ANALYSIS OF LOCALIZED LIMB LOADS FOR INJURY RISK DURING RETURN TO RUNNING PROTOCOLS FOLLOWING ACL RECONSTRUCTION

by

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Abstract

Introduction: Running is a typical goal after anterior cruciate ligament reconstruction (ACLR). Return to running (RTR) protocols are intended to provide a safe, incremental exposure to mechanical loads associated with running but none have been evaluated using existing injury prediction thresholds. Additionally, the influence of daily physical activity (PA) level and adherence to RTR protocol guidelines on predicted injury risk is unknown.

Objectives: The purpose of this study was to estimate patellofemoral joint (PFJ), tibiofemoral joint (TFJ), and Achilles tendon (AT) injury risk associated with participation in three different RTR protocols as a function of overall daily PA level and protocol adherence.

Methods: Average PFJ, TFJ, and AT force impulse/step during walking and running among 38 people with a history of ACLR were used to estimate cumulative impulse data at each site for each day for three RTR protocols. These RTR protocol impulse estimates were summed with the cumulative impulse at each site at progressively greater daily PA levels and input into two published injury prediction equations, the acute:chronic workload ratio (AC ratio) and percent change in daily load. A clinical scenario of nonadherence was evaluated by one week of no running followed by one week of doubling the mileage required in the protocol.

Results: Assuming adherence, the AC ratio was below predicted injury risk thresholds at all sites, regardless of PA level (Figure 1A). However, the percent change injury model predicted increased PFJ injury risk when daily PA levels were less than 3,400 steps/day (Figure 1B). The RTR nonadherence model resulted in an AC ratio exceeding injury risk thresholds with PA levels below 2,300, 2,700, and 7,700 steps/day for the AT, TFJ, and PFJ, respectively, while the percent change model predicted increased injury risk at all sites regardless of PA level. The PFJ was at greatest risk for injury in each RTR protocol, regardless of adherence or daily PA level.

Conclusions: The results of this study provide a basis for PA and protocol adherence recommendations and insight to the etiology of injuries associated with RTR after ACLR.

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Introduction

Anterior Cruciate Ligament (ACL) injury is a common injury that often occurs in people that are involved in multi-directional sports. ACL reconstruction surgery is a typical treatment choice following this injury, particularly among athletes who intend to return to sport. The annual incidence of ACL reconstruction in the United States is 123 ACL per 100,000 people for males between the ages of 18-29 and 62-72 ACL reconstructions per 100,000 people for females between the ages of 15-34 years (Janssen et al. 2012). More than 80% of people post ACLR return to running 6-24 months after surgery (Grindem et al. 2014). Unfortunately, many people experience running-related injuries as they resume running and other athletic participation. For example, 50% of people experience patellofemoral pain within the first year after surgery (Li et al. 2011).

Rehabilitation guidelines following ACLR typically include a program intended to facilitate a return to running (Adamset al. 2012). These programs are intended to provide patients with a progressive and incremental exposure to mechanical stimuli associated with running. By doing so, tissues that are affected by these stimuli theoretically have time to remodel and become more resilient to progressively greater loads. Clinicians have many options when it comes to picking a return to running (RTR) protocol for their patients. However, to date, no RTR protocol has been evaluated using existing injury prediction thresholds.

The acute chronic (AC) ratio is an index of athlete preparedness for sport that can be used as an injury prediction model. The basis of this model is the comparison of work done over the past week (acute workload) compared to the work prepared over the past four weeks (chronic workload). An AC ratio of 1.5 or higher has been associated with an increased risk of injury (Blanch & Gabbett 2016,Gabbett 2016, Gabbett et al. 2016, Hulin et al. 2016, Murray et al. 2016). A moderately-high AC ratio (1.31-1.58) has also been found to represent a significantly higher risk of injury than those with a lower ratio (Hulin 2016). Because this is a comparison between what was recently done to what the athlete has prepared for, this formula can be applied to any comparison scenario that is deemed relevant to the practitioner (Blanch & Gabbett 2016).

Another model of injury prediction is based on the percent change in daily running loads. This modelevaluates the change in physical activity workloads to predict injury risk over a two-week period. A thirty percent increase in activity for a given week is associated with an increase in injury risk (Nielsen et al. 2014).

Because these prediction models take into the account the change in workload over the past 2-4 weeks, overall daily physical activity level can affect the injury risk. Consistently high chronic workloads may prevent injury by preparing the athlete for high acute workloads. On the other hand, the same acute workload place a person who has a low chronic workload at higher risk of injury than that of someone with a high chronic workload (Hulin 2016). Similarly, adherence to training protocols intended to titrate workload exposure may affect injury risk. For example, athletes that do not participate in holiday training over breaks have a higher risk of injury when returning to play because their lower chronic workload (Gabbett et al 2016). The adherence of the athlete is similar to if a patient decided not to follow the prescribed protocol for a week or more.

