Jogging Biomechanics after Exercise in Individuals with ACL-Reconstructed Knees

CHRISTOPHER KUENZE[1], JAY HERTEL[2], ARTHUR WELTMAN[2], DAVID R. DIDUCH[3], SUSAN SALIBA[2], and JOSEPH M. HART[2]

[1]*Department of Kinesiology and Sport Sciences, University of Miami, Coral Gables, FL;* [2]*Department of Kinesiology, University of Virginia, Charlottesville, VA; and* [3]*Department of Orthopaedic Surgery, Sports Medicine Section, University of Virginia, Charlottesville, VA*

ABSTRACT

KUENZE, C., J. HERTEL, A. WELTMAN, D. R. DIDUCH, S. SALIBA, and J. M. HART. Jogging Biomechanics after Exercise in Individuals with ACL-Reconstructed Knees. *Med. Sci. Sports Exerc.*, Vol. 46, No. 6, pp. 1067–1076, 2014. **Purpose**: Return to recreational activity is a common goal for the clinician and patient after ACL reconstruction (ACLR) and structured rehabilitation. Decreased peak knee flexion angle and external knee flexion moment during walking and jogging have been indicated as significant contributors to cartilage degeneration over time after knee joint injury. The purpose of this investigation was to measure the effects of 30 min of exercise on knee joint kinetics and kinematics in participants with a history of ACLR. **Methods**: ACLR participants (n = 20, 9 females and 11 males) and healthy controls (n = 23, 11 females and 12 males) participated in an observational laboratory study. Gait analysis was performed on all subjects before and after a 30-min exercise protocol. Sagittal and frontal plane kinematics and kinetics were measured in the involved limb in the ACLR group and compared with healthy control participants across the gait cycle using 90% confidence intervals. Significant differences between groups were established as a consecutive 3% of the gait cycle in which 90% confidence interval did not overlap. **Results**: Preexercise, ACLR participants were more hip flexed with higher magnitude external hip flexion moments and lower magnitude external knee flexion moments during the stance phase compared with healthy controls. ACLR participants experienced preexercise to postexercise declines in hip flexion angle and external hip flexion moment along with increases in external knee flexion moment when compared with healthy controls. **Conclusions**: Exercise-related adaptations in hip and knee biomechanics are different in individuals with a history ACLR when compared with healthy controls despite a return to recreational activity. The biomechanical response to fatiguing exercise observed in this investigation may provide insight into one potential source of elevated knee injury risk and reduced long-term knee joint health after ACLR. **Key Words:** FATIGUE, EXTERNAL KNEE FLEXION MOMENT, RETURN TO ACTIVITY, QUADRICEPS AVOIDANCE

ACL reconstruction (ACLR) is the most common treatment option for physically active individuals after ACL injury (12,25). Individuals commonly target returning to preinjury levels of physical activity as the goal after ACLR (4). In many cases, despite completing structured rehabilitation, individuals experience persistent alterations in lower extremity function well after being cleared to return to activity (18). Alterations in muscle strength and activation as well as balance and proprioception may have a negative effect on movement patterns during daily activity and participation in sports that can put individuals at risk of reinjury and long-term joint degeneration (12,16,24).

Alterations in walking and jogging gait biomechanics after ACLR, including reduced external knee flexion (17,23,35,38) and increased knee adduction (8,36) moments, may help to explain the alarmingly high rates of knee joint osteoarthritis in this population (2,8). Reductions in peak external knee flexion moment and increases in peak external knee adduction moment during walking and jogging have been indicated as significant contributors to cartilage degeneration after ACLR (1–3). The reduction in external knee flexion moment has been shown to occur more commonly in individuals with weak or inhibited quadriceps muscles (5,23). Reductions in external knee flexion moment during walking and jogging may persist for as long as 2 yr after ACLR although individuals have returned to their normal level of physical activity (9,28). Increased external adduction moment and reduced external knee flexion moment are indicative of reduced ability to dynamically absorb forces during function and are thought to lead to altered joint loading patterns (2,3,15,36,38). It remains unclear how physical activity, such as jogging or participation in sports, may exacerbate the changes in biomechanics seen in a nonfatigued state and what implications this might have for the risk of subsequent injury.

Address for correspondence: Christopher Kuenze, Ph.D., A.T.C., Department of Kinesiology and Sport Sciences, 1507 Levante Ave, #130, Coral Gables, FL 33146; E-mail: c.kuenze@miami.edu.

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Little information is currently available about the gait and landing adaptations to exercise that occur after ACLR (21,22, 26,34). It has been hypothesized that a decreased ability of the quadriceps to dynamically absorb force at the knee joint due to muscle fatigue may result in excessive knee joint loading (2,3). In healthy participants, decreased quadriceps strength and activation have been measured after lower extremity exercise (21,33). Following local fatigue protocols (26,34) and more general lower extremity fatiguing exercise protocols (21), the quadriceps muscles of those with a history of ACLR have been shown to be less susceptible to reductions in strength and activation when compared with their healthy counterparts. The difference in response to exercise after ACLR may have significant implications in regard to the ability to adequately adapt to and absorb joint loads during functional activity; however, the translation of the quadriceps fatigue to the kinematic and kinetic patterns of dynamic movement after ACLR is unclear. Further study of the effects of exercise on lower extremity gait mechanics may allow patients and clinicians to have a clearer understanding of the impact that a full return to activity may have on knee joint health in the presence of lower extremity neuromuscular and movement dysfunction.

