Chapter 2

Mechanical Properties and Performance in Skeletal Muscles

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Introduction

The mechanical properties of skeletal muscle determine its performance. Mechanical properties are defined here as those properties of skeletal muscle that can be measured by parameters derived from mechanics: force, length, velocity, work and power. The performance achieved in many sports depends to a large degree on these parameters, for example, on the power an athlete can produce or the velocity (speed) he or she can achieve or impart on an implement. Human joints are typically crossed by many muscles; therefore, athletic performance depends typically on the properties of many muscles, as well as their exact coordination. Coordination is defined here as the interaction of the force–time histories of muscles that contribute to a movement, and thus, because of the geometry of the musculoskeletal system, the moment–time histories of these muscles about joints. The coordination of muscles is tremendously important for achieving precise movements or movements that maximize the work performed or the power produced, features that are of primary significance for optimal performance in many sports. However, coordination of muscles is an issue of motor control rather than mechanics; it will only be included in this chapter when required for clarity.

Despite the well-accepted relationship between the mechanical properties of skeletal muscle and performance in many sports, there is a sparsity of muscle mechanics research in sports. Also, in the practical application of physical training aimed at improving sport performance, athletes and coaches rarely consider the mechanical properties of skeletal muscles with the exception of force (strength); strength training is a well-accepted mode for improving muscular strength. The reasons for this rather sad state of affairs is not clear; however, the following factors might be partly responsible for the lack of muscle mechanics research in sport.

• Most mechanical properties of skeletal muscle are non-linear, therefore their mathematical description is not always trivial.

• It is virtually impossible to determine even the most basic properties of individual skeletal muscles *in vivo* and non-invasively.

• The time dependence of the mechanical properties (e.g. with increasing fatigue) are virtually unknown.

Because muscle mechanics research in sports is rare, it is not appropriate to write a literature review here. Such a review would reveal a sketchy, incomplete picture that might confuse rather than enlighten, or worse yet, might lead to inappropriate interpretations and generalizations. Therefore, the goals of this chapter are:

• to present some basic considerations regarding the mechanical properties of skeletal muscle; and

• to give examples of how principles of muscle mechanics might be applied to evaluate or improve sports performance

Basic considerations

In this section, five considerations regarding muscle mechanics will be presented. First, the proposed mechanism of muscular force production is

introduced. From this mechanism, many mechanical properties of muscle can be derived directly. Second, selected mechanical properties of skeletal muscle are introduced. Third, the *in vitro* or *in situ* mechanical properties of skeletal muscle derived from laboratory experiment cannot be directly used for *in vivo* human skeletal muscles. Selected examples will be shown to illustrate this point. Fourth, athletes are injured frequently or have musculoskeletal pain. It is discussed how pain and injury might influence muscular performance. Fifth, skeletal muscle is a biological tissue with a tremendous ability to adapt. Issues of muscular adaptation and the possible influence of such adaptations are discussed. Increases in mass and strength of muscles, arguably the most important factor for muscular performance, will be deliberately omitted from this discussion because this topic is covered elsewhere in this book and would require too much space for proper coverage. Here, we discuss muscular adaptations that are typically ignored in sports sciences.

Mechanism of muscular force production

The accepted mechanism of muscular contraction and force production is the sliding filament theory (Huxley & Hanson 1954; Huxley & Niedergerke 1954) combined with the cross-bridge theory (Huxley 1957; Huxley & Simmons 1971). According to the sliding filament theory, shortening and lengthening of muscle is brought about by the sliding of actin relative to myosin filaments. Force transmission from the myosin to the actin filament is thought to occur by a series of periodically arranged myosin-sidepieces (the cross-bridges) that can attach to periodically arranged, specialized sites on the actin filament. Some of the basic assumptions underlying the cross-bridge theory that are directly relevant for deriving the mechanical properties of skeletal muscle are:
• cross-bridges are periodically arranged on the myosin filament;
• cross-bridges attach to specialized sites that are periodically arranged on the actin filament;
• each cross-bridge produces the same average force and has the same capacity to perform mechanical work;
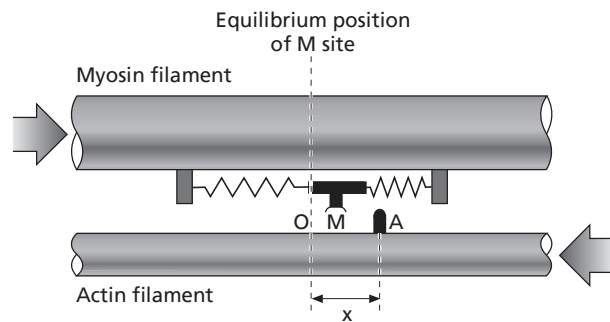
Fig. 2.1 Schematic illustration of a cross-bridge link between myosin and actin filaments as proposed by Huxley (1957). The so-called 'x-distance' is defined as the distance from the cross-bridge equilibrium position (O) to the nearest cross-bridge attachment site on the actin filament (A). (Reprinted from Huxley (1957), pp. 255–318, with permission from Elsevier Science.)

