Assessment of objective dynamic knee joint control in anterior cruciate ligament deficient and reconstructed individuals

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A R T I C L E   I N F O

A B S T R A C T

Background: There is a lack of objective dynamic knee joint control measures that can be related to the status of the anterior cruciate ligament (ACL). The purpose of this study was to introduce two novel measures and apply a third to determine how dynamic knee joint control changes in relation to ACL status during dynamic movements.

Methods: Twenty patients (13 male) were tested pre- (ACLd) and 10-months post- (ACLr) ACL reconstructive surgery and matched to an uninjured participant (CON). Kinetic and kinematic data were synchronously recorded with a force platform and motion capture system. Three objective control measures including dynamic angular stiffness, knee joint center excursion (KJCE), and knee joint center boundary (KJCB) were assessed for each participant when completing the side cut and hop tasks.

Results: During the side cut, stiffness was found to be significantly lower in ACLd (0.06 ± 0.01 Nm/kg/°) and ACLr (0.07 ± 0.02 Nm/kg/°) compared to CON (0.08 ± 0.02 Nm/kg/°), while there were no differences in stiffness during the hop. No significant differences were observed in the KJCE during the side cut, while KJCE was significantly greater (p = 0.006) during the hop in CON compared to the ACLd. There were no differences in KJCB.

Conclusions: These high-functioning ACL injured in both ACLd and ACLr phases, aside from reduced stiffness, were able to complete both tasks with similar dynamic control as the CON. Although improvements in self-perceived control between ACLd and ACLr have been observed, this lack of improvement in objective control demonstrates a gap between a patient's self-efficacy and the level of control.

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1. Introduction

With the increasing rates of anterior cruciate ligament (ACL) ruptures during physical activity [1], a better understanding of dynamic knee joint control and the lack there of leading to injury and re-injury is imperative. Many past studies have examined the biomechanics of ACL deficient (ACLd) and reconstructed (ACLr) patients during various dynamic tasks and have arrived at a general consensus that these injured groups complete the same movement with reduced knee flexion angles and knee extensor

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moments [2–7]. Unfortunately, these traditional kinematic and kinetic variables are only representations of the movement and are not indicative of the patient's dynamic knee joint control, which may be changing in relation to the improved subjective functional performance observed in the ACLr state of recovery [8]. This level of insight however, remains unknown to the researcher or clinician and needs to be developed in order to consolidate subjective and objective levels of joint control.

Defining dynamic joint control is a difficult task as it can be described in many ways with respect to stability. Passive stability can be defined by the contributions of passive soft tissue elements surrounding a joint, whereas active stability is governed by the surrounding musculature. Therefore, dynamic stability and thus the dynamic joint control of said stability would have contributions from both the passive and active stabilizers due to the ligaments, joint capsules, menisci, muscles, etc. all governing the amount of translational and rotational laxities during dynamic tasks. With respect to objective passive measures, very common clinical tests include the Lachman and pivot-shift tests that allow the clinician to measure translational and rotational laxities of the knee joint. The knee's ability to limit translational and rotational movement can be viewed as the ability to passively control joint movement. Unfortunately, a simple measure of passive anterior laxity whether by manual Lachman or KT-1000 instrumentation has been found to be uncorrelated with various functional tests including Noyes' [9] battery of hop tests in the ACLd [10] and ACLr state [11,12]. Furthermore, even though these tests provide information regarding the knee's passive restraints, these assessments are done in static and non-weight bearing situations. Therefore, their validity as dynamic knee joint control measures is questionable when the focus is on relating ACL injuries to joint control during dynamic and weight bearing tasks.

One measure of dynamic control has been joint angular stiffness, calculated as the change in joint moments as a function of the change in joint angles [13–15]. These studies suggest an increase in joint stiffness increases dynamic joint control since it would require greater magnitudes of applied forces to induce a displacement in joint position, and therefore protecting the soft tissue from harmful amounts of tissue strain. Even though this concept of joint stiffness has been applied to the knee during elementary movements such as gait, it has yet to be used to describe the knee during more demanding dynamic tasks. Furthermore, this measure of stiffness has yet to be applied to ACLd and ACLr states who are known to have altered joint angles and moments during gait and jump landing [3,5].

