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Original Research

Knee mechanics during a change of direction movement in division I athletes following full return to sport from anterior cruciate ligament reconstruction

Nicole Clark [a], Trent Forshey [a], Ivan Mulligan [a], Curtis Kindel [b, *]

[a] Department of Physical Therapy, Saint Francis University, P.O Box 600 Loretto, PA, 15940, USA
[b] Anderson University, 225 S. Pleasantburg Dr. Suite B3, Greenville, SC, 29607, USA

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ABSTRACT

Objectives: The objective of this study was to determine whether Division I athletes following anterior cruciate ligament reconstruction (ACLR), and who are medically cleared to return to sport, demonstrate faulty knee mechanics during a change of direction maneuver, as evidenced by the presence of genu valgum on VICON® motion analysis system of 5° or greater.
Study design: Cross-sectional study.
Setting: University.
Participants: Ten Division I athletes performed a 90° change of direction movement on both the ACLR and unaffected limbs.
Main outcome measures: Knee mechanics were assessed using the VICON® motion analysis system. Knee position was analyzed in the frontal plane and peak genu valgum position was determined during the functional movement.
Results: Eight out of ten athletes (80%) demonstrated genu valgum $\geq 5°$ on the ACLR limb during a 90° cutting movement. Fourteen out of twenty (70%) of the knees assessed demonstrated genu valgum $\geq 5°$ during a 90° cutting movement.
Conclusion: Athletes who have fully returned to sport following an ACLR demonstrate substantial genu valgum during a cutting maneuver, which suggests an increased risk for future injury. These results show an increased need during ACL rehabilitation to focus on existing biomechanical deficits during sport-specific movements.

1. Introduction

Anterior cruciate ligament (ACL) ruptures have been heavily researched over the years in the rehabilitation field due to its rise in prevalence amongst athletes. It has been well established that ACL injuries most commonly occur without contact, when an athlete decelerates from a sagittal movement and quickly plants the foot to change direction (Havens & Sigward, 2015; Kristianslund & Krosshaug, 2013; Weinhandl et al., 2013). Certain risk factors place an athlete at an increased risk for sustaining a non-contact ACL rupture during a change of direction in sport. Most significant modifiable risk factors include neuromuscular control, strength, muscular imbalances, and BMI. Injury prevention programs and rehabilitation programs have focused on addressing these factors in an attempt to prevent initial ACL injury, return to sport safely from an ACL reconstruction (ACLR), and prevent a secondary ACL injury. It is also important to note that secondary ACL injuries are more likely in both the ipsilateral and contralateral limb compared to individuals without a previous ACL injury (Bryant, Kelly, & Hohmann, 2008; Paterno et al., 2012, 2014; Wiggins et al., 2016). With these athletes having an increased risk to re-injure, it puts into question whether they were properly prepared to return to activity or if deficiencies were still present in neuromuscular control, strength, and muscular imbalances.

Research has shown deficits in motor control, strength, and inter-limb symmetry following ACLR during various stages of rehab and in fully cleared athletes who have returned to sport for an extended period (Briem, Ragnarsdóttir, Árnason, & Sveinsson,

* Corresponding author. University Center Greenville, 225 S. Pleasantburg Dr. Suite B3, Greenville, SC, 29607, USA.
E-mail address: ckindel@andersonuniversity.edu (C. Kindel).

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2016; Dingenen, Janssens, Claes, Bellemans, & Staes, 2014; Paterno, Ford, Myer, Heyl, & Hewett, 2007; Schmitt, Paterno, & Hewett, 2012; Xergia, Pappas, Zampeli, Georgiou, & Georgoulis, 2013). Changes in motor control, demonstrated by decreased loading response and increased genu valgum during single leg hopping and vertical drop jumps, can be seen in athletes as early as six months post-op and beyond two years following surgery (Xergia et al., 2013). Additionally, in athletes who have fully returned to play, they have been found to have decreased vertical ground reaction forces and loading rate in the involved limb during dynamic jumping activities; as well as decreased force production of the quadriceps and poorer performance on hop tests (Paterno et al., 2007). During functional activities, hamstring activation and strength are important due to their ability to maintain appropriate tibiofemoral alignment and prevent excessive anterior tibial translation. It has been identified that athletes who are one to six years post-op ACLR have inter-limb muscle activation differences in hamstring firing time, which also differ from a healthy control cohort (Briem et al., 2016). Return to play criteria attempts to assess these deficits to ensure a safe return to sport; however, protocols lack in their evaluation of carry-over into sport-specific activities.

