

## ***Musculoskeletal Assessment in Soccer: A Review***

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### **Abstract**

Muscular strength is generally measured using either of the following methods, one repetition maximum (1- RM) of a weight-lifting exercise, a resisted maximal effort and portable or laboratory-based dynamometry. The 1- RM method refers to measurements of maximum strength using a strength training device such as a barbell or stationary weight-lifting machine. Dynamometry can be divided into two separate methods according to the muscle action involved. Isometric dynamometers assess the force exerted during static muscular actions typically associated with the back, legs and upper limb, e.g. hand (grip). The classical method of recording isometric muscle strength was cable tensiometry, later replaced by use of load cells and force transducers. In experimental studies, maximal voluntary contraction (MVC) is employed as the criterion for muscle strength, typically registered using strain-gauge assemblies. Such devices are relatively inexpensive and convenient to use in and out of the laboratory. Hand grip dynamometers are possibly the most widespread devices for measuring strength however there is concern regarding the strength in the muscle involved in isometric gripping and the generalisation to large muscle group or whole-body strength.

The main limitation of such dynamometers is that they do not replicate sport specific activity. Dynamic strength assessment is the preferred method when assessing athletic performances opposed to isometric testing because of the large neural and mechanical differences between isometric and dynamic muscular action. This recommendation is supported by a number of studies that have found a poor association between isometric strength and dynamic performance in strength-based activities.

Isokinetic dynamometry is used to assess dynamic muscle action whereby the velocity of limb movement is held constant throughout the range of movement and the resistance applied is equal to the muscular torque during the movement. Such a device allows accurate measurement of torque throughout many limb movements under concentric and eccentric muscle actions. With the subject maintaining a static position, the dynamometer also allows measurement during isometric muscle action. In order to measure absolute strength it is advised that a relatively low velocity is used to allow for production of maximal torque throughout the movement. The protocol used to establish maximum torque can vary, but this function is most often evaluated following several submaximal repetitions and from the first two or six maximal repetitions. Although such dynamometers allow for isolation of specific muscle groups through a single joint motion, they are limited in their representation of typical sports activities. In this paper some important isokinetic parameters relevant to soccer will be discussed.

**Keywords:** Isokinetic; Muscle strength, Injury; H/Q Ratio

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### ***Modes of testing muscle strength***

The modes of testing muscle strength have been categorised into three types, namely isometric, isotonic (isoinertial) and isokinetic modes. Isometric muscle strength assessment involves contraction against a fixed object. A muscle's maximum production of static force against a fixed resistance and at a speed of 0 rad.s<sup>-1</sup> is thereby recorded. Early objective testing of isometric strength was performed with cable tensiometry for multiple joints, whilst hand-grip and back-lift dynamometry were

employed for specific muscle groups.

The peak value of isometric strength is expressed as maximum voluntary contraction (MVC). Due to the specific fixed joint angle and the muscle tested, these static tests are minimally functional but have high reliability. The utility of this assessment is improved when isometric tests are performed at multiple angles/positions through a joint's range of motion. In this way strength-angle curves can be generated for a particular joint motion e.g. elbow flexion or knee extension.

Isometric strength is relevant in maintaining a soccer player's balance on the pitch and also in contributing to ball control. Reilly (1996a) claimed that soccer players are generally found to be only a little above average in isometric muscle strength. This may be deemed to reflect inadequate attention to resistance training in their training programme at that time. Besides, isometric strength may not truly reflect the ability to exert force in dynamic conditions. It was considered also to be a poor predictor of muscle performance in the game.

Isotonic testing involves a fixed resistance (constant load) and a variable speed. Isotonic strength can be measured dynamically with dumb-bells, barbells, and various commercial devices. Abernethy et al. (1995) stated that the term "isoinertial" should be used instead of isotonic. The strength of a particular muscle group is commonly determined by testing the maximum amount of weight that can be lifted through a joint's range of motion for either one repetition (1-RM) or ten (10-RM).

