UWL REPOSITORY

repository.uwl.ac.uk

Novel isokinetic dynamometry of the thigh musculature during anterior cruciate ligament rehabilitation in professional soccer: an explorative case study

This is the Accepted Version of the final output.

UWL repository link: https://repository.uwl.ac.uk/id/eprint/14011/

Alternative formats: If you require this document in an alternative format, please contact: open.research@uwl.ac.uk

Novel isokinetic dynamometry of the thigh musculature during anterior cruciate ligament rehabilitation in professional soccer: an explorative case study

1   **Novel isokinetic dynamometry of the thigh musculature during anterior cruciate**

2   **ligament rehabilitation in professional soccer: an explorative case study**

3

4   **Abstract**

5   The purpose was to assess the isokinetic strength adaptations of eccentric knee flexors (eccKF)

6   and concentric knee extensors (conKE) in a professional male soccer player during anterior

7   cruciate ligament (ACL) rehabilitation. Progress was monitored relative to a non-injured

8   control group. Isokinetic strength assessments were initiated 18 weeks post ACL reconstruction

9   and comprised assessments at eight angular velocities between 60 and $270°·s^{-1}$. The

10   assessments ceased at the point where the player was cleared for return to play 6 months after

11   reconstructive surgery by his club. The results identified that conKE peak torque of the

12   treatment limb and eccKF peak torque of both lower limbs demonstrated meaningful changes.

13   In addition, the eccKF angle of peak torque also demonstrated meaningful change that occurred

14   at increased knee extension. The inclusion of additional angular velocities and angle specific

15   measures provide new insight into rehabilitation and return to play.

16   **Key points**

17   • Angle specific isokinetic strength assessments should be conducted at varying angular

18   velocities at the point of return to play.

19   • Isokinetic assessments should consider an angle specific function strength ratio at the

20   point of return to play.

21   • The slope of the force-velocity curve is changeable through rehabilitation

22   **Key words**

23   Knee injury, strength profiling, soccer, hamstring, quadriceps

1   **Introduction**

2   A study in professional male soccer reported that only 65% of players who sustain an anterior

3   cruciate ligament (ACL) injury return to previous competitive levels three years after injury.[1]

4   Secondary ACL injuries are also common amongst professional soccer players, attributed to

5   strength impairments of knee flexor (KF) and extensor (KE) musculature at the point of return

6   to play.[2,3] Given the functional role in stabilising the knee,[4] adaptation of the KF and KE

7   musculature during rehabilitation is of primary importance.

8   Isokinetic assessments of concentric KF and KE strength are used to identify rehabilitation

9   responses and bilateral asymmetry at the point of return to play.[5,6] However, failure to consider

10   the functional eccKF:conKE ratio[7] and slow testing velocities in relation to injury mechanism

11   limits functional interpretation. Specifically, ACL injury risk is associated with lower

12   functional eccKF:conKE ratio's that indicate higher KE strength relative to the KF

13   musculature, thereby increasing ACL strain.[8] As functional movements associated with ACL

14   injury[9,10] exhibit increased knee angular velocities[11], isokinetic strength assessments should

15   therefore be characterised by KF and KE at similar testing velocities. Furthermore, whilst

16   isokinetic assessment of KF and KE strength is common within professional soccer,[12] the sole

17   use of functional eccKF:conKE ratio fails to consider that KF and KE peak torques (PT) occur

18   at different knee joint angles.[13] When considering the injury mechanisms associated with ACL

19   injury,[14,15] angle specific strength measures should be considered at relevant knee extension

20   angles and angular velocities.

21   A common return to play criteria in professional soccer assesses bilateral strength asymmetry

22   of both the injured and non-injured lower limbs, where values less than 10% are considered

23   acceptable.[8] However, following a prolonged rehabilitation period, the detrained and atrophied

24   non-injured limb may not represent a suitable control. Therefore, a healthy control group may

1

1   be used to help identify whether strength deficits exist in injured populations.[6] Return to play

2   guidelines also suggest KE strength asymmetries greater than 10% and returning to play before

3   9 months postoperative surgery are significant predictors of ACL re-injury,[8] thus reiterating

4   the importance of sufficient rehabilitation. The primary aim of this study was to observe

5   changes in a professional soccer player's isokinetic bilateral strength at varying angular

6   velocities during late stage rehabilitation from ACL reconstructive surgery. A second aim of

7   the study was to compare these data to that of a healthy control group. The final aim of this

8   study was to consider both angle specific and non-angle specific strength ratios at the point of

9   return to play.

