The Effect of Conservatively Treated ACL Injury on Knee Joint Position Sense.

Abstract

Background: Proprioception is critical for effective movement patterns. However, methods of proprioceptive measurement in previous research have been inconsistent and lacking in reliability statistics making it applications to clinical practice difficult. Evidence has suggested damage to the anterior cruciate ligament (ACL) can alter proprioceptive ability due to a loss of functioning mechanoreceptors. The majority of patients opt for reconstructive surgery following this injury. However, some patients chose physical therapy programmes without a surgical intervention.

Purpose: The purpose of this study was to determine the effect of ACL deficiency following conservative treatment without surgery and return to physical activity on knee joint position sense. A secondary purpose was to report the reliability and measurement error and hence comment on the clinical significance of joint position sense measurement.

Study Design: Observational study design using a cross-section of ACL deficient patients and matched external controls.

Methods: Twenty active conservatively treated ACL deficient patients who had returned to physical activity and twenty active matched controls were included in the study. Knee joint position sense was measured using a seated passive-active reproductive angle technique. The average absolute angle of error score, into 10°-30° of knee flexion was determined.

Results: The ACL deficient patients had a greater error score (7.9°±3.6) and hence poorer static proprioception ability that both the contra-lateral leg (2.0°±1.6; *p*=0.0001) and the external control group (2.6°±0.9; *p*=0.0001). The standard error of the mean (SEM) of this JPS technique was 0.5° and 0.2° and the smallest detectable difference (SDD) was 1.3° and 0.4° on asymptomatic and symptomatic subjects respectively.

Conclusion: This study confirms a proprioceptive deficiency in the knee joint following ACL injury without surgical treatment, potentially due to a reduction in functioning mechanoreceptors in the ligament over time. Therefore this deficiency may increase in ACL patients who return to physical activity levels. The differences between the ACL deficient knee and the external control group were above the SEMs and SDDs of the measurement which suggests clinical relevance. Longitudinal studies are needed to evaluate if patients who return to activity with a joint position sense deficiency develop secondary injuries.

Levels of Evidence: Individual Cohort Study (2b)

Clinical Relevance: Clinicians should include proprioceptive assessment in ACL physical therapy programmes using the suggested joint position sense technique to inform their clinical practice. If a deficit is still present when the patient has returned to activity, this may increase their likelihood of re-injury and future knee problems.

Key Words; Anterior Cruciate Ligament; Injury; Joint Position Sense; Knee.

What is known about the subject: It is known ACL injury may reduce proprioceptive ability. However, the majority of patients opt for reconstructive surgery and hence most proprioception research considers this population rather than populations who opt out of surgery. Furthermore, proprioceptive methods have been inconsistent and lacking in reliability statistics that may not be appropriate for ACL patients.

What this study adds to the existing knowledge: This study considers a group of patients who have opted for conservative treatment of an ACL injury using physical therapy and have returned to full activity. This study also uses an appropriate and reliable proprioceptive method to collect joint position sense data. Importantly, results illustrate a proprioceptive deficit despite the patient group returning to play. Therefore, clinicians should aim to incorporate proprioceptive measures into evaluation programmes following physical therapy treatment to ensure this aspect of rehabilitation has been completed.

1. Introduction

The anterior cruciate ligament (ACL) is the most commonly injured knee ligament[1] with an estimated 6.5 injuries per 10,000 athletic exposures[2]. Furthermore, following this injury there is a significantly greater risk of suffering secondary problems such as osteoarthritis in the damaged limb and injury to the uninjured knee[3]. These secondary problems may be linked to altered proprioception following damage to the ACL[4]. The ACL contains neural elements such as Ruffini nerve endings, Golgi-like tendon organs and Pacinian corpuscles[5-7] and connections have been reported between these mechanoreceptors and the central nervous system. Proprioception plays a critical role in efficient motor control[8-9]. Therefore, if ACL mechanoreceptors become injured then important afferent information regarding knee position and movement may be altered and lead to altered motor control patterns that could produce secondary injuries[10].

