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Original Research

Examination of ankle function in individuals with a history of ACL reconstruction

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ABSTRACT

Objective: To determine the relationship between self-reported ankle and knee function, and to examine differences in ankle function between healthy and injured limbs in individuals with a history of ACL reconstruction (ACLR).
Design: Cross-sectional.
Setting: Laboratory.
Participants: A total of 18 adults with a history of ACLR.
Main outcome measures: Participants completed four patient-reported outcomes: the Knee Injury and Osteoarthritis Outcome (KOOS), the Fear-Avoidance Belief Questionnaire, the modified Disablement in the Physically Active Scale, and the Quick-Foot and Ankle Ability Measure (Quick-FAAM). Additional ankle function measures collected bilaterally included plantar cutaneous sensation, dorsiflexion range of motion and dorsiflexion and plantarflexion strength.
Results: Three KOOS-subscales were significantly, moderately correlated to the Quick-FAAM for the injured limb. There were differences in the uninjured and injured Quick-FAAM scores. No other differences were observed in ankle function measures.
Conclusions: Self-reported ankle and knee function are correlated in participants with a history of ACLR. Clinicians should be made aware of the influence of this health condition on the distal joint, and treatment strategies to address these perceived impairments should be considered.

1. Introduction

Individuals who participate in physical activity have a risk of sustaining a musculoskeletal injury. Approximately 50% of these injuries are to the lower extremity(Hootman, Dick, & Agel, 2007). Specifically, injury to the anterior cruciate ligament (ACL) can account for approximately 6.3% of all sport related injuries (Rosa et al., 2014), and is often one of the most debilitating lower extremity injuries experienced by physically active individuals(Lohmander, Englund, Dahl, & Roos, 2007). Most often individuals who sustain an ACL injury undergo ACL reconstruction (ACLR). The primary impetus behind ACLR is to return the patient to their previous levels of function and restore overall joint health. In order to achieve these goals, patients must undergo extensive post-ACLR rehabilitation which includes early weight bearing, exercises to increase range of motion, strength, proprioception and balance, as well as, functional exercises(Malempati, Jurjans, Noehren, Ireland, & Johnson, 2015). However, despite this comprehensive rehabilitation plan, 20% of patients do not meet all of the functional criteria at return to play (Toole et al., 2018), and these patients continue to self-report functional deficits after return to activity(J.M. Hoch, Sinnott, Robinson, Perkins, & Hartman, 2017; Ingelsrud, Granan, Terwee, Engebretsen, & Roos, 2015). Additionally, approximately 33% fail to return to their previous levels of activity(Ardern, Taylor, Feller, & Webster, 2012, 2014).

Individuals post-ACLR are 15 times more likely to sustain a second ACL injury to the ipsilateral or contralateral limb within their first year of return to physical activity(Fukuda et al., 2013). A recent report documented re-injury rates up to 24-months after return revealed 9% of the population re-injured their graft, and 20.5% tore the contralateral ACL(Paterno, Rauh, Schmitt, Ford, & Hewett, 2014). Of even more concern are the poor post-revision

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ACLR outcomes that have been reported in the literature(Wright et al., 2011). However, previous research has focused predominantly on knee specific interventions to decrease the risk of re-injury, often overlooking other lower limb impairments which may result in additional injury risk such as ankle function. Ankle function is important to overall lower limb function, and deficits in ankle function have been identified as a contributing risk factor to lower extremity injury(Gabbe, Finch, Wahswelner, MPhysio, & Bennell, 2014; Malliaras, Cook, & Kent, 2006). Relationships between measures of ankle dorsiflexion range of motion (DROM), knee displacement, and ground reaction forces during landing have also been established, where individuals with limited ankle DROM exhibit less knee flexion displacements and greater ground reaction forces and could be at a greater risk for ACL injury (or re-injury)(Fong, Blackburn, Norcross, McGrath, & Padua, 2011). It has also been determined that ankle DROM (Wahlstedt & Rasmussen-Barr, 2015) and plantar cutaneous sensation on the foot and malleolus are decreased in post-ACLR participants compared to healthy controls(Hoch, Perkins, Hartman, & Hoch, 2017). Thus, it is important for clinicians to assess ankle function in post-ACLR patients in order to identify deficits that may predispose an individual to further injury and warrant additional treatment interventions.