Therefore, the purposes of this study were to compare frontal and sagittal plane kinematics and kinetics during jogging between participants with a history of ACLR and healthy controls before and after exercise. We hypothesized that participants with a history of ACLR would exhibit smaller knee flexion angles and smaller magnitude external knee flexion moments in the stance phase before exercise and would experience smaller magnitude reductions in both variables from the preexercise to postexercise condition. We also hypothesized that participants with a history of ACLR would exhibit larger hip flexion angles, ankle plantarflexion angles, and trunk flexion angles along with larger magnitude external hip flexion and ankle dorsiflexion moments in the stance phase before exercise and would experience smaller magnitude reductions in both variables from the preexercise to postexercise condition.

METHODS

Subjects

On the basis of previous group investigations focused on changes in sagittal plane knee joint kinematics and kinetics after fatiguing exercise in participants with a history of knee joint injury, we estimated that 12 participants per group would be needed in this study (10,37). However, as this investigation was part of a larger project, 20 ACLR participants (9 females and 11 males) and 23 healthy volunteers (11 females and 12 males) participated in this study (Table 1). Participants were included if they were between the ages of 18 and 40 yr old, had a body mass index less than 35, were recreationally active (exercised at least three to five times a week at a moderate intensity for no less than 30 min), and had been released from rehabilitation by a medical professional (13). Participants were excluded if they had a self-reported history of lower extremity joint sprain within the past 6 wk, a neurological disorder, a cardiopulmonary disorder, or an inability to complete 30 min of aerobic exercise. The participants included in the ACLR group were those who have recovered at least 6 months after a unilateral primary ACLR by a hamstring or patellar tendon autograft. Participants in the ACLR group were excluded if they had a multiple ligament reconstruction, significant chondral resurfacing procedure [microfracture or osteochondral autograft transfer system (OATS) procedures], significant surgical complication, or history of graft failure. Meniscectomy or meniscal repair at the time of ACLR was not an exclusion criteria in this study as long as participants did not exhibit clinical signs or symptoms of meniscal injury or failed meniscal repair (joint line pain or chronic effusion) at the time of testing. This study was approved by our university's institutional review board, and all subjects provided informed written consent before enrollment.

Preexercise Measures

Patient-reported outcomes. The Tegner Activity Scale was used to assess the physical activity level of subjects at the time of testing (7). A 10-cm visual analog scale was used to assess knee pain at the time of testing as well as pain during a double-limb squat. The International Knee Documentation Committee subjective knee evaluation (19) was used to measure knee-related function in all subjects.

Gait analysis. We performed a three-dimensional video gait analysis using a 12-camera motion analysis system (Vicon Motion Systems, Inc., Lake Forest, CA) with a spatial error of 0.42 mm and a mean error of angle reproduction of 0.16° for all subjects (27). Retroreflective markers were affixed bilaterally over the left and right posterior superior iliac spine, anterior superior iliac spine, lateral midthigh, lateral femoral condyle, lateral midcalf, and lateral malleolus using a two-sided tape in accordance with the plug-in-gait model (20). Markers were outlined on the skin using a marker, affixed directly to the skin using adhesive discs and Leukotape (BSN Medical, Charlotte, NC), and left in place throughout the testing session. Static trials were collected to calibrate the marker

TABLE 1. Participant demographics.

	Healthy	ACLR	*P*
Age (yr)	21.9 ± 3.6	22.7 ± 5.2	0.56
Sex	12 M/11 F	11 M/9 F	0.93
Height (cm)	168.5 ± 8.7	172.2 ± 7.2	0.14
Weight (kg)	69.6 ± 13.8	72.7 ± 13.7	0.46
BMI	24.3 ± 3.3	24.4 ± 3.6	0.93
VAS for current pain (cm)	0.0 ± 0.1	0.3 ± 0.6	0.01*
VAS during a squat (cm)	0.1 ± 0.4	0.2 ± 0.5	0.41
Current Tegner Activity Score	6.4 ± 1.2	6.4 ± 1.2	0.98
IKDC total	99.3 ± 1.6	89.4 ± 10.7	<0.001*
Graft source	X	11 HS/9 BTB	X
Time since surgery (months)	X	33.9 ± 23.4	X

Data are presented as mean ± SD.

*Significant difference between groups ($P \leq 0.05$).

HS, hamstring autograft; BTB, patellar bone–tendon–bone; IKDC, International Knee Documentation Committee.

setup and to provide reference for jogging analysis. Participants walked on the treadmill at a self-selected pace for 5 min as warm-up and to acclimatize to the treadmill and marker setup. Kinematic and kinetic data were then collected while subjects jogged on the treadmill at a speed 9.66 km·h^{-1} (11,27). We selected 9.66 km·h^{-1} because it was comfortable jogging pace for all participants, regardless of the current activity level. Three 15-s trials were collected to ensure at least 10 full gait cycles during each trial.

Kinematic data were sampled at 250 Hz, bilateral marker data were Woltring-filtered, and joint angles were calculated as previously described (14). Synchronized ground reaction force data were collected using a multiaxis strain gauge force plate imbedded under a custom-built treadmill (AMTI OR 6–7, Watertown, MA). Vertical ground reaction forces were sampled at 1000 Hz. A threshold of 60 N was used to determine initial contact and toe-off during jogging (31). Kinetic data were estimated as external joint moments using inverse dynamics and normalized to the product of the subject's body mass and height (N·m·[kg·m]$^{-1}$).