Current rehabilitation and return to sport protocols vary based on surgical reconstruction method and surgeon guidelines, but it is widely accepted that return to sports criteria include a lower extremity strength test and single leg dynamic assessment that could include a hop test, vertical drop test, or excursion test looking for proper neuromuscular control (Gobbi & Francisco, 2006; Hartigan, Axe, & Snyder-Mackler, 2010; Thomeé et al., 2011). An area of significance during single leg testing is control of knee position during static and dynamic exercises, specifically controlling the amount of genu valgum, or knee adduction, that occurs through improper motor control or strength. Dynamic genu valgum has been identified as one key factor that could leave athletes more vulnerable for injury as it places the ACL at an increased risk for rupture (Boden, Sheehan, Torg, & Hewett, 2010; Hewett et al., 2005; Olsen, Myklebust, Engebretsen, & Bahr, 2004). Shin, Chaudhari, and Andriacchi (2009) determined that during a 100 Nm knee valgus moment, which was greater than the previously reported valgus moments of at-risk individuals, the researchers observed only 3° of valgus. Therefore, even small amounts of valgus can have deleterious effects. However, to date, there is a lack of evidence in the literature showing that joint mechanics or genu valgum during a change of direction are often looked at or considered when determining if the athlete can safely return to play. It is the aim of this study to assess the excursion of genu valgum found in athletes who have fully rehabilitated from ACLR to determine if differences are present in affected and non-affected limbs.

This study aims to assess the mechanics of change of direction, via knee valgus angle, of affected and non-affected limbs in athletes following completed rehabilitation and medical clearance of anterior cruciate ligament reconstruction. While much research has been done to examine plyometrics and strength post-op ACL reconstruction, no research has assessed change of direction. As the primary mechanism of injury for ACL ruptures, change of direction should be evaluated further. Based on current literature, we hypothesize there will be significant differences in lower extremity mechanics between the affected and non-affected limbs in our subjects which, according the Hewett et al. may be inferred to represent motor control (Hewett et al., 2005).

2. Methods

This study aimed to assess knee valgus angle during a change of direction movement in athletes who have received full medical clearance and are greater than or equal to one year post-op ACLR. The Institutional Review Board of Saint Francis University approved the study protocol and all participants received a written informed consent before participation.

2.1. Subjects

Participants were recruited from a local division I university via e-mail letter to the university's athletic training staff. Inclusion criteria included: healthy adults ages 18–30 with an ACLR greater than or equal to one year before testing, and full medical clearance for return to sport and activity. Participants were also required to be free from lower extremity injuries on both limbs within the past year and were able to perform a change of direction activities. Exclusion criteria included a history of ACLR on bilateral extremities, history of lower extremity injury on either limb within the past year, and subjects who could not safely perform change of direction activities.

2.2. Procedures

Following recruitment and fulfillment of inclusion and exclusion criteria, each participant completed the Informed Consent form and was officially included in the study. Participants participated in a 5 min warm up on the recumbent bike and then they received instruction in requirements for cutting movement using the VICON motion analysis system. Placement of 18 reflective markers on the participants occurred with nine markers placed on each lower extremity at pre-specified landmarks. These landmarks included PSIS, ASIS, iliac crest, mid-thigh, lateral epicondyle, mid-calf, lateral malleolus, calcaneus, and second metatarsal. Participants were instructed in the cutting maneuver, which involved sprinting straight forward at full speed, cutting ninety degrees quickly, and then sprinting straight again. Tape was placed on the floor to more accurately direct each participant. Each participant performed one submaximal practice trial on each leg before performing the maximal testing trial. One maximal testing trial was recorded for each leg. Adequate rest of greater than 1 min was provided between trials, to ensure maximal efforts.