Up to 90% of ACL injured patients opt for surgical reconstruction of the damaged ligament[11]. However patients can also chose to conservatively treat the injury with a physical therapy programme. There have been fewer studies considering the proprioception of these patients compared to those who have the reconstructive surgery, perhaps due to the availability of this population. However, the available literature provides a contrasting view of proprioception and ACL deficient patients. A number of studies report a joint position sense (JPS) deficit in ACL deficient patients[12-15]. Fremerey et al[12] reported JPS measurements from a group of acute ACL injured patients treated conservatively with physical therapy (< 12 days post injury) and chronic ACL injured patients (mean 12 months post injury). The chronic group had undergone ACL reconstructive surgery and physical therapy for up to 12 months. Results indicated that only the acute patient group had significantly poorer JPS in their injured and uninjured knees compared to an external control group. Hugn-Maan et al[13] and Katayama et al[14] reported a significantly reduction in JPS in chronic patient groups who had undergone a period of physical therapy in the injured knee when compared to the uninjured knee. The number and functionality of remaining mechanoreceptors in an injured ACL is thought to reduce with time[16]. Therefore, it is plausible that patients who have opted for conservative treatment of the injury who may have a reduction in proprioception over time due to the loss of any initially functioning mechanoreceptors.

Contrastingly, other studies have reported no knee JPS deficiency after conservative treatment[17-19]. Roberts et al[17] and Jensen et al[18] compared "copers" and "non-copers" defined as patients have undergone physical therapy without surgical intervention, but the copers are able to return to physical activity, whereas the non-copers have continued problems with neuromuscular control. Both studies failed to find any differences in knee JPS between these groups. Furthermore, Fonseca et al[19] did not find any differences in JPS between a group of functioning ACL deficient patients (copers) and either the contralateral leg or an external control group. These authors suggest that knee proprioceptive acuity was not directly influenced by the damage to the ligament and that muscle spindles may play the dominant role in joint position sense. In addition, other articular mechanoreceptors located in areas such as the capsule, tendons and adjacent joints may compensate for the loss of sensory information from the ACL.

An alternative reason for the lack of significant differences in the aforementioned papers is the sensitivity of the measurement tool. Although clinical practitioners use joint position sense to inform their practice and include proprioceptive exercises in physical therapy programmes[20-21] the majority of literature on proprioception lacks detail on the reliability of the measurement and it is therefore unclear how much information is actually measurement noise[22-24]. Furthermore the literature lacks information on the severity or stage of the injury[12-15, 17, 19] which may threaten internal validity of the results. Hence, as reliability is lacking in the majority of studies it is possible that the differences or lack of those differences in proprioception ability found after an ACL injury are due to measurement error[22,24]. Furthermore, there is no consensus on the threshold of proprioceptive deficiency that would be clinically or functionally relevant. Jensen et al[18] suggest a deficiency of greater than 3° to be clinically important, whereas Burgess et al[25] and Callaghan et al[26] suggest a value for normal joint position errors of less than 5°, however these values appear arbitrary.

Therefore, the purpose of this study was to consider the effects of chronic ACL deficiency treated without ACL reconstructive surgery but with physical therapy on knee joint position sense of patients who had returned to physical activity. A secondary aim was to report the reliability and measurement error of the selected joint position sense technique.

2. Methods

2.1 Participants

Twenty active (Tegner score 5.5±1.2) ACL patients with total rupture stage III tears (ten male, ten female; age 30±4.5years, mass 77.4±4.76kg, height 1.63±0.24m; time since injury 11±2 months) took part in the study, recruited using purposive sampling methods. Diagnosis of their injury was confirmed by clinical laxity testing (anterior drawer test, Lachman's test and pivot shift test) and further verified by either arthroscopic or Magnetic Resonance Image (MRI) examination. All patients suffered the injury through non-contact means and none of the patients had concurrent medial collateral ligament or meniscal injuries at the time of the ACL injury. The patients had completed a standard physical therapy programme that included proprioceptive exercises following Herrington[27]. Twenty active (Tegner 5.0±1.2) participants with clinically normal knees were matched to the ACL deficient participants by age, gender and physical activity (ten female, ten male; age 30.5±9.37 years, mass 71.5±14.78 kg, height 1.7±0.11 m). All participants were free from current lower extremity injury and any chronic disease that may affect proprioception such as visual or vestibular function, peripheral neuropathy and diabetes mellitus[28]. All participants read an information sheet and provided written informed consent. This study was approved by the university ethics board (REP10/068).