10   **Case Presentation**

11   *Patient*

12   The case was a 26 year-old professional male soccer player (height: 184.50cm; mass: 84.50

13   kg) from the English Football League Division Two. The injury occurred in January 2016

14   during a contact situation where the case collided with an opponent attempting a tackle, injuring

15   the dominant right lower limb (defined as the preferred kicking limb).[13] The present injury

16   occurred during the first 15 minutes of a match. The ACL injury was confirmed by a magnetic

17   resonance imaging scan, revealing a grade III tear. Surgical reconstruction of the right ACL

18   was performed via patella tendon graft 7 weeks after injury. An injury also occurred to the

19   medial collateral ligament (MCL) with a grade III tear to the right lower limb ~5 months prior

20   to the present injury. The case has also previously injured their left ACL ~8 years prior to the

21   present injury. A hamstring tendon was used to reconstruct their left ACL.

22   **Intervention**

23   During the first visit to the laboratory, case and club consent were obtained for the assessment

24   of isokinetic (System 4, Biodex Medical Systems, New York, USA) eccentric KF (eccKF) and

25   concentric KE (conKE) strength from 18 weeks post ACL reconstruction to return to play. To

2

1   replicate the club training times[16] testing was conducted between 1000-1200 hours over five

2   trials, comprising one familiarisation trial and four isokinetic strength assessments interspersed

3   by two weeks. Before each trial, a standardised 5 minute warm-up on a stationary cycle

4   ergometer was completed (Monark, 824E, Sweden) at 60W.

5

6   Bilateral isokinetic strength of eccKF and conKE were completed at eight angular velocities

7   completed in the order of 150, 180, 120, 210, 90, 240, 60 and 270°·s^{-1}.[17] At each angular

8   velocity, the case was instructed to exert maximal effort for 3 repetitions, with no performance

9   feedback.[12,18] The dynamometer setup was adjusted specifically for the participant in line with

10   the manufacturer's guidelines, with the cuff of the lever arm secured around the ankle proximal

11   to the malleoli. The case was secured in a seated position with the hip positioned at

12   approximately 90°. Restraints were applied proximal to the knee joint across the thigh, waist

13   and chest. The repetition eliciting the highest PT was further analysed to quantify the

14   corresponding angle of peak torque (APT) and the slope of the force-velocity curve (M)[19]:

15                    $$M = (\text{Torque}[Y2 - Y1]) / (\text{Angular Velocity}[X2 - X1])$$

16   The M value quantified the slope of the force-velocity curve by each PT value for eccKF and

17   conKE contractions across angular velocities (i.e. Y2 and X2 referred to PT data at 270°·s^{-1},

18   whereas Y1 and X1 referred to PT data recorded at 60°·s^{-1}). The M value was used to describe

19   the slope of the force-velocity curve for the respective musculature. Strength ratios were

20   defined as the eccKF:conKE ratio[7] derived from the peak eccKF and conKE values. When

21   considering that ACL injuries have previously been reported to occur when the shank is in a

22   more extended position,[9,14] the strength ratios (angle specific eccKF:conKE ratio) were also

23   calculated from torque data recorded at the angle of maximal knee extension (40° of knee

24   flexion) common to all testing velocities. A rehabilitation response was determined by

3

1   comparing the data recorded for both the treatment and uninvolved limbs across weeks of the

2   rehabilitation. The within-subject standard deviation for all four assessments were used to

3   calculate standard error of measurement (SEM),[20] with bilateral changes greater than the SEM

4   being regarded as meaningful.[21] To determine a treatment effect, the data recorded from the

5   initial assessment (week 18) was compared to that at the point where the club decided the player

6   was returning to play (week 24). Where appropriate, both the rehabilitation and treatment

7   effects were quantified using both absolute and relative differences.

8   In addition to the aforementioned analyses, the final isokinetic strength assessment (week 24)

9   was compared to a control group of 26 male soccer players (age 26.19 ± 4.65 years; height

10   181.65 ± 5.71 cm; mass 82.19 ± 9.01 kg) who were injury free ≥ 6 months, prior to data

11   collection. All players within the control group had no previous history of surgery or trauma to

12   the knee. The control group were recruited from the same team to control for differences in

13   training. The control group data comprised average PT, APT, and the eccKF:conKE ratio data

14   recorded from isokinetic bilateral strength assessments of the eccKF and conKE musculature

15   at angular velocities of 180, 270 and $60^{\circ} \cdot s^{-1}$.