The concept of isokinetic exercise was introduced in the scientific literature by Hislop and Perrine (1967) and Thistle et al. (1967). It is defined as dynamic muscular action when velocity of movement is controlled and held constant by a special isokinetic (fixed speed) device. Isokinetic devices allow individuals to exert as much force as possible in discrete movements up to a pre-determined velocity.

### **History of isokinetic assessment**

The development and improvement of isokinetic technology have made objective quantification of muscle strength possible. Isokinetic assessment can be of major use in sports science to predict muscle performance and to monitor performance factors. In sports medicine it can be useful in injury prevention, and in diagnostic and rehabilitation programmes (Chan et al., 1996).

In recent years, the measurement of muscle force under conditions of constant velocity has become accepted part. Part of this appeal may be attributed to the facility by which isokinetic dynamometers provide information about dynamic muscular contractions, information that previously was not easily obtainable. Hill (1922) used a flywheel, a series of pulleys, and a hand tachometer to control and record velocity in calculating work and the mechanical efficiency of human muscles. Laird and Rozier (1979) reported that force, work, and power in dynamic exercise, where velocity is not controlled, are not easily measured because the changing mechanical advantage of the limb-lever system alters the force applied to the muscles through the range of motion employed.

The isokinetic assessment technique has been widely used in the last 25 years in hundreds of scientific research projects and it has been used also in testing and performance enhancement for even longer. The first publications of isokinetic exercise were in the late 1960s (Hislop and Perrine, 1967; Thistle et al., 1967; Moffroid et al., 1969). Since that time thousands of authors have reported isokinetic movements as part of their test methodology or their use in training programme.

Hill (1965) suggested that an instrument should be developed to record concentric and eccentric forces in human muscle. Komi (1969) introduced a dynamometer that recorded forces at constant speeds during both concentric and eccentric exercise. The most used of the contemporary isokinetic dynamometers have been the Biodex

(Biodex Medical system Inc.), the original Cybex II machine (division of Lumex Inc.) introduced by Hislop and Perrine (1967), and by Thistle and co-workers (1967), Isosystem, Spark, the Kin-Com (Chattanooga Group Inc.), the Lido (Loredan Biomedical), and the Merac (Universal Gym Equipment Inc.). The Cybex II is an electrically driven device, whereas the Kin-Com is hydraulically driven. The major differences in the dynamometers can be found in the maximum angular velocities they offer, and in the ability to test or accommodate negative (eccentric) muscle actions. Unique features of some of the equipment should be mentioned: the Sparks system allowed for high velocities but was not commercialised outside further. Kin-Com was the first to use 'eccentric' modes: Kin-Com and Lido have come and gone. The most enduring system has been Cybex, for a long time did not use eccentric mode. Developments should be traced chronologically rather than mixed up as at present Also Bio-Dex is more recent.

In the late 1960s, isokinetic machines included a simple computer program capable of comparing the information related to bilateral ratio, updated to enable the calculation of total work, power and endurance. The facilities, which are set up on the dynamometer, can provide immediate feedback to the therapist and the patient too. Progression in terms of accessories has also provided more scale for muscle testing and rehabilitation. It is now possible to test all limbs.

### **Important isokinetic parameters relevant to soccer**

#### ***Force-velocity relationship***

The effect of the linear velocity during muscle shortening or lengthening on the force output has been examined extensively since the pioneering work of Hill (1938). The ability of a muscle to generate concentric force is greatest at slow angular velocities and decreases non-linearly as the velocity increases. These changes are evident in isokinetic assessment and are compatible with the classical force-velocity relationship described by Hill (1938) and others. From the early study of Fenn and March (1935), Hill (1938, 1950), Katz (1939), and Wilkie (1950), in experiments on frogs, dogs, fishes, cats and other animals, it has been known that when the velocity of shortening (contraction) increased, the force exerted by the muscle decreased in a non-linear way.

