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Changes in patellofemoral pain resulting from repetitive impact landings are associated with the magnitude and rate of patellofemoral joint loading

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ABSTRACT

Background: Although a relationship between elevated patellofemoral forces and pain has been proposed, it is unknown which joint loading variable (magnitude, rate) is best associated with pain changes. The purpose of this study was to examine associations among patellofemoral joint loading variables and changes in patellofemoral pain across repeated single limb landings.
Methods: Thirty-one females (age: 23.5(2.8) year; height: 166.8(5.8) cm; mass: 59.6(8.1) kg) with PFP performed 5 landing trials from 0.25 m. The dependent variable was rate of change in pain obtained from self-reported pain scores following each trial. Independent variables included 5-trial averages of peak, time-integral, and average and maximum development rates of the patellofemoral joint reaction force obtained using a previously described model. Pearson correlation coefficients were calculated to evaluate individual associations between rate of change in pain and each independent variable ($\alpha = 0.05$). Stepwise linear multiple regression ($\alpha_{enter} = 0.05$; $\alpha_{exit} = 0.10$) was used to identify the best predictor of rate of change in pain.
Findings: Subjects reported an average increase of 0.38 pain points with each landing trial. Although, rate of change in pain was positively correlated with peak force ($r = 0.44$, $p = 0.01$), and average ($r = 0.41$, $p = 0.02$) and maximum force development rates ($r = 0.39$, $p = 0.03$), only the peak force entered the predictive model explaining 19% of variance in rate of change in pain ($r^2 = 0.19$, $p = 0.01$).
Interpretation: Peak patellofemoral joint reaction force was the best predictor of the rate of change in pain following repetitive singe limb landings. The current study supports the theory that patellofemoral joint loading contributes to changes in patellofemoral pain.

1. Introduction

Patellofemoral pain (PFP) is a common yet complex multifactorial condition that can affect one's quality of life (Davis and Powers, 2010; Powers et al., 2012; Witvrouw et al., 2014). Patellofemoral pain has been cited as the most common lower extremity injury among runners (Taunton et al., 2002), and is reported to affect females 2 to 10 times more often than males (Fulkerson, 2002; Fulkerson and Arendt, 2000; Robinson and Nee, 2007). A hallmark sign of PFP is the onset or exacerbation of anterior knee pain with high impact activities such as running, (Ho et al., 2014; Noehren et al., 2012) and landing from a jump (Willson et al., 2008). Furthermore, reduction or abolishment of PFP typically occurs during activities characterized as having reduced patellofemoral joint (PFJ) loading (Crossley et al., 2015).

It has been proposed that PFP can be caused by elevated patellofemoral joint reaction forces (PFJRFs) (Dye, 2005; Goodfellow et al., 1976). However, research relating PFJRFs and PFP has not confirmed this hypothesis. For example, persons with PFP exhibit lower peak PFJRFs compared to healthy controls during walking (Chen and Powers, 2014; Heino-Brechter and Powers, 2002), running (Chen and Powers, 2014), and stair ambulation (Brechter and Powers, 2002; Chen and Powers, 2014). It has been proposed that the lower peak PFJRFs may be the result of compensatory behavior to minimize patellofemoral joint loading during functional tasks.

A high PFP prevalence among persons who engage in high impact activities such as running suggests that the PFJ loading rate may be

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more predictive of symptom behavior than peak loading (Schaffler et al., 1989). This premise is supported by Cheung and Davis, who reported that following a running retraining intervention, improved PFP symptoms were associated with a reduced rate of lower limb loading (Cheung and Davis, 2011). Thus, it is conceivable that an elevated PFJ loading rate may evoke PFP (Cheung and Davis, 2011).

An important step in designing optimal intervention strategies for persons with PFP is to gain a complete understanding of the relationship between PFJ loading and changes in PFP. Therefore, the purpose of the current study was to examine the associations among various measures of PFJ loading (peak PFJRF, PFJRF rate, PFJRF impulse) and changes in perceived PFP across repeated single limb landings (SLL). Based on previous literature, we hypothesized that PFJRF loading rate would be more predictive of PFP rate of change than peak PFJRF or PFJRF impulse.