16   **Comparative outcomes**

17   Tables 1 and 2 summarise the biweekly rehabilitation responses for the uninvolved and

18   treatment limbs during the assessment period. At the initial assessment (Week 18), bilateral

19   differences in eccKF PT were greater than the SEM at only $150-180^{\circ} \cdot s^{-1}$ (Table 1). By Week

20   24 the bilateral difference in PT was smaller than the SEM at all testing velocities (Table 1).

21   In contrast, the initial assessment at Week 18 revealed that bilateral differences in conKE PT

22   were greater than the SEM at all testing velocities (Table 2). This bilateral difference was

23   maintained throughout the rehabilitation period, with the bilateral difference less than the SEM

24   at Week 24 only at the highest testing velocity of $270^{\circ} \cdot s^{-1}$.

4

1   [Table 1 near here]

2   [Table 2 near here]

3 Table 3 summarises the overall treatment effect during the rehabilitation period. Meaningful

4 changes (greater than SEM) were achieved in eccKF PT at all velocities for the treatment limb,

5 and all velocities except 150-180°·s^{-1} in the uninvolved limb. The treatment limb also showed

6 a meaningful change in eccKF APT at all velocities except 210°·s^{-1} and 270°·s^{-1}. Meaningful

7 changes in eccKF APT in the uninvolved limb were observed at 90°·s^{-1} and 210-270°·s^{-1}. In

8 conKE PT, meaningful changes were evident at all velocities in the treatment limb, whilst no

9 meaningful changes were observed in the uninvolved limb. The APT data recorded for the

10 treatment limb's conKE data also identified a meaningful effect at all angular velocities except

11 120°·s^{-1} and 240°·s^{-1}. The uninvolved limb showed a meaningful change in conKE APT only

12 at 60°·s^{-1} and 180°·s^{-1}.

13   [Table 3 near here]

14 In relation to the additional analyses, it was also identified that the eccKF and conKE slopes

15 (as determined by the *M* values) decreased and increased respectively during the rehabilitation

16 period. Table 4 identifies differences between the eccKF:conKE ratio and angle specific

17 eccKF:conKE ratio data at the point of return to play, with increased angle specific

18 eccKF:conKE ratios (40° knee flexion) being identified for both the uninvolved and treatment

19 limbs.

20 The control group PT values (normalised to body mass) are illustrated in Figure 1. At return to

21 play, conKE PT data recorded for the uninvolved limb was within 10% of that elicited from

22 the control group. The conKE PT data recorded for the treatment limb was lower when

23 compared to the mean data, but were within the range of the control group (Figure 1). As

5

1   identified in Figure 1, the eccKF PT data recorded across both of the case's limbs were similar

2   to that of the control group. Due to the observed strength deficits in the conKE musculature,

3   the eccKF:conKE ratio for the treatment limb were greater than both the uninvolved limb and

4   the control group (Figure 2).

5   [Figure 1 near here]

6   [Figure 2 near here]

7   [Table 4 near here]

8   **Discussion**

9   The aims of this study were threefold. Firstly, to quantify the strength characteristics of the

10   eccKF and conKE musculature across a range of angular velocities during late stage ACL

11   rehabilitation in a professional soccer player. Secondly, to compare these data to that of a

12   healthy control group. Thirdly, to consider both angle specific and non-angle specific strength

13   ratios at the point of return to play.

14   Typically practitioners identify strength asymmetries between injured and non-injured limbs,

15   forming part of return to play criteria.[8] However, the use of bilateral asymmetries are not

16   entirely appropriate as detraining effects can also occur in a non-injured limb.[5] In relation to

17   the first aim, at week 18 large bilateral differences were observed across all angular velocities

18   for both the eccKF and conKE musculature. The bilateral differences did fluctuate throughout

19   the rehabilitation period; however, lower bilateral differences were consistently identified for

20   the eccKF data, with differences lower than the SEM identified at the final assessment. The

21   conKE data however elicited a response whereby the bilateral differences were consistently

22   greater than those associated with the eccKF data, and at the final assessment, the observed

23   differences were greater than the SEM. When considering the role of the KE musculature in

6

1   relation to knee stability,[14] these data therefore suggest that at the point of return to play, the

2   player may be at an increased risk of re-injury.[2,3,8] Consequently, practitioners should monitor

3   and focus on restoring conKE strength after an ACL injury. Especially when considering that

4   the current rehabilitation programme appears to be insufficient to develop the PT of the conKE

5   musculature. It should however be acknowledged that for the current case, the club deemed

6   the player to be ready to return to play even with the knowledge of these data.