Another simple measure of dynamic control after ACL injury has been knee angular excursion, defined by the change in sagittal plane angle during various dynamic tasks. This knee excursion is greater in the ACL injured limb during gait and hopping [16,17], greater in poor functioning ACLd patients during a step task [18], and may improve in women between the ACLd and ACLr states [16]. This method is limited though as it only considers knee joint angular excursion in one dimension while it is well-known that ACL contributes to knee joint control in more than just the sagittal plane [19] and non-contact injury mechanisms are a combination of forces in multiple planes [20]. Thus, a measure of three-dimensional knee joint center (midpoint between the two femoral epicondyles) excursion (KJCE) in the global coordinate system is warranted. Since this KJCE measure considers the knee movement in three dimensions, it provides more information than the traditional unidimensional sagittal angle. Furthermore, since KJCE is rooted in the global reference frame, it better represents the holistic knee joint motion including the unwanted "wobble" exhibited by an unstable knee during dynamic tasks. This measure of control has the potential to be a better representation of knee joint movement and thus could be a powerful objective representation of a patient's subjective report.

Finally, movement variability has also been used to assess knee control after ACL injury. It is believed that there is an optimal level of variability in human movement as a rigid system exhibits inflexible motor behavior that is uncompliant when exposed to a perturbation. Highly variable systems are also deemed as sub-optimal as they are noisy and unstable, thereby exhibiting greater amounts of entropy [21,22]. Decker and colleagues [23] have concluded that loss of variability, which is associated with a more rigid and repeatable movement pattern is observed in the ACLd knee while increased variability beyond the optimal level, which is associated with a noisy and irregular movement pattern is found in the ACLr knee. Even though this review indicated abnormal levels of variability, the included studies were cross-sectional and therefore it still remains unknown how or if movement consistency (i.e. variability) changes longitudinally with respect to ACL status. This measure also provides conflicting results since depending on the definition, the ACLd limb has no changes to [24] or decreased [25] variability, whereas both increased [26] and decreased [27] variability have been observed in ACLr populations. This could be addressed by a novel measure that quantifies a knee joint center boundary (KJCB) within a participant's dynamic task trials. Since identifying the optimal level of variability is difficult, one consideration that can be made is that since a healthy population has yet to endure a knee injury, their variability can be considered optimal. Therefore, a simple measure of movement consistency that can be compared among healthy, ACLd, and ACLr groups could provide insight into how variability, and in effect knee joint control, change throughout the ACL recovery process.

Since longitudinal dynamic knee joint control remains unknown in relation to patients prior to, and shortly after, ACL reconstruction, the purpose of this study was to compute two novel measures of dynamic knee joint control (KJCE and KJCB) and apply them along with a third (stiffness) to determine how dynamic knee joint control changes in relation to ACL status. To address this purpose, we assessed three objective measures of control during hop and side cut maneuvers that were performed by healthy, and injured individuals during their ACLd and ACLr phases of recovery. It was hypothesized that for all measures, control would be greatest (high stiffness, and low KJCE and KJCB) in the healthy participants, lowest in the ACLd phase, and the ACLr phase would show increased control compared to the ACLd phase while not reaching levels seen in the healthy controls.

2. Material and methods

2.1. Participants

As part of a larger project, 47 ACL injured participants were recruited and completed the larger experimental protocol at the University of Copenhagen (see [8] for details). Of these 47 participants, 17 were comfortable completing the side cut and 18 completed the hop

Table 1

Participant characteristics means and (standard deviations) of healthy (CON), anterior cruciate ligament deficient (ACLd) and reconstructed (ACLr). Pre Inj: is the patient's self-reported Tegner score prior to their injury. Inj: is the patient's self-reported Tegner score in the ACLd state at the time of testing.

