

Review article

DEVELOPMENTS IN THE USE OF THE HAMSTRING/ QUADRICEPS RATIO FOR THE ASSESSMENT OF MUSCLE BALANCE

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ABSTRACT

Isokinetic moment ratios of the hamstrings (H) and quadriceps (Q) muscle groups, and their implication in muscle imbalance, have been investigated for more than three decades. The conventional concentric H/Q ratio with its normative value of 0.6 has been at the forefront of the discussion. This does not account for the joint angle at which moment occurs and the type of muscle action involved. Advances towards more functional analyses have occurred such that previous protocols are being re-examined raising questions about their ability to demonstrate a relationship between thigh muscle imbalance and increased incidence or risk of knee injury. This article addresses the function of the hamstring-quadriceps ratio in the interpretation of this relationship using the ratios Hecc/Qcon (ratio of eccentric hamstring strength to concentric quadriceps strength, representative of isolated knee extension) and Hcon/Qecc (ratio of concentric hamstring strength to eccentric quadriceps strength, representative of isolated knee flexion).

KEY WORDS: Muscle contraction, isokinetic, thigh, muscle balance.

KAS KUVVET DENGESİNİ ÖLÇMEK İÇİN HAMSTRING/QUADRICEPS ORANININ KULLANIMINDAKİ GELİŞMELER

ÖZET

Hamstring (H) ve quadriceps (Q) kas gruplarının izokinetik hareket oranı ve onların kas dengesi için anlamı üç dekadadan daha fazladır araştırılmıştır. 0.6 normal değeri ile klasik konsentrik H/Q oranı tartışmaların ön sıralarında yer almıştır. Bu, hareketin meydana geldiği kasın aktivasyon tipindeki eklem açısını göz önünde tutmamaktadır. Onların (klasik oranın) uyluk kas dengesi ve artmış diz yaralanma riski veya sıklığı arasındaki bir ilişkiyi gösterme yetenekleri hakkındaki soruların büyümesi önceki protokollerin tekrar incelenmesi gibi önerileri daha fonksiyonel analizlere yönlendirmiştir. Bu yazıda hamstring-quadriceps oranının fonksiyonu, bu ilişkinin yorumunda kullanılan Hecc/Qcon (eksentrik hamstring kuvvetinin konsentrik quadriceps kuvvetine oranı, izole diz ekstansiyonun bir temsilcisi) ve Hcon/Qecc (konsentrik hamstring kuvvetinin eksentrik quadriceps kuvvetine oranı, izole diz fleksiyonun bir temsilcisi) oranlarını incelenmektedir.

ANAHTAR KELİMELEER: Kas kasılması, izokinetik, uyluk, kas dengesi.

THE CONVENTIONAL H/Q RATIO

In clinical and scientific research, knee joint and thigh muscle function have conventionally been described using a variety of techniques. These include visual inspection of the moment-joint angle curve (Grace et al., 1984), the single point peak mo-

ment (Thorstensson et al., 1976), moment at a specified knee joint angle (Perrine and Edgerton, 1978; Thorstensson et al., 1976), and most commonly the hamstring-quadriceps peak moment ratio (Nosse, 1982; Kannus and Jarvinnen, 1990).

Angle specific moment curves represent the moment produced throughout the range of motion

(ROM). The visual shape of such a curve can provide a template from which muscular and joint pathologies can be assessed and monitored through a rehabilitation regimen (Rothstein et al., 1987) and compared to the uninjured limb. They are displayed as either concentric or eccentric moments throughout the ROM for single muscle groups contracting at a given joint angular velocity (Figure 1).

Figure 1 presents data, which illustrates the difference in the moment production for the quadriceps and hamstring muscle groups throughout a 90° ROM. Similar patterns have been observed by others (Osternig et al., 1986; Westing and Seger,

1989; Aagaard et al., 2000). Angle-specific moment curves have proved useful in identifying and monitoring rehabilitation in pathologies such as chondromalacia patella in which peak moment ratios may be normal but decrements in moment may be present at other joint angles (Cabri and Clarys, 1991). They may also identify decrements in muscle function not apparent through analysis of peak moment alone (Osternig, 1986). However, angle specific moment curves do not account for the functioning of the antagonist, thereby not providing a comprehensive description of reciprocal muscle function.