Similar results have been observed in humans (Moffroid et al., 1969; Thorstensson et al., 1976; Lesmes et al., 1978; Perrine and Edgerton, 1978; Campbell, 1979; Gregore et al., 1979; Barnes, 1980a; Osternig et al., 1983; Perrin, 1993) with muscular torque decreasing as the angular velocity of movement increased. This decrease occurs because at fast velocities the numbers of cross-bridges formed, and the force they exert, are reduced. Barnes (1980b) suggested that the decline in torque output due to increasing angular velocity is a result of different neurological activation patterns of motor units at different velocities. A higher output at faster angular velocities indicates a higher percentage of motor units in fast twitch fibres (Gregor et al., 1979). However, with an increase in linear velocity as muscle length is increased in eccentric contractions, the force exerted is increased (Wilkie, 1950; Chapman, 1976; Thorstensson et al., 1976).

The force-velocity relationship has also been replicated in isokinetic assessments of soccer players. Costain and Williams (1984) measured the quadriceps and hamstring torque levels of 16 high school soccer players using a Cybex II dynamometer at slow ( $0.54 \text{ rad.s}^{-1}$ ) and fast ( $3.24 \text{ rad.s}^{-1}$ ) speeds. They reported a significant decrease in peak torque in both muscle groups from the slow to the fast speed. In addition, Stafford and Grana (1984) assessed the knee extensors and knee flexors of 60 intercollegiate soccer players at functional angular velocities of  $1.62$ ,  $3.24$ , and  $5.4 \text{ rad.s}^{-1}$  on the Cybex II and found the same results.

In a comprehensive study, Oberg and colleagues (1986) recorded the isokinetic torque of knee extension and knee flexion in three groups of Swedish male soccer players (national team players,  $n = 13$ ; division I,  $n = 15$ ; division IV,  $n = 180$ ) and a group of non-soccer players ( $n = 32$ ) at 0.54 and 3.24  $\text{rad}\cdot\text{s}^{-1}$  angular velocities using a Cybex II device. Torque values decreased with angular velocity. They also observed quite similar results in another study involving 180 soccer players (Oberg et al., 1984).

More recently, Cometti and co-workers (2001) investigated the isokinetic strength of 95 French soccer players in different level of play, including elite, sub-elite and amateur players. The subjects were tested at different velocities from 2.16 to 5.4  $\text{rad}\cdot\text{s}^{-1}$  using an isokinetic ergometer (Biodex). The force-velocity curve was consistent with previous studies (Moffroid et al., 1969; Scudder, 1980; Oberg et al., 1984, 1986; Ghena et al., 1991; Kannus, 1994; Mognoni et al., 1994). More recently Rahnema et al. (2003, 2005, 2006) conducted some studies on English soccer players and observed similar findings with the previous studies.

In summary, the studies cited tend to show a drop in peak isokinetic torque with increasing angular velocity of movement. When velocity is fast there is not sufficient time to recruit all motor units. The suggestion is that there are different patterns of motor unit recruitment at different speeds and qualities inherent to isokinetic measurement, which cause reduced torque output at higher speeds. The reason for such a decline lies in the different recruitment capabilities of different muscle fibres (Grimby, 1985). At lower speeds, both type I and II fibres can be activated maximally while with increasing angular velocity it follows that the slow-twitch type I fibres will remain passive first followed by the fast-twitch type IIA fibres. The type IIB fibres are the last to be recruited, but usually at high angular velocities, the torque output becomes reduced (Kannus, 1994).

