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Impact loading following quadriceps strength training in individuals with medial knee osteoarthritis and varus alignment

Crystal O. Kean [a],*, Rana S. Hinman [b], Tim V. Wrigley [b], Boon-Whatt Lim [c], Kim L. Bennell [b]

[a] *School of Health, Medical, and Applied Sciences, Central Queensland University, Rockhampton, QLD, Australia*
[b] *Centre for Health, Exercise and Sports Medicine (CHESM), Department of Physiotherapy, The University of Melbourne, Victoria, Australia*
[c] *School of Sports, Health and Leisure, Republic Polytechnic, Singapore*

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ABSTRACT

Background: Greater impact loading at initial contact is postulated to play a role in the progression of osteoarthritis. Quadriceps weakness is common in individuals with knee osteoarthritis and may contribute to high impact loading. The purpose of this study was to examine the effects of quadriceps strengthening on impact loading parameters.
Methods: Data from 97 individuals with knee osteoarthritis who participated in a randomized clinical trial examining effects of a 12-week quadriceps strengthening program was used to conduct this secondary exploratory analysis. Participants completed a three-dimensional gait assessment within 10% of 1.0 m/s from which maximum rate of loading (Body Weight/second), average rate of loading (Body Weight/second), and peak vertical ground reaction force during early stance (Body Weight) were determined. Peak isometric quadriceps strength (Nm/kg) was also assessed.
Findings: There was a significant increase in quadriceps strength in the training group (mean change (95%CI): 0.35(0.25, 0.045) Nm/kg, $P = 0.01$) with no change in the control group (mean change (95%CI): 0.03(-0.39, 0.45) Nm/kg, $P > 0.05$). There were no changes in impact loading variables. With data from both groups combined, changes in quadriceps strength explained 3% of variance in the change in maximum rate of loading. Change in quadriceps strength was not predictive of the change in peak vertical ground reaction force or average rate of loading.
Interpretations: While change in strength was predictive of change in maximal loading rate, this explained only a small proportion of the variance. Future research examining the role parameters such as neuromuscular control play in impact loading are warranted.

1. Introduction

Knee osteoarthritis (OA) is a chronic musculoskeletal condition and mechanical loading plays a crucial role in its pathophysiology (Vincent et al., 2012). The majority of the knee OA biomechanical literature has focused on the external knee adduction moment, which provides an estimate of relative load in the medial compared to the lateral tibiofemoral compartment. However, impact forces shortly after initial foot contact may also contribute to the development and progression of knee OA (Collins and Whittle, 1989; Radin et al., 1972; Radin et al., 1973; Whittle, 1999). Using animal models it has been demonstrated that repetitive impact loading results in subchondral bone microdamage, which has been linked to cartilage thinning (Burr and Radin, 2003). While impact loading has been implicated in OA pathogenesis in animal studies, its role in the development and progression in humans is less clear. However, a theoretical rationale for the importance of impact loading can be developed.

Firstly, high frequency impact forces are propagated through the lower limb and attenuated by the active and passive structure of the lower extremities, such as the heel pad, ligaments, muscles, bone, and cartilage. Impairments to the active and passive structures of the body may therefore limit the body's ability to attenuate impact resulting in forces across the articular surfaces of the lower limb joints (i.e. knee) that are beyond the tissues' load-bearing capacity, particularly to cartilage regions that are unaccustomed to such loading (Andriacchi et al., 2004). While no longitudinal studies have examined the relationship between impact loading and development or progression of knee OA in humans, magnitude and loading rates of the vertical ground reaction force have been associated with cartilage damage, knee pain and knee OA (Collins and Whittle, 1989; Mundermann et al., 2005; Radin et al., 1972; Radin et al., 1991).

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* Corresponding author at: School of Health, Medical, and Applied Sciences, Rm1.09/Bld 81, Bruce Highway, Central Queensland University, Rockhampton, Queensland 4700, Australia.
E-mail address: c.kean@cqu.edu.au (C.O. Kean).

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High rates of loading have been suggested to be due to reduced muscle strength and deficits in neuromuscular control (Mikesky et al., 2000; Radin et al., 1991). For example, the quadriceps may play a role in decelerating the shank and femur prior to and just after initial ground contact, and thus reduce the impact loads (Jefferson et al., 1990; Mikesky et al., 2000). Weakness of the muscles surrounding the knee, particularly the quadriceps, is commonly exhibited by individuals with knee OA (Bennell et al., 2011; Cheing and Hui-Chan, 2001; Diracoglu et al., 2009; Messier et al., 1992; Palmieri-Smith et al., 2009). In addition, quadriceps weakness is related to pain and poor physical function (Maly et al., 2006; O'Reilly et al., 1998; Slemenda et al., 1997; Topp et al., 2000) as well as progression of radiographic and symptomatic knee OA (Bennell et al., 2011). Accordingly, quadriceps strengthening exercises are a fundamental element of health care for these individuals (Bennell and Hinman, 2011; Bennell et al., 2013; Lange et al., 2008). We conducted a large randomized controlled trial (RCT) evaluating effects of quadriceps strengthening and found no change in the knee adduction moment (Lim et al., 2008); however, strengthening the quadriceps may assist in attenuating impact loads occurring near initial contact (Bennell et al., 2013; Brandt et al., 2008). The aims of this study were to conduct secondary exploratory analyses of data from our RCT to examine: i) the effects of a 12-week quadriceps strengthening program on impact loading during early stance, and ii) the relationship between changes in quadriceps strength and changes in impact loading.