Kinematic and kinetic data were collected using the VICON Workstation software (Version 5.0; VICON Motion Systems, Inc.) and extracted for analysis using a custom LabVIEW program (Version 8.2.1; National Instruments, Austin, TX). In each condition, the within-group mean values of each kinematic and kinetic variables were reduced to 101 data points representing 0%–100% (heel strike to immediately before ipsilateral heel strike) of the gait cycle. For jogging, 0%–40% of the gait cycle was operationally defined as the stance phase of gait (early stance, 0%–12%; midstance, 12%–24%; late stance, 24%–40%), whereas 41%–100% was defined as the swing phase of gait (29,30).

Exercise Protocol

The exercise protocol consisted of repeated cycles of treadmill walking at a self-selected pace (5 min) as well as jump squats and lateral hopping (1 min) (21). During walking phases, the treadmill incline was increased 1.0°·min^{-1} until an incline of 15.0° was achieved. Five cycles (walking and jumping exercises) were completed, for a total of 30 min of exercise. During the final 30 s of each bout of walking, the participants were asked to rate their level of perceived exertion (RPE) using the Borg Scale (6) and their level of fatigue using a visual analog scale (VAS) for fatigue (cm), and heart rate (bpm) was recorded. If the retroreflective markers fell off during the completion of the exercise protocol, the markers would be replaced on the skin in their original positions based on the outline, and static trials were recollected to ensure the fidelity of the data.

Postexercise Measures

Immediately after the exercise intervention, subjects returned to the treadmill for postexercise data collection, which was exactly the same as preexercise data collection.

Statistical Analysis

Demographic data were compared between groups using independent-samples *t*-tests except for sex, which was compared using a chi-square analysis. Frontal and sagittal plane kinematic and kinetic group mean values were calculated for each 1% of the gait cycle, and these values were plotted graphically with 90% confidence intervals (CI) to compare between groups in the preexercise and postexercise state. Statistical significance was defined as portions of the gait cycle where 90% CI did not overlap for a minimum of three consecutive percentages of the gait cycle (27). In addition, preexercise to postexercise mean differences for all frontal and sagittal plane kinematics and kinetics during the stance phase of gait were calculated and plotted with the associated 90% CI in both groups. These graphs present a between-group comparison of within-group preexercise to postexercise change for each kinematic (Δ°) or kinetic variable (ΔN·m·[kg·m]$^{-1}$). Significant differences between groups were reported as the portion of the gait cycle during which the 90% CI do not overlap as well as the peak magnitude of difference (portion of the gait cycle %, mean difference ± SD) between groups during that period of the gait cycle.

Comparisons of heart rate, RPE, and VAS for fatigue were made between groups using separate repeated-measures ANOVA. Significant interactions were further investigated for between-group differences at each time point using Fisher's LSD *post hoc* test. Statistical analyses were performed using the Statistical Package for the Social Sciences (Version 21.0; SPSS Inc., Chicago, IL). Kinematic and kinetic graphs were generated using Microsoft Excel (Version 2010; Microsoft Corp. Redmond, WA).

RESULTS

Preexercise Running Biomechanics

Physiologic and patient-reported measures of exertion during exercise. VAS for fatigue ($P = 0.49$) and RPE ($P = 0.49$) were not significantly different between groups across the 30-min exercise protocol. There was a significant group–time interaction for heart rate ($P = 0.01$), with postexercise heart rate being significantly greater in the ACLR group ($P = 0.05$, ACLR = 143.4 ± 19.3, healthy = 130.4 ± 22.6).

Sagittal plane kinematics and kinetics before exercise. There were no significant differences in hip, knee, or ankle joint kinematics between groups (Fig. 1). Participants with a history of ACLR had significantly higher magnitude external hip flexion moments throughout (10%–12%, 0.38 ± 0.03 N·m·[kg·m]$^{-1}$ and 22%–24%, 0.27 ± 0.02 N·m·[kg·m]$^{-1}$) stance phase (Fig. 2). ACLR participants had significantly lower magnitude external knee flexion moments during the early stance (9%–11%, 0.22 ± 0.02 N·m·[kg·m]$^{-1}$) and midstance (14%–16%, 0.24 ± 0.02 N·m·[kg·m]$^{-1}$) (Fig. 2). There were no significant differences between groups for sagittal

