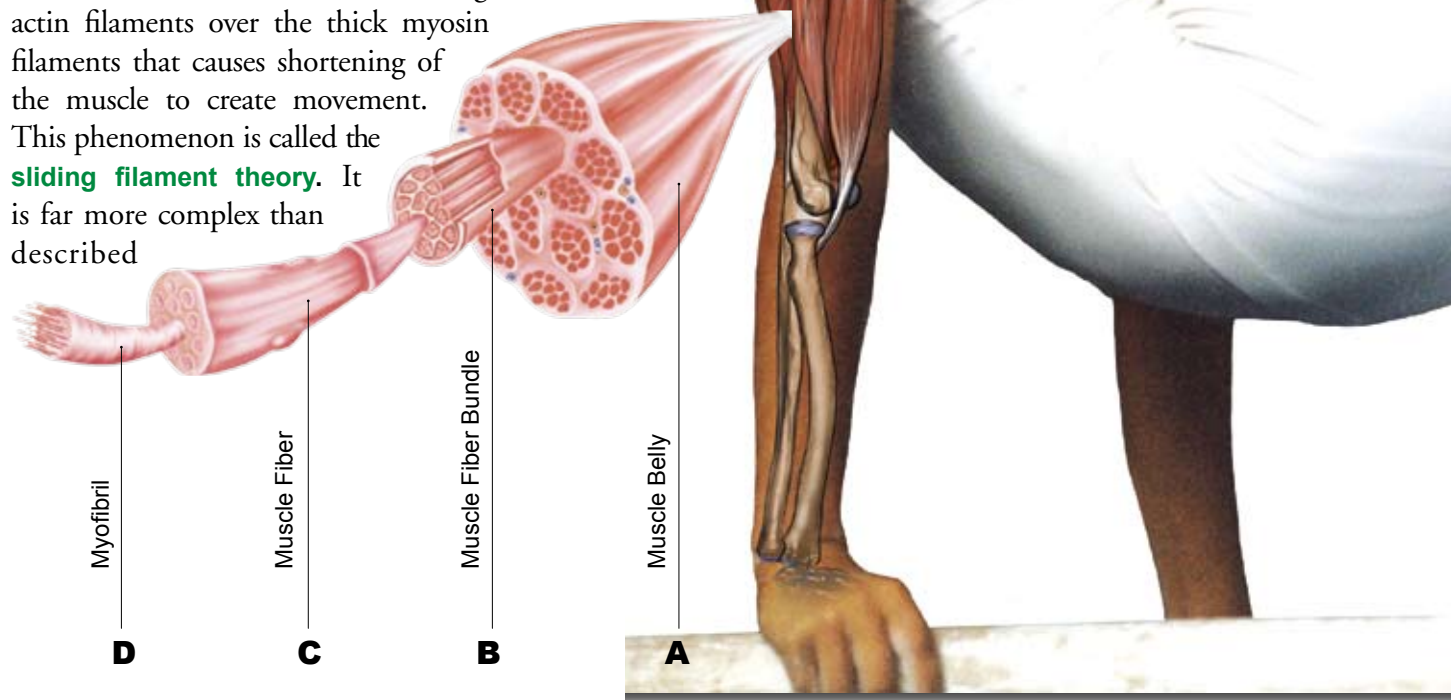


Figure 4.2 Components of skeletal muscle. **A.** Muscle belly (2 inches, or 50 mm, in diameter). **B.** Muscle fiber bundle (0.5 mm). **C.** Muscle fiber (0.05-0.1 mm). **D.** Myofibril (0.001-0.002 mm).