### ***Quadriceps vs hamstrings***

The quadriceps muscle group possesses higher mean torque values (20-40 % greater) than the hamstrings at all angular velocities (Goslin and Charteris, 1979; Wyatt and Edwards, 1981). These muscle groups are the prime movers in knee extension and knee flexion. Stafford and Grana (1984) tested the quadriceps and hamstrings muscles of 60 intercollegiate soccer players at angular velocities of 1.62, 3.24, and 5.4  $\text{rad}\cdot\text{s}^{-1}$  by means a Cybex II dynamometer. The quadriceps possessed greater torque than the hamstring muscles at all angular velocities, and the level of differences varied for different speeds (33 % at 1.62, 28 % at 3.24, 20 % at 5.4  $\text{rad}\cdot\text{s}^{-1}$ ). Agre and Baxter (1987) investigated the musculoskeletal profile of 25 male collegiate soccer players at 0.54  $\text{rad}\cdot\text{s}^{-1}$  and found a greater value (40 %) in the quadriceps than in the hamstrings in their subjects. If the quadriceps strength greatly exceeds that of the hamstrings, the ability to resist knee extension is reduced which may result in a forced stretch of the hamstrings and consequent muscle damage (Fowler and Reilly, 1993). So, for minimising injury risk, attention should be paid to keeping the hamstrings to quadriceps ratio closer to unity than was observed (Agre and Baxter, 1987; Fowler and Reilly, 1993). The technical hamstring/quadriceps ratio was used. Whilst it was a crucial indicator of a desirable ratio for clinical assessment, it was useful in guiding rehabilitation programmes of soccer players (Fowler and Reilly, 1993, Rahnema et al., 2003, 2005, 2006). Its limitations were based on its static nature, the use of a single angle and its relevance to field conditions.

### ***Reciprocal muscle group ratio***

The muscle groups on both sides of a joint act reciprocally to produce smooth and coordinated motion. When a muscle group produces a desired joint action it is the agonist for the observed motion. The muscle group producing the opposite joint action,

is the antagonist (Perrin, 1993). The reciprocal muscle group ratio has been thought to be an indicator of muscular balance or imbalance around the joint (Baltzopoulos and Brodie, 1989). Because of the important role of both muscle groups in knee stability, the hamstring-quadriceps ratio is one of the most important variables used in isokinetic assessment of dynamic movements.

Optimal values for the strength ratio of reciprocal muscle groups have been suggested in the literature (Moffroid, 1969; Gilliam, 1979; Goslin and Charteries, 1979; Wyatt and Edward, 1981; Kannus, 1990). The hamstring/quadriceps strength ratio varies between 50 % and 62 % in healthy people (Moffroid et al., 1969; Coplin, 1971; Gilliam, 1979; Knapik and Ramos, 1980; Parker, 1982) while ratios for soccer players vary between 41 % and 81 % depending upon the angular velocity of movement. Gilliam (1979) showed that the knee flexion/extension ratio was 60% at 0.54 and 77% at 3.24 rad.s<sup>-1</sup> for high school American football players.

The hamstring/quadriceps ratio increases with increasing velocity (Gilliam et al., 1979; Scudder, 1980; Davies et al., 1981; Wyatt and Edward, 1981; Stafford and Grana, 1984; Oberg et al., 1986). Oberg and colleagues (1986) reported that the knee flexion/knee extension ratio (hamstring/quadriceps ratio) was significantly higher for soccer players than for their reference group, but there were no significant differences between the different groups of soccer players. Stafford and Grana (1984) found an increasing ratio with increasing angular velocity in soccer players, reflecting the greater relative fall in torque of the quadriceps as velocities increased. The soccer players had a higher ratio than non-players, so it seems that soccer training improves strength in the knee flexors. One hundred and fifteen high school football players were screened isokinetically for the torque generating capabilities of the knee extensors and flexors and for muscle imbalances by Gilliam (1979) at angular velocities of 0.54 and 3.24 rad.s<sup>-1</sup>. He reported that flexion to extension ratio at the slow speed was greater for the linemen than the receivers and backs. It seems that linemen are less predisposed to hamstring injury than players in other positions. Cometti and co-workers (2001) reported that the hamstring/quadriceps ratios proposed with two different methods were significantly lower in the amateur group than in the elite group, except at 5.4 rad.s<sup>-1</sup>. It can be noted that several years of soccer training and match-play at a high level improve the hamstring/quadriceps ratio in professional players and they are less prone to injury than the less skilled players.