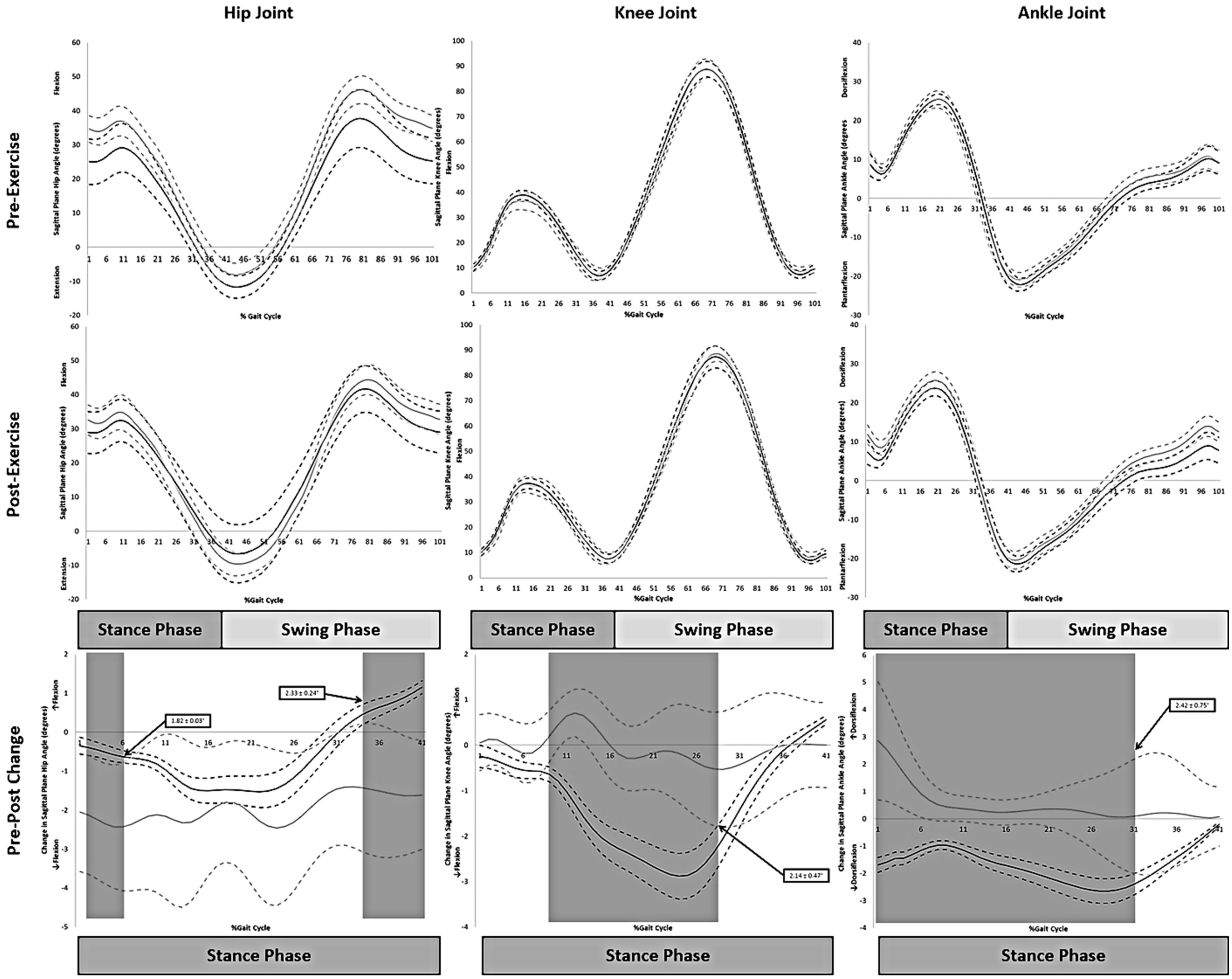

FIGURE 1—Mean preexercise, postexercise, and pre- to postexercise change in sagittal plane kinematics with 90% CI. Highlighted areas indicate significant differences (90% CI do not overlap for at least 3% of the gait cycle) between groups.

plane hip, knee, or ankle kinetics during the swing phase of gait.

Frontal plane kinematics and kinetics before exercise. Participants with a history of ACLR ran with more adducted knees during the swing phase (56%–60%, 10.71° ± 0.67°) (Fig. 3). There were no significant differences for any of the kinetic variables measured between groups during the stance or swing phases of gait (Fig. 4).

Preexercise to Postexercise Changes in Gait Biomechanics

Change in sagittal plane kinematics and kinetics after exercise. In the postexercise state, there were no significant differences for any of the kinematic or kinetic variables between groups during the stance or swing phases of gait (Figs. 1 and 2). However, ACLR participants experienced significantly higher magnitude declines in hip flexion angle during the during early stance phase (3%–6%, 1.82° ± 0.03°) and late stance phase (35%–40%, 2.33° ± 0.24°) and significantly smaller magnitude declines in knee flexion angle (9%–28%, 2.14° ± 0.45°), ankle dorsiflexion angle (1%–31%, 2.42° ± 0.75°), and trunk flexion angle (0%–40%, 1.01° ± 0.35°) compared with healthy controls throughout the stance phase (Fig. 1). ACLR participants experienced larger magnitude declines in external hip flexion moment (8%–10%, 0.19 ± 0.06 N·m·$[\text{kg}\cdot\text{m}]^{-1}$) compared with the healthy control group. ACLR participants also experienced a larger magnitude increase in external knee flexion moment (8%–10%, 0.12 ± 0.04 N·m·$[\text{kg}\cdot\text{m}]^{-1}$) compared with the healthy control group (Fig. 3).

Change in frontal plane kinematics and kinetics after exercise. There were no significant kinematic or kinetic differences between groups in the postexercise state. ACLR participants experienced significant declines in knee adduction angle (1%–3%, 2.47° ± 0.14°) compared with healthy