• actin and myosin filaments are essentially rigid;
• cross-bridges attach and detach according to rate functions that are dependent exclusively on the so-called 'x-distance', the distance from the cross-bridge head in its equilibrium position (Fig. 2.1) to the nearest attachment site (A in Fig. 2.1) on the actin filament;
• the instantaneous force of a cross-bridge depends on the x-distance exclusively; and
• each cross-bridge cycle is associated with the hydrolysation of one adenosine triphosphate (ATP).

For a thorough review of the cross-bridge theory and its mathematical formulation, the reader is referred to Huxley (1957), Huxley and Simmons (1971), Pollack (1990) and Epstein and Herzog (1998).

When expressing the cross-bridge theory mathematically, mechanical parameters such as the force, work or the energy required for a given contractile process can be calculated. Also, many of the mechanical properties can be derived directly from the cross-bridge theory. For example, the shape and extent of the so-called plateau and descending limb of the sarcomere force–length relationship (Gordon *et al*. 1966), and the concentric part of the force–velocity relationship observed experimentally (Hill 1938) can be approximated and explained by the theory. However, it must be pointed out that many experimental observations

cannot be explained or are not part of the original formulation of the cross-bridge theory; such observations include the long-lasting effects of contraction history on force, or the heat production and force during eccentric contraction. Nevertheless, the cross-bridge theory provides, at present, the best basis for understanding and explaining the mechanical properties of skeletal muscle.

Although it may be argued that there is no need for athletes and coaches to understand the cross-bridge theory in its details, it should be recognized that muscular properties and performance in a given situation can be predicted reasonably well when equipped with some basic knowledge of the mechanisms underlying muscular contraction. The mechanical properties arising from the cross-bridge model should be known by every coach as they might influence sport performance dramatically.

## Mechanical properties of skeletal muscle

Five mechanical properties of skeletal muscle will be discussed here. Only the basic characteristics of these properties are emphasized. Details that are not directly relevant for muscular or sport performance are ignored, therefore the following must be viewed as a 'simplified' or 'textbook' version of reality,

and other references should be consulted if more detailed information is sought. The five properties introduced here include:
- the force–length relationship;
- the force–velocity relationship;
- the power–velocity relationship;
- the endurance time–stress relationship; and
- selected history-dependent force properties.

THE FORCE–LENGTH RELATIONSHIP

The force–length relationship of skeletal muscle relates the maximal, isometric force to length. The term 'isometric' may relate to any specified level. For example, when talking about the muscle or sarcomere force–length relationship, the whole muscle or the sarcomeres are kept at a constant length, respectively. The force–length relationship is a static property of skeletal muscle; that means, a point on the force–length relationship is obtained by setting the muscle length, activating the muscle maximally, and then measuring the corresponding steady-state force (Fig. 2.2a). In order to obtain a second point, the muscle is relaxed (deactivated), set at the new length of interest and then reactivated maximally. It is not possible to go from point 1 (F_1) to point 2 (F_2) along the force–length relationship (Fig. 2.2b),
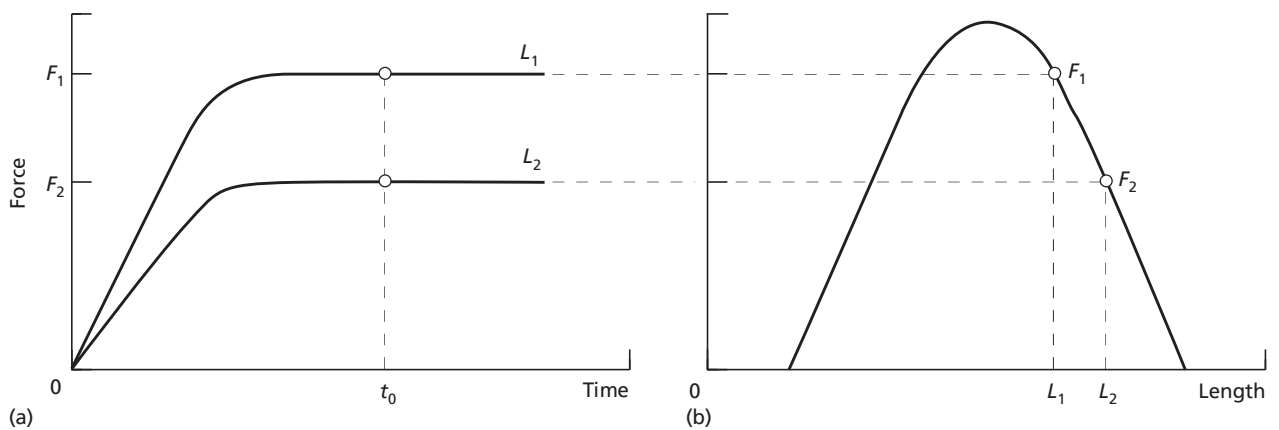
Fig. 2.2 Schematic illustration of how force–length relationships of muscles are determined, thereby emphasizing the static, non-continuous nature of the force–length relationship. (a) Force–time curves for two separate, fully activated contractions, one at a length L_1, the other at a length L_2. In both contractions, a steady-state force is measured, F_1 and F_2, respectively. (b) Force–length curve illustrating how the results of the experiment shown in (a) are used to determine the force–length relationship. Note that it is not possible to take a fully activated muscle and stretch it from L_1 to L_2 (or shorten it from L_2 to L_1) such that the force trace follows that shown in (b), because of the static, discontinuous nature of the force–length relationship.
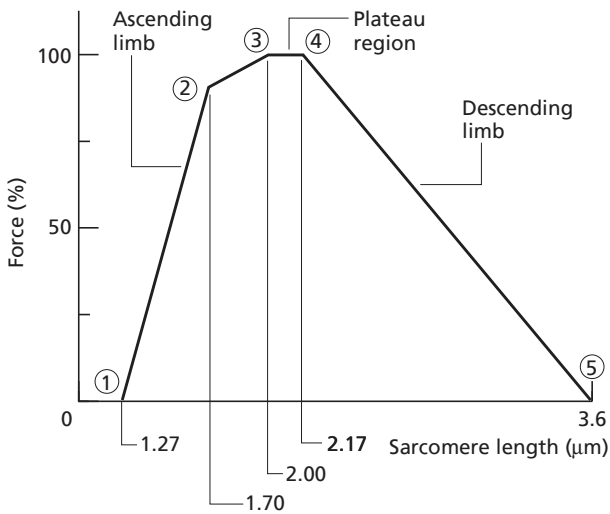
Fig. 2.3 Sarcomere force–length relationship as first described by Gordon *et al.* (1966) for frog skeletal muscle.

