Isokinetic strength of the quadriceps and hamstrings and functional ability of anterior cruciate deficient knees in recreational athletes

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Abstract

Objective—To test the hypothesis that increasing the hamstrings and quadriceps (H:Q) isokinetic strength ratio will, in the short term, improve the functional ability of an anterior cruciate ligament (ACL) deficient knee.

Methods—The isokinetic muscular characteristics at a speed of 60° s⁻¹ and 180° s⁻¹ of 46 recreational athletes with an arthroscopically confirmed ACL tear were determined using the Cybex II+ isokinetic dynamometer. The variables tested included peak torque, endurance ratio, total work output, and explosive power. Functional ability was scored with the Cincinnati rating system, measuring the severity of pain and swelling, the degree of giving way, and the overall ability to walk, run, ascent and descent stairs, jump and twist.

Results—Among all muscular characteristics, the H:Q ratio at 180° s⁻¹ at 30° of knee flexion was shown to have the highest correlation to the functional score ($r = 0.6249$, $P < 0.001$). All variables involving hamstring strength were shown to be significantly correlated to the functional ability score ($P < 0.01$), while none of the variables involving quadriceps strength showed significant correlation with the functional ability of the injured knee.

Conclusions—The H:Q ratio is strongly correlated to the functional ability of ACL deficient knees in Chinese recreational athletes. It could be used as an additional measure to guide in the decision making process in the management of ACL deficient knees.

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Key terms: anterior cruciate ligament; isokinetic strength; hamstring/quadriceps ratio; rehabilitation

Anterior cruciate ligament (ACL) injury in athletes is common,¹⁻³ and its management remains controversial. An untreated ACL tear may result in deterioration of knee function with development of rotatory instability, meniscal tears, progressive degeneration of articular cartilage, and eventually post-traumatic arthritis.¹⁻⁴⁻⁸ Some investigators believe that primary repair or reconstruction is mandatory to maintain stability and physiological biomechanics of the knee, enabling athletes to return to their original sports with minimal disruption.⁹⁻¹² Others claim good

results with return to high level of sport participation in patients who underwent conservative treatment with a thorough rehabilitation programme.⁴⁻⁷⁻⁹⁻¹³⁻¹⁵ The diversity of such opinions is compounded by the many surgical procedures described.⁴⁻¹⁶

Strengthening the hamstring muscles has been found to enhance the functional ability of the ACL deficient knee.¹⁷⁻²¹ This is probably due to the fact that, with an overall increase in both the hamstring and quadriceps strength, and increase in the hamstring to quadriceps ratio (H:Q), antero-lateral subluxation of the tibia may be minimised.²²

We explored the correlation between the H:Q ratio and short term functional outcome among athletes with ACL deficient knees, and assessed whether an increase in H:Q ratio approaching 1 resulted in a significant improvement of the functional ability of ACL deficient knees in recreational athletes.

Methods

Forty six Chinese recreational athletes who attended the sports injury clinic of the Prince of Wales Hospital gave their informed consent to participate in the study. There were 28 males [average age 24.2 (SD 8.4) years; average weight 64.8 (9.2) kg] and 18 females [average age 24.1 (4.24) years; average weight 54.5 (5.5) kg]. All the subjects were recreational athletes (table 1), who were injured during the practice of their sport. They were clinically and arthroscopically diagnosed as having a complete tear of the ACL.

Two weeks after arthroscopy, the quadriceps and hamstring muscle groups were isokinetically tested using the Cybex II+ isokinetic dynamometer at the speeds of 60° s⁻¹ and 180° s⁻¹. The main variables tested were peak torque, total work, endurance ratio and average power. The testing apparatus was regularly calibrated according to the manufacturer instructions.²³ The functional ability of the injured knee was assessed using the

Table 1 Details of the sports practised by the injured athletes

Sports	Male	Female
Football	15	0
Basketball	4	6
Badminton	3	2
Table tennis	2	1
Volleyball	2	2
Tennis	1	1
Dancing	0	4
Track and field	1	2
Total	28	18

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Cincinnati rating scale²⁴ with some modifications to suit the local setting (appendix).

