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SOMATOSENSORY DEFICITS IN POST-ACL RECONSTRUCTION PATIENTS: A CASE–CONTROL STUDY

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ABSTRACT: *Introduction*: Diminished cutaneous detection thresholds have been identified in patients with multiple orthopedic conditions, and these phenomena may occur in postanterior cruciate ligament reconstructed (ACLR) patients. The purpose of this study was to determine if differences in lower extremity cutaneous detection thresholds exist in post-ACLR patients when compared with healthy controls. *Methods*: Fifteen individuals who were post-ACLR and 15 individuals who had no history of knee injury participated. Light touch cutaneous detection thresholds were assessed at 4 locations on the foot and ankle (first metatarsal, fifth metatarsal, medial malleolus, and lateral malleolus). Nonparametric statistics examined group differences between the sites. *Results*: ACLR subjects had decreased cutaneous sensation at the first metatarsal and medial malleolus compared with healthy controls. *Conclusions*: Somatosensory deficits are present in post-ACLR patients. Future research should investigate these phenomena longitudinally in post-ACLR individuals along with somatosensory targeted interventions.

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Approximately 250,000 anterior cruciate ligament ruptures (ACL) occur in the United States each year.[1] A large portion of these injuries occur in young, physically active individuals participating in athletic activities.[2] Individuals who desire to return to competitive sports often undergo ACL reconstruction (ACLR) with the goal of restoring knee stability.[3] Although the primary goal of reconstructive surgery is to recover the mechanical stability of the knee, long-term consequences secondary to this injury continue to affect patients. It is estimated that approximately 50% of individuals who undergo ACLR will develop osteoarthritis 10–20 years following the injury.[4] More immediate consequences manifest as activity limitations, participation restrictions, and sensorimotor deficiencies.[5–7] Therefore, it is imperative to identify underlying impairments following ACL injury and subsequent reconstruction to improve short- and long-term health in these patients.

Injury to the ACL not only leaves the patient lacking a mechanical restraint instrumental to joint stability but also impairs sensorimotor function.[5–7]

Abbreviations: 1st-met, first metatarsal; 5th-met, fifth metatarsal; ACL, anterior cruciate ligament; ACLR, anterior cruciate ligament reconstruction; CNS, central nervous system; ICC, intraclass correlation coefficient

Key words: foot; knee injury; light touch; sensorimotor; sensory

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Because the ACL plays a key role in the central somatosensory feedback loop by providing information on knee joint position and movement,[8] it is no surprise this neural feedback mechanism is affected, and sensorimotor deficits such as joint position sense, muscle inhibition, and postural control arise.[5–7] Somatosensory function may be further disrupted in individuals who have undergone ACLR because of damage to cutaneous nerves during surgical procedures. For example, disruption to branches of the saphenous nerve has been well documented, particularly in individuals who received a hamstring or bone-patellar-bone autograft.[9–15] Therefore, various sources of somatosensory information may be impaired in individuals who are post-ACLR.

The somatosensory deficits following ACLR have been traditionally examined local to the knee. However, examining somatosensation beyond the knee may provide additional insights into the long-term consequences of ACL injury. While there is limited evidence regarding somatosensory alterations distal to the knee following ACL injury, the vibrotactile perception threshold of the medial malleolus was lower (more sensitive) in a cohort of individuals who were $\geq$10 weeks post ACL injury or $\geq$16 weeks post ACLR compared with control subjects.[16] Despite these findings, higher vibrotactile perception thresholds have been documented throughout the lower extremity in individuals with knee osteoarthritis.[17]

The underlying mechanisms associated with changes in tactile sensation distal to the knee in these patient populations are unclear; however, this is an important area of research, as diminished sensory input could have a deleterious effect on protective muscular reflexes and mechanical loading on the joint.[16,18] Examining cutaneous acuity in post-ACLR individuals who are beyond postsurgical rehabilitation, but have most likely not begun to develop knee osteoarthritis, may elucidate if this facet of somatosensation contributes to sensorimotor deficits following ACL injury or the pathogenesis of knee osteoarthritis. Therefore, the purpose of this study is to determine if cutaneous detection thresholds on the ankle and foot are different in individuals who are $\geq$1 year post-ACLR compared with uninjured matched controls. We hypothesize

Table 1. Demographic information [median (Interquartile range)] for study subjects.*

	ACLR (n = 15)	Healthy (n = 15)	P-Value
Age (years)	22 (5)	21 (6)	0.90
Height (cm)	167.6 (12.7)	167.6 (17.8)	0.54
Mass (kg)	68.2 (18.2)	68.2 (14.6)	0.94
NASA score	7.4 (3.0)	6.0 (2.0)	0.03
Years since surgery	4 (4)	NA	

Separate Mann-Whitney U tests were used to determine differences between groups.

that individuals who are ≥1 year post-ACLR will have higher detection thresholds compared with controls, indicating that diminished sensation is present in the distal lower extremity.