Each of these injury prediction models is generally based on activity level, not on the actual magnitude, duration, or frequency of the mechanical force experienced at typical injury sites during the activities. As such, the utility of either injury risk model for site-specific injury prediction using localized limb loads is currently unknown. Additionally, the effect of daily physical levels and nonadherence scenarios (e.g. relapse, breaks, inconsistent added load) on injury risk at specific sites over RTR protocols has not been evaluated.

The purpose of this study is to:

1. Quantify injury risk at common injury sites including the Patellofemoral joint (PFJ), Tibiofemoral joint (TFJ), and Achilles Tendon (AT) over the course of 3 RTR protocols using the AC ratio and percent change methods
2. Evaluate estimated injury risk as a function of overall Physical Activity (PA) level and a clinical scenario of nonadherence

Methods

*Participants*Data from 38 participants (14 males, 22 yr, 170.7 kg) with a history of unilateral ACLR (3.8 yr post op) were used in this study. Complete inclusion and exclusion criteria, data collection procedures, and more detailed explanation of the methods used to quantify musculoskeletal loads have been previously published (Bowersock, et al 2017). Importantly, partcipants were required to have a Tegner score of at least 5 (i.e. participating in recreational sports or activity that includes running or jumping 2 days a week) and have no pain associated with running or walking. Participants were excluded if they had a lower extremity surgeries other than a unilateral ACLR. All participants provided informed consent prior to data collection.

Return to Running Protocol

Three protocols from varies genres, including a published journal, protocol 1, (Adams et al. 2012), and popular social media, protocol 2 (Durall), and a textbook, protocol 3, (Duke &Brotzman 2011) were used as a basis for limb loads associated with RTR following ACLR . Any protocol including anything other than walking and running were exempt because data collected were only for walking and running.

Data Collection

Full methodology for the data collections can be found elsewhere (Bowersock, 2017). Briefly, kinematic walking and running data were collected with a 10-camera motion capture system and ground reaction force data from a treadmill instrumented with force plates (BERTEC Corp., Worthington, OH, USA). These data were used to calculate hip, knee and ankle joint angles, net joint moments, and joint reaction forces using an inverse dynamics approach. These signals were then used as inputs to a biomechanical model to derive hamstrings, quadriceps, and gastrocnemius muscle forces. These muscle forces, combined with joint reaction forces, yielded estimated patellofemoral joint (PFJ) contact force, tibiofemoral joint (TFJ) contact force, and Achilles tendon (AT) force during each condition. The average PFJ, TFJ, and AT force impulse per step was calculated over the course of 5 stance phases while running and walking for each participant. For the purpose of this study, we used only data collected while walking and running at participant’s preferred speed (2.7 m/s) and stride length.

Total Daily Load

The impulse per step data was used to model three different return to running protocols to determine the cumulative load (figure 1) for each day of the protocol for the PFJ, TFJ, and Achilles Tendon. The cumulative load for walking and running were added together to get the total cumulative load for each day of each RTR protocol.

Protocol Loading

$$\text{Cumulative Load Walking} = \mathrm{I} * \frac{d}{2 * Step\ Length}$$

$$\text{Cumulative Load Running} = \mathrm{I} * \frac{d}{Stride\ Length}$$

Figure 1. Cumulative load was calculated as the impulse multiplied by the number of steps it would have taken to finish a bout of exercise prescribed in the protocol.

To evaluate the effect of PA level on injury risk, the RTR cumulative load for each day of each RTR protocol was added to progressively greater PA levels that ranged from 1,000- 10,000. For the purpose of this study, we assumed that all PA was in the form of walking. Accordingly, the daily PA load was the PFJ, TFJ, and AT impulse during each participant's preferred walking condition multiplied by the number of steps per day. Total daily load was the sum of daily cumulative RTR load plus the modeled PA level (figure 2). Injury risk was evaluated at the PFJ, TFJ, and Achilles Tendon for each day of each protocol. The AC ratio and percent change method were used to determine injury risk. Results were presented as graphs (graphs 1-6) that expressed injury risk as a function of PA level (total number of steps per day outside the protocol).

$$Total\ Daily\ Load = Cumlative\ Load + Daily\ PA\ constant$$

Figure 2. Total Daily Load formula. Injury risk was evaluated using the total daily load for each day of the protocol for the PFJ, TFJ, an Achilles Tendon.