An individual training programme was designed according to the first Cybex test results. Pain relief and control of swelling were achieved using local ice application and inter-ferential therapy. Isokinetic muscle training at the speeds of 60° s⁻¹ and 180° s⁻¹ 10 min at each speed of training²⁵ was performed three times a week for six weeks under the supervision of at least one of the investigators.

The isokinetic training programme aimed to strengthen the quadriceps and hamstring muscle groups, and to establish a high H:Q ratio on the injured side, minimising contra-lateral strength discrepancies. The training programme was adjusted individually according to each athlete's progress, setting the goal of a difference of 15% or less between quadriceps strength, and an H:Q ratio of the injured knee approaching 1. During the rehabilitation period, patients were required not to participate in any other form of strength training and not to undergo any further medical or physiotherapy treatment to the knee. The patients were informed that they would be excluded from the study if they performed additional training, or received additional medical or physiotherapy care. None did.

The patients were encouraged to report to the medical members of the team should any problems occur. After the rehabilitation period, the second Cybex and Cincinnati rating scale tests were performed. When the results of these two tests were compared, and the percentage changes in muscle characteristics and functional ability were calculated using the formula:

$$\frac{\text{Result of the 2nd test} - \text{result of the 1st test}}{\text{Result of the 1st test}} \times 100$$

The functional score percentage change was then correlated with the percentage change between the different isokinetic muscle strength variables. Statistical analysis was performed using the SPSS/PC+ Version 3.0 computer program.²⁶ Pearson's correlation and the two tailed paired *t* test were used. Significance level was set at *P* < 0.05.

Results

Twenty two athletes injured their dominant knee and 24 injured their non-dominant knee. Thirty two athletes (70%) presented with an isolated ACL tear, and 14 (30%) presented with an ACL injury associated with an unstable meniscal tear which was arthroscopically resected. The two groups did not show any significant difference in their isokinetic strength characteristics and functional ability, either before or after rehabilitation. Their data were therefore pooled, and are presented together.

The average score of the first Cincinnati test was 61.7(SD 12.2), and of the second Cincinnati test, 72.5(14.1), with an average increase of 17.3% (*P* < 0.05). When the percentage changes of the functional score were tested against the muscle strength

Table 2 Correlation between the muscular characteristics and Cincinnati score of the injured knee

The following four variables have a significance level of <i>P</i> < 0.001 and <i>r</i> values ranging from 0.6249–0.4479:		
Functional scores	<i>r</i>	<i>P</i>
H:Q 180 knee 30	0.6249	< 0.001
H:Q PKTAE	0.4721	< 0.001
H 180 knee 30	0.4646	< 0.001
H 60 knee 30	0.4479	< 0.001
The following variables have a significance level of <i>P</i> < 0.01 and <i>r</i> values ranging from 0.4383–0.3436:		
Functional scores	<i>r</i>	<i>P</i>
H:Q 180 PT	0.4383	< 0.01
H 180 PT/BW	0.4240	< 0.01
H 60 PT	0.4134	< 0.01
H:Q W	0.4099	< 0.01
H 60 PT/BW	0.4026	< 0.01
H:Q 60 knee 30	0.3752	< 0.01
H:Q 180 PT	0.3685	< 0.01
H PKTAE	0.3531	< 0.01
H:Q 60 PT	0.3436	< 0.01
The following variables have no significant correlation with the increase in functional score (<i>P</i> > 0.05):		
Q 60 PT	Q 60 PT/BW	Q PKTAE
Q 60 knee 30	Q 180 PT/BW	H:Q END
Q 180 knee 30	Q 180 PT	
Q END	H END	

variables measured, a statistically significant association (*P* < 0.05) was shown with the H:Q ratio, measured at 180° s⁻¹ at 30° (*r* = 0.6249, *P* < 0.001), with the H:Q peak torque acceleration energy (*r* = 0.4721, *P* < 0.001), and with most of the isokinetic strength variables of the hamstring muscles (see table 2 for details).