The agonist-antagonist relationship for knee flexion and extension may be better described by the more functional ratio of eccentric hamstring to concentric quadriceps, known as the dynamic control ratio (DCR). It is thought that this functional hamstring/quadriceps ratio is more suitable to recognise the ability of the knee flexors in stabilising the knee joint than the conventional ratio. Ideally the hamstrings should be able to resist as much force as the quadriceps can produce, which equates to a DCR of 1.0. Due to characteristics of the force-velocity curve it is unlikely that this value will be attained for all movement speeds, but it is important that a value of 1.0 is attained at movement speeds typical of placekicking. Cometti et al. (2001) reported that due to the importance of the hamstring muscles in some specific soccer activities and the need for stabilisation of the knee joint during critical events, it is recommended that trainers should pay more attention to eccentric actions during strength training, in order to minimise the likelihood of injury occurrence. In soccer, the knee flexors are used concentrically to flex the knee and extend the hip in preparation for a kick and are used eccentrically to control knee extension and hip flexion towards the end of the kicking action (Clarys et al., 1988). If the knee extensor strength greatly exceeds that of the hamstrings, the ability to resist knee extension is reduced and may result in a forced stretch of the hamstrings with consequent muscle damage (Fowler and Reilly, 1993). Rahnama et al. (2003) reported that due to change in DCR because of fatigue players will be at more risk of injury.

### **Bilateral muscle group comparison (left/right ratio)**

A lot of interest associated with isokinetic dynamometry lies in the determination of muscle imbalances either left/right or agonist-antagonist relationships because of the common belief that muscle imbalance is related to injury. One of the most common comparisons made by clinicians to assess patient progress is between contralateral limbs. Contralateral differences in measurements of muscle strength greater than 10-15 % are considered to represent significant asymmetries (Elliot, 1978; Gleim et al., 1978; Davies, 1984). Such inconsistency is thought to predispose to injury at or around the given joint (Kannus, 1994). Kannus (1994) classified bilateral discrepancy into three groups including normal (imbalance in strength of less than 10 %), possibly abnormal (imbalance in strength between 10-20 %) and probably abnormal groups (imbalance in strength greater than 20 %).

Grace and co-workers (1984) investigated the strength of quadriceps and hamstrings of 206 high school soccer players and the relationship between the bilateral asymmetry with occurrence of injury. They found no association between muscle imbalance of 10 % and frequency of injury. It should be noted that the muscle imbalance could be as a predictor for muscle injury.

It seems a susceptibility to injury may only be released when muscle imbalance exceeds 10%. Early studies have shown that a contralateral strength difference of 10 % or greater may be a contributing factor to injury (Wyatt and Edwards, 1981; Grace et al., 1984). Chin and co-workers (1994) stated that there were respectively eight and twelve out of 21 subjects who had contralateral hamstrings imbalance ratios greater than 10 % when measured at slow and fast isokinetic speeds.

Mognoni and co-workers (1994) tested the knee extensors of 24 junior soccer players using an isokinetic dynamometer (Cybex II) at 1.05, 3.14, 4.19 and 5.23 rad.s<sup>-1</sup>. At all speeds the torque values of knee extensors were higher in the non-dominant limb and the differences were significant at 3.14 rad.s<sup>-1</sup> (4.2 %), at 4.19 rad.s<sup>-1</sup> (6.2 %) and at 5.23 rad.s<sup>-1</sup> (6.2 %). The strength of the knee extensors turned out to be somewhat higher in the non-dominant limb than in the dominant limb. A possible explanation for this is that during kicking the knee of the non-dominant limb is bent so that its extensor muscles support both the weight of the body and the reaction of the torque developed by the opposite limb. Forces exerted in this biomechanical situation may act as a training stimulus.