	Hop			Side cut		
	CON	ACLd	ACLr	CON	ACLd	ACLr
Male/female	11/7	11/7	11/7	11/6	11/6	11/6
Age (years)	26.7 (6.7)	27.5 (5.9)	28.4 (5.9)	26.6 (3.6)	27.8 (5.9)	28.7 (5.9)
BMI (kg/m^2)	24.0 (3.0)	24.4 (3.2)	24.7 (3.4)	24.0 (3.0)	24.4 (3.3)	24.6 (3.6)
Time since injury (months)	–	12.5 (18.7)	–	–	10.4 (9.9)	–
Time since surgery (months)	–	–	10.5 (1.7)	–	–	10.5 (1.7)
Tegner	7.2 (1.5)[a,c]	Pre Inj: 6.8 (1.5) Inj: 3.6 (1.7)[a,b]	5.8 (1.5)[c,b]	7.6 (1.3)[a,c]	Pre Inj: 6.9 (1.6) Inj: 3.5 (1.6)[a,b]	5.6 (1.7)[c,b]
IKDC	99.4 (1.5)[a,c]	65.6 (11.0)[a,b]	77.4 (9.6)[b,c]	99.3 (1.7)[a,c]	64.0 (9.2)[a,b]	76.3 (9.8)[b,c]

[a] Indicates significance between healthy and ACLd.
[b] Marks significance between ACLd and ACLr.
[c] Indicates significance between healthy and ACLr.

movement in both the ACLd and ACLr states (Table 1). Complete rupture of the ACL was confirmed clinically by the physician (positive Lachman and Rolimeter tests) and via magnetic resonance imaging or arthroscopy, and each patient underwent an ACL reconstruction procedure. All participants received a double-bundle hamstrings autograft except two males who received a bone–patellar tendon–bone autograft, one male undergoing an Achilles tendon allograft, and one male who received an iliotibial band autograft. All ACLr patients received a standardized 20-week rehabilitation program that focused on range of motion, balance, strength, and functional training, with a ramping degree of effort throughout the program. Each of these patients was matched with a healthy control (CON) based on sex, leg tested (dominant or non-dominant), body mass index, age, and Tegner score. The inclusion criteria for CON included no previous lower limb surgical operations, no additional serious lower limb injury including fractures or sprains within six months prior to testing, and any diseases that affect neuromuscular function. This study was approved by the local ethics committee for the Capital Region of Denmark and the University of Ottawa Research Ethics Board.

2.2. Protocol

Once participants provided informed consent, they changed into tight-fitting spandex and were outfitted with a whole-body cluster marker set [28]. Kinematic data were collected (six MX and four T series, Vicon, UK) at 100 Hz. Ground reaction force (GRF) data were synchronously sampled at 1000 Hz using one force plate (OR 6-5-1, AMTI, USA). For a hop attempt to be deemed successful, participants began on their non-test limb and jumped forward, landing with their test limb within the boundaries of the force plate and maintained balance. Distance was self-selected but needed to be greater than stepping distance to ensure it was a hop. Participants were asked to complete the movement at the maximum speed they were comfortable with, which caused them to drive their mass forward into the landing and abruptly arrest their momentum instead of completing a relaxed hopping motion. For the side cut, participants were again instructed to complete the movement as fast as they were comfortable with, cut onto the force plate at a 45° angle, have their entire foot plant within the boundaries of the force plate, and then cut off from the force plate again at a 45° angle. Three successful trials were considered for each participant.

2.3. Data analysis

Data analysis was completed using a Matlab (2013a, Mathworks, USA)–OpenSim (3.3, Simtk, USA) application program interface. Marker trajectories and GRFs were filtered with matching 4th order zero-lag low pass Butterworth filters with cut-off frequencies of 15 Hz. A whole-body OpenSim model [29] was modified to include three unprescribed rotational degrees of freedom at each knee. Scaling, inverse kinematics, and inverse dynamics were used to compute hip, knee, and ankle angles and internal joint moments.

Dynamic knee joint stiffness was calculated as the change in sagittal knee moment (from inverse dynamics) over the change in knee sagittal angle (Davis and DeLuca [15] from the point of initial foot contact to the maximum knee extensor moment (Figure 1) and reported as an absolute value. Knee joint center (KJC) was defined as the midpoint between the medial and lateral femoral epicondyle markers and KJCE was calculated as the Euclidean distance of the KJC from the appointed start and end points of the movements.

Thus, KJCE was the Euclidean distance that the KJC traveled throughout the task of interest. For the side cut, KJCE was computed for the entire stance phase while for the hop, KJCE was calculated from initial contact to the following 100 ms as ACL injuries most commonly occur within this time frame [30] and we did not want the period of voluntary balance control to influence our measures.