2. Methods

2.1. Participants

This was a secondary analysis of a 12-week RCT that evaluated the effects of quadriceps strengthening on the knee adduction moment, pain and physical function in people with knee OA (Lim et al., 2008). Baseline and follow-up strength and gait data were available for 97 individuals (91% of trial participants; 49 quadriceps strengthening group and 48 control group).

For the RCT, participants were recruited from the Melbourne area through newspaper and community club advertisements. All participants had tibiofemoral OA in at least one knee that fulfilled the ACR classification criteria (Altman et al., 1986), medial knee pain, medial compartment osteophytes and medial joint space narrowing greater than that in the lateral tibiofemoral joint. Exclusion criteria were previous lower extremity joint replacement; knee surgery or intraarticular injection within previous 6 months; systemic arthritis, >5° valgus malalignment; currently (or intending to begin) participating in a lower limb strengthening program or physiotherapy; and any health condition that would preclude participation in an exercise program. Randomization was performed by an independent researcher not involved in eligibility screening or outcome assessment and was concealed from the researcher (B-WL) who conducted the outcome assessments. Group allocation was completed using a random table in which participants were stratified by lower limb alignment in blocks of 6. Ethics approval was provided by the University of Melbourne Human Research Ethics Committee and written informed consent was provided by each participant. Further details on recruitment, eligibility screening and randomization procedures can be found in Lim et al. (2008).

2.2. Intervention

Participants in the quadriceps strengthening program were given a home-based program which consisted of five non-weight bearing exercises targeting the quadriceps performed 5 times weekly (for more details on the program see Lim et al., 2008). Each participant's program involved 7 visits to one of six experienced musculoskeletal physiotherapists. The physiotherapist taught the participant the exercises and progressed the exercise dosage. The control group was not given any type of intervention and participants were asked to avoid starting a new exercise program.

2.3. Strength and gait analysis

Strength and gait assessments were carried out by a blinded researcher (B-WL). Quadriceps strength testing and gait analysis were completed at baseline and at week 13 (post-baseline). Isometric quadriceps strength was assessed at 60° knee flexion using a Kin-Com 125-AP dynamometer (Chattecx Corporation, Hixson, TN, USA). Participants performed a two contraction submaximal warm-up followed by three 5-second maximal contractions with 15-seconds rest between contractions. The highest peak force of the 3 maximal trials was then multiplied by the lever length (in meters) and divided by body mass to give normalized torque (Nm/kg).

A three-dimensional gait analysis was performed using the Plug-in-Gait marker set (Davis et al., 1991) and with participants wearing the same pair of their own low-heeled shoes at both assessments. Kinematic and kinetic data were collected using an 8-camera motion analysis system (Vicon, Oxford, UK) in synchrony with two force plates (AMTI Inc., Watertown, MA, USA). Participants walked over an 8-meter walkway at a self-selected speed and a standardized speed of within 10% of 1 m/s until 5 trials with clean force plate strikes were obtained at each speed. For this secondary analysis only the standardized data was used due to the influence gait speed can have on gait biomechanics. For each trial the following variables were determined:

1) Maximum rate of loading (BW/s) defined as the maximum rate of change of the post-foot-contact vertical ground reaction force (F_z);
2) Peak F_z (BW) — Maximum F_z during first half of stance;
3) Average rate of loading (BW/s) — Peak F_z divided by the time taken to reach peak F_z;
4) Presence or absence of heel strike transient – using a method previously described by Hunt et al. (2010) it was determined that a heel strike transient was present if during the period between 50% Peak F_z magnitude and Peak F_z, the magnitude of F_z peaked and then decreased by >0.5% of the first F_z peak magnitude.

For each continuous variable (maximum loading rate, peak F_z and average loading rate), the average of the five trials was calculated. It was determined that heel strike transients were present if a heel strike transient was evident in ≥75% of a participant's trials. Subsequently heel strike transients were absent from a participant's walking if heel strike transients were not present in any trials. Those who displayed heel strike transients in <75% but >0% of trials were classified as undefined and are not reported.

3. Statistical analysis

Independent *t*-tests (continuous variables) and chi-square tests (categorical variables) were performed to compare group baseline characteristics. To investigate the effects of a quadriceps strengthening program, separate two-way ANOVAs (time × group) were used to compare quadriceps strength and loading variables (maximum rate of loading, peak F_z and average loading rate) over time and between groups. When a significant interaction was present, post-hoc pairwise comparisons with Bonferroni correction were performed.

To examine the relationship between change in quadriceps strength and change in impact loading (maximum rate of loading, peak F_z and average loading rate) while controlling for group (exercise vs control), change in pain during walking, and change in gait speed between test sessions, data from the two groups were combined and hierarchical regression analyses performed. Although gait speed was controlled (within 10% of 1.0 m/s), there was potential for small changes in gait speed to still occur between baseline and follow-up sessions; hence our decision to control for these small changes in the regression analyses. All statistical analyses were completed using SPSS v22.0 (IBM, Chicago, Illinois,