Alterations in sensorimotor function of the foot and ankle in post-ACLR patients may be explained through recent theories which involve reorganization of the central nervous system (CNS) initiated by a loss of mechanoreceptor-mediated afferent feedback(Ward et al., 2015). The tibial nerve provides direct innervation to the ACL (Kennedy, Alexander, & Hayes, 1982) and ACL injury may trigger a cascade of altered lower extremity somatosensation affecting the afferent information received by the CNS(Ward et al., 2015). In addition, ACL patients commonly experience decreased activation of the quadriceps muscle group(Hart, Pietrosimone, Hertel, & Ingersoll, 2010; Ward et al., 2015). However, it is less well known if motor deficits are present in the musculature responsible for ankle plantarflexion and dorsiflexion following ACL injury. Deficits in somatosensory and motor structures innervated by the tibial nerve may provide additional insights into recent theoretical models that present potential mechanisms for afferent-mediated changes in CNS organization following joint injury(Kapreli & Athanasopoulos, 2006; Ward et al., 2015).

Patient-reported outcomes, such as the Knee Injury and Osteoarthritis Outcome Score (KOOS), are utilized frequently in the care of patients after ACLR and in ACLR research. However, to our knowledge, no studies have investigated self-reported ankle function in the post-ACLR population nor have examined the relationship of self-reported ankle function and knee function in this population. In addition, few studies have investigated ankle function bilaterally within a post-ACLR population. Due to the influence of ankle function on lower extremity function and injury risk, further investigation into body function and structure impairments specific to the ankle, and self-reported limitations and restrictions compared bilaterally in post-ACLR participants is necessary. The primary purpose of this study was to examine differences in self-reported ankle function, DROM, plantar cutaneous sensation and strength measures between post-ACLR limbs and healthy limbs in a post-ACLR population. We hypothesized that self-reported ankle function, DROM and strength measures would be decreased in the post-ACLR limb when compared to the uninjured limb A secondary purpose was to examine the relationship between self-reported knee function across five different subscales and self-reported ankle function. We hypothesized those individuals with decreased self-reported knee function would also have decreased self-reported ankle function.

2. Materials and methods

2.1. Design

A cross-sectional study design was used to examine differences in ankle function between limbs in post-ACLR subjects. Variables of interest for this study were scores on the Quick-Foot and Ankle Ability Measure (Quick-FAAM), weight-bearing ankle DROM, plantar-flexion and dorsiflexion strength, and plantar cutaneous detection thresholds. All subjects were tested bilaterally for all measures.

2.2. Participants

A total of 18 participants with a history of unilateral ACLR (average time since surgery 7 ± 3 years) participated (Table 1). Participants self-reported regular participation in moderate physical activity, described as "fairly light to somewhat hard" or vigorous physical activity described as "somewhat to very hard" on a perceived exertion scale(Garber et al., 2011). Subjects were excluded if they had history of injury or surgery to the involved limb within the past year, history of bilateral ACLR, history of repetitive ankle sprain to either limb, or other health conditions that may affect balance and light touch sensation thresholds. This study was approved by the IRB, and all subjects read and signed an IRB approved informed consent document before data collection.

2.2.1. Procedures

The participants reported to the laboratory for one test session. After informed consent, the participants completed a health history questionnaire which collected information such as age, gender, race, ethnicity and anthropomorphic measurements. Additional questions examined lower extremity injury history, limb dominance, and participation in physical activity. In addition, subjects provided information pertaining to their index surgery such as year of surgery, graft type, and rehabilitation protocol including whether or not immobilization bracing was utilized post-operatively. Next the patients completed four PROs: the Fear Avoidance Belief Questionnaire (FABQ) (Waddell, Newton, Henderson, Somerville, & Main, 1993), the KOOS for their reconstructed knee only (Roos, Roos, Lohmander, Ekdahl, & Beynnon, 1998), the modified Disablement in the Physically Active Scale (mDPA) (Houston, Hoch, Van Lunen, & Hoch, 2015), and the Quick-FAAM which assess ankle function bilaterally (Hoch, Hoch, & Houston, 2016) electronically. These measures were used to describe the participant's overall HRQL, self-reported knee function, ankle function, and fear-

Table 1
Participant profile, including demographics and patient-reported outcome scores.