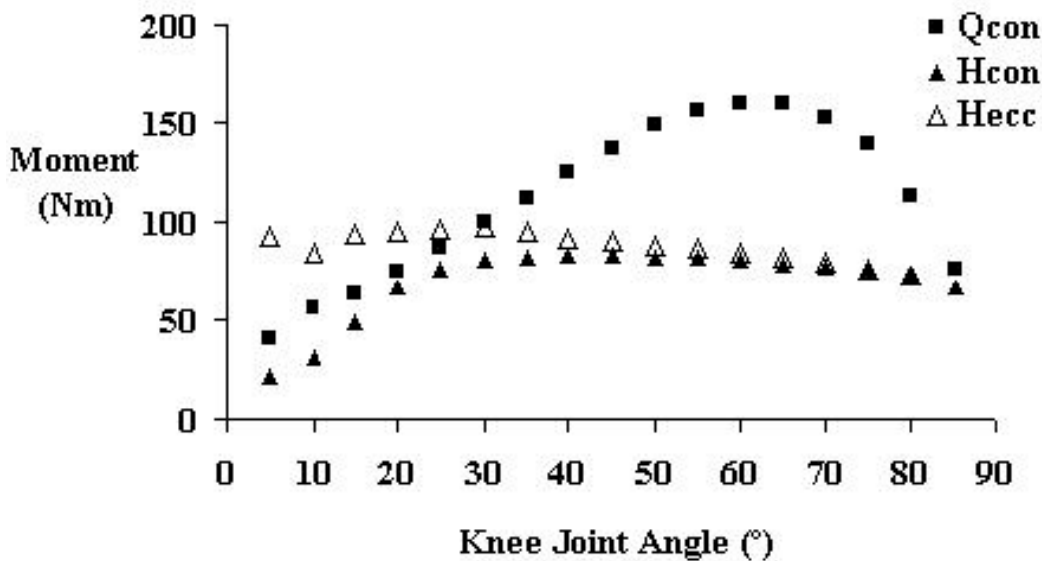


Figure 1. Moment of force of the concentric quadriceps (Qcon), eccentric hamstrings (Hecc) and concentric hamstrings (Hcon) as a function of knee joint angle. Moments are representative of $60^{\circ}.s^{-1}$ in a seated position. 0° represents full knee extension. Adapted from Coombs et al. (2002).

The most frequently reported strength ratio of the muscles of the knee has been the concentric hamstring-quadriceps ratio (Hcon/Qcon). Steindler (1955) advanced the generalisation that absolute knee extension muscle force should exceed knee flexion force by a magnitude of 3:2 i.e. Hcon/Qcon of 0.66. Values ranging from 0.43-0.90 for this knee flexor-extensor ratio have been reported, although it is dependent on angular velocity, test position, population group and use of gravity compensation (see reviews by Nosse, 1982 and Kannus, 1994). There seems to be little consensus of a normative value for this conventional H/Q ratio, although 0.6 appears to have gained some general acceptance. For instance, Heiser et al. (1984) stated that injury prevention by detection of muscle imbalances should be based on a minimum Hcon/Qcon ratio of 0.60 at an angular velocity of $1.05 \text{ rad}.s^{-1}$ ($60^{\circ}.s^{-1}$).

The use of peak moment ratios to describe normal knee function accounts for the main muscle groups of the thigh but has two major limitations. Firstly, the concentric quadriceps moment is

normally compared with the concentric hamstring moment. This situation does not arise during functional movements. Instead, eccentric antagonist co-activation and serial elastic tension resist concentric agonist contraction eccentrically, or vice versa (Osternig et al., 1986). Secondly, they are normally cited irrespective of the joint angle at which they occur, which ignores the effect of muscle length. By failing to take into account the angle at which the moment is produced, erroneous conclusions may arise regarding the normal functioning of the muscle at joint angles other than that at which the observation occurs (Cabri and Clarys, 1991). Assessing muscle balance is considered important, but independently, the peak moment ratios and angle specific moment curves provide only a limited amount of information. A more functional approach to assessing muscle balance is required.