On the other hand, no statistically significant association was found with most of the variables relating to the quadriceps (see table 2).

Discussion

The pattern of ACL deficiency in this series is similar to other reports,^{4 27} with a male to female ratio of 1.5:1.

From the assessment of the isokinetic characteristics of the quadriceps and hamstring muscles and the correlation with the Cincinnati functional score, several points emerged. Firstly, the H:Q ratio, when the knee is at 30° of flexion at a speed of motion of 180° s⁻¹, shows the highest correlation with the increase in functional scoring. Secondly, all the other characteristics of the hamstrings muscle group show a statistically significant correlation to the functional score. Finally, the quadriceps muscular characteristics show no significant correlation with the functional score.

Based on these points, the working hypothesis that increasing the H:Q ratio at high angular velocities will result in a significant improvement of the functional ability of an ACL deficient knee is proven. The converse is also true; thus athletes with a low H:Q ratio will have low functional ability.

In most studies, only peak torque values, an expression of maximum strength at a set angular velocity, are given, and other variables are not expressly stated.^{28–30} When planning a rehabilitation programme for the hamstring muscle group, endurance should be trained as well, and measures of this variable should also be included.³¹ Accordingly, when trying to achieve an H:Q ratio of 1, a rehabilitation

programme should also try to produce a significant increase in the endurance ratio of the quadriceps and of the hamstring, aiming for it to equal 1. Furthermore, the angle of occurrence of the peak torque should also be given.³²⁻³⁴

On the basis of the evidence produced, hamstring training should be one of the main issues of rehabilitation of an ACL deficient knee, at least in the short term. Training of all muscle strength attributes, including peak torque strength, power, endurance, and peak torque acceleration energy, should be planned.

The quadriceps muscle characteristics have been shown to have very little correlation with the functional ability of the ACL deficient knee.³⁵⁻³⁶ However, maintaining quadriceps strength at a level of at least 85% of that of the uninjured knee is essential for the general functioning of the knee.³⁵⁻³⁶ Since most studies showed no significant difference in the bilateral knee muscle strength measured isokinetically,²⁸⁻³⁰⁻³⁷⁻⁴¹ bilateral muscle strength symmetry should be maintained in the physiological range. However, in order to achieve a high H:Q ratio in the ACL injured knee at the same time, one should consider allowing a low percentage of bilateral quadriceps discrepancy, provided the quadriceps muscle is trained early enough to avoid atrophy, as studies have shown that the quadriceps muscle group of an ACL injured knee is more prone to develop atrophy than the hamstrings.¹⁸⁻²² Nyland *et al*, in a case study of a rehabilitation programme on the knee function following an ACL reconstruction, reported a residual 11% strength deficit even after one year of rehabilitation.²⁹ Campbell *et al* reported that the average torque of knees operated for ACL deficiency was 10–12% less than that of normal knees.³¹ Costill *et al* also reported a 20% torque deficit in knees operated for ACL deficiency.⁴¹ Costain *et al* remarked that rehabilitating an injured knee to 80% of the level of the normal knee was probably inadequate, particularly if the patients are athletes returning to competition.³⁹ It is therefore essential to maintain the quadriceps of the ACL injured knee at a level of at least 85% of the uninjured one to ensure the patients return to sports participation and are safe enough to compete in the future.