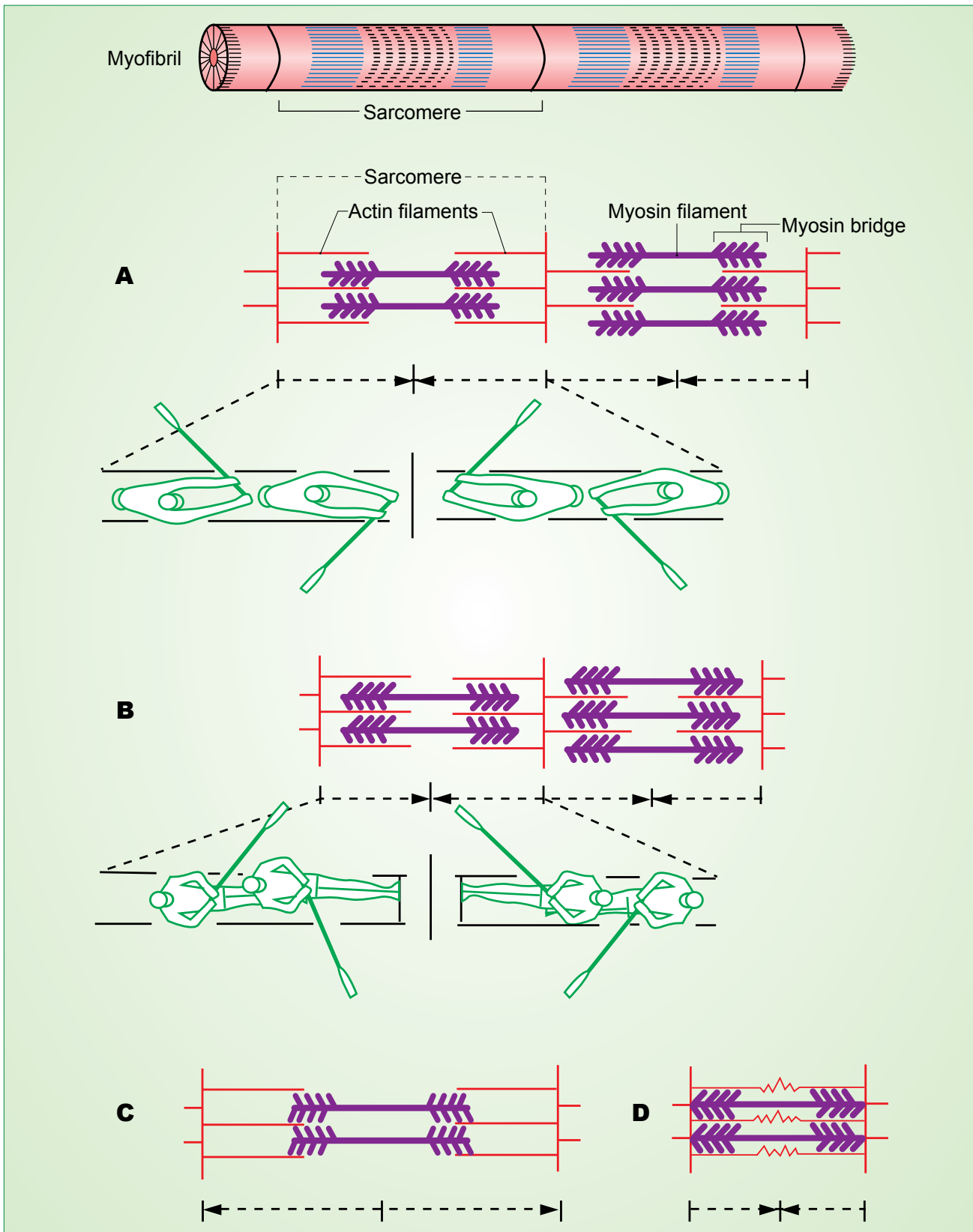


Figure 4.3 Longitudinal section of a myofibril and simplified representation of muscular contraction: **A.** At rest. **B.** Contraction. **C.** Powerful stretching. **D.** Powerful contraction.



Rowing Simulation When a signal comes from the motor nerve activating the fiber, the heads of the myosin filaments temporarily attach themselves to the actin filaments (Figure 4.3 B), a process termed **cross bridge formation**. In a manner similar to the stroking of the oars and the subsequent movement of a rowing shell, the movement of the cross bridges causes a movement of the actin filaments in relation to the myosin filaments, leading to shortening of the sarcomere. A single “stroke” shortens the sarcomere by approximately 1 percent of its length, and the nervous system is capable of activating cross bridge formation at a rate of 7 to 50 per second. Since the sarcomeres are attached to one another in series, the shortening of each sarcomere is additive. The total amount of fiber shortening amounts to some 25 to 40 percent of myofibril length.