EVIDENCE OF THIGH MUSCLE CO-ACTIVATION

It has been suggested that the role of the hamstring muscles during leg extension is to assist the anterior cruciate ligament (ACL) in preventing anterior tibial drawer forces (More et al., 1993; Yasuda and Sasaki, 1987), by increasing the posterior pull, increasing joint stiffness and reducing anterior laxity force during quadriceps loading to oppose its force (Baratta et al., 1988). This helps in preventing overextension, decelerates the leg prior to full extension and stabilises the knee joint throughout the ROM (Baratta et al., 1988). The hamstrings play a key function in maintaining knee joint stability, especially where there is a deficient ACL. Tensile stress on the ACL is significantly reduced when the hamstrings and the quadriceps co-activate during extension, compared to quadriceps activation alone (Yasuda and Sasaki, 1987; Draganich and Vahey, 1990; More et al., 1993). Eccentric muscle actions, however, have a potential role in the aetiology of injuries in hamstring muscles, which are particularly prone to injury (Stanton and Purdam, 1989).

The cause of hamstring injuries is still unclear, although it has been suggested that muscle imbalance between the hamstring and quadriceps may predispose towards injury (Burkett, 1970; Grace et al., 1984). A 'normal' Hcon/Qcon ratio of 0.6 is frequently used as an injury prevention and rehabilitation tool (Baltzopoulos and Brodie, 1989; Kannus, 1994) but the reasoning behind its use does not relate to functional movements seen during both daily living and sporting activities. DeProft et al. (1988a,b) showed that soccer players, who incorporated strength training into their normal soccer training, improved strength and kick performance significantly over non-footballers and those who trained normally. They suggested that in addition to their normal training, footballers should train their quadriceps concentrically and hamstrings eccentrically for improved kick performance. This implies that the relationship between eccentric hamstring and concentric quadriceps strength is important.

Co-activation of the quadriceps and hamstring muscles during isokinetic leg extension and flexion movements is evident in varying degrees at angular velocities up to $6.98 \text{ rad}\cdot\text{s}^{-1}$ ($400^\circ\cdot\text{s}^{-1}$) (Osternig et al., 1986; Baratta et al., 1988; Amiridis et al., 1996; Kellis and Baltzopoulos, 1997; Aagaard et al., 2000). Osternig and co-workers (1986) measured integrated electromyographic activity (iEMG) of the quadriceps (vastus lateralis muscle) and hamstrings (biceps femoris muscle) with surface electrodes, simultaneously during continuous leg extension-flexion cycles performed at $1.75 \text{ rad}\cdot\text{s}^{-1}$ ($100^\circ\cdot\text{s}^{-1}$) and $6.98 \text{ rad}\cdot\text{s}^{-1}$ ($400^\circ\cdot\text{s}^{-1}$). Nine highly trained distance-runners and sprinters were analysed for antagonist co-activation during this continuous concentric activity. Muscle co-activation was calculated as the

percentage of the mean iEMG activity from the same muscle group during its agonist phase. Greater iEMG of both antagonist muscles, the hamstrings during knee extension and the quadriceps during knee flexion, was observed for sprinters compared to distance runners, with generally higher mean muscle co-activation at $6.98 \text{ rad}\cdot\text{s}^{-1}$ compared to $1.75 \text{ rad}\cdot\text{s}^{-1}$. The hamstrings co-activated to a greater extent during agonist quadriceps contraction (8-59%) compared to the quadriceps during agonist hamstring contraction (5-8%). Amount of co-activation was dependent on angular velocity and type of training. This suggests that sport-specific muscle balance is required. Persons with a greater percentage of fast twitch fibres, such as sprint-trained athletes, may require greater muscle balance due to the explosiveness of the exercise undertaken. Higher H/Q ratio would represent greater balance, and of particular interest would be Hecc/Qcon due to the high quadriceps moment production observed during knee extension. A Hecc/Qcon ratio of 1.0 would be the recommendation. This point of equality is discussed in detail in the following section.