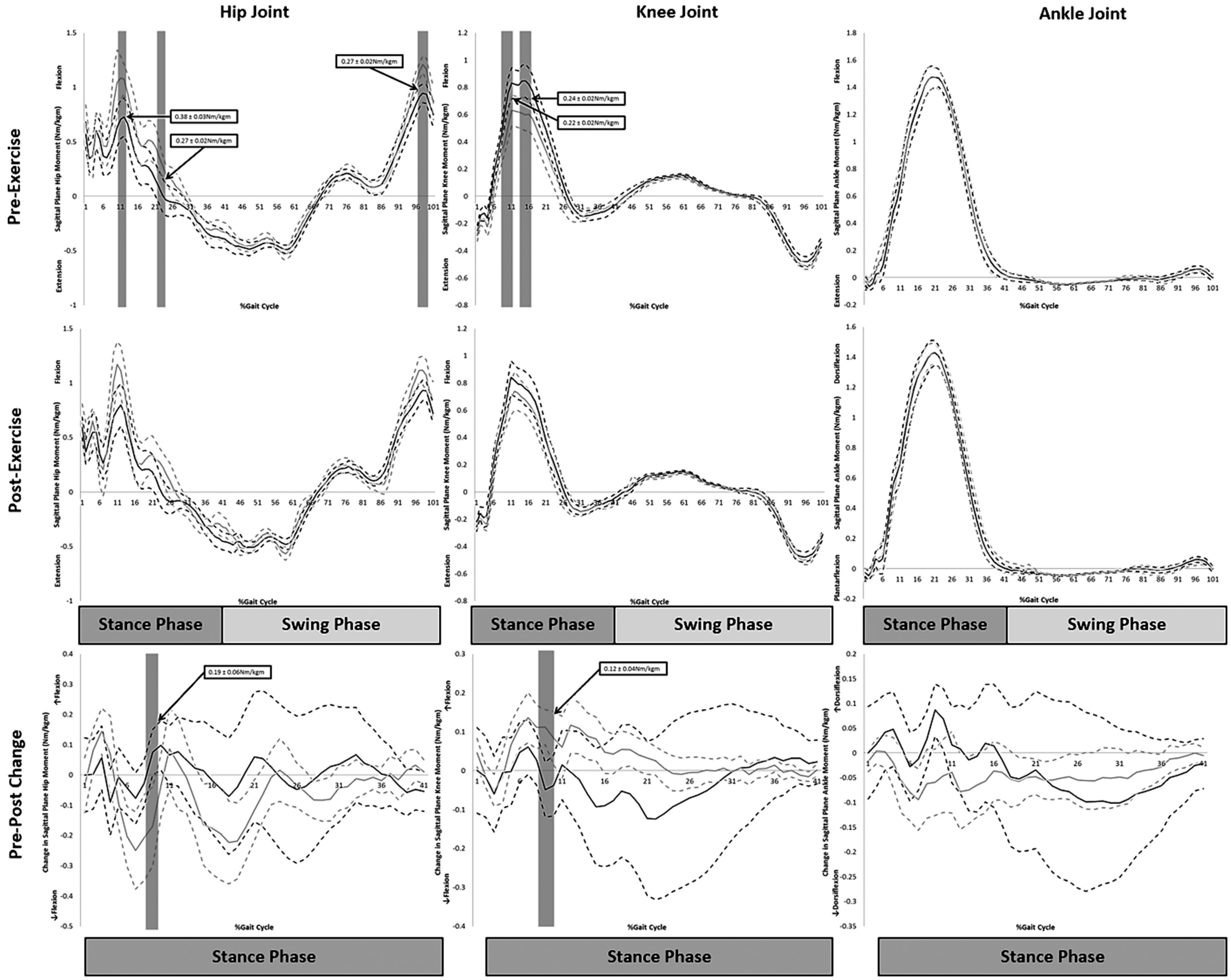

FIGURE 2—Mean preexercise, postexercise, and pre- to postexercise change in sagittal plane kinetics with 90% CI. Highlighted areas indicate significant differences (90% CI do not overlap for at least 3% of the gait cycle) between groups.

controls (Fig. 3). There were no significant between-group differences in preexercise to postexercise kinetic changes (Fig. 4).

DISCUSSION

Participants with a history of ACLR exhibited sagittal plane alterations in knee joint kinetics and kinematics during the stance phase as a result of fatiguing exercise that may be indicative of quadriceps preservation throughout the exercise protocol. It has been proposed that these reductions in external knee flexion moment may be related to persistent quadriceps weakness, which is commonly reported after ACLR and may result in reduced ability to absorb load at the knee joint during functional movement (23). After completing 30 min of exercise, the ACLR group experienced larger declines in external hip flexion moment near the peak loading of the stance phase, whereas the external knee flexion moment significantly increased compared with the healthy control group. Despite participation in the same level of activity as their healthy counterparts, participants with a history of ACLR demonstrate a pattern of quadriceps preservation and increased kinetic demand at the hip, as seen in larger magnitude declines in external hip flexion moments during exercise. We feel that the pattern observed in sagittal plane knee moments is indicative of potential adaptations and movement strategies that enable those with a history of ACLR to preserve quadriceps function throughout the 30 min of exercise. The source of preservative strategy is not clear; however, it may be a result of persistent quadriceps weakness after ACLR, which have been shown to produce similar sagittal plane kinematic and kinetic profiles (23). Quadriceps sparing patterns during gait may reduce demand on the quadriceps muscle during exercise. When coupled with increased hip extensor muscle involvement, individuals experiencing quadriceps weakness after ACLR may be able to maintain their level of physical activity despite persistent