Acute: Chronic Ratio (AC ratio)

The AC ratio is a comparison of workload that compares the workload done over the past week to the workload prepared for over the past four weeks. The exponentially weighted moving average (EWMA) method was used to calculate the AC ratio (figure 2). The EWMA method mathematically emphasizes more recent exposures so that workload during the RTR protocol done 3 days ago has more of an effect on injury risk than workload done 20 days ago (Murray et al. 2016). An AC ratio greater than 1.5 is associated with an increased risk of injury (Blanch & Gabbett 2016,Gabbett 2016, Gabbett et al. 2016, Hulin et al. 2016, Murray et al. 2016).

$$\mathrm{EWMA}_{\mathrm{today}} = \mathrm{Load}_{\mathrm{today}} * \lambda + (1-\lambda) * \mathrm{EWMA}_{\mathrm{yesterday}}$$

$$\lambda = \frac{2}{N+1},\ N = 7{,}28\ (\text{Acute, Chronic})$$

$$\textbf{AC ratio} = \frac{EWMA_{acute}}{EWMA_{chronic}}$$

Figure 2. AC Ratio formula using the EWMA method. Acute represented the past week and chronic represented the past four weeks. AC ratio is acute divided by the chronic. Anything above 1.5 is associated with an increased risk of injury.

The AC ratio formula and cumulative loading formula were used to derive a formula that expressed the AC ratio as a function of number of steps per day outside the protocol (Figure 3).

$$AC = \frac{.5xI_w + \frac{1}{4} * \frac{3}{4}^{0}\ C_p + \frac{1}{4} * \frac{3}{4}^{1}\ C_{p-1} + \frac{1}{4} * \frac{3}{4}^{2}\ C_{p-2} \ldots + \frac{3}{4}^{n}\ C_b}{.5xI_w + \frac{2}{29} * \frac{27}{29}^{0}\ C_p + \frac{2}{29} * \frac{27}{29}^{1}\ C_{p-1} + \frac{2}{29} * \frac{27}{29}^{2}\ C_{p-2} \ldots + \frac{27}{29}^{n}\ C_b}$$

Figure 3. AC ratio as a function of steps per day on peak injury risk. X is the number of bilateral steps per day. I_w is the impulse/step while walking. C_p is the Cumulative load for the protocol on the day with the peak injury risk. C_{p-1}, C_{p-2} and so forth are the cumulative loads days prior to the peak. C_b is the baseline workload (walking the entire protocol). N is the day of the protocol with the peak risk. Also note the exponents for $\frac{3}{4}$ (acute) and $\frac{27}{29}$ (chronic) increase numerically for each day prior to the peak.

Injury risk was calculated using a previously published formula (Blanch & Gabbett 2016) that expressed injury risk as a function of AC ratio (figure 4). The final graphs expressed injury risk as a function of total steps per day outside the protocol (graphs 1-3). Based on this formula, an injury risk percent greater than 6.56 % is associated with an increased risk of injury.

$$\boxed{\text{Injury Risk (\%)} = 9.98(\text{AC Ratio})^2 - 18.42(\text{AC Ratio}) + 11.73}$$

Figure 4. Injury risk formula previously published by Blanch and Gabbett (2016). Injury risk over 6.555 (AC ratio of 1.5) is associated with an increased risk of injury.

Percent Change

The percent change method is a comparison between the change in workload over the past two weeks (Figure 5). A percent change greater than 30 percent is associated with an increased risk of injury (Nielsen et al. 2014).

$$\boxed{\textbf{\% change} = \frac{(Total\ Loadweek_1 - Total\ Loadweek_0)}{Total\ Loadweek_0} * 100}$$

Figure 5. Percent Change formula. Anything above 30% increase in workload is associated with an increased risk of injury.

The percent change formula and cumulative loading formula were used to derive a formula that expressed percent change as a function of number of steps per day outside the protocol (*Figure* 6). The final graphs expressed workload percent change as a function of total steps per day outside the protocol (graphs 4-6).

$$\boxed{\%\ Change = \frac{C_{Load\ past\ 7\ days} - C_{Load\ past\ 8-14\ days}}{3.5xI_w + C_{Load\ past\ 8-14\ days}} * 100}$$

Figure 6. Percent change as a function of steps per day outside the protocol. C_{load} is the total cumulative load for the week described. X is the number of bilateral steps per day outside the protocol. I_w is the impulse/step for walking.3.5 comes from 7/2. 7 days in a week and it is dvided by two because the injury risk is only calculated for the involved limb.

Adherence and Nonadherence

Injury risk was evaluated for each of the three protocols in both an adherence and nonadherence scenario. Adherence was modeled by following the protocol verbatim. Nonadherence was modeled by simulating a week off from the protocol followed by doubling the protocol the following week. The nonadherence model was consistent across all three protocols.