Chin and colleague (1994) measured the isokinetic muscle strength of 21 elite junior Hong Kong soccer players at 1.08 and 4.32 rad.s<sup>-1</sup> angular velocity using a Cybex II isokinetic dynamometer. They did not find a significant bilateral difference in the knee extensors (except the absolute peak torque measured at 1.08 rad.s<sup>-1</sup>). Their results were consistent with findings of other groups (Oberg et al., 1986; Rhodes et al., 1986, Rochcongar et al., 1988). These data provided strong evidence that the strength capabilities of soccer players were similar in both legs at least in this group. For the knee flexors, the dominant leg scored significantly higher than the non-dominant leg at both speeds. This superiority may be due to the difference in muscle involvement in kicking the ball. Olson and Hunter (1985) reported that the quadriceps strength of both kicking and non-kicking legs is important for leg swing action in kicking the ball, while only the kicking (dominant) leg flexor is important in the action which causes deceleration of the leg and foot following the kick.

Kirkendall (1985) indicated that soccer players tend to be within clinical norms (10 %) in contralateral muscle balance. Therefore, specific weight training is required where appropriate for correcting of the subjects' contralateral muscle imbalance in order to avoid sports injuries.

In spite of the importance attributed to muscular balance, the extent to which imbalance in contralateral limb symmetry predisposes an athlete to injury has been

questionable (Osternig, 1986). The relationship between bilateral muscle imbalance and the occurrence of injury is still unclear.

### ***Fast-speed/slow-speed ratio***

Oberg and co-workers (1986) investigated the dynamic muscle strength of the quadriceps and hamstrings in Swedish male soccer players in different divisions including the national team players ( $n = 13$ ); division I ( $n = 15$ ); division IV ( $n = 180$ ) and a group of non-soccer players ( $n = 32$ ) at 0.54 and 3.24  $\text{rad}\cdot\text{s}^{-1}$  angular velocity using a Cybex II device. They reported a relatively greater fast-speed/slow-speed ratio in national players compared to other two groups of soccer players (0.64 vs 0.58). The reference group showed a higher fast-speed/slow-speed ratio for knee extensors than did division I and division IV players (0.67 vs 0.58). They reported also that the fast-speed/slow-speed ratio for the knee extensors was lower for most of the soccer players than for the non-players. This observation suggests that soccer training has more of an effect on slow than on fast movements. In another study of muscle strength exhibited by soccer players in different positions, Oberg and colleagues (1984) did not find any significant differences. Rahnama and co-workers (2003) also found similar results. Soccer training might be improved if more practice in fast movements was added.

### ***Eccentric vs concentric***

Eccentric actions develop greater tension than concentric muscle actions performed at the same angle, and might be more effective in improving muscle strength (Albert, 1995) and several studies have confirmed this view-point (Komi and Rusko, 1974; Ghena et al., 1991; Kannus, 1994, Cometti et al., 2001). Westing and Seger (1989) investigated the eccentric and concentric torque-velocity characteristics in twenty female subjects. Quadriceps and hamstring strength of subjects were tested at 1.08 to 6.48  $\text{rad}\cdot\text{s}^{-1}$  using the Sparks system. They reported that mean concentric torque was significantly lower than the corresponding eccentric torque. They observed that mean eccentric torque did not change significantly with increasing eccentric velocity for either the quadriceps or hamstring muscles. At each test velocity, the concentric hamstring/quadriceps ratio was significantly lower than the corresponding eccentric hamstring/quadriceps ratio.

Using factor analyses to explore fitness data collected from times during the soccer in 31 professional soccer players, Reilly and Thomas (1980) found that the greatest proportion of the covariance between individuals was reputedly identified as relating to body size. They explored the findings in terms of the discrete physical demand of particular positional rules. They concluded that professional soccer teams should be considered as a heterogeneous group and that mean values for body size may be misleading. Nevertheless, other symptom and factors extracted by the multivariate analysis included "body density" (reflecting the lean mass content) endurance and leg strength, these components being independent of size.