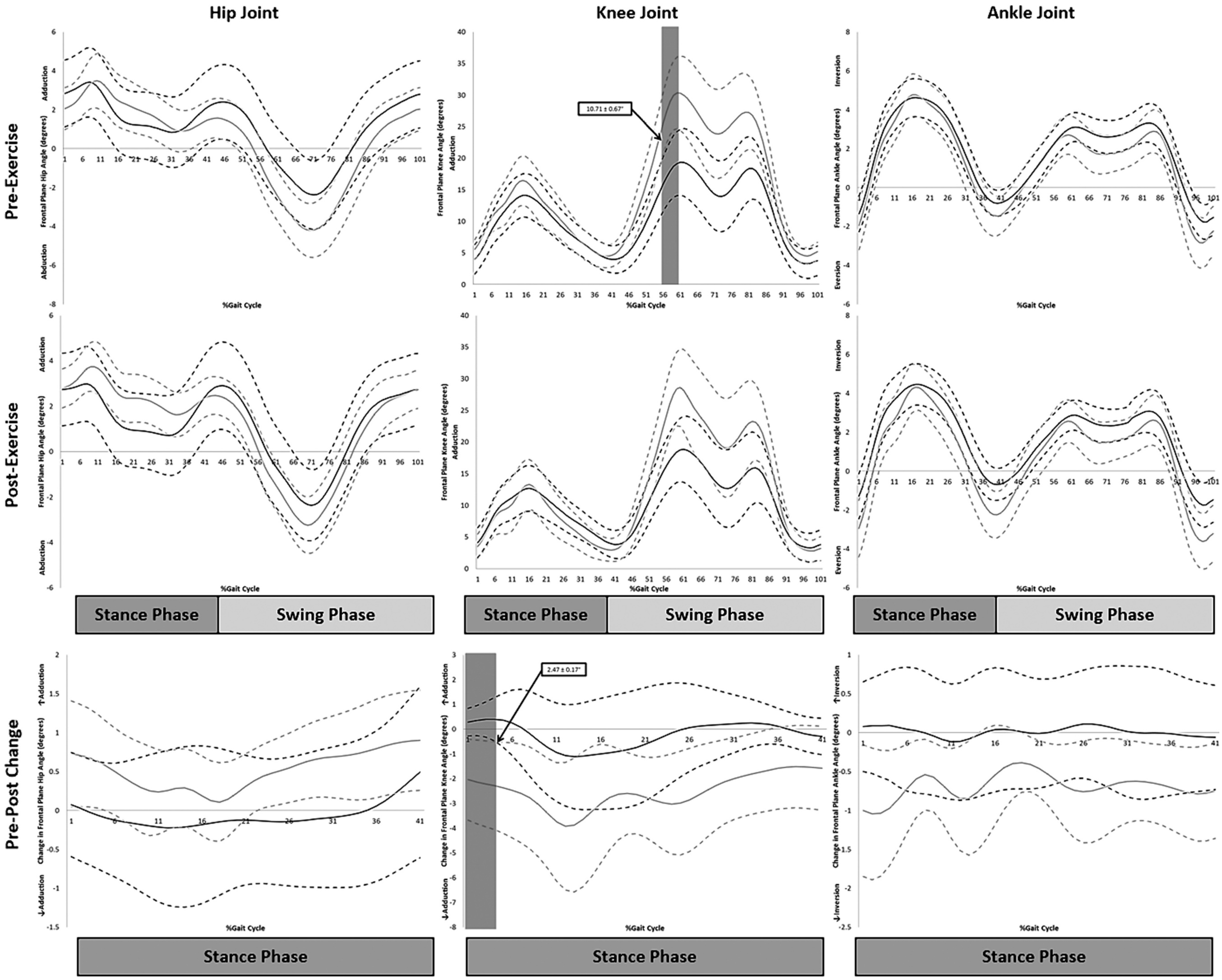

FIGURE 3—Mean preexercise, postexercise, and pre- to postexercise change in frontal plane kinematics with 90% CI. Highlighted areas indicate significant differences (90% CI do not overlap for at least 3% of the gait cycle) between groups.

neuromuscular dysfunction. The presence of altered knee and hip joint biomechanics may provide important information about the effects of physical activity on knee joint loading in young, active participants after ACLR.

Preexercise kinematics and kinetics. At the point of peak joint loading during the stance phase of gait, participants with a history of ACLR exhibited smaller magnitude external knee flexion moments when compared with healthy controls (Figs. 1 and 2). One possible source of a reduced external knee flexion moments is a reduction in the contribution from the knee extensors during gait, which has been called *quadriceps avoidance gait* (5). Because knee extension weakness is common in this population, concern exists that the underlying cause of reductions in external knee flexion moment may be due to persistent quadriceps weakness. In addition, reduced external knee flexion moments may be accompanied by proximal compensations after ACLR, which promote decreased ability among ACLR participants to dynamically absorb functional loads at the knee joint. Participants in this study did not see accompanying increases in trunk flexion (Fig. 5) but instead experienced reduced external knee flexion moments during the early stance phase coupled with increased external hip flexion moments at peak hip loading as well as during terminal stance phase (Fig. 2). The shift to a more hip-dominant strategy of managing lower extremity moments when compared with healthy participants during gait highlights a potential strategy adopted by those with a history of ACLR to cope with the reductions in external knee flexion moments that are present in the preexercise state.

Quadriceps dysfunction is a common clinical concern after ACLR, with deficits in quadriceps strength and activation that may persist well after a full return to activity (32). Quadriceps weakness and activation failure have been linked to altered sagittal plane knee joint biomechanics, such as reduced knee flexion angle and reduced external knee flexion moment during functional tasks after knee joint injury