2.2 Design and Procedures

The study used a retrospective observational study design. Uninjured participants removed the shoe and sock from their dominant leg. ACL deficient participants removed both shoes and socks. Participants were prepared for data collection by placing markers on the following anatomical points; a point on a line following the greater trochanter to the lateral epicondyle, close to the lateral epicondyle (placement of a marker directly on the greater trochanter is difficult due to clothing), the lateral epicondyle and the lateral malleolus of both legs for ACL deficient participants and dominant leg for uninjured participants.

Clinical knee JPS measurements were collected using a protocol determined as the most appropriate for comparison to an ACL deficient population. Both bundles of the ACL are taut in 10°-30° of flexion and hence have maximal mechanoreceptor activity in this range of motion[29]. Therefore, testing JPS in this range may allow participants to produce their maximum performance of knee joint position sense. Furthermore, previous studies on reliability of JPS measurement confirmed similar techniques provided excellent[30] test-retest reliability statistics in asymptomatic patients (intra-class correlation coefficient = 0.79, SEM = 0.5° and SDD = 1.3°)[31] and ACL patients (intra-class correlation coefficient = 0.96, SEM = 0.2° and SDD = 0.4°)[32].

The participants were seated on the end of a treatment couch and blindfolded. The leg was passively moved by the experimenter through 10-30° of knee flexion from a starting angle of 0° to a target angle at an angular velocity of approximately 10°/s. The researcher used a grid to ensure the target position was located in this range (see figure 1). The participant then actively held the leg in this position for 5s. A photograph of the leg in the target position was taken using a standard camera (Casio Exilim, EX-FC100, Casio Electronics Co., Ltd. London, UK) placed 3m from the sagittal plane of movement on a fixed level tripod (Camlink TP-2800, Camlink UK, Leicester, UK). Parallax error was reduced by ensuring the camera lens was positioned orthogonally to the field of motion using spirit levels and measurement of a 90° angle between the plane of motion and the centre of the camera lens. The leg was then passively returned to the starting angle and the participant was instructed to actively move the same leg to the target angle and hold the leg in this position. Another photograph was taken and the participant instructed to move their leg back to the starting position. The process was repeated five times. The ACL deficient group completed the test using both legs. The uninjured group used their dominant leg only.

FIGURE 1 NEAR HERE

2.3 Data Reduction

Knee angles were measured using two-dimensional manual digitizing software (ImageJ, U. S. National Institutes of Health,, Maryland, USA, http://imagej.nih.gov/ij/, 1997-2012). Knee joint position sense was calculated from the average delta scores between target and reproduction angles across five flexion trials producing absolute error scores (AES) in which only magnitude was measured. Means, standard deviations and 95% confidence intervals were presented. Confidence intervals are provided to indicate the true boundaries in which a mean would fail, in this case, the 95% boundary[33]. Confidence intervals present the results using the same data measurement as the mean and as such, can improve the clarity of true meaning of the sample data[33]. Confidence intervals at the 95% level were calculated using the following equation[33, p.748]

$$\text{Lower boundary of confidence interval} = \bar{X} - (1.96\ X\ SE)$$

$$\text{Upper boundary of confidence interval} = \bar{X} + (1.96\ X\ SE)$$

All statistical analysis was completed in SPSS (Version 19, IBM Corporation, New York, USA). The Shapiro-Wilk test was used to examine normality of data, which was not confirmed. Log transformation of data did not solve the issue of normality, hence non-parametric statistical analysis was utilised. A related samples Wilcoxon signed rank test compared differences between the ACL deficient leg and the contralateral leg. Independent sample Mann-Whitney U tests were used to compare the differences between ACL deficient legs and external controls, and contralateral legs of the ACL deficient participants and external controls. The level of acceptable significance was set at $p<0.05$. Effect sizes (r) were calculated using the following equation[34, p.531]