except, possibly, if the length change was carefully controlled by a complex and varying activation of the muscle during the experiment.

The sarcomere force–length relationship may be derived accurately based on the cross-bridge theory (Gordon *et al.* 1966). Specifically, the plateau region and the descending limb of the force–length relationship can be determined directly from the amount of myofilament overlap and the assumptions of the cross-bridge theory that: (i) the actin and myosin filaments are essentially rigid; (ii) they have periodically aligned attachment sites and cross-bridges, respectively; and (iii) each cross-bridge exerts the same amount of force and work independently of other cross-bridges and its own time history (Fig. 2.3).

In principle, the muscle force–length relationship states that the maximal force of a muscle depends on its length. In the human musculoskeletal system, the length of a muscle can be related to the angle(s) of the joint(s) the muscle is crossing. Therefore, there is an optimal length or joint angle at which muscular force is maximal. Knowing this length may be important for optimal sport performances. For example, during bicycling, the geometry of the bike dictates directly over which range of the force–length relationship the leg muscles work. Choosing the appropriate bike geometry for each individual

athlete therefore is of utmost importance for success in bicycling (Yoshihuku & Herzog 1990).

THE FORCE–VELOCITY RELATIONSHIP

The force–velocity relationship describes the relation between the maximal force at optimal length (the length at which the muscle can exert its maximal isometric force) and the corresponding speed of muscle shortening. For shortening (concentric) contractions, the force–velocity relationship has been described in mathematical form for over 60 years (Fenn & Marsh 1935; Hill 1938). In fact, Hill's (1938) force–velocity equation is still used today more often than any other equation to describe the force–velocity relationship of shortening muscle. It states:

$$F = \frac{F_0 b - av}{b + v} \qquad (2.1)$$

where F is the maximal force of a muscle at optimal length, F_0 is the maximal isometric force at optimal length, v is the speed of shortening, and a and b are constants with units of force (N) and speed (m · s^{-1}), respectively. A corresponding well-accepted equation for the force–velocity relationship of lengthening (eccentric) contractions does not exist.

For concentric contractions, the maximal force a muscle can produce at optimal length decreases with increasing speeds of shortening (Fig. 2.4) until it reaches a critical speed, v_0, at which the external
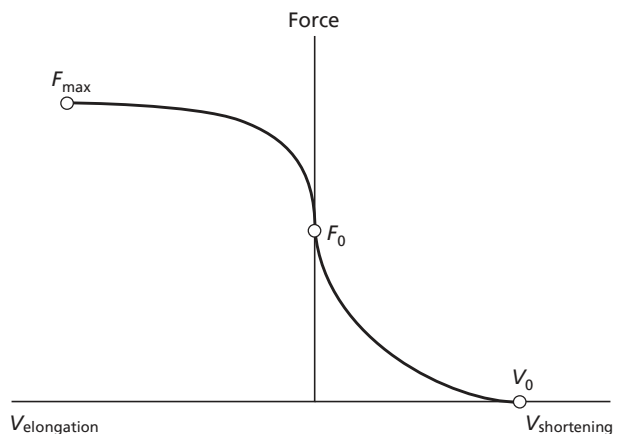