From a clinical point of view, it has been suggested that there is no relationship between isokinetic concentric strength of individual muscles and injuries in soccer players (Paton et al., 1989), but it has also been suggested that poor eccentric muscle strength of the hamstring group may cause hamstring strains (Stanton and Purdam, 1989). Worrell et al. (1991) did not find any differences in either concentric or eccentric lower limb muscle torque between injured and uninjured athletes. Eccentric actions produce greater loading of the elastic component of skeletal muscle, which may help to improve sprinting and jumping performance, and may be useful in the rehabilitation (Kellis and Baltzopoulos, 1995). If the risk of strains and tears is to be reduced, the ability of the muscle to resist forces should be improved (Bennett and Stauber, 1986).

### ***Playing position and muscle strength***

Since fitness demands tend to vary with positional roles, muscle strength values may depend on the player's position (Reilly, 1996b). Oberg et al. (1984) reported that goalkeepers and defenders have higher knee extension torque at  $0.52 \text{ rad}\cdot\text{s}^{-1}$  than midfield players and forwards, but when the result was corrected for body size, the positional effect was not observed. Togari et al. (1988) in a study on Japanese soccer league players reported that the goalkeepers were significantly stronger than the forwards at slow ( $1.05 \text{ rad}\cdot\text{s}^{-1}$ ) speeds, midfield players being intermediate. When the angular velocity was raised to  $3.14 \text{ rad}\cdot\text{s}^{-1}$ , the positional effect disappeared. This effect may be due to the specific nature of training for goalkeepers compared to the players in other positions. Consequently, the data should be corrected for body size.

### ***Muscle strength, preferred leg, non-preferred leg and fatigue***

Rahnama et al. (2005) tested dynamic strength of knee flexors (hamstrings) and knee extensors (quadriceps) of forty-one elite and sub-elite soccer players using an isokinetic dynamometer at angular velocities of  $1.05$ ,  $2.09$ ,  $5.23 \text{ rad}\cdot\text{s}^{-1}$  (in a concentric mode) and  $2.09 \text{ rad}\cdot\text{s}^{-1}$  (in an eccentric mode). They showed a significant difference between the preferred and non-preferred leg. Furthermore, they concluded that the lower strength of the knee flexor muscles of the preferred leg may be associated with the differential use of these muscles during the kicking action and thus constitutes a unique training effect associated with soccer. This in turn can lead to muscular imbalance which is generally regarded as an injury risk factor.

Rahnama and co-workers (2003) established the effects of exercise that simulates the work rate of competitive soccer players on the strength of the knee extensors and knee flexors. They studied thirteen amateur soccer players' muscle strength before and after a fatiguing exercise corresponding in work rate to a game of soccer. They concluded that there is a progressive reduction in muscle strength that applies across a range of functional characteristics during exercise that mimics the work rate in soccer.

Rahnama et al. provided the first data on tackles using video analysis (Tscholl et al., 2007). They analyzed every action during the game that involved the ball and classified these events into three categories: no injury potential, injury potential and actual injury. They stated that injury risk was highest in the first and last 15 minutes of the game, reflecting the intense engagements in the opening period and the possible effect of fatigue in the closing period (Rahnama et al., 2002). In a follow up study they found that fatigue may decrease muscle strength which it can lead to injury.

### ***Muscle strength and soccer skill***

There has been some interest in explaining the relationship between muscle strength of the knee extensors and ball-kicking performance. Cabri et al. (1988) looked at kick performance (the distance the ball was kicked) and peak torque of the knee flexors and extensors at  $3.65 \text{ rad}\cdot\text{s}^{-1}$ . Observations on a group of professional players were compared to values for non-players who transpired to have lower muscular strength in both muscle groups, in concentric and eccentric modes. The highest correlations with the distance kicked were found for eccentric knee flexion ( $r = 0.77$ ) and concentric knee extension ( $r = 0.74$ ). The quadriceps muscles are important in generating power for the kick whilst the hamstrings are engaged eccentrically in the braking action around impact.