Quantification of antagonist activity has been extensively reviewed (Kellis, 1998) indicating that different methods are used to normalise antagonist activity, making it difficult to compare findings. For example, Baratta et al. (1988) normalised hamstring EMG activity during a concentric knee extension to the EMG of the same muscle during concentric knee flexion. Draganich et al. (1989) quantified antagonist EMG activity using the maximum isometric value for normalisation. Both showed approximately 10% maximal antagonist hamstring activity during a concentric knee extension. Physiologically, these methods of normalisation are incorrect (see review by Kellis (1998) for details). Antagonist EMG activity should be expressed relative to EMG activity of the same muscle when acting as agonist under eccentric conditions i.e. eccentric hamstring EMG during concentric knee extension normalised to eccentric hamstring EMG during eccentric knee extension. Using this methodological approach, higher antagonist hamstring EMG values of 20-30% have been reported (Donne and Luckwill, 1996; Kellis and Baltzopoulos, 1997; Aagaard et al., 2000). Eccentric hamstring activity has also been reported in a variety of activities in which knee extension occurs, including the soccer kick (Cabri and Clarys, 1991).

The question of co-activation in the form of a muscle ratio using iEMG with respect to muscle imbalance and injury has not been addressed. Muscle balance ratios that are easy to understand and interpret, and relate to the functional activities seen during sports, would be more relevant to athletes.

THE FUNCTIONAL H/Q RATIO

The hamstring-quadriceps ratio has until recently been based on the concentric strength of these two muscle groups. Co-activation of these muscle groups is known to occur and takes place through opposing contraction modes. During leg extension the quadriceps contract concentrically (Qcon) and the hamstrings contract eccentrically (Hecc). Conversely, the hamstrings contract concentrically (Hcon) and the quadriceps eccentrically (Qecc) during leg flexion. Therefore, in order to accurately assess the balancing nature of the hamstrings about the knee joint the hamstring-quadriceps ratio should be described either as an Hecc/Qcon ratio representing knee extension, or an Hcon/Qecc ratio representing knee flexion.

Evaluation of isokinetic eccentric antagonistic strength relative to concentric agonist strength may provide a relationship of value in describing the maximal potential of the antagonistic muscle group. It might be more useful in determining an injury risk compared to the conventional Hcon/Qcon ratio. Dvir et al. (1989) was the first to report the Hecc/Qcon ratio and referred to it as a 'dynamic control ratio'. Since then the need to express the H/Q ratio functionally as an eccentric-concentric ratio has become more evident.

Donne and Luckwill (1996) reported an average Hecc/Qcon moment ratio throughout the ROM of 0.63 ± 0.07 . They did not take into account muscle length, i.e. joint angle, in their analysis. Aagaard et al. (1995, 1998) considered joint angle and a change in angular velocity. They showed that the conventional H/Q ratio (i.e. Hcon/Qcon, Hecc/Qecc) was insensitive to changes in velocity between $0.52 \text{ rad}\cdot\text{s}^{-1}$ and $4.19 \text{ rad}\cdot\text{s}^{-1}$ ($30^\circ\cdot\text{s}^{-1}$ and $240^\circ\cdot\text{s}^{-1}$), and between knee flexion angles of 0.52 rad and 0.87 rad (30° and 50° , where 0° represents full knee extension), values remaining between 0.47 and 0.56. In contrast, the functional Hecc/Qcon ratio increased above 1.00 with increasing velocity and more extended knee joint positions. The Hcon/Qecc ratio representative of knee flexion was considerably lower, decreasing from 0.60 to 0.28 with an increase in angular velocity. This is reasonable based on the lower maximal capacity of the hamstrings compared to the quadriceps. It has been suggested (Lestienne, 1979) that the greater mass of the quadriceps may provide a greater visco-elastic effect and hence an enhanced ability to passively control and decelerate the flexion motion. However, Lestienne (1979) did not correct for the effect of gravity. The reduced Hcon/Qecc simply reflects that the specific length-tension and force-velocity properties were impaired for the hamstring muscles and enhanced for the quadriceps muscles during fast forceful knee flexion.

Net (or resultant) joint moments are recorded on an isokinetic dynamometer, with contributing factors from both the agonist and antagonist muscle groups, and other muscles and ligaments that cross the joint. Gross muscle moments about the knee have been estimated using EMG recordings from the hamstrings and quadriceps (Kellis and Baltzopoulos, 1997; Aagaard et al., 2000). The actual antagonist moment exerted by the hamstring muscles during isolated isokinetic knee extension was calculated. For example, Aagaard et al. (2000) used 0.17 rad (10°) intervals over a 1.57 rad (90°) range of knee motion but did not present their findings in the form of an Hecc/Qcon ratio. If calculated, Aagaard et al. (2000) would have reported an increase in this moment ratio from 0.48 to 1.29 as the leg was extended.