Fig. 2.4 Schematic force–velocity relationship for shortening and lengthening muscle.

force of the muscle becomes zero. The speed, v_0, can be calculated from Eqn 2.1 by setting F to zero, therefore:

$$v_0 = \frac{F_0 b}{a} \qquad (2.2)$$

For eccentric contractions, the force a muscle can exert increases with increasing speeds of lengthening until a critical speed is reached at which the force becomes constant independent of the speed and equals about 1.5–2.0 times the maximal isometric force at optimal length, F_0 (Fig. 2.4). Since the force of a muscle depends on its contractile speed, force also depends on movement speed. For example, it has been well described that the force that can be exerted on the pedals during bicycling decreases with increasing speed of pedalling (Hull & Jorge 1985; Patterson & Moreno 1990; Sanderson 1991).

The shape of the force–velocity relationship depends strongly on the fibre type distribution within a muscle. Although the force per cross-sectional area (stress) of a slow-twitch and fast-twitch muscle fibre is about the same, the maximal speed of shortening differs by a factor of about 2 (Fig. 2.5). Therefore, for a given speed of shortening a predominantly fast-twitch fibred muscle can exert more force than a predominantly slow-twitch fibred muscle, although their isometric force (per cross-sectional area) is about equal. This observation explains why athletes with a high percentage of fast-twitch fibres typically perform better than athletes with a high percentage of slow-twitch fibres in events where a high speed of movement execution is combined with high force requirements—for example, in all sprinting, throwing and jumping events of track and field.

THE POWER–VELOCITY RELATIONSHIP

The power–velocity relationship can be derived directly from the force–velocity relationship since power, P, is the vector dot product of force ($\mathbf{F}$, vector) and velocity ($\mathbf{v}$, vector):

$$P = \mathbf{F} \cdot \mathbf{v} \qquad (2.3)$$

which might be reduced to the scalar multiplication of the force magnitude, F, and the speed, v, for the special case of power in a skeletal muscle; i.e.

$$P = Fv \qquad (2.4)$$

For concentric contractions, the power a muscle can exert is zero for isometric contractions (because $v = 0$) and for contractions at the maximal speed of shortening, v_0 (because $F = 0$). Power output of a muscle reaches a peak at a speed of about 30% of the maximal speed of shortening (Fig. 2.6). Therefore, in an athletic event in which power output should be maximized, it is of advantage to perform the movement at such a speed (if possible) that the major muscles contributing to the task contract at about 30% of their maximal speed of shortening. It has been suggested that animals take advantage of the
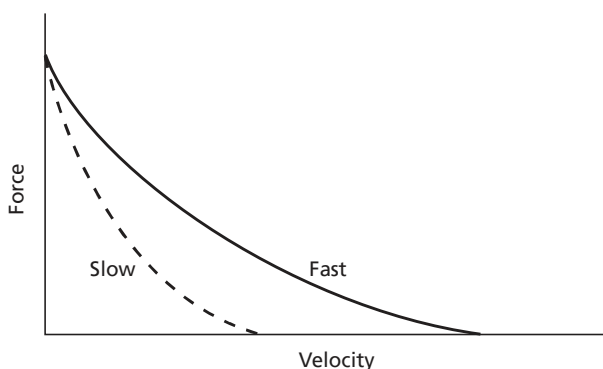

Fig. 2.5 Schematic force–velocity relationship for shortening contractions of a slow-twitch and a fast-twitch muscle fibre.
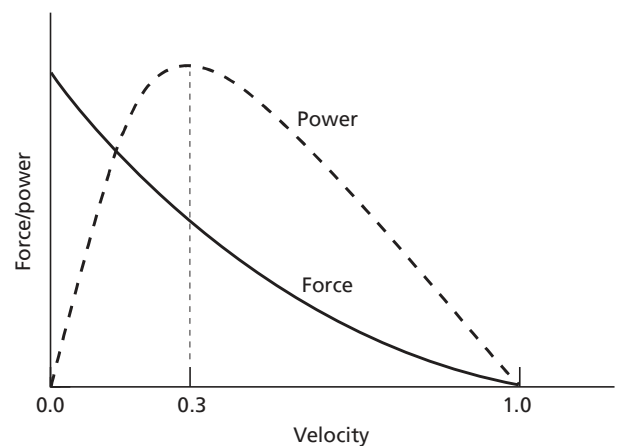

Fig. 2.6 Force–velocity and corresponding power–velocity relationship for shortening muscle.

power–velocity relationship of their muscles when escaping from predators. For example, it has been proposed that the frog leg muscles that contribute to jumping all contract close to 30% of their maximal shortening velocity, and so are able to produce near maximal power output of the legs (Lutz & Rome 1993). Quick, large jumps are taken by frogs to avoid being eaten by predators.

In some sports, movement speed can be selected by the athletes. Again, I would like to use the example of bicycling. When cycling at 40 km · h⁻¹, the athlete has a variety of gear ratios available to produce a given power output. Therefore, the athlete can directly manipulate movement speed (pedalling rate) for a given performance (cycling at 40 km · h⁻¹). The choice of proper gearing (pedalling rate) may be a decisive factor in the success of a cyclist.