There are certainly some limitations to our study, mainly resulting from the relatively small series of patients and the short period of follow up. One should also take into consideration intraindividual variation in isokinetic muscle testing, and the subjectivity of the Cincinnati rating system. Our study did not show significant differences between athletes with isolated ACL tears and those with an ACL tear associated with a meniscal tear. This could be due either to the small size of our study sample, to the short length of follow up, or to a combination of these factors. It has been shown that meniscectomy results in secondary degenerative changes to the involved compartment of the knee, resulting in a long term decrease in functional abilities.⁴²⁻⁴³ We are

planning a long term study to determine whether the favourable H:Q ratio has been maintained, and, if so, it still shows such a significant correlation with the functional ability of the knee. Also, it would be interesting to see whether any differences develop between athletes with an isolated ACL tear and those in whom an ACL tear was associated with an unstable meniscal tear requiring resection.

Despite these limitations, in the short term the H:Q ratio is strongly correlated with the functional ability of ACL deficient knees in Chinese recreational athletes. Together with additional criteria, such as proprioception,⁴⁴⁻⁴⁵ the H:Q ratio could be used as an additional measure to guide in the decision making process in the management of ACL deficient knees.

Appendix

The modified Cincinnati rating scale

SYMPTOMS (50 POINTS)

Pain

- 20 No pain, normal knee
- 16 Occasional pain with strenuous sports or heavy work
- 12 Occasional pain with recreational sports or moderate work, frequently brought on by sports
- 8 Pain usually brought on by sports, light recreational activities or moderate work
- 4 Pain is a significant problem with activities as simple as walking and standing. Unable to do sports
- 0 Pain present all the time, not relieved with rest

Swelling

- 10 No swelling, normal knee
- 8 Occasional swelling with strenuous sports or heavy work
- 4 Swelling limits sports and moderate work
- 2 Swelling brought on by simple walking activities and light work
- 0 Severe problem all the time

Giving way

- 20 No giving way, normal knee
- 16 Occasional giving way with strenuous sports or heavy work
- 12 Occasional giving way with light recreational activities or moderate work, not able to twist on cut suddenly
- 8 Giving way limits sports and moderate work
- 4 Giving way with simple walking activities and light work
- 0 Severe problem with simple walking activities

FUNCTION (50 POINTS)

Overall activity level

- 20 No limitation, normal knee
- 16 Perform sports including vigorous activities, but at a lower performance level
- 12 Light recreational activities possible with rare symptoms, more strenuous activities cause problems
- 8 No sports or recreational activities possible, walking possible with rare symptoms
- 4 Walking activities of daily living cause moderate symptoms
- 0 Walking activities of daily cause severe problems, persistent symptoms

Walking

- 10 Normal, unlimited
- 8 Slight/mild problem
- 6 Moderate problem: smooth surface up to 800 m
- 4 Severe problem: only two to three blocks possible
- 2 Severe problem: requires walking aids

Stairs

- 10 Normal, unlimited
- 8 Slight/mild problem
- 6 Moderate problem: 10–15 steps possible
- 4 Severe problem: requires banister, support
- 2 Severe problem: only one to five steps possible

Running activity

- 5 Normal, unlimited: fully competitive, strenuous
- 4 Slight/mild problem: run half speed
- 3 Moderate problem: only 2–4 km possible
- 2 Severe problem: only one to two blocks possible
- 1 Severe problem: only a few steps

Jumping or twisting activities

- 5 Normal, unlimited, fully competitive
- 4 Slight/mild problem: some guarding, but sports possible
- 3 Moderate problem: gave up strenuous sports
- 2 Severe problem: affects all sports, must constantly guard
- 1 Severe problem: only light activity possible