7   When considering the previous criticisms of bilateral comparisons to inform return to play

8   decisions,[5] an alternative method is to compare the data recorded from the injured player to that

9   of a non-injured control group. This was considered in relation to the second aim of the study,

10   with the conKE and eccKF PT data recorded for both limbs being within the range of the

11   control group. These data therefore suggest that relative to a non-injured population, the case

12   possessed sufficient thigh muscular strength characteristics, thus suggesting they may be

13   appropriately adapted to return to play. The current data did however identify that the eccKF:

14   conKE ratio was considerably larger for the treatment limb when compared to both the

15   uninvolved limb and the control group's data. This response is a result of the impaired conKE

16   musculature identified at the point of return to play, and further advocates the use of a number

17   of strength characteristics to determine a player's readiness to return to play. Furthermore,

18   when considering the aforementioned bilateral differences identified across the rehabilitation

19   period, these data also support the use of a number of methods to inform return to play

20   decisions.

21   The rehabilitation responses for the treatment limb identified large changes in PT for both the

22   eccKF and conKE musculature at all angular velocities, with direct influence on the force

23   velocity slopes. Specifically, improvements were identified across all velocities; however,

24   these improvements did elicit a trend for a reduced absolute magnitude change as a main effect

25   for increased velocity. As such, although the *M* value increased for the conKE data of the

7

1   treatment limb, the observed change in the slope was small due to the somewhat similar

2   upwards shift in torque identified for all testing velocities.   The slope of the eccKF PT recorded

3   across the angular velocities decreased during the rehabilitation period for both lower limbs.

4   As such, the eccKF slope at the point of return to play better resembled that previously observed

5   in non-injured players, whereby more consistent PT is observed across all testing velocities.[22]

6   These novel findings suggest that the force-velocity slope is modifiable through rehabilitation

7   and training, with this response being relative to both the muscle group and contraction type.

8   These data therefore have potential implication for exercise prescription and training adaptation

9   monitoring.

10   Although the changes in conKE APT were variable in both lower limbs during the assessment

11   period, APT of eccKF demonstrated large changes with greater force production at increased

12   knee extension angles. The observed shift of eccKF PT towards increased knee extension

13   suggests that the KF musculature may better conditioned to stabilise the knee joint at those

14   angles associated with ACL injury.[14] These data therefore identify the importance of including

15   a number of isokinetic metrics when analysing training induced changes in strength

16   characteristics.

17   The calculation of the eccKF:conKE ratio is typically performed using peak torque data without

18   consideration that eccKF and conKE peak at different knee joint angles.[7] These ratios therefore

19   negate consideration of angle matched torques, and also the consideration of ipsilateral

20   imbalances in an extended position, where ACL injuries have previously been identified to

21   most likely occur.[14] Previous studies have therefore attempted to assess angle specific

22   eccKF:conKE ratios in soccer players, with a consensus that these players typically possess

23   increased eccKF torque towards more extended knee angles when compared to the conKE

24   musculature. This is supported by the current data, whereby the angle specific eccKF:conKE

25   ratio values were notably higher in the treatment limb, as a result of impaired conKE torque at

8

1   increased knee extension angles across all testing velocities. This response was not however

2   observed to the same magnitude for the non-angle specific eccKF:conKE strength ratio. These

3   data therefore reiterate the importance of ensuring the conKE musculature possesses sufficient

4   strength at more extended knee angles, and raises questions about the use of non-angle specific

5   strength ratios as a means of determining return to play.

6   **Clinical Bottom Line**

7   This present study provides insight into how the strength characteristics of the eccKF and

8   conKE musculature adapted to late stage ACL rehabilitation in a professional male soccer

9   player. It was identified that at the point of return to play, bilateral differences were identified

10 for the conKE data recorded from the case's treatment limb, with potential implications for an

11 increased risk of injury.[2,3,8] In contrast to this, irrespective of limb, the conKE and eccKF PT

12 data was identified to be within the range associated with a non-injured control group.

13 Observed changes were also identified for the eccKF APT data as a result of the rehabilitation

14 process, thus suggesting the ability to modify this metric through training. The observed

15 response was for eccKF PT to occur in a more extended knee position, thus potentially offering

16 a protective mechanism to future ACL injury risk. An additional novel consideration of the

17 current study was to quantify the force-velocity slope as a method of assessing the

18 rehabilitation response. This method could be considered for future work to provide a single

19 number to quantify the shift in this slope, thus providing an understanding of the velocity

20 dependent training response. The final consideration of the current study was to compare both

21 angle specific and non-angle specific strength ratios. The current data identified that strength

22 ratios towards a more extended knee angle identified large ipsilateral strength deficits that were

23 not of the same magnitude with the non-angle specific ratios. These data therefore support the

24 use of ipsilateral, bilateral, and between group comparisons and the use of a number of strength

25 metrics to better inform return to play decision-making.