Throughout the ROM the Hecc/Qcon ratio changes, whether using net or gross moments. There is a decrease in the concentric quadriceps moment from 90° of knee flexion to 0° (full extension) and a relatively constant eccentric hamstring moment, giving the increase in Hecc/Qcon at increasing angular velocity (Aagaard et al., 1995) and when approaching full knee extension (Aagaard et al., 1998). The length-tension properties of the quadriceps were gradually impaired at high velocities, reducing from $1.20\text{-}0.86 \text{ rad}$ ($69\text{-}49^\circ$), whereas the length-tension properties of the hamstrings remained unaltered at $0.37\text{-}0.44 \text{ rad}$ ($21\text{-}25^\circ$). This suggests that the eccentrically co-contracting hamstrings have a dynamic role in maintaining the stability of the knee during forceful knee extension. This agrees with the findings of Osternig et al. (1986) who showed that eccentric hamstring activation increased sharply in the last 0.44 rad (25°) of concentric knee extension. On average, 58% of the iEMG seen during hamstring agonist activity (i.e. during concentric knee flexion) was generated by the hamstrings during knee extension at the same joint angles.

An Hecc/Qcon ratio of 1.0, which we have labelled the point of equality, indicates that the eccentrically acting hamstrings have the ability to fully brake the action of the concentrically contracting quadriceps. During fast knee extension and towards full extension the eccentrically acting hamstrings have been shown to produce a braking joint flexor moment that is equal to or greater than the extensor moment exerted by the quadriceps (Aagaard et al., 1995, 1998). This would help to reduce anterior displacement of the tibia on the femur and prevent hyperextension of the knee. Where in the ROM this point of equality occurs may be of use as an indicator of normal function.

During everyday activities, the ACL is stressed in the first 45° of knee flexion then relaxes

as the knee flexes further. During isokinetic exercise, varying amounts of ACL force or strain have been shown through a greater ROM, from full knee extension to 80° of flexion, although peak ACL force occurred at 35-40° (Toutoungi et al., 2000). The hamstring muscles function synergistically with the ACL (Yasuda and Sasaki, 1987; More et al., 1993) and hamstring co-contraction is effective during knee extension in decreasing anterior and rotary displacement of the tibia, from 15° to 80° of knee flexion (Hirokawa et al., 1991). So there may be a need for additional antagonistic hamstring activity and force as the knee flexes. It has been suggested that hamstring muscle activity during leg extension helps stabilise the joint throughout the ROM (Baratta et al., 1988). The aim of training would, therefore, be to shift the point of equality towards a more flexed knee joint position so there is increased potential for stability through a greater ROM. Ratios will vary depending on the relative strengths and weaknesses of the hamstrings and quadriceps, which would be determined by training, and possibly by genetics. It might be that in less explosive sports (i.e. not sprinting or multiple sprint sports) the position of the point of equality is less important.

Until experimental work is carried out, which can relate the point of equality to functional ability and injury risk, there is no solution to this question.

It would be interesting to see where in the ROM changes in the ratio occur, and also what effect training has on temporal and quantitative activation of the hamstrings, and on other factors such as electromechanical delay.

FUTURE DIRECTIONS IN THE USE OF THE H/Q RATIO

Data published to date, which has analysed Hecc/Qcon or Hcon/Qecc ratios outside of this limited joint range of 0.52-0.87 rad of knee flexion, is minimal. This is surprising considering that the knee flexor optimum length for isometric torque production is known to occur at approximately a 0.35-0.52 rad (20-30°) joint angle and the knee extensor optimum between 1.05-1.22 rad (60-70°) (Westing and Seger, 1989).

It has been suggested that modelling the Hecc/Qcon relationship through a 90° range of knee extension motion may provide a necessary tool for analysing thigh muscle balance (Garbutt et al., 2001; Coombs et al., 2002). Further work from our laboratory using a different protocol to that previously used by Garbutt et al. (2001) and Coombs et al. (2002) has shown there is a continual rise in the Hecc/Qcon ratio when extending the leg compared to the relatively unchanged Hcon/Qcon ratio over the same range of motion (Figure 2).