THE ENDURANCE TIME–STRESS RELATIONSHIP

The three properties of skeletal muscle discussed so far do not take fatigue into account. Fatigue of skeletal muscle is defined here as the inability of a muscle to maintain a required force. Fatigue occurs fast when a muscle exerts large forces (or stresses). Maximal forces may only be sustained for a few seconds. However, a muscle that exerts a very small force relative to its maximal force may do so for an almost infinite amount of time (Fig. 2.7).
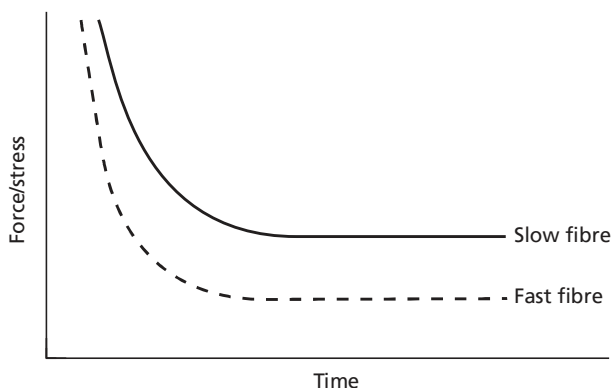
A predominantly slow-twitch fibred muscle

**Fig. 2.7** Schematic force/stress–time relationship for a fast-twitch and a slow-twitch fibre.

can maintain a given amount of stress for a longer period of time than a predominantly fast-twitch fibred muscle (Fig. 2.7). Therefore, athletes with predominantly slow-twitch fibred muscles typically perform better than athletes with predominantly fast-twitched fibred muscles in sports that require long periods of muscular involvement at relatively low force levels—for example, long-distance running.

SELECTED HISTORY-DEPENDENT PROPERTIES

History-dependent properties of skeletal muscles have largely been ignored in muscle mechanics despite the fact that they have been observed experimentally and well described for at least half a century (e.g. Abbott & Aubert 1952; Maréchal & Plaghki 1979; Edman & Tsuchiya 1996; Herzog & Leonard 1997). History-dependent properties refer to properties of skeletal muscle (e.g. its ability to produce force) that depend on the contractile history. These properties are dynamic in nature and therefore are different from the static properties described so far.

The two history-dependent properties selected for this chapter are the force depression following muscle shortening and the force enhancement following muscle stretching. Force depression following muscle shortening refers to the observed phenomenon that the isometric force following muscle shortening is reduced compared with the corresponding purely isometric force (Fig. 2.8). Although this phenomenon has been well accepted for a long time (Abbott & Aubert 1952; Maréchal & Plaghki 1979) the mechanism causing force depression is not understood (Maréchal & Plaghki 1979; Herzog 1998). Also, force depression following muscle shortening has only recently been observed in human skeletal muscle (De Ruiter et al. 1998) and has been demonstrated to occur during voluntary human contractions in only a single study to date (Lee et al. 1999).