9

1   **References**

2   1. Walden, M., Hagglund, M., Magnusson, H. and Ekstrand, J. ACL injuries in men's

3   professional football: a 15-year prospective study on time trends and return-to-play rates

4   reveals only 65% of players still play at the top level 3 years after ACL rupture. *Br J Sports*

5   *Med.* 2016*;* 50(12):744-750.

6   2. Schmitt, L.C., Paterno, M.V., Ford, K.R., Myer, G.D. and Hewett, T.E. Strength

7   Asymmetry and Landing Mechanics at Return to Sport after Anterior Cruciate Ligament

8   Reconstruction. *Med Sci Sports Exerc.* 2015*;* 47(7): 1426-1434.

9   3. Kyritsis, P., Bahr, R., Landreau, P., Miladi, R. and Witvrouw, E. Likelihood of ACL graft

10   rupture: not meeting six clinical discharge criteria before return to sport is associated with

11   a four times greater risk of rupture. *Br J Sports Med.* 2016; 50.15: 946-951.

12   4. Kellis, E. Arabatzi, F. and Papadopoulos C. Muscle co-activation around the knee in drop

13   jumping using the co-contraction index. *J Electromyogr Kinesiol.* 2003; 12(3):229-238.

14   5. Thomas, A.C., Villwock, M., Wojtys, E.M. and Palmieri-smith, R. Lower Extremity

15   Muscle Strength After Anterior Cruciate Ligament Injury and Reconstruction. *J Athl Train.*

16   2013*;* 48(5): 610-620.

17   6. Czaplicki, A., Jarocka, M. and Walawski, J. Isokinetic Identification of Knee Joint Torques

18   before and after Anterior Cruciate Ligament Reconstruction. *PLoS One. 2015;* 10(12):1-

19   13.

20   7. Aagaard, P., Simonsen, E.B., Magnusson, S.P., Larsson, B. and Dyhre-poulsen, P. A new

21   concept for isokinetic hamstring: quadriceps muscle strength ratio. *Am J Sports Med.*1998*;*

22   26(2): 231-237.

23   8. Grindem, H., Snyder-Mackler, L., Moksnes, H., Engebretsen, L. and Risberg, M.A. Simple

24   decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-

25   Oslo ACL cohort study. *Br J Sports Med.* 2016; 50(13): 804-808.

8

1 9. Olsen, O.E., Myklebust, G., Engebretsen, L. and Bahr, R. Injury Mechanisms for Anterior
2   Cruciate Ligament injuries in Team Handball: A Systematic Video Analysis. *J. Orthop.*
3   *Sports Phys. Ther*. 2005; 32(4): 1002-1012

4 10. Pappas, E., Hagins, M., Sheikhzadeh, A., Nordin, M., Rose D. Biomechanical differences
5   between unilateral and bilateral landings from a jump: Gender differences. *Clin J Sport*
6   *Med.* 2007; 17(4):263-268.

7 11. Nedergaard, N., J., Kersting, U., Lake, M. Using accelerometry to quantify deceleration
8   during a high-intensity soccer turning manoeuvre. *J Sports Sci*. 2014; 32(20):1897-1905.

9 12. Croisier, J., Ganteaume, S., Binet, J., Genty, M. and Ferret, J. Strength imbalances and
10   prevention of hamstring injury in professional soccer players: a prospective study. *Am J*
11   *Sports Med.*2008 36(8):1469-1475.

12 13. Eustace, S.J., Page, R.M. and Greig, M. Contemporary approaches to isokinetic strength
13   assessments in professional football players. *Science and Medicine in Football.* 2017;1(3)
14   251-257.

15 14. Boden, B., P., Dean, G., S. Mechanisms of anterior cruciate ligament injury. *Orthopedics*.
16   2000; 23(6):578-586.

17 15. Hsiao, S., Chou, P., Hsu, H. and Lue, Y. Changes of muscle mechanics associated with
18   anterior cruciate ligament deficiency and reconstruction. *J Strength* Cond Res. 2014;
19   28(2):390-400.

20 16. Rae, D., Stephenson, K. and Roden, L. Factors to consider when assessing diurnal variation
21   in sports performance: the influence of chronotype and habitual training time-of-day. *J*
22   *Appl Physiol.* 2015; 115(6):1339-1349.

23 17. Greig, M. The influence of soccer-specific fatigue on peak isokinetic torque production of
24   the knee flexors and extensors. *Am J Sports Med.* 2008; 36(7):1403-1409.