- 1 Sandberg R, Balkfors B. The durability of anterior cruciate ligament reconstruction with the patellar tendon. *Am J Sports Med* 1988;4:341–3.
- 2 Kaplan N, Wickiewicz TL, Warren RF. Primary surgical treatment of anterior cruciate ligament rupture. A long term follow-up study. *Am J Sports Med* 1990;18:354–8.
- 3 Torg JS, Comad W, Kalen V. Clinical diagnosis of anterior cruciate ligament instability in athletes. *Am J Sports Med* 1967;4:84–93.
- 4 Glove TP, Miller SJ, Kent BE, Sanfore TJ, Garrick JG. Non-operative treatment of torn anterior cruciate ligament. *J Bone Joint Surg [Am]* 1983;65A:184–92.
- 5 McDaniel WJ, Dameron TB. The untreated anterior cruciate ligament rupture. *Clin Orthop* 1983;172:158–63.
- 6 Feagin JA, Colonel OO, Curl WW. Isolated tear of the anterior cruciate ligament: 5-year follow-up study. *Am J Sports Med* 1976;14:95–100.
- 7 McDaniel WJ, Dameron TB. Untreated ruptures of the anterior cruciate ligament. *J Bone Joint Surg [Am]* 1980;62A:696–705.
- 8 Marshall JL, Rubin RM, Wang JB, Fetto JF, Arnoczky SP. The anterior cruciate ligament. The diagnosis and treatment of its injuries and their serious prognostic implications. *Orthop Rev* 1978;7:35–46.
- 9 Marshall JL, Rubin RM. Knee ligament injuries. A diagnostic and therapeutic approach. *Orthop Clin North Am* 1977;8:641–68.
- 10 Marshall JL, Warren RF, Wickiewicz. Primary surgical treatment of anterior cruciate ligament lesion. *Am J Sports Med* 1982;10:103–7.
- 11 O'Donoghue DH. Reconstruction for medial instability of the knee. Technique and results of six cases. *J Bone Joint Surg [Am]* 1973;55A:941–55.
- 12 Nicholas JA. The five in one reconstruction for antero-medial instability of the knee. Indications, technique, and the results in fifty-two patients. *J Bone Joint Surg [Am]* 1973;55A:899–922.
- 13 Chick RR, Jackson DW. Tears of the anterior cruciate ligament in young athletes. *J Bone Joint Surg [OO]* 1978;10:970–3.
- 14 Nicholas JA, Strizak AM, Veras G. A Study of thigh muscle weakness in different pathological states of the lower extremity. *Am J Sports Med* 1976;4:241–8.
- 15 Paulos L, Noyes FR, Grood E, Butler DL. Knee rehabilitation after anterior cruciate ligament reconstruction and repair. *Am J Sports Med* 1981;9:140–7.
- 16 Clanton TO, Delee JC, Sanders B, Neidre A. Knee ligament injuries in children. *J Bone Joint Surg [Am]* 1979;61A:1195–201.
- 17 Highgenboten CL, Jackson AW, Meske NB. Concentric and eccentric torque comparisons for knee extension and flexion in young adult males and females using the kinetic communicator. *Am J Sports Med* 1988;16:234–7.
- 18 Vegso JJ, Genuario SE, Torg JS. Maintenance of hamstrings strength following knee surgery. *Med Sci Sports Exerc* 1985;17:376–9.
- 19 Arvidsson I, Eriksson E. *The crucial ligaments. Counteracting muscle atrophy after ACL injury: scientific bases for a rehabilitation program.* Edinburgh: Churchill Livingstone, 1987:454.
- 20 Engle RP. Hamstring facilitation in anterior instability of the knee. *Athletic Training* 1988;23:226–9.
- 21 Galway HR, Macintosh DL. The lateral pivot shift: a symptom and sign of anterior cruciate ligament insufficiency. *Clin Orthop* 1980;147:45–51.
- 22 Kannus P. Ratio of hamstring to quadriceps femoris muscles' strength in the anterior cruciate ligament insufficient knee. Relationship to long term recovery. *Phys Ther* 1988;6:961–5.
- 23 Lumex Inc. *Cybex II + service and parts manual.* New York: Division of Lumex inc, 1985.
