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ORIGINAL RESEARCH

THE EFFECT OF CONSERVATIVELY TREATED ACL INJURY ON KNEE JOINT POSITION SENSE

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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. Researchers have suggested that 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 conservative rehabilitation options rather than surgical intervention.

Purpose: The purpose of this study was to determine the effect of ACL deficiency on knee joint position sense following conservative, non-operative treatment and return to physical activity. A secondary purpose was to report the reliability and measurement error of the technique used to measure joint position sense, (JPS) and comment on the clinical utility of this measurement.

Study Design: Observational study design using a cross-section of ACL deficient patients and matched uninjured 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, between 10°-30° of knee flexion was determined. This error score was derived from the difference between the target and repositioning angle.

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 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 minimum detectable change (MDC) was 1.3° and 0.4° on asymptomatic and symptomatic subjects respectively.

Conclusion: This study confirms a static proprioceptive deficiency exists in the knee joint following ACL injury and rehabilitation, potentially due to a reduction in functioning mechanoreceptors in the ligament over time. The differences between the ACL deficient knee and the control group were above the SEMs and MDCs 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)

Key Words: Anterior cruciate ligament, joint position sense, knee

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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 modified 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 rehabilitative program. There have been fewer studies considering the proprioception of these patients compared to those who have undergone reconstructive surgery, perhaps due to the availability of this population. However, the available literature provides a contrasting view regarding proprioception and ACL deficient patients. A number of authors have reported 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 who had undergone ACL reconstructive surgery and rehabilitation for up to 12 months postoperatively (mean 12 months post injury). Results indicated that only the acute patient group had significantly poorer JPS in their injured and uninjured knees compared to an uninjured control group. Hugn-Maan et al[13] and Katayama et al[14] reported a significant reduction in JPS in chronic ACL 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 authors have reported no knee JPS deficiency after conservative treatment of ACL injury[17-19]. Roberts et al[17] and Jensen et al[18] compared "copers" and "non-copers", both of whom had undergone physical therapy without surgical intervention, but the copers are defined as those able to return to physical activity, whereas the non-copers have continued problems with neuromuscular control during similar physical activity. Both groups of authors 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 offered directly from the ACL.

An alternative reason for the lack of significant differences in JPS 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 error. [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 artefact. [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 determine the effect of ACL deficiency on knee joint position sense following conservative, non-operative treatment and return to physical activity. A secondary purpose was to report the reliability and measurement error of the technique used to measure joint position sense and comment on the clinical utility of this measurement.

METHODS

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 ± 2months) 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 program that included proprioceptive exercises as proposed by 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 ± 9.37years, mass 71.5 ± 14.78kg, height 1.7 ± 0.11m). All participants were free from current lower extremity injury and any chronic disease that may have affected 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).

Design and Procedures

The study used an observational 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 suggested by the authors 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 large[30] test-retest reliability statistics in asymptomatic patients (intra-class correlation coefficient = 0.79, SEM = 0.5° and MDC = 1.3°)[31] and ACL patients (intra-class correlation coefficient = 0.96, SEM = 0.2° and MDC = 0.4°).[32]

The participants were seated at the end of a treatment couch and blindfolded. The leg was passively moved by the experimenter between 10-30° of knee flexion from a starting angle of 0° to a random 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 (Figure 1). The participant then actively held the leg in this single position between 10 and 30° of knee flexion for five seconds (Figure 1). 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 three meters 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 center of the camera lens. The leg was then passively returned by the researcher to the starting angle of 0° and then the participant was instructed to actively move the same leg back to the target angle and hold the leg in this position. Another photograph was taken and

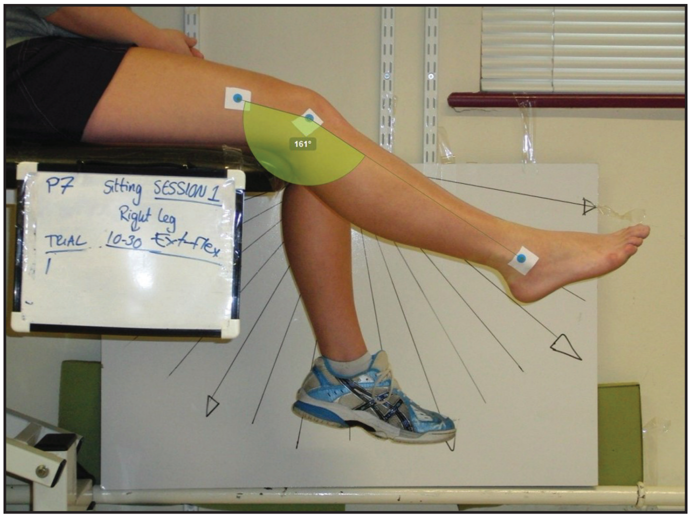

Figure 1. *Typical set up and analysis for knee joint position sense data collection.*

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.