Reilly and Drust (1997) reported broadly similar results for female players. They used the Lido Classic (Davis, CA) system to record peak torque at velocities of  $1.05$ ,  $2.09$ ,  $3.14$ ,  $4.19$ ,  $5.24$ ,  $6.28$  and  $6.98 \text{ rad}\cdot\text{s}^{-1}$ . Correlations were established between kick performance and all velocities up to  $6.98 \text{ rad}\cdot\text{s}^{-1}$ . The failure to find significant



correlation at this velocity may be linked with an increasing measurement error during first movements.

A question that follows these studies is whether improving muscle strength causes an increase in kick performance. De Proft et al. (1988) focussed on training different leg muscles of soccer players in addition to these normal training twice a week over a full season. They found that improvements in knee extension strength (concentric) and in knee flexion strength (eccentric) were high correlated with increases in kick performance. This relationship was not found in the reference group of players not participating in the additional training programme. The findings underline the relevance of the concentric torque of the quadriceps and the eccentric torque of the hamstrings. Whilst muscular factors are therefore important in a basic soccer skill such as soccer, technical skills may determine the outcome in a game where kicking is performed under competitive stress and pressure from opposing players.

### **Reliability of muscle function tests**

A major prerequisite for measurement of muscular performance is reliability. Reliability is defined as consistency of a measurement when all conditions are thought to be held constant (Rothstein, 1985). The mechanical reliability of the Lido dynamometer for torque measurement at different speeds was established by Aitkens et al. (1987). They reported a regression line slope of 1.01 for observed/expected torques, which led the authors to conclude that the internal calibration is very accurate, through a wide range of loads. Isokinetic testing of knee flexion and extension bilaterally at  $1.05 \text{ rad.s}^{-1}$  and  $4.18 \text{ rad.s}^{-1}$  on 17 normal, healthy subjects with a mean age of 29 years on this dynamometer produced high intra-class correlation coefficients (0.83- 0.94) which supports the reliability of measuring muscular strength based on torque and work values (Lord et al., 1987). Patterson and Spivey (1992) investigated the validity and reliability of the Lido active Isokinetic system and reported that this system is both valid and reliable for assessing muscle strength (mean correlation coefficient relating observed to expected torques was = 0.98). It can be concluded that the isokinetic dynamometer is a reliable research tool. In the later study, Coldwells et al. (1994) reported a significant test-retest correlation ( $p < 0.001$ ,  $r = 0.80$ ) for leg strength and back strength ( $p < 0.001$ ,  $r = 0.91$ ) when using a computer-controlled dynamometer (Lido Active, Davis, CA).

### **Conclusions**

In summary, selected aspects of musculoskeletal strength in soccer, namely, type of muscle actions, types of modes of testing muscle, strength, history of isokinetic assessment, comparison of isometric, isotonic, and isokinetic modes of muscle testing, force-velocity relationship, quadriceps vs. hamstrings, reciprocal muscle group ratio, bilateral muscle group comparison, fast-speed/slow-speed ratio, eccentric vs. concentric, provide important information on musculoskeletal strength in soccer.

The assessment of muscle function has become increasingly important as it is realised that there is a large variation in this human attribute, which is affected by both individual and environmental factors. The identification of asymmetric weakness or laxity within an individual player may be more important than comparison between team members. Isokinetic dynamometry can be used to assess strength as it allows the comparison of hamstrings/quadriceps strength ratio, left /right leg ratio and fast-speed to slow-speed ratio to identify any muscle imbalance and deficit in specific muscle groups.

Elite players are likely to have elevated levels of muscle strength due to the requirements of a high performance level and freedom from injury. Yet in the course of their habitual training, they may develop imbalances and tightness not evident in those

playing at a lower level. Therefore, this aspect of musculoskeletal function needs to be investigated.

There are few data related to muscle function that can be used to compare elite and sub-elite soccer players. The data that are available are influenced by anthropometric variables nor standardised between groups. Furthermore, protocols on which assessments have been based are not uniform. This variation makes it difficult to result inferences about injury predisposition, although useful as reference strength profile.

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