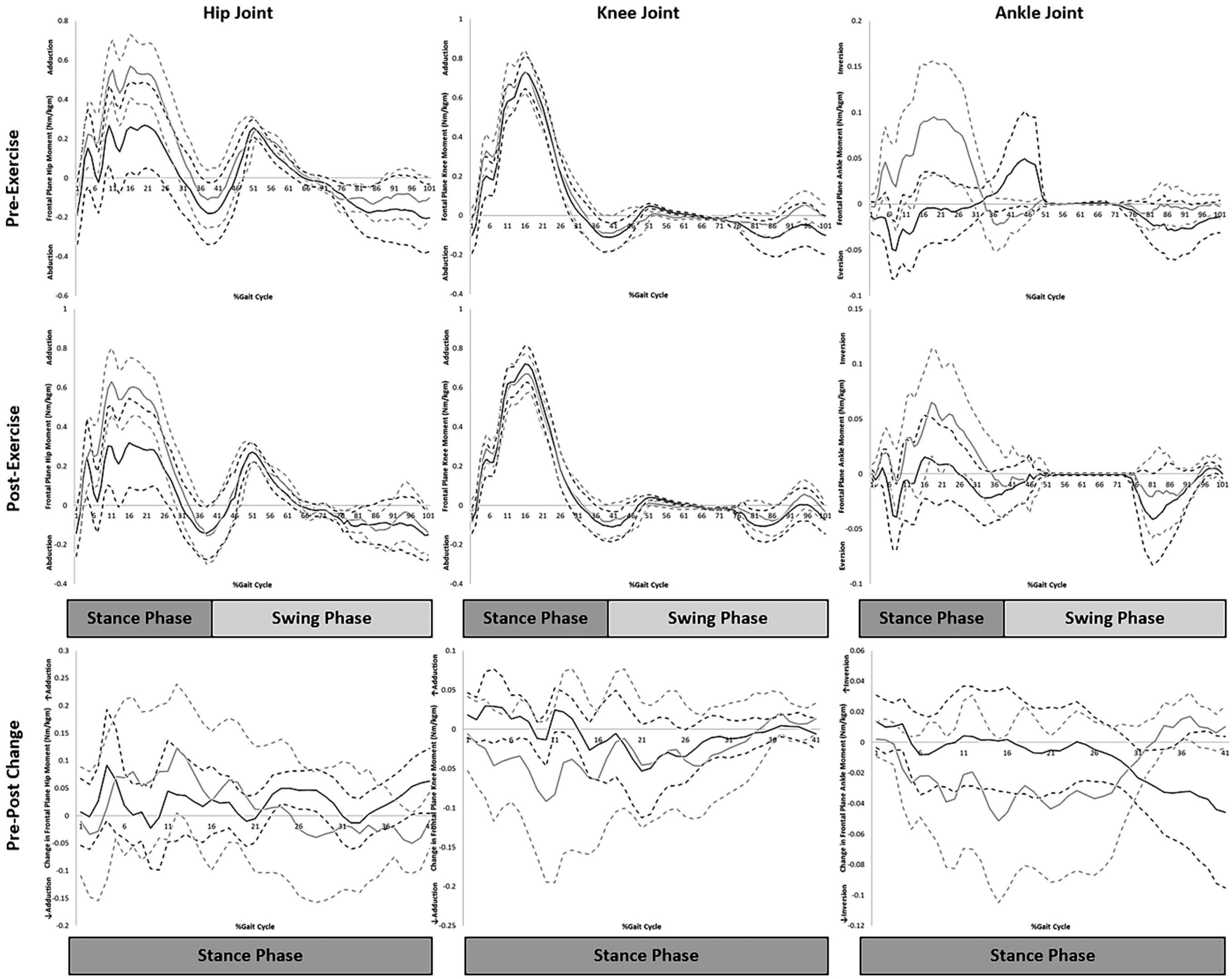

FIGURE 4—Mean preexercise, postexercise, and pre- to postexercise change in frontal plane kinetics with 90% CI. Highlighted areas indicate significant differences (90% CI do not overlap for at least 3% of the gait cycle) between groups.

(23,39). Unlike previous investigations that have reported altered sagittal plane kinetics after ACLR, quadriceps strength and quadriceps activation were not used as inclusion criteria in this study (23,36). Although reduced quadriceps strength and activation where not considered inclusion criteria for this study, clear reductions of external knee flexion moment were

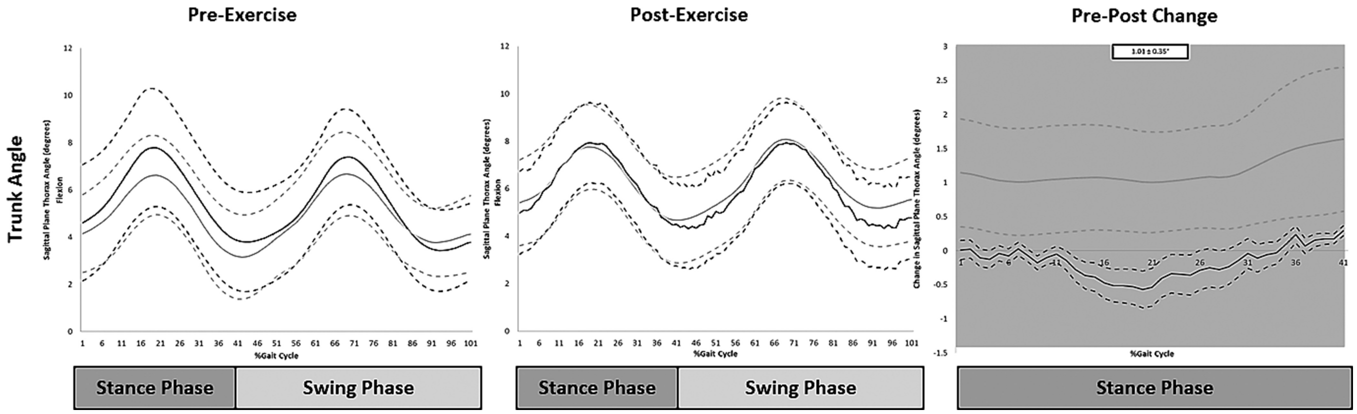

FIGURE 5—Mean preexercise, postexercise, and pre- to postexercise change in sagittal plane trunk kinematics with 90% CI. Highlighted areas indicate significant differences (90% CI do not overlap for at least 3% of the gait cycle) between groups.

present during peak loading in the ACLR when compared with healthy controls. This pattern of sagittal plane kinetics may be indicative of a compensation that develops early after injury in response to decreased quadriceps function, increased knee joint effusion, and pain (18,23). However, despite the high level of physical activity and self-reported function present in our participants after ACLR, it is clear that abnormal gait biomechanics, which may have significant implications for long-term joint health, persist well beyond the point of clearance for return to activity.