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 (between 10-30° of knee 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 fall, 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]

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

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

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 utilized. 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]

RESULTS

Figure 2 and Table 1 illustrate 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

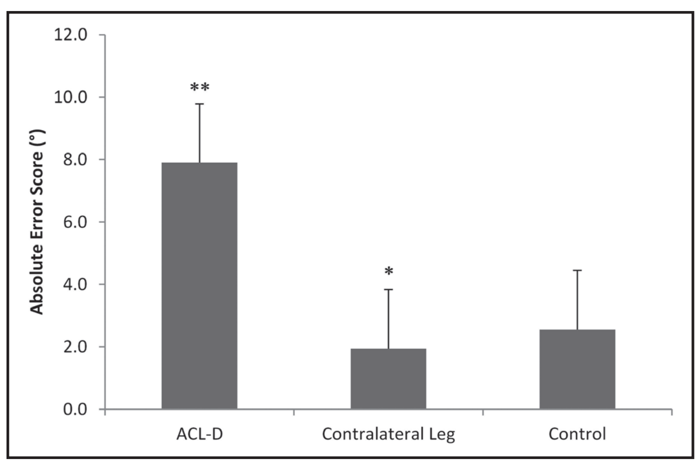

Figure 2. *Mean and standard error joint position sense absolute error scores for ACL-D and normative populations.*

*ACL-D = anterior cruciate ligament deficient. **Significantly different than contralateral leg and control group. *Significantly different than control group.*

Table 1. *Comparisons of knee error scores, reported in degrees.*

Group	Error scores Mean (95% CIs)	p-value vs ACL-D Injured Leg	Effect size
ACL-D injured leg	7.9 (6.3, 9.5)		
ACL-D contra-lateral leg	2.0 (1.3, 2.7)	<0.001	-0.61
Uninjured control leg	2.6 (2.2, 3.0)	<0.001	-0.77

(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 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 MDC values (1.3° and 0.4°) found for asymptomatic and symptomatic patients respectively.

DISCUSSION

The aim of this study was to consider the effects of chronic ACL deficiency treated with physical therapy only (no reconstructive surgery) on static knee joint position sense in patients who had returned to physical activity. The results suggest that 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 authors 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 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 may support this theory, however this theory could only be confirmed with histological research evidence both after the initial injury and after rehabilitation.

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 program 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 control subject's leg respectively. Therefore longitudinal studies may identify whether 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 with altered static position sense does not impair performance. The patients had all returned to physical activity levels corresponding to competitive and recreational sports and were free from injury at the time of testing. It is possible joint position sense is not related to functional movement. [24] The results of a recent literature review did not illustrate any significant correlations between ACL deficiencies and reduced functional performance. [24] Therefore it is possible patients are able to use appropriate motor control strategies in order 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 criticized.[22,24] It is important that reliability and sensitivity is reported to acknowledge any error that may occur due to measurement only. In the current study the differences between ACL patients and the contralateral and external control legs were above the SEM and MDC values provided in previous studies with similar measurement strategies.[31,32] Therefore, for this sample, the differences were clinically relevant.

An interesting finding was that patient's uninjured limbs had better knee joint position sense than the controls, however the effect size was only moderate. Previous research has indicated the opposite to this finding; that the contralateral limb of ACL patients demonstrates poorer knee proprioception than controls. [28] The improved ability in the contralateral leg in patients may be attributed to a training effect achieved during rehabilitation programs. The uninjured limb may compensate 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 would stimulate more mechanoreceptors during testing. [42] A further limitation is the lack of a power calculation to determine an appropriate sample size. However, accompanying effect sizes demonstrate medium to large effect sizes and the SEM and MDC are also reported. Another limitation was that there was 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.

CONCLUSION

The findings of the current study demonstrate that patients who underwent conservative treatment of an ACL injury have a reduction in knee joint position sense when compared to the contralateral knee and controls. As there is a lack of evidence to support a link between function and static knee joint position sense ability, it may be that 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 may 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.

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