$$r = \frac{Z}{\sqrt{N}}$$

Effect sizes were interpreted using Cohen's classifications as follows; 0 – 0.1 is a small effect, 0.1-0.3 is a small to medium effect, 0.3-0.5 is a medium to large effect and 0.5 and above is a large effect[30].

3. Results

Figure 2 illustrates JPS differences between ACL deficient patients, their contralateral leg and an external control group. The average JPS error score in the ACL deficient group was 7.9°±3.6 (95% CI [6.3, 9.5]). In comparison, the contralateral leg and control group error scores were 2°±1.6 (95% CI [1.3, 2.7]) and 2.6°±0.9 (95% CI [2.2, 3.0]) respectively.

Statistical analysis revealed significantly greater JPS ability in the control group (p = 0.0001, r = -0.77) and contralateral leg (p = 0.0001, r = -0.61) when compared to the ACL deficient leg. The external control group also had a significantly lower JPS ability (higher error score) than the ACL patient's contralateral knee (p = 0.02, r = -0.37). The differences between the ACL injured knees and the contralateral knees and control knees were 5.9° and **5.3°** respectively; these values are above the stated SEM values (0.5° and 0.2°) and SDD values (1.3° and 0.4°) for asymptomatic and symptomatic patients respectively.

FIGURE TWO NEAR HERE

4. Discussion

The aim of this study was to consider the effects of chronic ACL deficiency treated with physical therapy only (no reconstructive surgery) on the knee joint position sense of patients who had returned to physical activity. The results suggests ACL deficient patients do have reduced joint position sense ability, specifically, position error was approximately 60% higher in the injured knee than their uninjured knee and external controls. Previous studies have also reported a reduction in knee JPS following ACL injury[12-15]. The number and functionality of remaining mechanoreceptors in an injured ACL is thought to reduce with time[13, 16]. A study on biopsy specimens taken from ACL remnants in ACL injured patients revealed normal mechanoreceptors for up to three months post-injury, however, all mechanoreceptors had disappeared after 12 months[35]. Therefore it may be that patients who follow a conservative treatment programme of physical therapy do not have a proprioceptive deficit in the initial stages of rehabilitation. However, 12 months after the injury, when the patients have returned to activity, this deficiency may have increased as the number of mechanoreceptors has decreased. The patients in the current study were on average 11 months from injury and therefore would concur with this theory, however of course this could only be confirmed with histological research evidence.

It would be useful to measure JPS of the ACL-D patient using a longitudinal research design to track proprioceptive ability throughout a physical therapy programme and once the patient had returned to activity. This has been considered in ACL reconstructed populations with findings recommending a range of six to 18 months for full proprioceptive restoration[36-40]. However, research is lacking in the proprioceptive development or decline of a conservatively managed ACL patient.

Furthermore, there is no consensus on the appropriate threshold for clinical relevance of joint position sense error. As previously stated Jensen et al[18] suggest a clinically relevant deficiency of greater than 3°, whereas Burgess et al[25] and Callaghan et al[26] suggest a value for normal joint position errors of less than 5°. The current study identified differences of 5.9° and 5.3° between ACL injured and the contralateral leg and external control leg respectively. Therefore longitudinal studies may identify when this difference becomes clinically important by recording if and when the patients become re-injured.

Another explanation for the current study finding is that knee joint position sense is not related to function and hence ACL deficiency does not impair performance. The patients had all returned to physical activity levels corresponding to competitive and recreational sports and were free from current injury at the time of testing. It is possible joint position sense is not related to functional movement[24]. A recent literature review failed to report any significant correlations between ACL deficiency and reduced functional performance[24].