- 24 Noyes FR, McGinniss GH, Moos LA. Functional disability in the anterior cruciate insufficient knee syndrome. Review of knee rating systems and projected risk factors in determining treatment. *Sports Med* 1984;1:278–302.
- 25 Wilk KE, Andrews JS. The effect of pad placement and angular velocity on tibia displacement during isokinetic exercise. *J Orthop Sports Phys Ther* 1993;17:24–30.
- 26 SPSS PC+V3.0. *Statistical package for the social sciences.* Chicago: SPSS, 1989.
- 27 Hawkins RI, Misamore GW, Merritt TR. Follow-up of the acute nonoperated isolated anterior cruciate ligament tear. *Am J Sports Med* 1986;14:205–10.
- 28 Hageman PA, Gillaspie DM, Hill LD. Effects of speed and limb dominance on eccentric and concentric isokinetic testing of the knee. *J Orthop Sports Phys Ther* 1988;10:59–65.
- 29 Nyland JA, Canic DP, Ray M, Duly MJ. A case study of an accelerated rehabilitation program on knee function following anterior cruciate ligament reconstruction. *J Sports Rehabil* 1993;2:53–62.
- 30 Wyatt MP, Edwards AM. Comparison of quadriceps and hamstring torque values during isokinetic exercise. *J Orthop Sports Phys Ther* 1981;3:202–10.
- 31 Campbell DE, Glenn W. Foot-pounds of torque of the normal knee and the rehabilitated postmeniscectomy knee. *Phys Ther* 1979;59:418–21.
- 32 Elmqvist LG, Lorentzon R, Largsstrom M, Fugl-Meyer AR. Reconstruction of the anterior cruciate ligament. *Am J Sports Med* 1988;16:455–62.
- 33 Renstrom P, Arm SW, Stanwyck TS, Johnson RJ, Pope MH. Strain within the anterior cruciate ligament during hamstring and quadriceps activity. *Am J Sports Med* 1986;14:83–7.
- 34 Hirokawa S, Solomonow M, Lu Y, Lou ZP, D'Ambrosia R. Anterior-posterior and rotational displacement of the tibia elicited by quadriceps contraction. *Am J Sports Med* 1992;20:299–306.
- 35 Howell SM. Anterior tibia translation during a maximum quadriceps contraction: is it clinically significant? *Am J Sports Med* 1990;18:573–8.
- 36 Hagood S, Solomonow H, Baratta R, Zhou B, D'Ambrosia R. The effect of joint velocity on the contribution of the antagonist musculature to knee stiffness and laxity. *Am J Sports Med* 1990;18:182–7.
- 37 Chmelaer RP, Shultz BB, Ruhing RO, Fitt SS, Johnson MS. Isokinetic characteristic of the knee in female, professional and university, ballet and modern dancers. *J Orthop Sports Phys Ther* 1988;9:410–8.
- 38 Thomas LE. Isokinetic torque levels of adult females: effects of age and body size. *J Orthop Sports Phys Ther* 1984;6:21–4.
- 39 Costain R, Williams AK. Isokinetic quadriceps and hamstring torque level of adolescent, female soccer players. *J Orthop Sports Phys Ther* 1984;5:196–200.
- 40 Tippelt SR. Lower extremity strength and active range of motion in college baseball pitcher. A comparison between stance leg and kick leg. *J Orthop Sports Phys Ther* 1986;8:10–4.
- 41 Costill DL, Finle WJ, Hakansjy AJ. Muscle rehabilitation after knee surgery. *Phys Sports Med* 1977;5:71–4.
- 42 Neyret P, Donell ST, Dejour H. Result of partial meniscectomy related to the state of anterior cruciate ligament. *J Bone Joint Surg [Br]* 1993;75B:36–40.
- 43 Neyret P, Donell ST, Dejour D, Dejour H. Partial meniscectomy and anterior cruciate ligament rupture in soccer players. A study with a minimum of 20 years followup. *Am J Sports Med* 1993;21:455–60.
- 44 Barrack RL, Skinner HB, Backlay SL. Proprioception in the anterior cruciate ligament knee. *Am J Sports Med* 1989;17:1–6.
- 45 Barrett DS. Proprioception and function after anterior cruciate reconstruction. *J Bone Joint Surg [Br]* 1991;73B:833–7.