Results

*Impulse per Step (Body Weight*Second)*

The impulse per step at the TFJ for running (1.205 BW*S, SD .227) is higher than the PFJ (.448 BW*S, SD .179) and Achilles Tendon (.716 BW*S, SD .112). While walking, the TFJ impulse per step (1.226 BW*S, SD .127) was higher than both the PFJ (.211 BW*S, SD .068) and Achilles Tendon (.808 BW*S, SD .117).

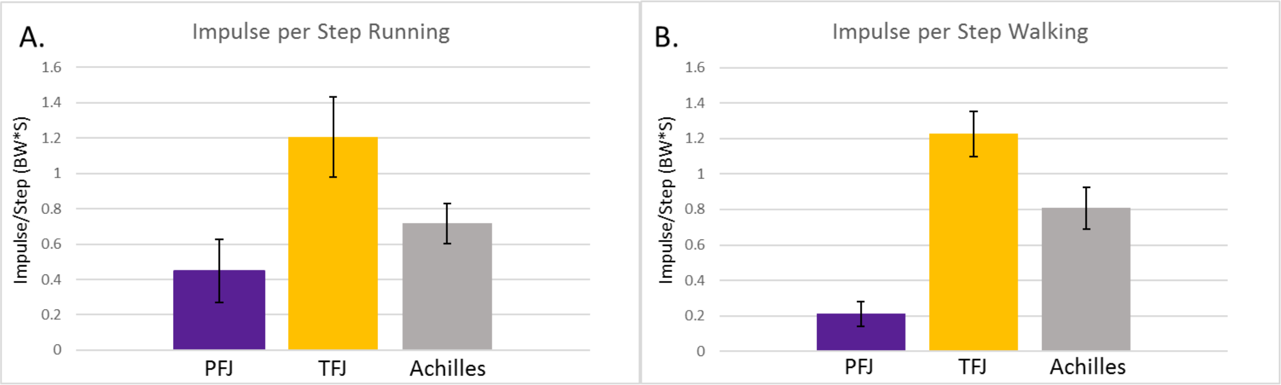


Figure 7. Impulse/step for the PFJ, TFJ, Achilles Tendon while running (A) and walking (B)

There is a greater impulse at the PFJ joint in running compared to walking (.237 BW*S, SD .135). Running has less of an impulse than walking at the TFJ (-.021 BW*S, SD .178) and Achilles Tendon (-.092 BW*S, SD .111).

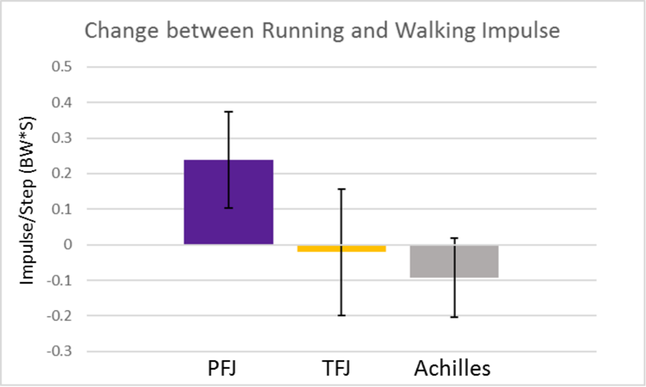


Figure 7. The difference of Impulse/step for running minus walking at the PFJ, TFJ, and Achilles Tendon

AC ratio and PA level

For each of the three protocols modeled (Protocol 1: Adams et al. 2012, Protocol 2:Durall , Protocol 3: Duke &Brotzman 2011), the AC ratio was below the injury threshold of 1.5(Injury Risk 6.56%) (Blanch & Gabbett 2016,Gabbett 2016, Gabbett et al. 2016, Hulin et al. 2016, Murray et al. 2016), for the PFJ, TFJ, and Achilles Tendon at all PA levels (Graphs 1-3). The highest risk of injury was at a daily physical activity level of 1,000 steps per day outside the protocol, the lowest PA level evaluated in the study. The PFJ was at the highest risk of injury for protocol 1 (1.25 Ratio, 4.28% Injury Risk), protocol 2 (1.22 Ratio, 4.39% Injury Risk), and protocol 3 (1.32 Ratio, 4.82% Injury Risk). The TFJ was the second highest risk of injury for protocol 1(1.13 Ratio, 3.66% Injury Risk), protocol 2 (1.17 Ratio, 3.84% Injury Risk), and protocol 3 (1.15 Ratio, 3.75% Injury Risk). The Achilles Tendon had the least risk of injury for protocol 1 (1.11 Ratio, 3.56% Injury Risk), protocol 2 (1.16 Ratio, 3.81% Injury Risk), protocol 3 (1.13 Ratio, 3.67% Injury Risk). These injury risks represent the peak injury risk over the course of each RTR protocol, all other days had an injury risk below the injury risk evaluated above.