Therefore it is possible patients are able to use appropriate motor control patterns to perform physical activity successfully.

A secondary aim was to report the reliability and measurement error of the selected joint position sense technique to ensure any JPS differences between ACL and control groups were not measurement error. The lack of reliability and sensitivity statistics with JPS techniques has been previously criticised[22, 24]. It is important reliability and sensitivity is reported to acknowledge any error in the measurement. In the current study the differences between ACL patients and the contralateral and external control legs was above the SEM and SDD values provided in previous studies[31, 32] of the measurement and therefore were not measurement error. Therefore, clinicians can be more confident there is a proprioception deficit in ACL patients following conservative treatment of an injury.

An interesting finding was patient's uninjured limb had better knee joint position sense than external controls, however the effect size was only moderate. Previous research has indicated the opposite to this finding; the contralateral limb of ACL patients having poorer knee proprioception than external controls[28]. The improved ability in the contralateral leg in patients may be attributed to a training effect during physical therapy programmes. The uninjured limb may use a compensation techniques due to a reduction in trust on the deficient side. Furthermore, patients may subconsciously train the uninjured limb to dissipate higher loads during movements such as landing and gait and hence increase muscle tone on the uninjured side which in turn may increase proprioceptive ability. However, it is still unknown if proprioception can be improved by exercise[41].

One limitation of the study is the use of passive positioning to the target angle; previous studies have suggested active positioning should be used as this will stimulate more mechanoreceptors during testing[42]. A further limitation is the lack of a power calculation to provide appropriate sample sizes. However, accompanying effect sizes demonstrate medium to large effect sizes and the SEM and SDD are also reported. There was also no direct measure of physical fitness or functional performance. Future studies should consider the longitudinal effect of ACL deficiency on joint position sense and functional and clinical relevance.

5. Conclusion

The findings of the current study demonstrate patients who have conservative treatment of an ACL injury have a reduction in knee joint position sense when compared to the contralateral knee and external controls. As there is a lack of evidence to support a link between function and knee joint position sense ability, it may be patients are able to successfully partake in physical activity without a reduction in performance. As this patient group had returned to physical activity, it is unclear what effect this will have on future re-injury risks. Future research should consider the longitudinal clinical relevance of competing in physical activity with a knee joint position sense deficiency.

7. References

1. Miyasaka KC, Daniel DM, Stone M, Hirshman P. The Incidence of Knee Ligament Injuries in the General Population. Am J Knee Surg 1991;4(1): 3-8.

2. Bien DP, Dubuque TJ. Considerations For Late Stage Acl Rehabilitation And Return To Sport To Limit Re-Injury Risk And Maximize Athletic Performance. International Journal of Sports Physical Therapy. 2015;10(2):256-271.

3. Hewett TE, Ford KR, Myer GD. Anterior Cruciate Ligament Injuries in the Female Athlete. Part 2: A Meta-Analysis of Neuromuscular Interventions aimed at Injury Prevention. Am. J. Sports Med 2006; 34(3): 490-498.

4. Lephart SM, Riemann BL Fu FH. Introduction to the Sensorimotor System. In SM Lephart FH Fu editors. Proprioception and Neuromuscular Control in Joint Stability, Human Kinetics; 2000. p. xvii.

5. Adachi N, Ochi M, Uchio Y, Iwasa J, Ryoke K, & Kuriwaka, M. Mechanoreceptors in the anterior cruciate ligament contribute to the joint position sense. Acta Orthop Scand 2002;73:330-334.

6. Duthon VB, Barea C, Abrassart S, Fasel JH, Fritschy D, Ménétrey J. Anatomy of the anterior cruciate ligament. Knee Surg Sport Tr A 2006;14(3): 204-213.

7. Hogervorst T, Brand RA. Mechanoreceptors in joint function. J Bone Joint Surg Am 1998;80(9): 1365-1378.

8. Riemann BL, Lephart SM. The sensorimotor system. Part I. The physiologic basis of functional joint stability. J Athl Train 2002; 37(1): 71-79.