Finally, the KJCB was calculated over the same time periods as the KJCE and was position normalized to allow for the trials within each participant to be comparable. Since KJC was expressed in the global coordinate system, the coordinates of the initial time point of each trial were subtracted from the rest of the respective trial, which normalized each within participants' trial to an
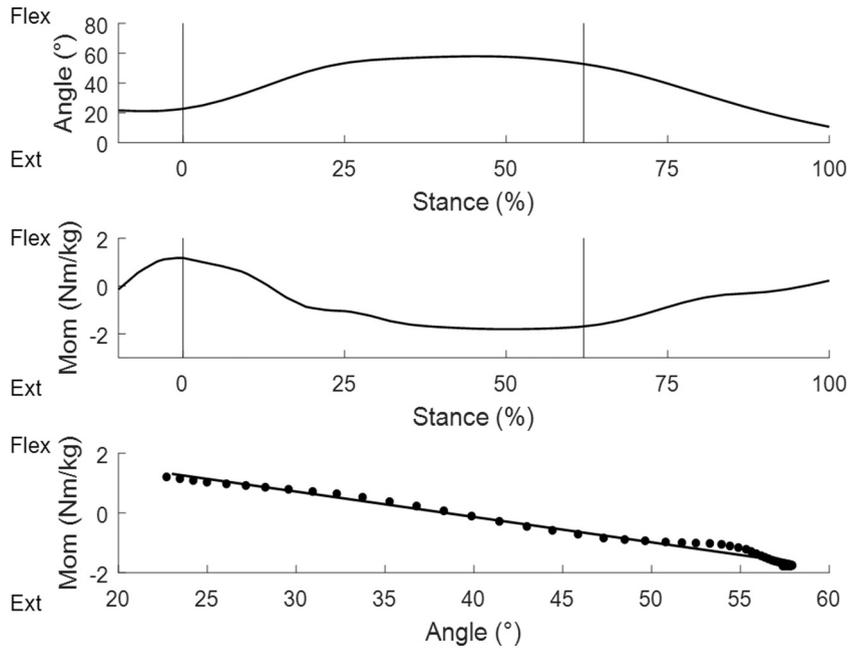
Figure 1. Top plot is knee sagittal plane angle of an example side cut trial, middle plot is sagittal plane knee internal joint moment, and the bottom plot is knee moment as a function of knee angle. Each dot represents a time point from initial contact to max knee extensor moment (vertical lines on top two plots). Stiffness is quantified as the slope of the line of best fit from the angle-moment scatter plot.

equivalent starting point. Then, at each subsequent time point, the Euclidean distance between KJC markers in all three trials was calculated and represented a boundary (Eq. (1)):

$$\sum_{i=1}^{n} \sqrt{(x_2-x_1)^2 + (y_2-y_1)^2 + (z_2-z_1)^2} + \sqrt{(x_3-x_2)^2 + (y_3-y_2)^2 + (z_3-z_2)^2} + \sqrt{(x_3-x_1)^2 + (y_3-y_1)^2 + (z_3-z_1)^2} \quad (1)$$

where n is the last time point in the trial, i is the frame number, and x, y, and z are the global knee joint center coordinates for the three trials (1, 2, 3).

A small Euclidean distance indicates that the KJC movement was more consistent than if the Euclidean distance was large. The boundary lengths (Euclidean distances) found at each time point were then summed and expressed in meters.

2.4. Statistical analysis

All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) (22.0, IBM, USA). Since the injured groups are dependent and the CON independent, we implemented a three research question approach: Q1) did the healthy and ACLd patients differ in dynamic knee joint control? Q2) Did the ACLd patients differ from the ACLr? Q3) Did the ACLr differ from healthy controls? Since all data were found to be normally distributed (Shapiro–Wilk test), independent t-tests were used to address Q1 & Q3, whereas a paired samples t-test was used to address Q2. Due to multiple comparisons, our alpha level of significance was reduced to 0.025. When differences were found to be significant, Cohen's effect size (d) was calculated to quantify the size of the difference.