9

1   18. Campenella, B., Mattacola, C.G. and Kimura, I.F. Effect of visual feedback and verbal

2   encouragement on concentric quadriceps and hamstrings peak torque of males and

3   females. *Isokinet Exerc Sci.* 2000; 8(1):1.

4   19. Rock, N., M. *Math for Everyone: Algebra I.* Team Rock Press; 2007.

5   20. Bland, J., M., and Altman D., G. Measurement Error. *BMJ.* 1996; 313:744-753.

6   21. Mchorney, C.A. and Tarlov, A.R. Individual-patient monitoring in clinical practice: are

7   available health status surveys adequate? *Quality Of Life Research: Qual Life*

8   *Res.*1995; 4(4):293-307.

9   22. Westing S.,H., Seger J., Karlson, E., Ekblom, K. Eccentric and concentric torque-velocity

10   characteristics of the quadriceps femoris in man. *Eur J Appl Physiol.* 1988; 58(1):100–104.

11   23. Small, K., McNaughton L., Greig M., Lovell R. The Effects of Multidirectional Soccer-

12   Specific Fatigue on Markers of Hamstring Injury Risk. *J Sci Med* Sport. 2010; 13 (1):120-

13   125.

1   **List of Tables**

2   Table 1: The rehabilitation responses of the PT, APT, and *M* data recorded for the eccKF

3   musculature of the uninvolved and treatment limbs. The bilateral differences for the biweekly

4   assessments are also presented, with a positive value representing a higher value for the

5   treatment limb.

6   Table 2: The rehabilitation responses of the PT, APT, and *M* data recorded for the conKE

7   musculature of the uninvolved and treatment limbs. The bilateral differences for the biweekly

8   assessments are also presented, with a positive value representing a higher value for the

9   treatment limb.

10 Table 3:   The treatment effect for the PT and APT data recorded for the eccKF and conKE

11 musculature of the uninvolved and treatment limbs. A negative PT value indicates a reduction

12 during the 6 week period. A negative APT value indicates a change towards more extended

13 knee angle.

14 Table 4. Angle specific and non-angle specific strength ratios recorded across all angular

15 velocities at the point of return to play

16

17

18

19

20

21

22

1   **Figure Legends**

2   Figure 1. Isokinetic peak torque (normalized to body mass) of conKE (A) and eccKF (B)

3   musculature recorded at 60, 180 and 270º·s^{-1} for both the uninvolved limb (– • –) and the

4   treatment limb (—•—) of the case, and also for the control group (——•—) at the point of return

5   to play.

6   Figure 2. The eccKF:conKE strength ratio recorded at 60, 180 and 270º·s^{-1} for uninvolved limb

7   (– • –), treatment limb (—•—) of present case and control group (——•—) at return to play.

Table 1: The rehabilitation responses of the PT, APT, and *M* data recorded for the eccKF musculature of the uninvolved and treatment limbs. The bilateral differences for the biweekly assessments are also presented, with a positive value representing a higher value for the treatment limb.

		Angular velocity															*M*
		$60° \cdot s^{-1}$		$90° \cdot s^{-1}$		$120° \cdot s^{-1}$		$150° \cdot s^{-1}$		$180° \cdot s^{-1}$		$210° \cdot s^{-1}$		$240° \cdot s^{-1}$		$270° \cdot s^{-1}$		
		PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	
Week 18	Uninvolved limb	133.0	33	136.4	43	152.6	30	171.1	31	162.7	36	136.8	55	138.3	72	153	67	0.10
	Treatment limb	114.9	52	135.3	43	133.8	46	132.2	68	125.4	49	141.6	48	142.9	77	155.9	75	0.08
	Bilateral difference	-18.1	19	-1.1	0	-18.8	16	-38.9	37	-37.3	13	4.8	-7	4.6	5	2.9	8	-0.02
	Asymmetry (%)	-14		-1		-12		-23		-23		-4		-3		-2		
Week 20	Uninvolved limb	113.4	28	78	51	123.4	37	122.7	46	121.1	36	106.6	70	121.5	66	115.4	57	0.01
	Treatment limb	169.8	34	154.6	34	157.8	35	135.7	39	147.9	37	147.3	38	151.6	40	146.4	70	0.11
	Bilateral difference	56.4	6	76.6	-17	34.4	-2	13.0	-7	26.8	1	40.7	-32	30.1	-26	31.0	13	0.10
	Asymmetry (%)	33		50		28		11		22		38		25		27		
Week 22	Uninvolved limb	156.9	38	150.2	29	151.9	37	147.8	36	152.0	31	146.9	37	149	77	155.8	71	0.01
	Treatment limb	159.2	36	161.8	33	157.8	41	145.6	37	150.8	38	156.2	73	153.1	80	163.4	76	0.02
	Bilateral difference	2.3	-2	11.6	4	5.9	4	-2.2	1	-1.2	7	9.3	36	4.1	3	7.6	5	0.01
	Asymmetry (%)	1		8		4		-1		-1		6		3		5		
Week 24	Uninvolved limb	177.9	29	187.1	34	183.5	32	178.3	33	185.1	33	180.3	33	172.6	35	178.4	43	0.00
	Treatment limb	185.2	30	184.6	29	185.2	32	184.8	33	184.3	32	177.6	34	179.1	36	177.4	78	0.04
	Bilateral difference	7.3	1	-2.5	-5	1.7	0	6.5	0	-0.8	-1	-2.7	1	6.5	1	-1.0	35	0.04
	Asymmetry (%)	4		-1		1		4		0		-1		4		-1		
	SEM	30.2	10	20.4	6	21.0	6	24.2	16	24.3	7	15.8	18	15.6	23	13.1	13	