9. Riemann BL, Lephart SM. The sensorimotor system. Part II. The role of proprioception in motor control and functional joint stability. J Athl Train 2002;37(1): 80-84.

10. Hart HF, Collins NJ, Ackland DC, Cowan, SM, Crossley KM. Gait Characteristics of People with Lateral Knee Osteoarthritis after ACL Reconstruction. Med Sci Sports Exerc 2015:47(11): 2406-2415.

11. Bien DP, Dubuque TJ. Considerations For Late Stage ACL Rehabilitation and Return to Sport to Limit Re-Injury Risk and Maximize Athletic Performance. Int J Sports Phys Ther 2015; 10(2): 256–271.

12. Fremerey RW, Lobenhoffer P, Zeichen J, Skutek M, Bosch U, Tscherne, H. Proprioception after rehabilitation and reconstruction in knees with deficiency of the anterior cruciate ligament. Bone Joint J 2000;82-B(6): 801-806.

13. Hung-Maan L, Cheng-Kung C, Jiann-Jong L. Correlation between proprioception, muscle strength, knee laxity, and dynamic standing balance in patients with chronic anterior cruciate ligament deficiency. The Knee 2009; 16(5): 387-391.

14. Katayama M, Higuchi H, Kimura M, Kobayashi, A, Hatayama K, Terauchi M, Takagishi K. Proprioception and performance after anterior cruciate ligament rupture. Int Orthop 2004;28(5):278-281.

15. Fischer-Rasmussen T, Jensen PE. Proprioceptive sensitivity and performance in anterior cruciate ligament-deficient knee joints. Scand J Med Sci Sports 2000;10(2): 85-89.

16. Dhillon MS, Bali K, Prabhakar S. Differences among mechanoreceptors in healthy and injured anterior cruciate ligaments and their clinical importance. Muscles Ligaments Tendons J 2012;2(1):38-43.

17. Roberts D, Fridén T, Zätterström R, Lindstrand A, Moritz U. Proprioception in people with anterior cruciate ligament-deficient knees: comparison of symptomatic and asymptomatic patients. J Orthop Sports Phys Ther 1999;29(10): 587-594.

18. Jensen TO, Fischer-Rasmussen T, Kjaer M, Magnusson SP. Proprioception in poor- and well-functioning anterior cruciate ligament deficient patients. J Rehabil Med 2002;34(3): 141-149.

19. Fonseca ST, Ocarino JM, Silva PLP, Guimarães RB, Oliveira MCT, Lage CA. Proprioception in Individuals with ACL-Deficient Knee and Good Muscular and Functional Performance. Res Sports Med 2005;13(1): 47-61.

20. Hewett TE, Myer GD, Ford KR. Theories on How Neuromuscular Intervention Programs May Influence ACL Injury Rates. In TE Hewett, SJ Shultz, LY Griffin editors. Understanding and Preventing Noncontact ACL Injuries, Human Kinetics; 2007. p. 75-91.

21. Ogard WK. Proprioception in Sports Medicine and Athletic Conditioning. Strength Cond J 2011;33(3): 111-118.

22. Relph N, Herrington L, Tyson S. The effects of ACL injury on knee proprioception: a meta-analysis. Physiotherapy 2014;100(3): 187-195.

23. Ozenci AM, Inanmaz E, Ozcanli H, Soyuncu Y, Samanci N, Dagseven T, Balci N, Gur S. Proprioceptive comparison of allograft and autograft anterior cruciate ligament reconstructions. Knee Surg Sports Traumatol Arthrosc 2007;15(12):1432-1437.

24. Gokeler A, Benjaminse A, Hewett TE, Lephart SM, Engebretsen L, Ageberg E, Engelhardt M, Arnold MP, Postema K, Otten E, Dijkstra PU. Proprioceptive deficits after ACL injury: are they clinically relevant? Br J Sports Med 2012;46:3:180-192.

25. Burgess PR, Wei JY, Clark FJ, Simon J. Signalling of Kinesthetic Information by Peripheral Sensory Receptors. Annu Rev Neurosci1982;5(1):171-188.