3. Results

There were no significant differences in hop distance (CON: 1.3 ± 0.2 m; ACLd: 1.2 ± 0.2; ACLr: 1.2 ± 0.1 m) or impact velocities (CON: 3.0 ± 0.4 m/s; ACLd: 2.8 ± 0.4 m/s; ACLr: 2.8 ± 0.4 m/s) (mean ± st dev) between all three groups in either task [8].

3.1. Q1: CON vs ACLd

For the hop, there was no difference in dynamic knee joint stiffness between CON (0.06 ± 0.01 Nm/kg/°) and ACLd (0.06 ± 0.02 Nm/kg/°). KJCE was significantly greater (p = 0.006, power = 0.82, d = 1.0) in the CON (0.20 ± 0.02 m) than in the ACLd (0.18 ± 0.02 m). Finally, as for KJCB, no significant difference was found between the CON (4.89 ± 3.10 m) and ACLd (5.82 ± 3.46 m).
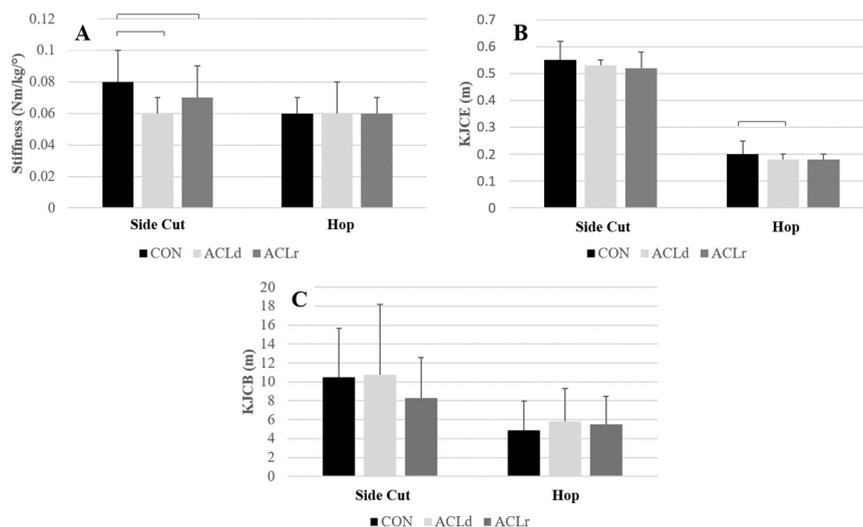
Figure 2. A) Stiffness, B) knee joint center excursion (KJCE) and C) knee joint center boundary (KJCB) means and standard deviation bars for healthy (CON), ACL deficient (ACLd), and ACL reconstructed (ACLr) patients during the side cut and hop movements. Horizontal bars denote significance ($p < 0.025$) between groups.

In the side cut task, stiffness was significantly greater ($p < 0.0005$, power $= 0.99$, $d = 1.51$) in the CON (0.08 ± 0.02 Nm/kg/°) than in the ACLd group (0.06 ± 0.01 Nm/kg/°; Figure 2A). There was no difference in KJCE between the CON group (0.55 ± 0.07 m) and the ACLd (0.53 ± 0.05 m; Figure 2B), nor in the KJCB between CON (10.50 ± 5.18 m) and ACLd (10.72 ± 7.46 m; Figure 2C).

3.2. Q2: ACLd vs ACLr

No significant differences were found in stiffness, KJCE, or KJCB during the hop or side cut tasks.

3.3. Q3: ACLr vs CON

For the hop, stiffness was similar between CON (0.06 ± 0.01 Nm/kg/°) and ACLr (0.06 ± 0.01 Nm/kg/°). The KJCE trended towards being greater ($p = 0.054$, power $= 0.49$, $d = 1.0$) in the CON (0.20 ± 0.02 m) than in the ACLr (0.18 ± 0.02 m), while no difference in KJCB was found between the CON (4.89 ± 3.10 m) and ACLr (5.52 ± 2.97 m).