Percent Change and PA levels

The maximum percent change in workload over each RTR protocol was at 1,000 steps per day (Protocol 1: Adams et al. 2012, Protocol 2:Durall , Protocol 3: Duke &Brotzman 2011), the lowest PA level evaluated in the study. The patellofemoral joint was above the injury risk threshold of a percent change higher than 30 percent (Nielsen et al. 2014) for protocol 1 (55.99%), protocol 2 (41.76%) and protocol 3 (66.6%). Injury risk was above the threshold for PA levels below 2,560 steps per day outside the protocol for protocol 1, 2,560 steps per day outside the protocol for protocol 2, and 3,340 steps per day outside the protocol for protocol 3. The TFJ was above the injury threshold for PA levels below 2,080 steps per day outside the protocol for protocol 1 and 1,280 steps per day outside the protocol for protocol 3. Protocol 1 (1,180 steps per day outside the protocol) and Protocol 3 (1,120 steps per day outside the protocol) were the only protocols that the PA levels were above the injury threshold for the Achilles Tendon (Graphs 4-6).

Injury Risk and Nonadherence

The maximum percent change in workload for each RTR protocol was at 1,000 steps per day (Protocol 1: Adams et al. 2012, Protocol 2:Durall , Protocol 3: Duke &Brotzman 2011), the lowest PA level evaluated in the study. Nonadherence increased injury risk for all three protocols for the AC ratio and percent change method for the PFJ, TFJ, and Achilles Tendon. The PFJ had the greatest risk of injury using both the AC ratio and percent change methods. For example, the injury risk to the PFJ is 35-50% greater across all protocols than either the TFJ or Achilles for the AC ratio (Table 1). Using the percent change method, the PFJ peak percent change was more than 90% greater than that of the TFJ and Achilles (Table 2).

For nonadherence, injury risk was above the injury threshold for the PFJ for activity levels below 6,480 steps per day outside the protocol for protocol 1, 7,720 steps per day outside the protocol for protocol 2, 8,920 steps per day outside the protocol for protocol 3 (Graphs 1-3). All models of adherence were under the threshold for injury at 1,000 steps per day outside the protocol. Across all protocols, injury risk using the AC ratio and injury risk formula increased 3-4 folds from the adherence to nonadherence models (Graphs 1-3). The percent change method produced a percent change over the injury threshold across all PA levels tested for all three protocols and across all three sites (Graphs 4-6).

Protocol Number	AC Ratio			Injury Risk (%)		
	PFJ	TFJ	Achilles	**PFJ**	TFJ	Achilles
1	**1.93**	1.54	1.54	**13.28**	7.63	7.04
2	**2.03**	1.69	1.65	**15.48**	9.17	8.84
3	**2.21**	1.91	1.54	**19.71**	12.97	12.15

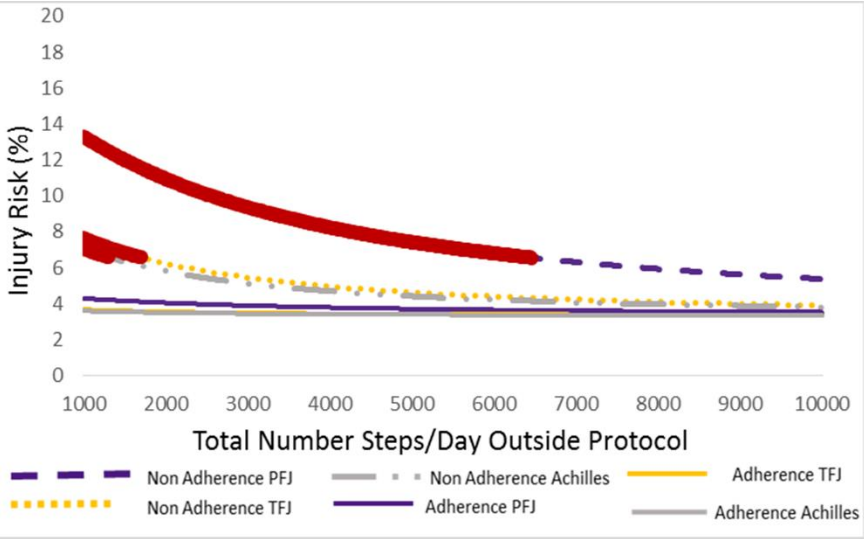
Table 1. Injury risk for Nonadherence model using AC ratio across all 3 protocols for the PFJ, TFJ, and Achilles. Injury risk is highest for the PFJ.