Descriptive Information	Mean (Standard Deviation)
Age	24.6 (4.6)
Gender (M/F)	6/12
Height (centimeters)	215.7 (107.2)
Weight (kilograms)	70.8 (15.2)
FABQ-PA	7.22 (4.8)
FABQ-Sport	10.7 (8.7)
KOOS-Symptoms	81.1 (12.7)
KOOS-Pain	91.2 (7.3)
KOOS-ADL	97.3 (3.5)
KOOS-Sport	85.6 (15.1)
KOOS-Quality of Life	73.6 (16.0)
MDPA-PSC	5.94 (5.7)
MDPA-MSC	1.5 (2.0)

Note: FABQ- Fear Avoidance Belief Questionnaire, PA-Physical Activity, ADL-Activities of Daily Living, MDPA-Modified Disablement in the Physically Active Scale, PSC— Physical Summary Component, MSC- Mental Summary Component.

avoidance beliefs. For the clinician and laboratory measures used to assess ankle function, the sensation testing was completed first for every participant, and the remaining outcome measures were completed in a counter balanced manner. The order of testing the involved and uninvolved limb was also counterbalanced.

2.3. Measures of ankle function

2.3.1. Self-reported ankle function

The Quick-Foot and Ankle Ability Measure (Quick-FAAM) is 12-item region specific PRO used to assess ankle function(Hoch et al., 2016). The Quick-FAAM is scored using a 5-point Likert scale, and the final score is converted to a percentage where a lower percentage indicates decreased self-reported ankle function. The Quick-FAAM demonstrated excellent internal consistency, with Cronbach's alpha of 0.94. The Quick-FAAM is responsive (Hoch, Powden, & Hoch, 2018), has strong test-retest reliability (Hoch et al., 2018), and is valid in a population with acute and sub-acute foot, ankle and to conditions(Hoch, Legner, Lorete, & Hoch, 2017).

2.3.2. Dorsiflexion range of motion

The weight bearing lunge test (WBLT) was used to assess ankle DROM (Bennell et al., 1998). First, participants were instructed to stand facing the wall with their hands placed on the wall in front of them. Next they were instructed to place the test limb at the 4 cm mark on the tape measure which was taped perpendicular to the wall. The subjects were then instructed to lunge forward and touch their knee to the wall while keeping the test foot firmly planted on the ground. If the subject was unable to touch his or her knee to the wall at the 4 cm mark, their great toe of the test limb was moved 1 cm forward and the task was repeated. If the subject remained in test position while executing the task, they were then progressed backwards in increments of 1/2 cm or if they failed the task, they were progressed forwards in increments of 1/2 cm. Maximal DROM was determined when the knee was no longer able to touch the wall and/or the heel was unable to remain on the ground. At the point of maximal DROM, the distance from the great toe to the wall was recorded (cm). The WBLT has excellent intrarater and interrater reliability with Intraclass correlation coefficients (ICC) of 0.97–0.98 and ICC 0.97–0.99, respectively(Bennell et al., 1998). Subjects were allowed 1 practice trial followed by 2 test trials. The average of the 2 test trials was used for data analysis.

2.3.3. Plantarflexion and dorsiflexion ankle strength

Concentric ankle dorsiflexion (DF) and plantarflexion (PF) peak torque was measured with the Biodex System 4 Pro dynamometer (Biodex System 4 Pro; Biodex Medical Systems, Inc., Shirley, NY). The testing procedures followed previously published protocols(Biodex Medical Systems). Concentric plantarflexion and dorsiflexion peak torque were assessed bilaterally at a velocity of 60 m/s and normalized to body weight. The subjects completed a 5-repetition practice trial and a 5-repetition test trial for each limb(Thomas, Villwock, Wojtys, & Palmieri-Smith, 2013). The average of the 5–repetition test trials for both plantarflexion and dorsiflexion isokinetic strength (Nm/kg) were used for data analysis.