During the side cut, stiffness was significantly greater ($p = 0.013$, power $= 0.72$, $d = 0.9$) in the CON (0.08 ± 0.02 Nm/kg/°) than in the ACLr group (0.07 ± 0.02 Nm/kg/°). KJCE did not differ significantly between the CON group (0.55 ± 0.07 m) and the ACLr (0.52 ± 0.06 m), nor did it differ for the KJCB between CON (10.50 ± 5.18 m) and ACLr (8.31 ± 4.24 m).

4. Discussion

The purpose for this study was to compute and assess two novel measures of dynamic knee joint control (KJCE and KJCB) and apply a third (stiffness) to determine how these measures change in relation to the status of the ACL during two demanding tasks. This was done by comparing dynamic joint stiffness, KJCE, and KJCB between healthy CON, ACLd, and ACLr participants throughout hop and side cut movements. It was found that 1) healthy matched participants have greater stiffness during the side cut and KJCE during the hop compared to the ACLd. 2) There were no statistically significant differences between ACLd and ACLr, while 3) stiffness was significantly greater in the CON during the side cut and KJCE trended towards significance during the hop when compared to ACLr.

From our past work [8], the ACLd patients exhibited significant deficits in self-reported functional ability, assessed through questionnaires including Lysholm, International Knee Documentation Committee (IKDC), Knee Injury and Osteoarthritis Score (KOOS), and Knee Numeric-Entity Evaluation Score (KNEES). Many of these deficits significantly improved after ACL reconstruction indicating that this procedure provided an increase in self-efficacy, as evidenced in significantly greater outcome scores in daily living and sporting activity domains. Even though this subjective increase was observed, the current results found few differences in all three objective control measures regardless of ACL status. In humans, reinnervation has been observed to occur after ACL reconstruction but the level of nerve signal has yet to reach those exhibited by healthy controls even after seven years [31,32]. Even though a majority of surgeons have recommended return to play after six months post-reconstruction [33], this is likely not enough time for reinnervation to occur within the knee. This would imply that our study participants, despite being cleared for full activity, would not have complete reinnervation and be performing tasks with a sensory deficit. Thus, at this stage of recovery, the main role of the ACL would be mechanical in nature. Although the clinical decision for return to play is multifactorial, from purely the perspective of the ACL, clearance will rely on the ACL as a mechanical constraint and not its neural input. This postulation concerning the lack of neural input is supported by ACLr (27.8 weeks post-reconstruction) having slightly but insignificantly worse kinesthesia than their ACLd counterparts [34]. Those patients

who contemplate undergoing reconstruction will likely experience improved confidence in their abilities [8], which may be related to the regained ACL mechanical stability but since they are still lacking that neural input, their kinematics and objective control when performing dynamic tasks may not improve.

The most sensitive measure of dynamic control to ACL status appeared to be stiffness during the side cut movement. A significantly less stiff knee was observed in the ACLd group and continued to be less stiff after reconstruction when compared to CON. This finding resembles that of Zeni Jr. and Higginson [13] who observed greater stiffness values in their control group compared to the participants with moderate osteoarthritis. Since this variable is derived from flexion angle and joint moment, it is pertinent to acknowledge our past work [8]. Here the injured patients were found to complete the hop with a significantly smaller amount of knee flexion and a decreased extensor moment, while during the side cut, only extensor moment was observed to decrease. Thus, if stiffness can truly be considered a measure of joint control, the approach of decreasing both angle and moment taken by the injured participants in each of their ACLd and ACLr states during the hop appears to be effective at maintaining joint stiffness and therefore control. Furthermore, this appears to be more effective than the approach of only reducing joint moment as seen in the side cut where significant decreases in joint stiffness were observed between the CON and both injured states. This knowledge of maintaining the relationship between joint angle and moment to preserve an appropriate level of stiffness and joint control is useful in not only designing an effective rehabilitation program but has the potential to be used in return to play assessments.