Protocol Number	Percent Change		
	PFJ	TFJ	Achilles
1	**1099.14**	507.12	462.55
2	**1104.51**	553.15	449.61
3	**1037.37**	494.92	448.54

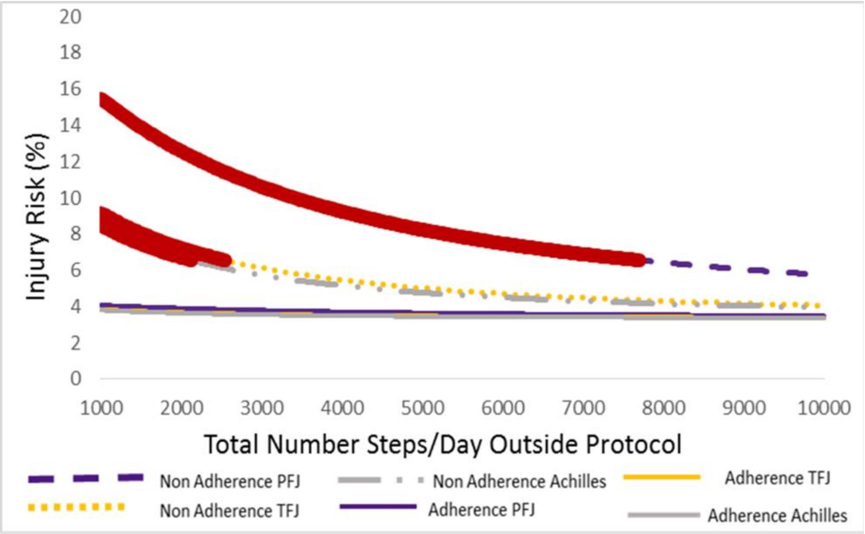
Table 2. Injury risk for Nonadherence model using percent change across all 3 protocols for the PFJ, TFJ, and Achilles. Injury risk is highest for the PFJ.

Peak AC Ratio Graphs

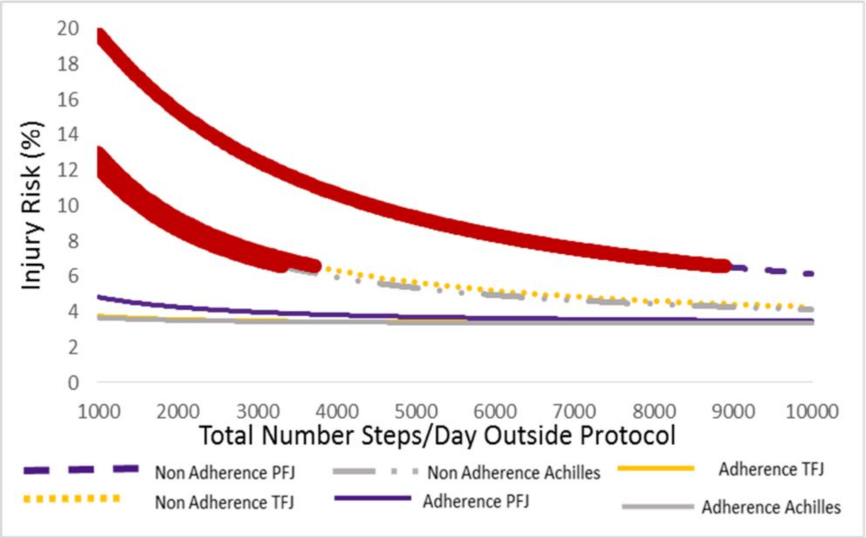
In graphs 1-3, a bold red line represents the physical activity levels yielding an injury risk over the injury threshold of a ratio of over 1.5 (Injury Risk 6.55%).



Graph 1. Injury risk converted from peak AC Ratio at the PFJ, TFJ, and AT over the course of RTR protocol one as a function of adherence and daily physical activity level. ***Bold Red lines*** *represent those PA levels that would yield an AC ratio > 1.5 (Injury Risk % > 6.555%)*