2.3.4. Light touch detection thresholds

A 20-piece Semmes-Weinstein Monofilament (SWM) kit was used to assess light touch sensation thresholds on the plantar aspect of the 1st metatarsal and the medial malleolus using a previously described 4-2-1 stepping algorithm. The testing began with the 4.74 monofilament and proceeded and the detection threshold was determined through the staircase application procedure previously described(Dyck, Obrien, Kosanke, Gillen, & Karnes, 1993; Snyder, Munter, Houston, Hoch, & Hoch, 2015). Previous research has demonstrated excellent interrater and intrarater reliability when measured in a healthy adult population(Snyder et al., 2015).

2.3.5. Statistical analysis

Descriptive statistics (means±standard deviations or frequency (%)) were calculated for all patient demographics. The data for the self-reported outcomes and plantar cutaneous sensation are ordinal in nature, therefore, medians (ranges) were calculated for all outcome variables. A total of 6 separate Wilcoxon Signed Rank Tests were used to assess differences in outcomes between the ACLR limb and healthy limb. A total of 5 separate spearman rank correlations were performed to examine the relationship between self-reported knee function on the KOOS subscales and the Quick-FAAM. The correlation coefficients were interpreted as no relationship (0.00–0.25), fair relationship (0.25–0.50), moderate relationship (0.51–0.75) and good relationship (>0.75)(Portney & Watkins, 2009). Alpha was set a priori $p < 0.05$ for all analyses. All statistical analyses were performed in IBM SPSS Statistics software version 22 (Armonk, New York).

3. Results

Participant profiles, including demographics and baseline PRO scores can be found in Table 1. Summary measures (median (range)) for all ankle function variables can be found in Table 2. There were significant differences between the uninjured limb (100.00 (3.7)) and the injured (98 (9.8)) limb on the Quick-FAAM ($p = 0.041$). No other significant differences were found between limbs for the other measures of ankle function (Table 2). The results of Spearman's rank correlation analysis revealed the Quick-FAAM measure of ankle function for the injured limb was moderately correlated to the KOOS-QOL ($r = 0.553$, $p = 0.017$, Fig. 1), the KOOS-Sport and Recreation ($r = 0.615$, $p = 0.007$, Fig. 2) and the KOOS-Activities of Daily Living ($r = 0.637$, $p = 0.004$, Fig. 3) subscales and had a week correlation to the KOOS-Symptoms ($r = 0.294$, $p = 0.252$) and the KOOS-Pain ($r = 0.400$, $r = 0.100$) subscales.

4. Discussion

Our primary purpose was to examine differences in ankle function between post-ACLR limbs and healthy limbs. We included a self-reported measure of ankle function along with DROM, strength and plantar cutaneous sensation as our measures of ankle function. Interestingly, the only significant difference between limbs was self-reported ankle function, which should be interpreted with caution as the difference was only 2% which also lies within the standard error of measure (2.3%) for the outcome measure. A secondary purpose was to examine the relationship between the KOOS subscales and the Quick-FAAM score of the limb with a history of ACLR. Our analysis revealed the Quick-FAAM score was correlated to three subscales of the KOOS instrument (KOOS-QOL, KOOS-Sport and Recreation, and KOOS-Activities of Daily Living).

The only significant difference in ankle function were between the injured and uninjured Quick-FAAM scores. The median score on the injured side was a 98, with a range of scores from 65 to 100 while the median score on the uninjured side was 100 with a range of scores from 85 to 100(M.C. Hoch et al., 2016). While these differences in scores were statistically significant, caution must be used when interpreting these results as the ceiling of the instrument is a 100; indicating no deficits in self-reported ankle function. After examining the individual items, 6 participants (35%) reported slight or moderate difficulty with cutting/lateral movements,

Table 2
Summary measures and results of statistical analysis for all ankle outcome variables.