2.3. Outcome measures

The knee position in the frontal plane was identified for the lower extremity that performed the cut for each maximal trial. 3-D motion-analysis data were recorded using an 8-camera motion-capture system (Vicon Motion Systems, Oxford, UK). A plug-in gait marker set was used (Davis, Õunpuu, Tyburski, & Gage, 1991). Motion data were collected at 120 Hz. Knee valgus was calculated through Nexus using the plane of the knee flexion axis and the ankle center, and is the angle between the long axis of the shank and the long axis of the thigh projected into this plane. Researchers utilized this data to identify the time span during the change of direction maneuver in which the athlete's testing extremity was performing the cutting maneuver. This was the time from which the limb came in contact with the ground to terminal push off. The peak valgus knee position, or maximal amount of knee valgus, was recorded during this time frame. The valgus position value was recorded as positive if the athlete was in valgus and negative if the athlete was in varus. Data were collected for both limbs for all participants (See Table 1). Five degrees or greater of knee valgus was determined significant for this study based on previous literature demonstrating this position to have high valgus loads (Bendjaballah, Shirazi-Adl, & Zukor, 1997; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001), and a control group having less than five degrees of valgus (Scholtis & Salsich, 2017).

Table 1: Peak knee valgus angle during cutting maneuver of

Table 1
Peak valgus angle during cutting maneuver.

Subject	Gender	Time Since Surgery (mos)	Affected Limb	Involved Lower Extremity (deg)	Uninvolved Lower Extremity (deg)
1	F	33	Right	**19.7**	**7.9**
2	F	20	Left	−1.8	**11.5**
3	F	32	Left	**7.2**	−0.7
4	M	22	Right	**8.6**	−3.7
5	F	36	Right	**5**	−5
6	M	55	Right	−1.1	1
7	F	28	Left	**14.7**	**17.8**
8	F	12	Left	**9.5**	**20.6**
9	F	20	Left	**32.1**	**13.3**
10	F	65	Left	**8.2**	**26.2**
Avg	–	32.3	–	10.2	8.9

involved and uninvolved limbs (bolded data indicate substantial values (e.g. equal or greater than 5° from neutral)).

3. Results

Ten participants were included in our study, ranging from ages 18–23 years old (Table 1). Six subjects had ACLR on their left lower extremity, and four subjects had ACLR on their right lower extremity. Two participants were male, and eight participants were female. The time since surgery ranged from just over one year to almost six years, with the average being 32.3 months post-op, or approximately 2.7 years.

The peak knee angle ranged from 1.8 degrees of varus to 31.1 degrees of valgus on the involved lower extremity. The average peak knee angle on the involved lower extremity was 10.2 degrees of valgus. The peak knee angle ranged from 3.7 degrees of varus to 26.2 degrees of valgus on the uninvolved lower extremity. The average peak knee angle on the uninvolved lower extremity was 8.9 degrees of valgus. The difference in the average peak valgus angle between the uninvolved and involved knees was 1.32° ($T = 0.28$, $p = .78$).

Out of the twenty knees tested, 14/20, or 70% of knees, had a substantial valgus angle during the cutting maneuver. The results demonstrated that 80% of the involved lower extremities demonstrated a substantial valgus angle during the cutting maneuver. Additionally, 60% of the uninvolved lower extremities demonstrated a substantial valgus angle during the cutting maneuver. No correlation was found between length of time since surgery and involved knee angle ($R = -0.30$, $p = .40$) nor length of time since surgery and uninvolved knee angle ($R = 0.07$, $p = .86$).

4. Discussion

In this study, researchers utilized a 5-degree measurement of error off of neutral as research has indicated for three-dimensional kinematic measurements (McGinley, Baker, Wolfe, & Morris, 2008). Therefore, any measurement less than 5 degrees of neutral was considered non-meaningful. Any measurement greater than or equal to 5 degrees of neutral were considered meaningful. Ideally, in regards to knee positioning, athletes should be performing movements without significant amounts of valgus or varus. Therefore, having values that are considered non-meaningful or are within 5 degrees of neutral would suggest ideal mechanics.