26. Callaghan MJ, Selfe J, Bagley PJ, Oldham JA. The effects of patellar taping on knee joint proprioception. J Athl Train 2002;37(1):19-24.

27. Herrington L. The rehabilitation of two patients with functionally unstable ACL deficient knees; a case report. Phys Ther Sport 2004;5:175-178.

28. Arockiaraj J, Korula RJ, Oommen AT, Devasahayam S, Wankhar S, Velkumar, S and Poonnoose PM. Proprioceptive changes in the contralateral knee joint following anterior cruciate injury. Bone Joint J 2013;95-B:188-191.

29. Barrack RL, Lund PJ, Skinner HB. Knee Joint Proprioception Revisited. J Sport Rehabil 1994:3:18-42.

30. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. Psychol Bull 1979;86(2):420-428.

31. Relph N, Herrington L. Inter-examiner, intra-examiner and test-retest reliability of clinical knee joint position sense measurements using an image capture technique. J Sport Rehabil 2015; Technical Report 12, http://dx.doi.org/10.1123/jsr.2013-0134.

32. Angoules AG, Mavrogenis AF, Dimitriou R, Karzis K, Drakoulakis E, Michos J, Papagelopoulos PJ. Knee proprioception following ACL reconstruction; a prospective trial comparing hamstrings with bone–patellar tendon–bone autograft, The Knee 2011: 18(2):76-82.

33. Gardner MJ, Altman DG. Confidence intervals rather than P values: estimation rather than hypothesis testing. BMJ 1986;292(15): 746-750.

34. Field A. *Discovering Statistics using SPSS*. London: Sage Publications; 2005.

35. Denti M, Monteleone M, Berardi A, Panni AS. Anterior cruciate ligament mechanoreceptors. Histologic studies on lesions and reconstruction. Clin Orthop Relat Res. 1994; 308: 29-32.

36. Friden T, Roberts D, Zatterstrom R, Lindstrand A, Moritz U. Proprioception after an acute knee ligament injury: a longitudinal study on 16 consecutive patients. J Orthop Res 1997; 15(5): 637-644.

37. Isaac, SM, Barker KL, Danial IN, Beard DJ, Dodd CA, Murray DW. Does arthroplasty type influence knee joint proprioception? A longitudinal prospective study comparing total and unicompartmental arthroplasty. The Knee 2007; 14(3): 212-217.