MATERIALS AND METHODS

Design. A case–control study design was implemented to determine if differences in cutaneous detection thresholds exist between subjects with and without a history of ACLR.

Population. Subjects were recruited through the use of informational fliers and word of mouth at Old Dominion University and the surrounding Hampton Roads, Virginia area. A total of 30 subjects were included with 15 subjects in the control group and 15 subjects in the ACLR group; demographic information can be found in Table 1. Subjects were included in the ACLR group if they were at least 1 year post-ACLR and had been cleared for physical activity, self-reported participation in all meaningful activities, were at least moderately physically active (NASA physical activity score ≥3), and were between the ages of 18 and 35. Subjects were excluded if they had a lower extremity injury in the test extremity within the preceding 6 weeks, a history of lower extremity surgery within 1 year, or a health condition that might affect balance. Control subjects had the same inclusion and exclusion criteria; however, they must have had no history of ACLR. Subjects were matched by gender, age, and limb dominance.

Procedures. Light touch cutaneous sensation was collected from multiple sites on the foot and ankle in all subjects during a single data collection session. All research procedures were approved by the Old Dominion University Institutional Review Board, and informed consent was obtained from each subject before data collection.

Instrumentation. *Cutaneous Detection Threshold Testing.* Cutaneous sensation detection thresholds were assessed using a 20-piece Semmes-Weinstein Monofilament kit (Texas Medical Design, Inc., Sugarland and Stafford, Texas) at 4 locations: the plantar aspect of the head of first metatarsal (1^{st}-met) and the base of fifth metatarsal (5^{th}-met) and both the medial malleolus and lateral malleoli. During data collection, subjects were positioned prone on a plinth with noise canceling headphones. All testing locations were palpated and marked using a washable marker before testing. A nylon monofilament was applied perpendicular to the skin with enough force to create a "C" shape and held for approximately 1 s. Subjects were instructed to state "yes" at any point a monofilament was perceived.

Testing at each site began with a 4.74 level monofilament, and a 4-2-1 stepping algorithm was used to determine cutaneous detection thresholds.[19–21] The algorithm[21] was repeated at all 4 testing locations in a counterbalanced order. This method has demonstrated acceptable interrater (intraclass correlation coefficient $[ICC]_{2,1}$ = 0.62–0.92) and intrarater reliability ($ICC_{2,1}$ = 0.61–0.85) for both novice and experienced clinicians.[21]

Statistical Analysis. Descriptive statistics were calculated for all demographic and dependent variables (median, interquartile range). Separate Mann-Whitney *U*-tests were conducted to determine group differences between demographic variables and cutaneous detection thresholds (medial malleolus, lateral malleolus, 5^{th}-met, 1^{st}-met). Nonparametric tests were used due to the ordinal distribution of the data and the small sample size. Significance was set *a priori* at $P < 0.05$ for all analyses. All statistical analyses were performed using SPSS (version 22, IBM Corp, Armonk, New York).

RESULTS

The results of the demographic analyses can be found in Table 1. There were no significant differences between any of the demographic variables besides the NASA physical activity scale (Table 1). Descriptive statistics and the results of the Mann-Whitney *U*-tests for the cutaneous detection thresholds can be found in Table 2. The results indicated significant differences between groups at both the 1^{st}-met and the medial malleolus, with the ACLR group having higher detection thresholds when compared with the healthy controls (Table 2).

DISCUSSION

The primary purpose of this study was to determine if differences in light touch sensory detection thresholds exist between post-ACLR subjects and healthy controls. The results indicated that individuals who were >1 year post-ACLR demonstrated decreased light touch sensitivity (or higher detection thresholds) at the 1^{st}-met and medial malleolus. As hypothesized, these findings suggest that individuals who have undergone ACLR experience

Table 2. Descriptive Statistics [Median (Interquartile Range)] for all Independent Variables.

Cutaneous detection threshold	ACLR group (n = 15)	Healthy group (n = 15)	P-Value
1st-Met	3.84 (0.33)	3.61 (1.73)	<0.001*
5th-Met	4.08 (0.56)	3.84 (1.34)	= 0.202
Med-Mal	4.31 (0.43)	4.08 (0.47)	= 0.002*
Lat-Mal	4.31 (0.85)	4.31 (0.90)	= 0.539

Med-Mal, medial malleolus; Lat-mal, lateral malleolus.