A cutting maneuver involving a ninety degree change of direction was utilized to mimic the demands required on the field or court in athletes who commonly tear their ACL, as well as, to assess mechanics during one of the most common movements resulting in an ACL tear. Although there is no standardized movement for assessing knee mechanics for a return to sport, other studies assessing knee mechanics in athletes without deficits utilized similar movements.

The range of values obtained for the involved knee demonstrated a wide variance, with a substantial bias towards valgus. No knees demonstrated substantial amounts of varus, and only two knees presented within 5 degrees of neutral. No correlation seems to exist between time since reconstruction and the amount of valgus present, suggesting that duration since the return to sport does not affect knee mechanics. For greater effect, the peak valgus angle of the subject who was 12 months post-op and the subject who was 65 months post-op were not substantially different. The results demonstrated that 80% of the involved knees demonstrated substantial valgus during a cutting maneuver.

The range of values obtained for the uninvolved knee also had a wide variety and also were biased towards valgus. The range was less than that of the involved knee and averaged with more varus relative to the involved knee. One knee demonstrated substantial amounts of varus, and three knees presented within 5 degrees of neutral. Sixty percent of the uninvolved knees demonstrated substantial valgus during the cutting maneuver, compared to the 80% in the involved knees. It is questionable whether returning an involved limb to the standard of the uninvolved limb should be considered the gold standard, as it is unclear if the current level of the uninvolved limb may have been present when the original injury occurred (Wilk, 2014).

The difference in the average peak valgus angle between the uninvolved and involved knees was 1.32° ($T = 0.28$, $p = .78$). While this is not a significant difference, and there was not necessarily a substantial difference in the percentage of individuals with a meaningful valgus angle, it is important to note that of all knees assessed, 70% demonstrated a meaningful valgus moment. These results raise multiple questions: Were the athletes predisposed to an ACL tear due to generally poor motor planning? Was the athlete's rehabilitation focused on motor control of the knee during sport-specific activities, such as changing direction? It is possible the rehabilitation addressed jumping and landing, but did not address specific activities of sport. It is also possible the athlete was trained in proper mechanics, but the motor programs were not maintained following medical clearance and return to sport. Additionally, was rehabilitation focused on the mechanics of both lower extremities? This research suggests that physical therapy following ACLR should address mechanics bilaterally and during change of direction activities, but further research is warranted in this area.

Certain limitations exist in this study. There was a small sample size of only ten subjects. The subjects had a brief 5 min warm-up, performed one practice trial, and then performed the captured trial, which may not have allowed the opportunity to perform at typical sport level. Although all subjects had undergone ACLR, it was impossible to standardize the surgeon, type of graft utilized, and protocol for rehabilitation following the surgery. Because this

study was a sample of convenience, there were more females (n = 8) than males (n = 2). Finally, this study examined subjects while cutting after being instructed to do so, and therefore anticipating the maneuver. However, most injuries occur during such unanticipated motions, and therefore the generalizability of these results may be limited. The authors recognize that numerous variables contribute to ACL injuries, but the hope is that this information can shed some light on dynamic valgus and lower extremity mechanics during cutting.

5. Conclusion

Athletes who have fully returned to sport following an ACLR demonstrate substantial genu valgum during a cutting maneuver, which suggests an increased risk for re-rupture or rupture of the contralateral limb. These results show an increased need during ACL rehabilitation to focus on existing biomechanical deficits during sport-specific movements. Also, rehabilitation programs for these individuals need to focus on motor control, which manifests through lower extremity mechanics, of both ipsilateral and contralateral lower extremities to better prepare for a return to sport. Future studies are needed to replicate data of determining knee valgus angles during a cutting maneuver following return to play from ACL reconstruction with larger sample sizes.

Conflicts of interest

None declared.

Ethical statements

This research project was reviewed and approved by the Institutional Review Board of Saint Francis University, Loretto, PA.

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Appendix A. Supplementary data

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