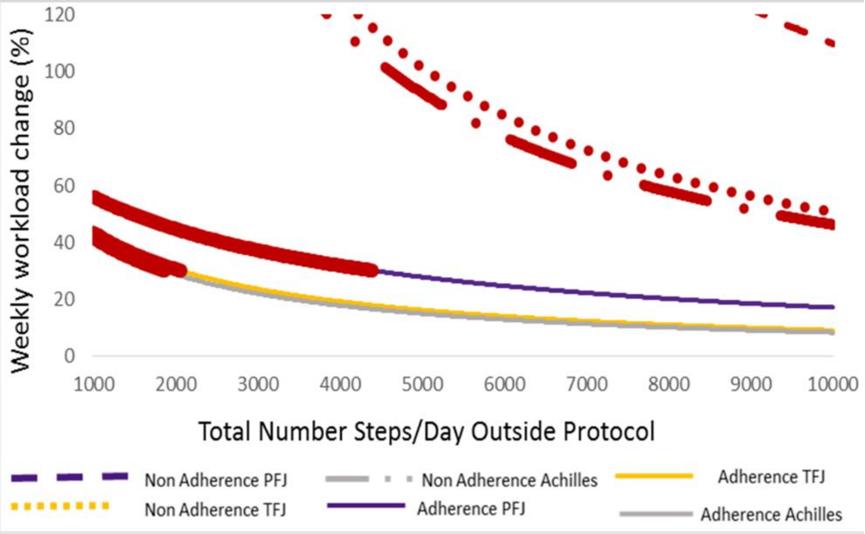
Graph 2. Injury risk converted from peak AC Ratio at the PFJ, TFJ, and AT over the course of RTR protocol two as a function of adherence and daily physical activity level. ***Bold Red lines*** *represent those PA levels that would yield an AC ratio > 1.5 (Injury Risk % > 6.555%)*



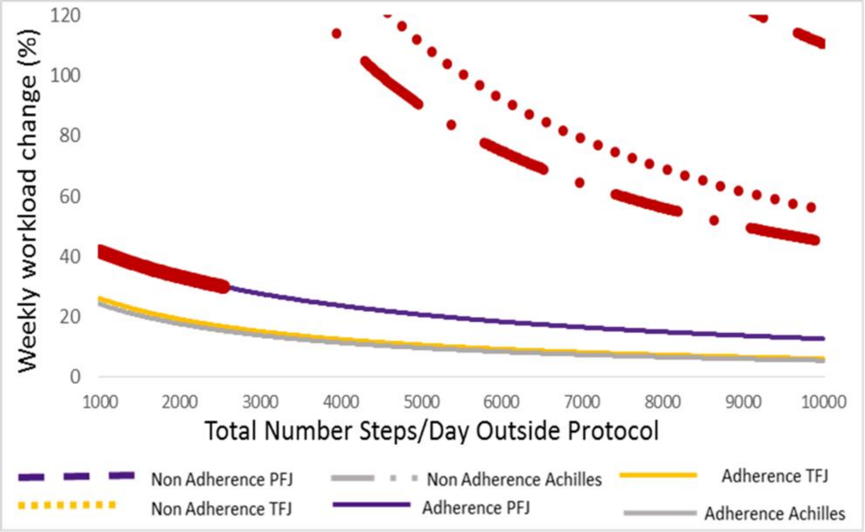
Graph 3. Injury risk converted from peak AC Ratio at the PFJ, TFJ, and AT over the course of RTR protocol Three as a function of adherence and daily physical activity level. ***Bold Red lines*** *represent those PA levels that would yield an AC ratio > 1.5 (Injury Risk % > 6.555%)*

Peak Percent Change Graphs

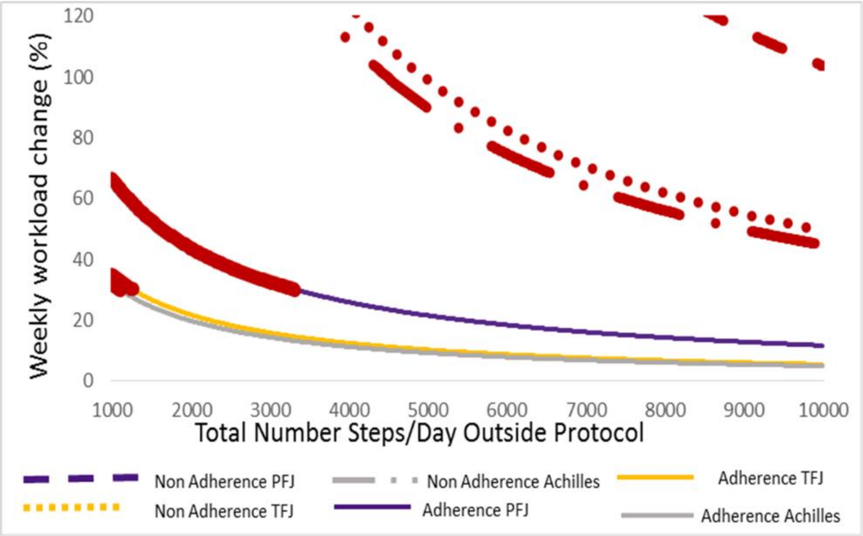
In graphs 4-6, a bold red line represents the physical activity levels yielding an injury risk over the injury threshold of percent over 30%.