Outcome Variable	Involved Limb Median (Range)	Uninvolved Limb Median (Range)	p-value
Semmes Weinstein 1st Metatarsal	3.42 (3)	3.42 (2)	0.470
Semmes Weinstein Medial Malleolus	4.31 (3)	4.17 (1)	0.176
Weight Bearing Lunge (cm)	8.75 (2.1)	8.63 (2.0)	0.886
Quick-FAAM (%)	98 (9.8)	100 (3.7)	0.041*
Plantar Flexion (Nm/kg)	0.70 (0.3)	0.78 (0.3)	0.554
Dorsiflexion (Nm/kg)	0.28 (0.06)	0.28 (0.07)	0.831

Note: Results of the Wilcoxon signed ranks test, significant at the $p < 0.05$ level.

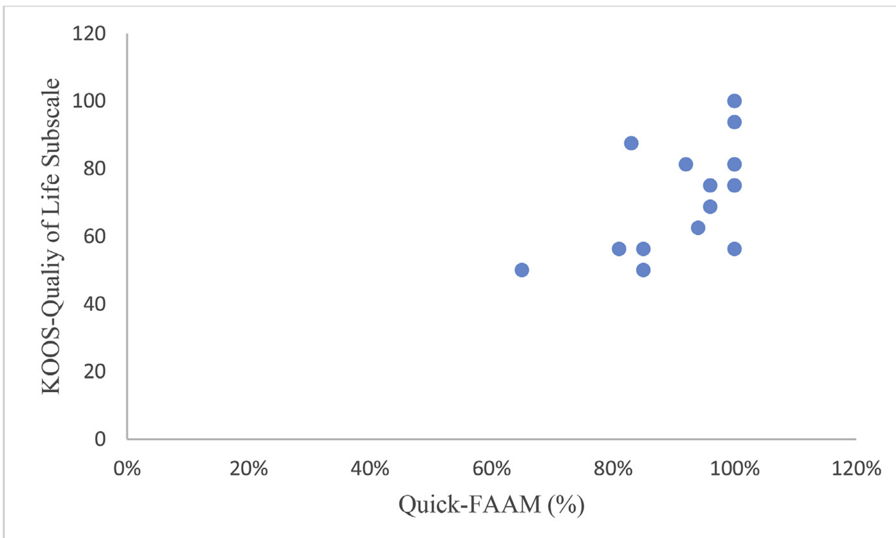

Fig. 1. The scatter plot representing the moderate relationship between the Quick-FAAM and the KOOS– Quality of Life subscale.

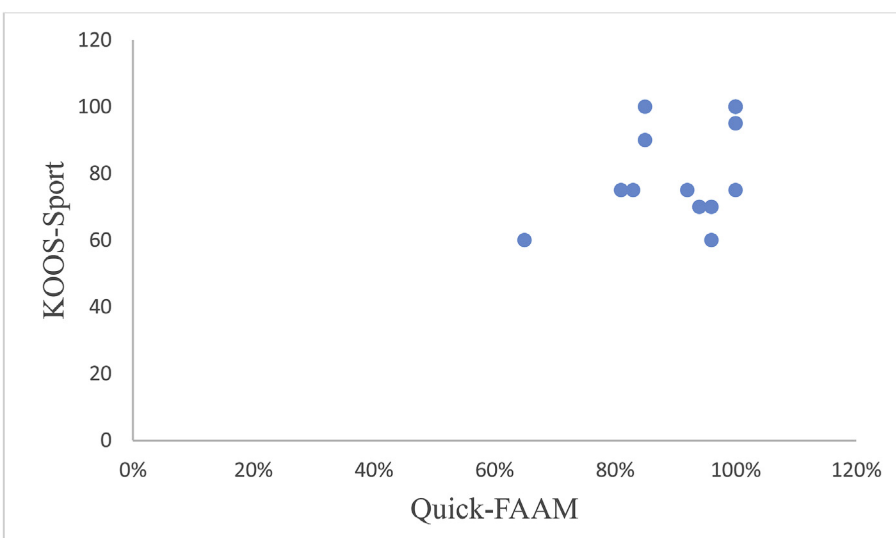

Fig. 2. The scatter plot representing the moderate relationship between the Quick-FAAM and the KOOS– Sport subscale.