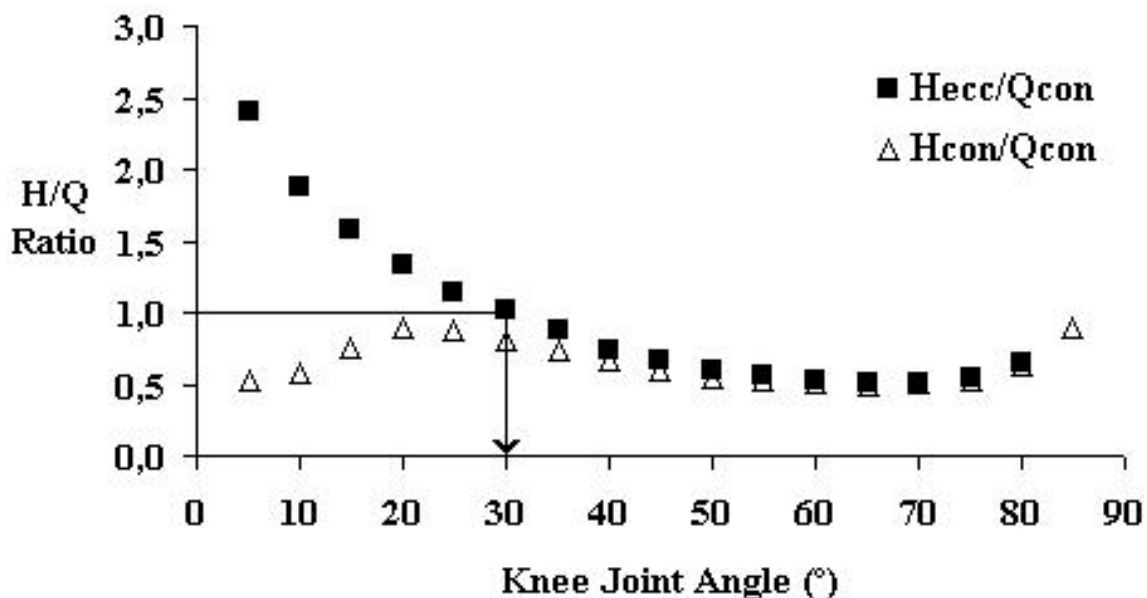


Figure 2. Hecc/Qcon and Hcon/Qcon ratios as a function of knee joint angle at 60°.s⁻¹ (unpublished data). 0° represents full knee extension. Arrow represents point of equality between Hecc and Qcon. Data was collected from a continuous knee extension-flexion protocol, with Qcon-Hcon separate to Hecc-Qecc.

This method of analysis may provide the basis of a model of normal knee function against which pathological states could be compared, helping in the understanding of the causes of hamstring and knee

injury, and aiding the development of a preventative approach through correct training and rehabilitation.

The practical significance of the Hecc/Qcon ratio should be addressed in further work. Relating

this ratio to functional tasks that are specific to a sport (i.e. a vertical jump for basketball players) may help identify if there is a weakness in the ROM, and a joint angle/muscle length that is more at risk of injury.

CONCLUSION

The use of the more functional H/Q ratio (Hecc/Qcon, Hcon/Qecc) proposed by Aagaard and colleagues (1995) is more physiologically and functionally sound than the conventional H/Q ratios (Hcon/Qcon, Hecc/Qecc) and thus more appropriate to use. Although the functional H/Q ratios account for the role of the antagonist in knee joint stabilisation at specific joint angles, they do not account for the hamstring-quadriceps relationship throughout the entire ROM. We have seen that this is important due to the difference in Hecc/Qcon and Hcon/Qcon throughout a 90° ROM (Figure 2).

Bilateral muscle asymmetry and muscle imbalances about the knee have been stated as the aetiology of many injuries, especially hamstring strains (Burkett, 1970). The question as to whether correction of any muscle imbalance could reduce the risk of injury, or if muscle imbalance causes injury, has not been fully investigated. The peak moment Hcon/Qcon ratio of 0.60 has previously been used to assess thigh muscle imbalance, but there is insufficient experimental evidence of its use as a predictor of injury. The analysis of the more functional H/Q ratios over the entire ROM and the positioning of the point of equality may help to address this unanswered question.

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