Graph 4. Peak percent change in weekly workload at the PFJ, TFJ, and AT over the course of RTR protocol one as a function of adherence and daily physical activity level. ***Bold Red lines*** *represent PA levels that would yield a percent change weekly workload >30%.*



Graph 5. Peak percent change in weekly workload at the PFJ, TFJ, and AT over the course of RTR protocol two as a function of adherence and daily physical activity level. ***Bold Red lines*** *represent PA levels that would yield a percent change weekly workload >30%.*



Graph 6. Peak percent change in weekly workload at the PFJ, TFJ, and AT over the course of RTR protocol three as a function of adherence and daily physical activity level. ***Bold Red lines*** *represent PA levels that would yield a percent change weekly workload >30%.*

Discussion

Purpose 1: Evaluate Patellofemoral joint, Tibiofemoral joint, and Achilles Tendon injury risk using general activity models in context of RTR protocols

Previous studies have shown that an AC ratio over 1.5 (Blanch & Gabbett 2016,Gabbett 2016, Gabbett et al. 2016, Hulin et al. 2016, Murray et al. 2016) and a percent change over 30% (Nielsen et al. 2014) are associated with increased injury risk. However, in this study, the AC ratio and percent change yielded different predictions over the course of three different RTR protocols. Looking at the adherence model, injury risk was below the threshold for the AC ratio at the PFJ, TFJ, and Achilles at all PA levels evaluated while percent change yielded values over the injury threshold for all three sites when PA levels were under 3,500 steps per day. The different injury risks across methods is attributed to the effects of time. When calculating percent change, time does not play a role in changing workload as long as the workload is within the week being observed (Blanch & Gabbett 2016, Williams et al. 2016). On the other hand, time is an important variable for the AC ratio because the ratio is affected more by the workload done the two days before the injury risk was calculated than the workload done five days before (Murray and Gabbett 2016, Williams et al. 2016).

The patellofemoral joint was at the greatest risk of injury for all protocols compared to the tibiofemoral joint and Achilles tendon. This can be attributed to the differences in impulse per step at each site when comparing walking to running (Figure 7). These results are consistent with previous literature and shows that the difference in force and stress is greatest at the PFJ compared to TFJ, and Achilles. The difference in TFJ peak force while running is 1.76 times greater than walking in healthy individuals (Saxby 2016) while the Achilles difference is 1.17 times greater (Willy et al. 2016, Weinert-Aplin et al. 2016). The PFJ stress while running is 2.25 times greater than that of walking (Willson et al. 2014, Brechter & Powers 2002). To our knowledge there is no data comparing walking and running post ACLR for the Achilles and PFJ. Because of the difference in force and stress for each site, it may be beneficial to use localized limb loading in injury risk predictions when looking at progression, especially in areas that increase running in larger doses than previous weeks.

Purpose 2: Evaluate estimated injury risk as a function of overall Physical Activity (PA) level and a nonadherence scenario

Physical activity levels have been shown to be lower in people with patellofemoral pain than those that are healthy (Culvenor et al. 2016). The results in this study showed that across all three protocols, the greatest risk of injury was at the PFJ. Also, injury risk was greatest with consistent lower activity levels for the PFJ as well as the TFJ and Achilles. This is consistent with the workload-injury paradox. Meaning, as long as acute workload is similar to the chronic, high chronic workloads protects against injury (Hulin et al. 2016). Consistent higher levels of physical activity are found to lower injury risk.

Nonadherence, seen on graphs 1-6 as the patterned lines, increases injury risk compared to the nonadherence model. Once again, the patellofemoral joint was at the greatest risk of injury. Patellofemoral pain (PFP) affects up to 50% of people post ACLR (Li et al. 2011). Because the PFJ is at the highest risk of injury and PFP is common, it might be beneficial to extend RTR protocols during phases when running distance progression is increased, especially when there are examples of nonadherence.

Clinical Relevance

Results of this study will provide clinicians with a basis of how physical activity levels affect injury risk while following a return to running protocol after ACLR. On average, people post ACLR have been shown to take 2,000 less than steps of the healthy controls. Only 24% of them meet the American Heart Association recommendation of 10,000 steps per day. The average number of steps taken by ACLR participant was 8,000 steps per day (Bell et al. 2017). Applying this to the data from this study, the average person two years post ACLR would be at risk for injury at the PFJ in this nonadherence scenario for both the AC ratio and the percent change method.

These results also demonstrate the benefit of RTR protocol adherence among following an ACLR. Lastly, these results give an insight on the etiology of injuries associated with RTR after

ACLR such as the increased risk of injury on the PFJ when running progression compared to walking.

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