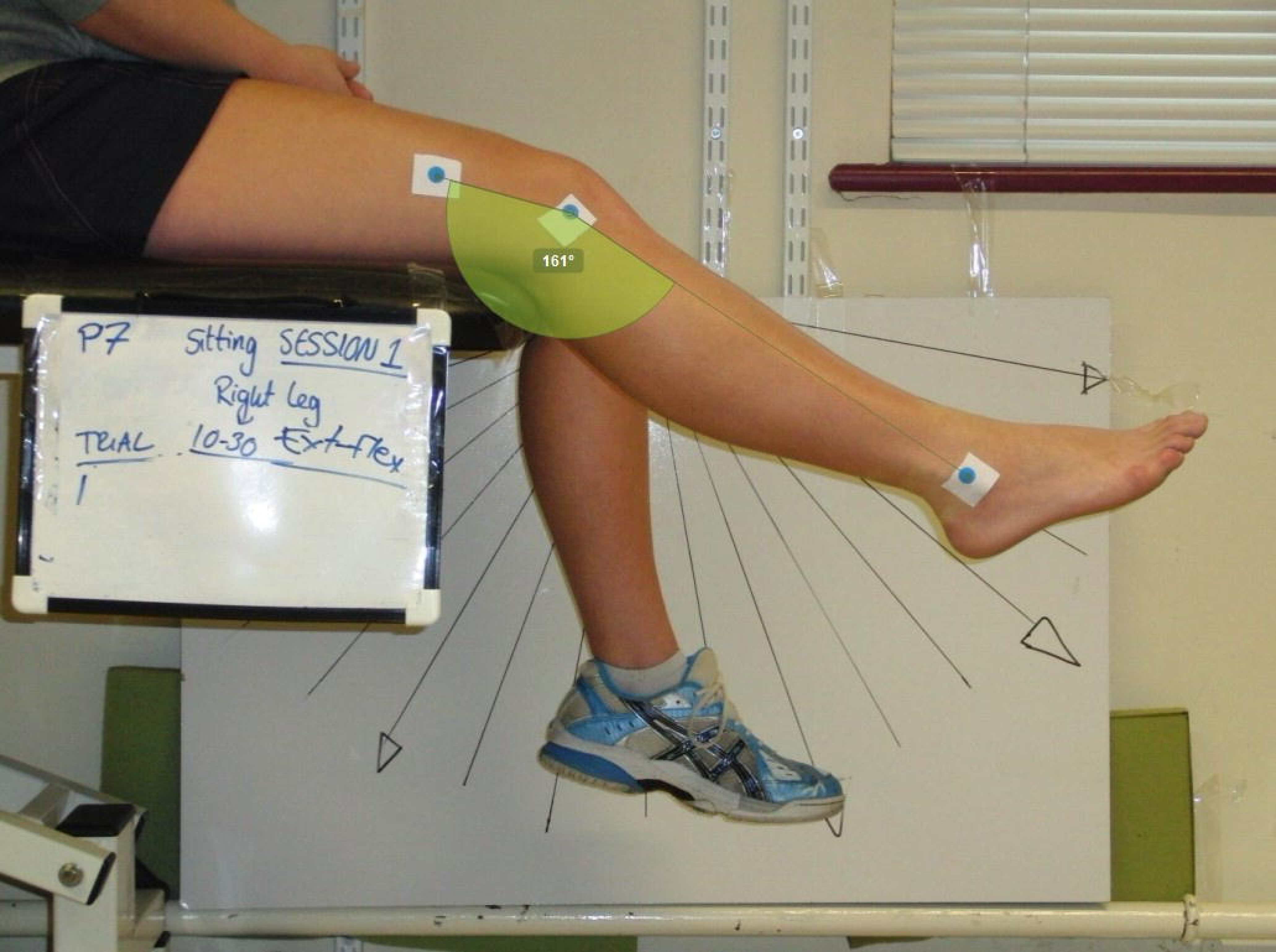
38. Iwasa J, Ochi M, Adachi N, Tobita M, Katsube K, Uchio Y. Proprioceptive improvement in knees with anterior cruciate ligament reconstruction. Clin Orthop Relat Res 2000; 381:168-176.

39. Reider B, Arcand MA, Diehl L, Mroczek K, Abulencia A, Stroud CC, Staszak, P. Proprioception of the knee before and after anterior cruciate ligament reconstruction. Arthroscopy 2003; 19(1): 2-12.

40. Fremerey RW, Lobenhoffer P, Zeichen J, Skutek M, Bosch U, Tscherne H. Proprioception after rehabilitation and reconstruction in knees with deficiency of the anterior cruciate ligament: a prospective, longitudinal study. J Bone Joint Surg Br 2000; 82(6): 801-806.

41. Ashton-Miller J.A, Wojtys EM, Huston LJ, Fry-Welch D. Can proprioception really be improved by exercises? Knee Surg Sports Traumatol Arthrosc 2001; 9:128-136.

42. Boisgontier MP, Swinnen SP. Proprioception in the cerebellum. Front Hum Neurosci 2014;8:212.


161°
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Right Leg
TRIAL 10-30 Ext-flex
1

12.0
10.0
8.0
6.0
4.0
2.0
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Absolute Error Score (°)
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*
ACL-D
Contralateral Leg
Control

Figure 1. Typical set up and analysis for knee JPS data collection.

Figure 2. Mean and Standard Error JPS Absolute Error Scores for ACL deficient and normative populations. ACL-D: Anterior Cruciate Ligament Deficiency. **Significantly different to contralateral leg and control group. *Significantly different to control group.