landing, and running, while 7 participants (41%) reported slight or moderate difficulty with starting and stopping quickly. These individual data are interesting, as these questions are similar to questions that are asked across the KOOS subscales; and the Quick-FAAM scores were moderately correlated with KOOS subscales in this population. Given the other variables of ankle function were not statistically different between limbs, and we did not include measures of knee function (strength, range of motion, etc.) we could hypothesize the general self-reported limitations by patients may be global in nature due to their injury. This then makes it

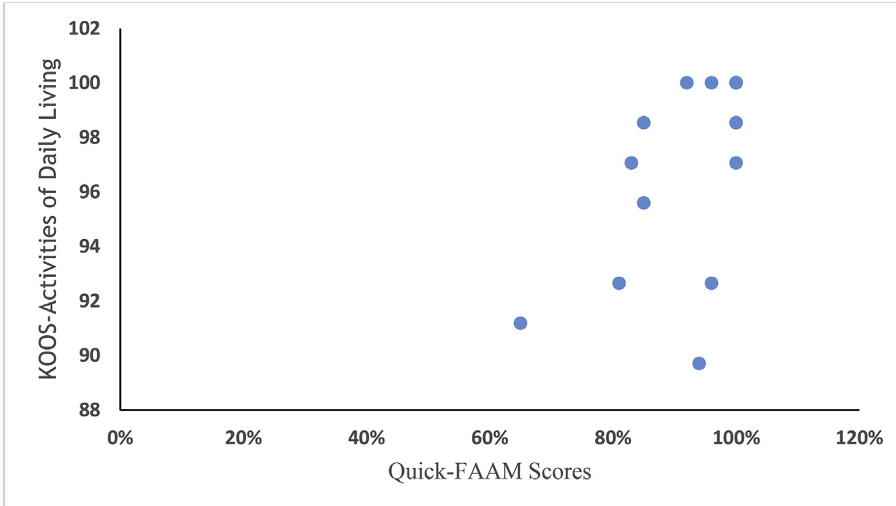

Fig. 3. The scatter plot representing the moderate relationship between the Quick-FAAM and the KOOS-Activities of Daily Living subscale.

challenging for patients to determine the root cause of their limitation and perceive the functional limitation to influence other joints. Therefore, rehabilitation specialists should continue to examine self-reported function globally and general quality of life as patients are perceiving these deficits to influence function at other lower extremity joints. Rehabilitation specialists should also continue to assess and treat the entire kinetic chain to address any impairments, limitations or restrictions that may exist.

We did not find differences in ankle strength (PF or DF) between limbs. Previous research found no differences in peak torque ankle strength between post-ACLR participants and healthy controls(Thomas et al., 2013). Thomas et al.(Thomas et al., 2013) compared pre-ACLR and 6-month post-ACLR PF and DF peak torque to healthy control participants. The authors identified no limb by group interactions preoperatively or postoperatively, no strength differences between groups preoperatively or postoperatively and no strength differences between limbs for either group preoperatively or postoperatively(Thomas et al., 2013). We hypothesized there would be differences in ankle strength between limbs as our group was post- ACLR for an average of 7 years, quite some time after the cessation of rehabilitation and potential for strength deficits to develop. However, we failed to accept our hypothesis. Our results are similar to those previously reported (Thomas et al., 2013), which suggest both PF and DF strength are regained during rehabilitation and are maintained after rehabilitation has ceased.

We also did not find differences in plantar cutaneous sensation at either the medial malleolus or the base of the 1st-metatarsal. We selected these sites based off of a previous investigation that identified decreased sensation at these locations when compared to healthy controls(Hoch et al., 2017b). Previously, the median cutaneous detection threshold for the involved limb for the post-ACLR group at the 1st-metatarsal site was 3.84 and 3.61 for the healthy control group; and the median cutaneous detection threshold for the involved limb for the post-ACLR group at the medial malleolus was 4.31 for the ACLR group and 4.08 for the healthy control group(Hoch et al., 2017b). The results of this study indicated the median detection threshold for the 1st-metarsal was lower for the involved limb than previously reported. However, for the medial malleolus, the values were the same as previously reported (4.31). As previously discussed, these sensory deficits may be related to graft type, specifically those patients who undergo a bone-patellar tendon bone autograph(Hoch et al., 2017b). Interestingly, 8 (44%) of the participants in this study reported a history of bone-patellar tendon-bone ACLR for either their primary or revision reconstructions. Therefore, if these plantar cutaneous detection thresholds are related to the type of graft utilized in the reconstruction, specifically the bone-patellar tendon-bone graft; the lower values at the 1st-metarsal may be attributed to the graft in this current population (e.g. hamstring autograft, allograft, etc.). Future research should continue to investigate plantar cutaneous detection thresholds in post-ACLR populations, and ensure to control for graft type as this may be a factor.