2. Methods

2.1. Subjects

Thirty-one females (mean (SD) age, 23.5 (3.8); height, 166.8 (5.8) cm; mass, 59.6 (8.1) kg; body mass index, 21.5 (2.9) kg/m^2) with PFP were recruited for this study. Participants were included if they were between 18 and 45 years of age, had a body mass index < 30 kg/m^2, and rated their level of physical activity from 5 to 9 on the Tegner Activity Scale (Tegner and Lysholm, 1985; Willson et al., 2008; Willson and Davis, 2008). Participants older than 45 years of age were excluded to minimize the potential influences of patellofemoral joint osteoarthritis. Additionally, participants must have reported insidious onset PFP of at least 3 weeks duration that was reproducible with at least 2 of the following activities: isometric quadriceps contraction, prolonged sitting, kneeling, squatting, running, or jumping. Operationally, PFP was defined as retro- or peripatellar pain (vague or localized) rated at minimum of 3 and maximum of 8 out of 10 on an 11-point visual analog scale.

Potential subjects were excluded if they were non-English speaking, had prior knee surgery or traumatic patellar dislocation, neurological involvement that would influence performance of single limb landings, were pregnant, or were taking pain medication at time of testing. Participants underwent a physical exam by a licensed physical therapist with 8 years of experience to rule out other potential knee pathologies (i.e. ligamentous instability, meniscus injury, and large knee effusion). Approximately 30% of screened individuals were excluded based on these criteria. The study protocol was approved by the Institutional Review Board of the affiliated university. Prior to participation all subjects provided written informed consent.

2.2. Instrumentation

Three-dimensional kinematic data were recorded at 250 Hz using an 8-camera Vicon Nexus motion capture system (Vicon, Centennial, CO, USA). Ground reaction force data were recorded at 2000 Hz using an in-ground force plate (Bertec, Columbus, OH, USA). Electromyography (EMG) data were recorded at 2000 Hz using a telemetered EMG system (Delsys Trigno, Boston, MA, USA). The EMG system had an input impedance > 10 Gohms, common mode rejection ratio > 80 dB and baseline noise < 0.75 μV root-mean-square.

2.3. Procedures

Participants donned standard shoes (New Balance Inc., Boston, MA, USA), a sports top, and spandex shorts. Height and body weight were measured and recorded. The symptomatic or most painful knee (in the case of bilateral pain) was identified and the subject was prepared for testing.

Electromyographic data from the knee flexor muscles were obtained to account for muscle co-contraction in the biomechanical model (see details below). Double differential EMG electrodes were placed on the skin over the muscle bellies and parallel to the fibers of the biceps femoris, semitendinosus, and medial and lateral gastrocnemius muscles using previously described techniques (Rainoldi et al., 2004). The skin was cleaned using abrasive gel and isopropyl alcohol and electrodes were positioned and secured with double-sided tape. Next, EMG signals were collected as participants performed 3, 5-s maximum voluntary isometric contractions (MVIC) of the hamstrings and gastrocnemius using a dynamometer (Biodex, System 3, Shirley, NY, USA). Prior to MVIC testing for each muscle group, subjects performed one or two submaximal practice trials to familiarize themselves with the task and minimize any potentially confounding learning effects. For the hamstrings MVIC, subjects were positioned with their hips and knees at 85° and 90° respectively. For the gastrocnemius MVIC, subjects were seated with their hips flexed to 85°, their knee fully extended, and their ankle plantar flexed to 15°. During each MVIC, subjects were secured with straps and instructed to contract with maximal effort.

Following MVIC testing, 14-mm reflective markers were placed on the first, second, and fifth metatarsal heads, medial and lateral malleoli and femoral epicondyles, iliac crests, anterior and posterior superior iliac spines. Additionally, rigid clusters of at least 3 non-collinear tracking markers were secured to the thighs, legs, and feet of each subject. A cluster of 4 markers secured to the mid-trunk was aligned such that it was in a plane approximately parallel to the frontal plane of the subject's trunk while in a static standing position (Fig. 1A). A static standing trial was recorded and used to define the local segmental coordinate systems and joint axes. All anatomic calibration markers, except those on the pelvis, were removed prior to the SLL trials.

Fig. 1. (A) Anatomic and tracking marker placement. (B) Starting position for single limb landing task.