Force enhancement following muscle elongation refers to the experimentally observed result that the isometric force following muscle stretch is higher and remains higher than the corresponding purely
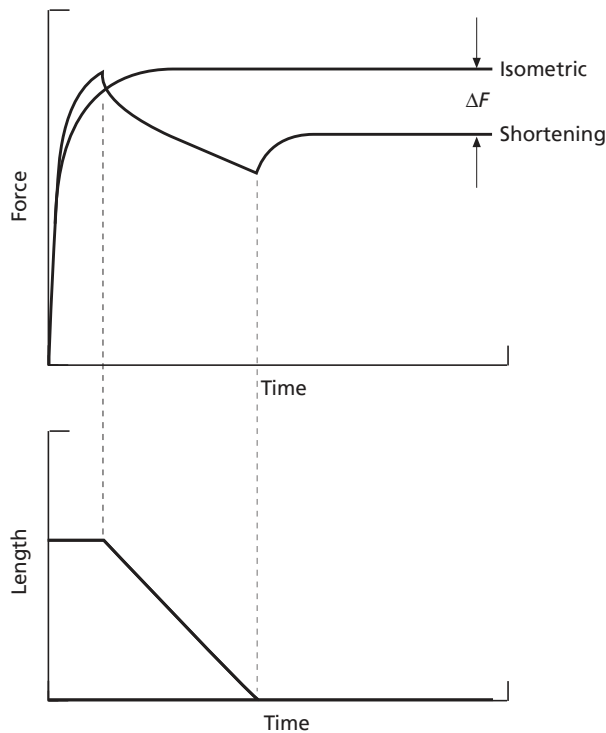
Fig. 2.8 Schematic illustration of force depression following muscle shortening. When comparing the maximal force of a purely isometric contraction to that of an isometric contraction that is preceded by a shortening of the muscle, it is observed that the isometric force following shortening is decreased (ΔF) compared with the purely isometric force at the corresponding muscle length.
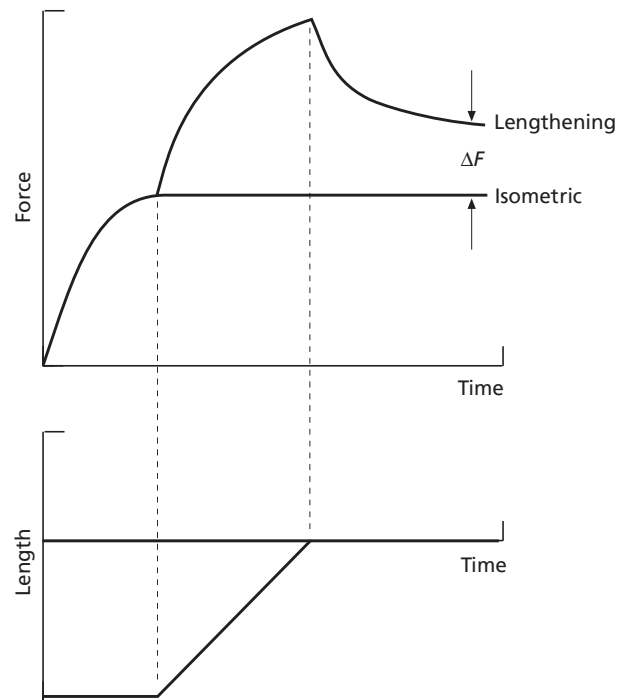
Fig. 2.9 Schematic illustration of force enhancement following muscle lengthening. When comparing the maximal force of a purely isometric contraction to that of an isometric contraction that is preceded by a lengthening of the muscle, it is observed that the isometric force following lengthening is increased (ΔF) compared with the purely isometric force at the corresponding muscle length.

isometric force (Fig. 2.9). Force enhancement following muscle stretch has only been observed in artificially stimulated non-human muscle preparations (Abbott & Aubert 1952; Edman & Tsuchiya 1996); therefore, the possible significance of this property in human skeletal muscle during voluntary contractions must still be established. Nevertheless, the idea that stretching a muscle before concentric use might be beneficial for performance enhancement appears attractive and is used by many athletes. For example, movements such as a golf swing, jumping or throwing of any object are typically (if the rules of the game allow and if time permits) preceded by a counter-movement in which the major muscles required for the task are actively prestretched.

Muscle properties in humans (special considerations)

With few exceptions, the mechanical properties of skeletal muscles described in the previous section were obtained from isolated preparations of animal muscles. Human muscles may differ from animal muscles, and furthermore human muscles are voluntarily activated in sports and exercise rather than artificially stimulated. Therefore, some of the properties described above might only apply to a limited degree to *in vivo* human skeletal muscles. I would like to give two conceptual examples why *in vivo* human skeletal muscle properties may differ substantially from those of isolated *in situ* (or *in vitro*) animal muscles.

These two conceptual examples may be broadly grouped into activation- and adaptation-dependent phenomena.

ACTIVATION-DEPENDENT PHENOMENA

When determining force–length, force–velocity, power–velocity, stress-endurance time, or history-dependent phenomena of isolated skeletal muscles, activation of the muscle is controlled, constant and artificial. Muscular contractions during human movement, and sport, are voluntary, and even maximal contractions are not performed at constant levels of activation. It has been proposed that during human voluntary contractions, activation may be increased when a muscle or muscle group contracts at full effort but the contractile conditions are not well-suited for large force production. For example, Hasler et al. (1994) argued that maximal voluntary activation of the knee extensor muscles (as recorded by surface electromyography, EMG) was increased towards full knee extension compared with levels of EMG at intermediate knee angles. The increase in EMG activity towards full knee extension was interpreted as an attempt of the neural control system to partly offset the unfavourable contractile conditions of the knee extensors at or near the fully extended knee.

Also, during maximal effort eccentric knee extensor contractions, the knee extensors should be 1.5–2.0 times as strong as during maximal effort isometric contractions, but they are not. Knee extensor activation is inhibited in this situation (presumably for reasons of safety) such that the eccentric force is about the same as that produced isometrically at the corresponding lengths (Westing et al. 1990).

Finally, pain or injury may not allow athletes to fully activate their muscles. For example, anterior knee pain, knee ligament injury, and knee effusion have all been shown to reduce the activation of the knee extensors achieved during maximal voluntary contractions in normal people and athletes (Suter et al. 1996; Huber et al. 1998). All these factors must be considered when assessing the potential for force, work and power output of muscles during athletic activities.