To produce an efficient rowing stroke, the oars must be optimally placed (i.e., reaching far enough, but not too far); similarly, for optimal cross bridge formation, the sarcomeres should be an optimal distance apart. For muscle contraction, this optimal distance is 0.0019 to 0.0022 mm. When the sarcomeres are separated by this distance, an optimal number of cross bridges can be formed per unit time. If the sarcomeres are farther apart, or closer together, than this optimal distance, then fewer cross bridges can be formed, resulting in less force development. If the sarcomeres are stretched

further apart, as occurs when the muscle is in a lengthened (i.e., extended or stretched) position (Figure 4.3 C), fewer cross bridges can form because the myosin projections have difficulty reaching the actin filaments; this results in a decreased ability to produce force. When the sarcomeres are too close together, as would occur when the muscle is shortened (flexed), the cross bridges in fact interfere with one another as they try to form, resulting in a smaller number of effective cross bridges being formed and, again, a decreased ability to develop force (Figure 4.3 D).

The distance between sarcomeres depends on the state of muscle stretch, which in turn is a product of the position of the joint. What this means to the development of muscle force is that maximal force is developed when an optimal number of cross bridges are formed, which occurs at an optimal joint angle. Thus, because muscle force depends on muscle length, maximal muscle force occurs at optimal muscle length. As a joint moves through its range of motion, the muscle(s) connecting the two segments of the joint will move from a stretched position to a compressed position, and therefore, at some point in the movement, will pass through a position, termed the optimal joint angle, at which the muscle is at optimal length for maximal force development (Figure 4.5). This means that there will be an optimal joint angle for maximal force development for each movement

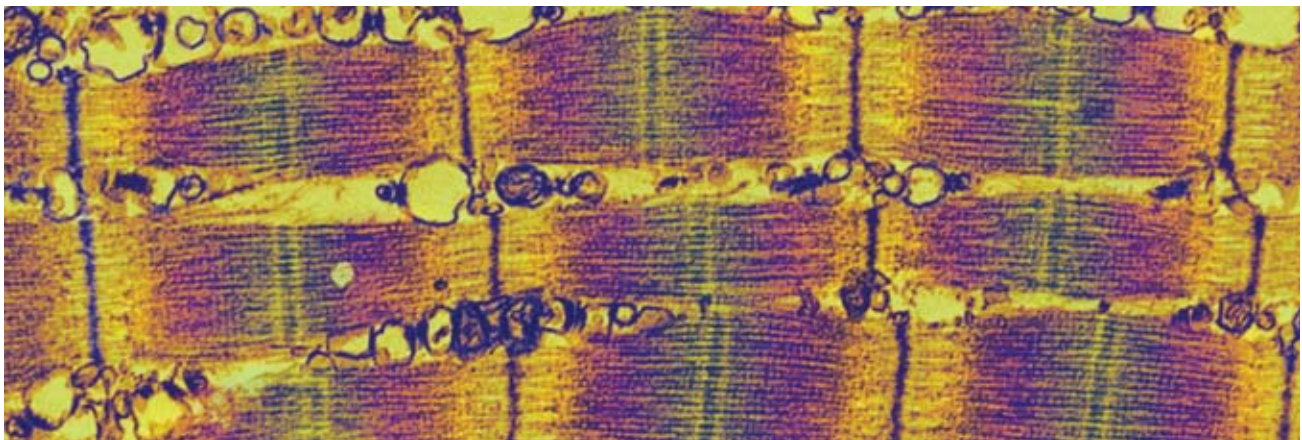


Figure 4.4 Microscopic view of several sarcomeres within a myofibril. The overlap arrangement of the actin and myosin strands results in the characteristic “striped” appearance of skeletal muscle.