Exercise-related changes in jogging biomechanics. After 30 min of exercise, ACLR participants experienced greater declines in hip flexion angle and external hip flexion moment along with greater increases in external knee flexion moment near peak joint loading during the stance phase when compared with the healthy control group (Figs. 1 and 2). These findings suggest a transition within the ACLR group from a preexercise pattern of managing lower extremity torques dominated by hip contributions during jogging to a more knee-driven strategy postexercise. The reduction in hip flexion angle after fatiguing exercise is consistent with recent findings involving a jump-landing task and may highlight the implications of exercise in the presence of altered sagittal plane ankle, knee, and hip biomechanics in the rested state (37). However, to our knowledge, this is the first time that differences in preexercise to postexercise change for sagittal plane kinematics at initial contact and kinetics near maximal loading have been observed in conjunction with changes at the hip. It should be noted that although kinetic differences between groups may be small in magnitude, they temporally occur at exactly the same point during the stance phase at both the hip (8%–10%, 0.19 ± 0.06 $\text{N}\cdot\text{m}\cdot[\text{kg}\cdot\text{m}]^{-1}$) and the knee joint (8%–10%, 0.12 ± 0.04 $\text{N}\cdot\text{m}\cdot[\text{kg}\cdot\text{m}]^{-1}$), respectively. Although the source of this observation is not clear, it would seem that the effects of fatigue on knee and hip kinetics after ACLR are most apparent around the time of maximal knee joint loading during jogging, which may have implications for aberrant knee joint loading throughout activity.

Quadriceps preservation (Fig. 2) throughout exercise may be considered to be a helpful compensation that enables those with a history of ACLR to participate in recreational activity; however, the implications of these compensations over time remains unclear. We observed a combination of quadriceps preservation, as seen in the small changes in the loading phase of the external knee flexion moment and the increased preexercise reliance on the hip extensors to compensate for the reduced preexercise external knee flexion moment. These concurrent adaptations may put those with ACLR at risk of exposing the knee joint to increasing loads as the hip extensors fatigue throughout exercise. Although not significantly different than the healthy group, postexercise participants with a history of ACLR tended to have smaller external knee flexion moments through midstance despite having experienced a significant increase from preexercise to postexercise (Fig. 2). The increased reliance on the knee extensors in a population that commonly experiences persistent quadriceps dysfunction after surgery (16) may put those with a history of ACLR at risk of increased joint loading in the absence of adequate dynamic knee joint load absorption (23).

LIMITATIONS AND FUTURE RESEARCH

There are several notable limitations that should be considered when evaluating the findings of this investigation. The lack of data regarding quadriceps strength limits our ability to draw conclusions related to the source of the biomechanical alterations observed in those with a history of ACLR. The cross-sectional design of this study and the choice to recruit participants from the community at large limited our ability to control for certain demographic and clinical factors. Access to detailed information regarding length and intensity of rehabilitation after ACLR was limited, which resulted in a reliance on subjective participant reports related to compliance with structured rehabilitation. The design of this study allowed us to gain a broad understanding of the ACLR population, but the wide range of time since surgery, the participant's age, and the relative activity level limited our ability to draw conclusions about the impact of exercise on jogging biomechanics at specific time points after ACLR. Future investigations should focus on understanding the impact of exercise on gait biomechanics after ACLR prospectively. In addition, it is essential that we develop a better understanding of the relationship between altered response to exercise and other common clinical measurements that have been shown to be persistently altered after ACLR. This approach will enable a clearer understanding of the underlying physiologic mechanism of this phenomenon while potentially identifying areas for intervention. Although the long-term implications of these differences are not clear, the interaction of quadriceps weakness after ACLR and the altered lower extremity biomechanics may be an important risk factor for increased knee joint loading and subsequent joint degeneration.

CONCLUSIONS

Individuals with a history of ACLR experienced alterations in hip, knee, and ankle kinematics and kinetics that were significantly different from healthy matched controls after 30 min of exercise. Most notably, ACLR participants exhibited larger magnitude declines in hip flexion angle and external hip flexion moment during the stance phase of gait, with accompanying increases in knee flexion angle and external knee flexion moment. This pattern of movement after exercise represents a departure from the reduced knee flexion angle and external knee flexion moment that has been commonly reported after ACLR when measured in a rested state. Better understanding the source of altered response to fatiguing exercise and the associated biomechanical deviations at the ankle, knee, and hip may help clinicians in better evaluating readiness for return to activity as well as targeting treatment at the terminal stages of rehabilitation. The source of these alterations is currently unclear, but the impact of persistent jogging knee and hip joint kinematic and kinetic alterations after exercise well after a return to full activity may begin to explain why those with a history of ACLR are at a significantly greater risk of subsequent knee joint injury as well as reduced long-term joint health.

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