ADAPTATION-DEPENDENT PHENOMENA

Although the mechanical properties of skeletal muscle, such as the force–length and force–velocity relationships, are typically treated as constant, invariant properties, it is well recognized that muscular properties may adapt to the requirements of everyday exercise and athletic training. For example, the force–length properties of high-performance cyclists and runners were found to differ significantly between the two groups of athletes, and appeared to have adapted to maximize cycling and running performance, respectively (Herzog et al. 1991a). Adaptations of strength following strength training and of endurance following aerobic training of skeletal muscles are other well-documented and well-accepted adaptations in athletes. These examples should serve to illustrate the possible danger of transferring muscle properties determined on in situ or in vitro preparations to the in vivo musculature of human athletes during competition.

Selected examples

Few examples exist in which muscle properties or muscle mechanics were used thoroughly and systematically to gain insight into the performance of an athlete or to maximize performance in a given sport. The possible exception to this rule is bicycling. Bicycling is an attractive sport to study from a muscle mechanics point of view because it is an essentially two-dimensional motion with few degrees of freedom. It can easily and realistically be studied in the laboratory, and output measures of mechanical performance (power, force, speed) can be determined in a straightforward way. Corresponding physiological measures, particularly those relating to the energetics of bicycling, have been determined for years using well-established testing procedures. Therefore, bicycling appears in many of the examples cited in the following pages.

When seated, the excursions of a cyclist's lower limb joints are basically given by the geometry of the bicycle, particularly the seat height, the handle bar length and the crank length. Therefore, the excursions of the lower limb muscles, as well as the

area of the force–length relationship over which the lower limb muscles are working during a full pedal revolution is, to a large extent, given by the bicycle geometry and the anatomy of the athlete. In the ideal case, bicycle geometry should be chosen such that all major cycling muscles operate at or near the plateau region of the force–length relationship. It has been determined theoretically that such a geometry is achieved when the seat height is about 510 mm and the crank length is about 170 mm for a subject with thigh and shank length of 430 and 440 mm, respectively (Andrews 1987; Yoshihuku & Herzog 1996).

Once the bicycle geometry is set, the speed of muscular contraction depends exclusively on the pedalling rate. For minimal oxygen consumption, pedalling rates of 50–65 revolutions per minute (r.p.m.) have been shown to be optimal (Seabury *et al.* 1977; Coast & Welch 1985; Marsh & Martin 1993). Power output on a street bicycle (free gear selection) is maximized at about 120 r.p.m. (Sargeant *et al.* 1981; McCartney *et al.* 1983; Beelen & Sargeant 1991; MacIntosh & MacEachern 1997) and on a track bicycle (no gear selection, 200 m sprint) at about 150 r.p.m. (Yoshihuku & Herzog 1990). Finally, during long-distance racing, top athletes prefer to pedal at rates of about 90 r.p.m. (Hagberg *et al.* 1981; Patterson & Moreno 1990; Marsh & Martin 1993). According to the power–velocity relationship, a pedalling rate of about 120 r.p.m. would be optimal. However, the constraints of track cycling (one gear,

maintenance of maximal power for about 15–20 s in a 200 m sprint with the corresponding preparation phase), or the goals in long-distance cycling require different pedalling rates for success. Although pedalling at 60 r.p.m. uses less oxygen than pedalling at higher rates, the power that can be produced at 60 r.p.m. is relatively low because for a given (high) power output, the pedal forces need to be high causing local muscular fatigue to occur quickly.

Sprinting at 150 r.p.m. on the track or 120 r.p.m. during road racing allows for a high power output with relatively small muscular forces. However, at these high pedalling rates oxygen consumption for a given power output becomes prohibitive, and so this cannot be the strategy of choice for long-distance riding. Riding at 90 r.p.m. is a good compromise between the force–velocity, power–velocity and endurance time–stress relationships, although why most top cyclists prefer to ride at or near 90 r.p.m. still awaits complete and satisfactory explanation.