**Significantly different from the control group (P < 0.05). Group differences examined using separate Mann-Whitney U-tests.*

somatosensory impairments associated with cutaneous receptors located in the foot and ankle. While our hypothesis was confirmed through statistical analysis, it should be pointed out that the median light touch sensory detection thresholds at the 1st-met for the ACLR group was classified as "diminished protective sensation" (3.84) and "normal" sensation (3.61) for the healthy group as reported by the manufacture guidelines.[21,22]

Similar guidelines have not been established for the ankle sites, which makes it challenging to determine the clinical relevance of the statistical differences identified at the medial malleolus. While the differences in light touch threshold were subtle, the median values for each group appear to be distinctive thresholds that may have future clinical application. For example, 12 of 15 ACLR subjects exhibited a 1st-met threshold $\geq$3.84, whereas 13 of 15 healthy subjects had thresholds $\leq$3.61. The degree to which these subtle threshold differences contribute to sensorimotor dysfunction, joint loading, or injury mechanisms is unclear. The clinical utility of the median threshold values from this study require further investigation but may provide preliminary markers to identify ACLR individuals with sensorimotor deficits and further examine the ramifications of this impairment.

These results are in line with previous research which identified decreased vibratory perception thresholds at the 1st-met, medial malleolus, lateral malleolus, medial femoral condyle, and lateral femoral condyle in subjects with radiographic knee osteoarthritis.[17] This is likely an important association given the relationship between ACL injury and development of knee osteoarthritis. These results are also in line with previous research that demonstrated decreased vibratory perception thresholds in ACLR patients who scored poorly on functional testing.[23] However, the results contrast with an investigation that identified increased vibratory perception threshold values at the medial malleolus and medial femoral condyle in individuals with a history of ACL injury and/or reconstruction when compared with controls.[16] The differences in results may exist, as the subjects included in our investigation were on average 4 years post-ACLR, and the subjects included in the previous investigation[16] were on average 24 months postinjury, 14 months post-ACLR, or had not undergone ACLR.[16] It is possible that light touch sensitivity may diminish over time in these individuals. Understanding the time course for alterations in cutaneous sensation requires additional research and may provide supplementary information regarding the secondary consequences associated with ACLR, such as re-injury and development of osteoarthritis.

Despite identification of light touch sensory detection threshold deficits in a variety of orthopedic knee conditions, the origin of these somatosensory alterations is unclear. The skin overlying the 1st-met is innervated primarily by the medial plantar nerve, a division of the tibial nerve. The skin overlying the medial malleolus is innervated primarily by the saphenous nerve, a division of the femoral nerve. Previous investigations of sensation local to the knee using difference methodologies have identified sensory changes in the cutaneous areas innervated by the saphenous nerve local to the knee for individuals who have undergone hamstring autograft ACLR[9–13] and bone–patellar tendon–bone autograft.[14,15] At this time, we cannot speculate whether or not graft or harvest type had an effect on light touch detection threshold changes in the subjects included in this research study. The subjects were asked to provide their graft type, and the majority were ipsilateral bone–patellar tendon–bone (n = 7; 47%); however, this information was self-reported, as the authors did not have access to surgical notes to confirm graft selection. Future research may consider investigating the different ACLR procedures and somatosensory deficits.

Because it is unlikely that all of the light touch detection threshold differences were the result of peripheral nerve injury or surgery, alternative theories which involve reorganization of the central nervous system (CNS) initiated by a loss of mechanoreceptor-mediated afferent feedback should be examined.[24] The tibial nerve provides direct innervation to the ACL,[25] and ACL injury may disrupt afferent input which may trigger a cascade of altered lower extremity somatosensation affecting the afferent information received by the CNS.[24] In addition, ACL patients commonly experience decreased activation of the quadriceps muscle group, which is innervated by the femoral nerve and is associated with decreased alpha motoneuron excitability.[5,24] It is possible that the light touch detection threshold differences we found may be a contributor or an analogous sensory response to the well-known residual motor deficiencies following ACL injury. Our findings may provide additional insights into recent theoretical models that present potential mechanisms for afferent-mediated changes in CNS organization following joint injury.[24,26]

This study has some limitations. The sample size included was small, and the group differences were subtle despite being statistically significant. Although the magnitude of the group differences was small and similar results have been identified in other studies[22,27] using the same testing procedures, future research should continue to explore this phenomenon using a larger subject population. In addition, this study did not blind the investigators to group membership. Future investigators should be blinded as to group membership by requiring the subjects to wear pants, and to ensure that investigators who collect sensation outcomes are blinded to group membership by placing the subjects prone before data collection. Finally, although we did not enroll any patients with foot abrasions or lesions, we did not control for potential confounding factors such as plantar calluses and hair surrounding the malleoli.

In conclusion, post-ACLR subjects demonstrated decreased light touch sensory detection thresholds at the 1st-met and medial malleolus when compared with healthy controls. These results suggest that additional components of the sensorimotor system, such as the somatosensory system, are affected in post-ACLR patients years after reconstruction. Target rehabilitation strategies aimed at improving not only motor function but also somatosensory function are warranted in these patients. Future research should continue to examine intervention strategies that are geared toward improving postural control and sensation in individuals following ACLR along with other orthopedic conditions that have demonstrated similar deficits.

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