Finally, there were no differences in DROM between limbs in this sample. However, the median values of DROM for either limb in this sample were much less than previous healthy control data(-Hoch, Staton, Medina McKeon, Mattacola, & McKeon, 2012). Previous investigations have determined DROM utilizing similar methods for a healthy control group, and the average DROM was 12.47 cm (Hoch et al., 2012); approximately 4 cm more than the post-ACLR group included in this study. Interestingly, when examining the raw data for the involved limbs, only one participant exceeded this measure. Limited DROM is associated with an increase in ACL injury risk(Fong et al., 2011). While it does not appear there are differences in DROM between limbs, both limbs in this group have less DROM than previously reported healthy populations (Hoch et al., 2012). At this time it is unknown if decreased DROM may have contributed to the ACL injury risk, or if decreased DROM may increase this sample's risk for future injury. However, clinicians should continue to assess DROM in post-ACLR patients and include interventions, such as joint mobilizations, to increase DROM if warranted. It is possible that the use of a knee extension brace and/or crutches post-operatively could contribute to decreases in DROM, and if the case, this should be addressed in rehabilitation.

4.1. Limitations

This study is not without limitations. First, we included patients that had a history of one ankle sprain on either limb. We elected to include people with a history of one lateral ankle sprain due to the previously reported relationship between ACL injury and acute lateral ankle sprain(Kramer, Denegar, Buckley, & Hertel, 2007). However, of the 18 participants included in our research, only six (n = 33%) had a history of ankle sprain. Of these six, three had an ankle sprain to the contralateral side, two to the ipsilateral side, and one participant did not remember which side due to the length of time since the ankle sprain. Therefore, we do not believe history of ankle sprain on the involved limb was a contributing factor to our results. Second, while we only included participants with unilateral ACLR; some participants had a history of two reconstructions on the same limb. We also did not collect mechanism of injury data for the ACL (contact or non-contact) injuries reported. Participants with both non-contact and contact injuries were included, therefore the results may be influenced based on the heterogeneous sample. We also did not include a healthy control group for comparison. Thus, we are only able to compare the injured limb of the participant to the uninjured limb. The inclusion of a healthy control group may have allowed for further understanding the ankle function variables. Specially, we were unable to rule out that reorganization of the CNS did not create bilateral deficiencies in lower extremity sensorimotor function. If centrally-mediated neurophysiologic changes did occur bilaterally, this could have dampened our ability to identify deficits in the involved limb. Finally, the participants were instructed to read the directions on each of the PROs individually; we did not read the directions for each PRO to each participant. Therefore, it is possible some participants may have skimmed or skipped over the instructions, and failed to answer the questions accurately regarding their knee health, ankle health, etc.

5. Conclusion

Our results indicate self-reported ankle function is correlated with many of the self-reported knee function domains including quality of life, sports and recreation, and activities of daily living Furthermore, there are significant differences in self-reported ankle function between injured and uninjured limbs in a post-ACLR population. However, the differences are minimal and must be interpreted with caution. These results indicate that clinicians should be cognizant of the patient's perspective regarding their post-ACLR limbs, even including measure of function for the distal, and potentially, proximal joints. Furthermore, while not different between limbs, this sample had significantly decreased DROM bilaterally. Decreased DROM is a risk factor for lower extremity injury, including ACL injury (Fong et al., 2011). Clinicians should continue to examine range of motion in the distal, and potentially proximal joints, in their post-ACLR patients. Addressing this impairment during the rehabilitation process may improve outcomes and decrease future injury risk in this population.

Conflicts of interest

None declared.

Ethical approval

The work presented was approved by both institutions IRB in which data collection took place. All participants provided their signed informed consent prior to their participation.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2019.01.002.

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