For maximal power output, athletes should use the primary muscles required for the task at optimal muscle length, at the optimal speed of shortening, and preferably after a stretch of the muscle (Fig. 2.10). Obviously, the musculoskeletal system is not built exclusively to maximize performance in a given sport, such as bicycling. However, muscles probably adapt to everyday exercise and training. The force–length properties of the human rectus femoris (RF) in cyclists are negative, those
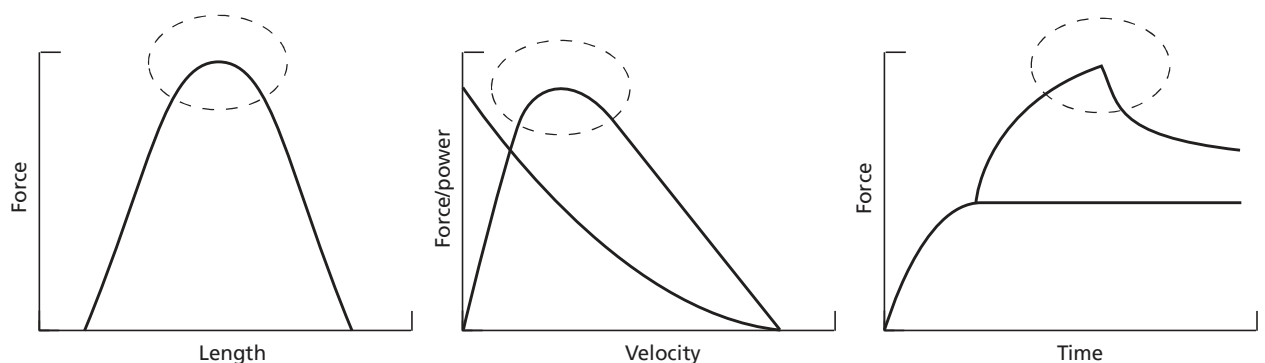
Fig. 2.10 Schematic force–length, force/power–velocity, and force–time curves illustrating that for maximal muscle power output, a muscle should be at a length close to optimal, should shorten at a speed close to optimal (i.e. at about 30% of the maximal speed of shortening), and should be used following a muscle stretch.
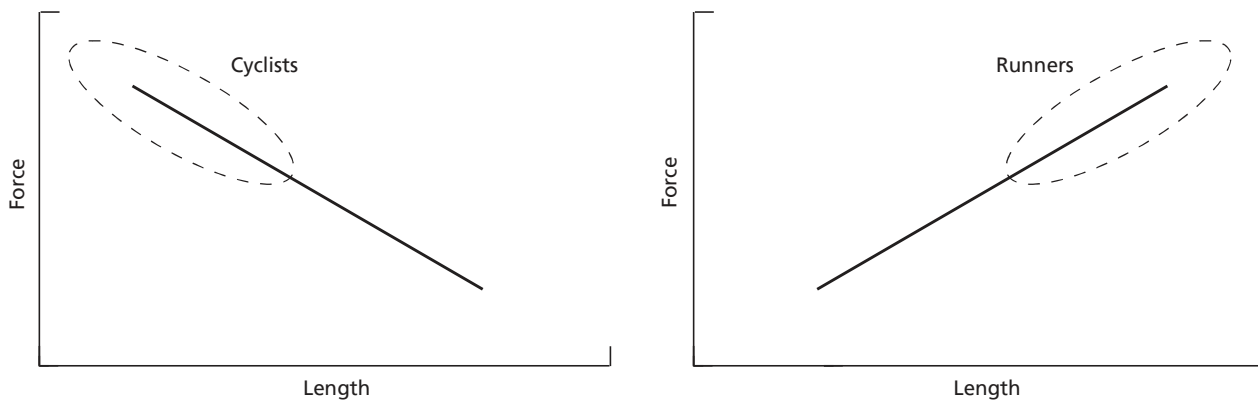
Fig. 2.11 Schematic illustration of the experimentally observed force–length relationships of human rectus femoris muscles in elite cyclists and elite runners.

of runners are positive (Herzog *et al*. 1991a), indicating that bicyclists are relatively stronger at short RF lengths and runners are relatively stronger at long RF lengths, as required for cycling and running, respectively (Fig. 2.11). This observation suggests that RF properties adapted in these athletes to accommodate the everyday demands of training and exercise. It has been speculated that such an adaptation could have occurred because of a change in the sarcomeres that are arranged in series in the RF fibres of these athletes (Herzog *et al*. 1991a), an attractive but as yet unproven speculation.

Independent of the mechanism of the muscular adaptation, it is safe to suggest that the RF force–length properties of the cyclists are not optimal for running and vice versa. This result has two interesting implications. First, cycling is not a good cross-training for running and vice versa, or in more general terms, cross-training could limit performance in the target sport. Second, in multievent sports, such as triathlon, even the most talented athlete will likely never be able to compete with the specialists in a particular discipline. For example, a highly talented runner who turns to triathlon cannot run with world-class runners even if the running training in terms of time, mileage and attempted intensity is the same for the triathlete as for the runners. The reason is not the amount or intensity of running but the fact that the properties

of the leg musculature will likely never be optimal for running because the triathlete also swims and cycles.

Final comments

Strength, power and endurance are attributes of skeletal muscles that often determine athletic success. The physiological adaptations of muscle to strength- and endurance-training are well known and documented. It was not the intent of this chapter to review the corresponding literature here. However, strength, power and endurance of a muscle are dramatically influenced by the length, speed and contractile history. This influence might be evaluated by knowing some of the mechanical properties of *in vivo* human skeletal muscles. Here, I have attempted to introduce some of these properties and demonstrate with selected examples how they might influence sport performance.

Two main difficulties arise when attempting to relate the properties of skeletal muscle to athletic performance:
• very little is known about the properties of individual, *in vivo* human skeletal muscles; and
• very little is known about the contractile conditions of the major task-specific muscles in sports.

Therefore, the current chapter cannot be viewed as a textbook chapter with all the answers. Rather, it

represents considerations that might turn out to be useful in the analysis of the biomechanics of sports. It is hoped that this chapter might motivate sports biomechanists to systematically and thoroughly investigate sports activities and performances in the light of muscle mechanics. This approach is sorely lacking and offers new opportunities to gain exciting insights into the biomechanics of sports.

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