Table 2: The rehabilitation responses of the PT, APT, and M data recorded for the conKE musculature of the uninvolved and treatment limbs. The bilateral differences for the biweekly assessments are also presented, with a positive value representing a higher value for the treatment limb.

		Angular velocity															M
		60° ·s⁻¹		90° ·s⁻¹		120° ·s⁻¹		150° ·s⁻¹		180° ·s⁻¹		210° ·s⁻¹		240° ·s⁻¹		270° ·s⁻¹	
		PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	
Week 18	Uninvolved limb	230.2	81	211.1	72	197.3	80	176.7	77	184.0	73	177.1	70	160.3	67	140.8	62	0.43
	Treatment limb	132.2	80	129.8	70	125.2	78	108.1	72	112.1	72	100.9	66	102.5	67	91.9	67	0.19
	Bilateral difference	-98.0	-1	-81.3	-2	-72.1	-2	-68.6	-5	-71.9	-1	-76.2	-4	-57.8	0	-48.9	5	-0.24
	Asymmetry (%)	-43		-39		-37		-39		-39		-43		-36		-35		
Week 20	Uninvolved limb	200.6	74	176.1	78	175.9	76	162.9	73	167.2	69	154.7	65	134.5	61	127.7	58	0.35
	Treatment limb	156.8	82	157.7	75	146.2	68	125.0	78	133.0	73	132.5	72	124.6	73	118.5	67	0.18
	Bilateral difference	-43.8	8	-18.4	-3	-29.7	-8	-37.9	5	-34.2	4	-22.2	7	-9.9	12	-9.2	9	-0.17
	Asymmetry (%)	-22		-10		-17		-23		-20		-14		-7		-7		
Week 22	Uninvolved limb	213.0	80	193.4	70	183.5	75	189.4	72	182.2	68	170.4	68	153.4	64	161.8	66	0.24
	Treatment limb	163.1	83	150.5	75	139.7	69	124.1	78	122.9	73	123.3	73	118.1	63	107.5	64	0.27
	Bilateral difference	-49.9	3	-42.9	5	-43.8	-6	-65.3	6	-59.3	5	-47.1	5	-35.3	-1	-54.3	-2	0.03
	Asymmetry (%)	-23		-22		-24		-34		-33		-28		-23		-34		
Week 24	Uninvolved limb	222.2	71	206.8	68	204.2	74	182.4	76	184.6	69	181.2	66	177.8	64	157.6	60	0.31
	Treatment limb	185.6	83	178.0	77	161.0	82	163.4	75	156.8	74	149.4	75	150.1	67	138.3	83	0.23
	Bilateral difference	-36.6	12	-28.8	9	-43.2	8	-19.0	-1	-27.8	5	-31.8	9	-27.7	3	-19.3	23	-0.08
	Asymmetry (%)	-16		-14		-21		-10		-15		-18		-16		-12		
	SEM	22.0	1	19.9	3	23.5	7	14.9	3	8.5	1	20.2	4	19.8	4	19.5	3	

Table 3: The treatment effect for the PT and APT data recorded for the eccKF and conKE musculature of the uninvolved and treatment limbs. A negative PT value indicates a reduction during the 6 week period. A negative APT value indicates a change towards more extended knee angle.