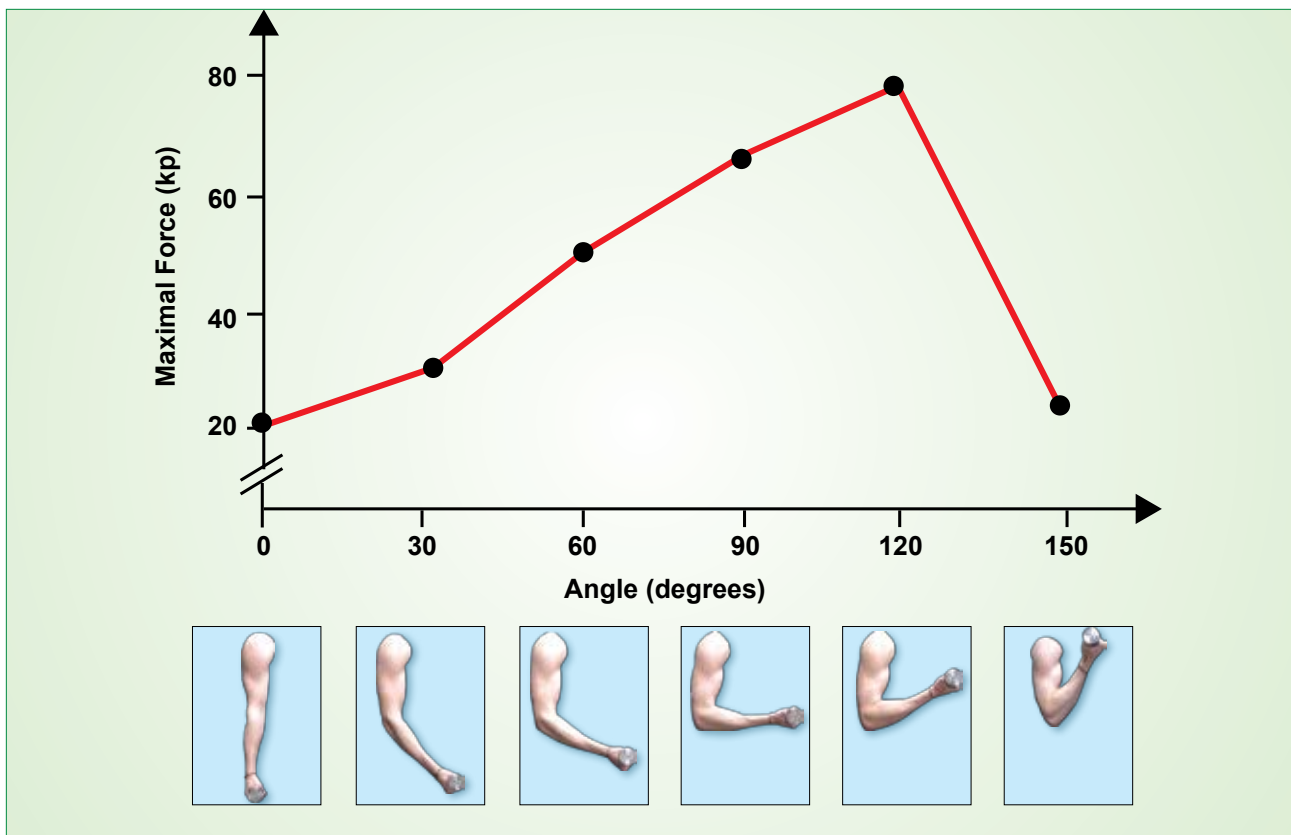


Figure 4.5 Maximal muscle force changes continuously throughout elbow flexion according to the joint angle.

Table 4.1 Relative involvement of muscle fiber types in sport events.

Event	Slow Twitch – Type I	Fast Twitch – Type II
100-m sprint	Low	High
800-m run	High	High
Marathon	High	Low
Olympic weightlifting	Low	High
Barbell squat	Low	High
Soccer	High	High
Field hockey	High	High
Football wide receiver	Low	High
Football lineman	High	High
Basketball	Low	High
Distance cycling	High	Low