Throughout the self-reported questionnaires and conversations with the patients, a recurring explanation of their lack of control or instability was that it felt "wobbly" or had "extra" movement. We attempted to quantify this perceived lack of control through the calculation of KJCE. Contrary to our hypothesis, no differences in KJCE were observed during the side cut while it was found to be greatest in the CON during the hop task. Since this perceived lack of control is not present in the objective quantification of the task in hand, it warrants further investigation as to whether or not these objective measures of control are related to the patient's self-perceived level of ability. Furthermore, these patients were considered high-functioning as they were able and willing to complete the side cut and hop in both the ACLd and ACLr states. Although the current work is limited to a 10-month post-operative time frame, previous work examining knee joint control based on changes in knee axis orientation [35] has been applied to patients 20 years after injuring their ACL treatment began [36]. Through this finite helical axis analysis, the authors noted that reconstruction improved stability in the anterior–posterior inclination but no changes to rotational stability compared to the patients who opted for the conservative approach. Although 20 years differs substantially from the current 10-month post-reconstruction test timing, the lack of improvement in rotational stability and stiffness appear to agree and warrant more investigations concerning the effectiveness ACL reconstructions have on restoring this rotational stability.

As stated earlier, the literature is inconclusive about movement variability in ACLd and our results of similar KJCB boundaries across groups within each task were contrary to our hypothesis. Although it is believed that there is an optimal level of variability [21,22] and an extensive review [23] has concluded that this optimal variability level paradigm appears to exist in ACL injured populations, what exactly this optimal level is has yet to be established. The lack of differences in our current results could be interpreted in two ways: the first is that our novel measures are not sensitive to either the groups or tasks that they were applied to. The second is that since our patients are functioning at such a high level, they are currently operating similar to the CON and at an optimal level of variability. To determine which one of these possible explanations is true, future work will be conducted to examine KJCB in a more inclusive study population that is comprised of a stratification of patients based on their level of perceived and objective functional ability.

One of our study's strengths is its test–retest design in which any confounding factors due to testing different participants (anthropometric, experience, etc.) are eliminated as the same patients were tested in both the ACLd and ACLr states. A limitation of this approach is that the participant pool was limited to only high functioning participants and therefore the results of the current study cannot be projected onto the group of patients unwilling to complete these movements in either ACL state. That being said, since these high functioning patients have relatively equal dynamic control and spatiotemporal values to healthy controls, their previously reported altered movement strategies could be used as benchmarks in the rehabilitation of patients with less function.

A second limitation is that only three trials were used to calculate stiffness, KJCE, and KJCB for each participant. This trial number is especially low for traditional variability measures but unlike a simple gait task, high trial numbers of hops and side cuts induces fatigue very rapidly, which in turn would influence the results. Although calculating variability on a small number of trials may provide inconsistency among testing sessions, the aspect of clinical feasibility needs to be considered. A simple measure of variability that is easy to implement is crucial for clinicians as they don't have the time or resources to collect, process, and analyze large amounts of trials. Therefore, the costs and benefits need to be considered when applying variability measures to small samples.

A third limitation to these measures is the amount of error induced by soft tissue artifact. Sagittal plane angles have been shown to be reliable but considerable errors are observed in the frontal and transverse planes [37,38]. Since our stiffness measure was contained to the sagittal plane, these angles and moments should not have been greatly influenced by soft tissue artifact. KJCE and KJCB however are three-dimensional measures and could contain error during these dynamic tasks. Fortunately, these measures are based on the KJC, which is defined as the midpoint between the two femoral epicondyle markers relative to the global reference system. Therefore, since the markers are placed on bony landmarks and not on top of considerable soft tissue, the average of these two values should to a certain extent mitigate the noise experienced by the markers during these tasks. Although motion capture systems that use surface markers are known to be inaccurate when trying to quantify knee joint translations [39], our current measures of KJCE and KJCB are not measures of tibiofemoral translations but rather the movement of this KJC in the global reference system.

In conclusion, very few differences in three objective measures of control were observed between healthy, and injured participants (in either ACLd or ACLr state) during hop and side cut movements despite considerable kinematic and kinetic differences

between healthy and both injured states. Even though these patients have been previously reported to have dramatic improvements in self-perceived control between the deficient and reconstructed state, these lack of improvements in objective control demonstrate a gap between a patient's self-efficacy and the level of control they implement while completing two demanding tasks. Therefore, a better understanding of the relationship between objective and subjective knee function is imperative in improving return to play guidelines in efforts to reduce the incidence of secondary pathologies such as ligament re-rupture and soft tissue degeneration.

Acknowledgments

Conflict of interest

The authors have no conflicts of interest to declare.

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