eccKF	Angular velocity															
	60° ·s^{-1}		90° ·s^{-1}		120° ·s^{-1}		150° ·s^{-1}		180° ·s^{-1}		210° ·s^{-1}		240° ·s^{-1}		270° ·s^{-1}	
	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)
Treatment effect uninvolved limb	44.9	-4	50.7	-9	30.9	2	7.2	2	22.4	-3	43.5	-22	34.3	-37	25.4	-24
Treatment effect treatment limb	70.3	-22	49.3	-14	51.4	-14	52.6	-35	58.9	-17	36	-14	36.2	-41	21.5	3
Treatment effect uninvolved limb (%)	25		27		17		4		12		24		20		14	
Treatment effect treatment limb (%)	38		27		28		28		32		20		20		12	
SEM	30.2	10	20.4	6	21	6	24.2	16	24.3	7	15.8	18	15.6	23	13.1	13

conKE	Angular velocity															
	60° ·s^{-1}		90° ·s^{-1}		120° ·s^{-1}		150° ·s^{-1}		180° ·s^{-1}		210° ·s^{-1}		240° ·s^{-1}		270° ·s^{-1}	
	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)	PT (Nm)	APT (°)
Treatment effect uninvolved limb	-8.0	-10	-4.3	-4	6.9	-6	5.7	-1	0.6	-4	4.1	-4	17.5	-3	16.8	-2
Treatment effect treatment limb	53.4	3	48.2	7	35.8	4	55.3	3	44.7	2	48.5	11	47.6	0	46.4	16
Treatment effect uninvolved limb (%)	-2		-3		-4		-1		-4		-4		-3		-2	
Treatment effect treatment limb (%)	29		27		22		34		29		32		32		34	
SEM	22	1	19.9	3	23.5	7	14.9	3	8.5	1	20.2	4	19.8	4	19.5	3

Table 4. Angle specific and non-angle specific strength ratios recorded across all angular velocities at the point of return to play

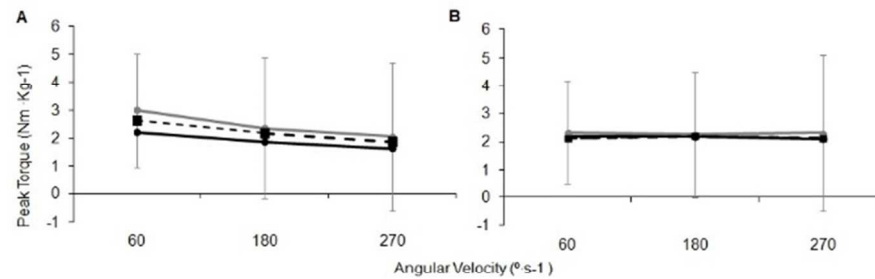|		Angular velocities							
		60°·s⁻¹	90°·s⁻¹	120°·s⁻¹	150°·s⁻¹	180°·s⁻¹	210°·s⁻¹	240°·s⁻¹	270°·s⁻¹
	Uninvolved limb eccKF:conKE ratio	0.80	0.90	0.90	0.98	1.00	1.00	0.97	1.13
Week	Uninvolved limb angle specific eccKF:conKE ratio	1.89	1.26	1.55	1.45	1.61	1.27	1.20	1.37
24	Treatment limb eccKF:conKE ratio	1.00	1.04	1.15	1.13	1.00	1.19	1.19	1.28
	Treatment angle specific eccKF:conKE ratio	1.88	1.97	1.68	1.40	1.38	2.07	1.93	1.75

Figure 1. Isokinetic peak torque (normalized to body mass) of conKE (A) and eccKF (B) musculature recorded at 60, 180 and 270⁰·s-1 for both the uninvolved limb ( ) and the treatment limb ( ) of the case, and also for the control group ( ) at the point of return to play.
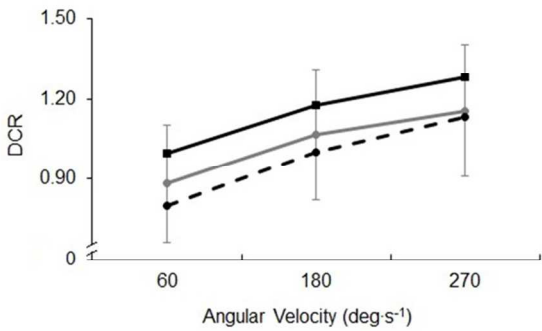
338x190mm (96 x 96 DPI)

Figure 2. The eccKF:conKE strength ratio recorded at 60, 180 and 270º·s-1 for uninvolved limb ( ), treatment limb ( ) of present case and control group ( ) at return to play.

338x190mm (96 x 96 DPI)