KNEE JOINT LOADS AND ASSOCIATION BETWEEN KNEE JOINT LOADS AND KNEE FLEXION ANGLE DURING A FORWARD LANDING TASK IN PEOPLE WITH AND WITHOUT CHRONIC ANKLE INSTABILITY

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The purpose of this study was to compare the knee joint loads (forces and impulse), compare muscle contribution to knee joint loads, and examine associations between knee flexion angle and knee joint loads during a forward jump-landing task in people with chronic ankle instability (CAI). Eight people with CAI and eight healthy controls performed forward jump-landings. Kinetics and kinematics were calculated using musculoskeletal modelling. There was no significant difference in knee joint loads and muscle contributions between groups. However, there were significant associations between knee flexion angle and knee anteroposterior force and impulse for each group separately and all participants combined. Our results may indicate that while CAI does not affect the knee joint loads, greater knee flexion angles may increase knee loading.

KEYWORDS: chronic ankle instability, OpenSim, knee joint load

INTRODUCTION: Chronic ankle instability (CAI) is one of the most common injuries in physically active people (Waterman et al., 2010). Indeed, approximately 75% of people who have experienced an initial lateral ankle sprain develop CAI (van Rijn et al., 2008). Many previous studies have provided evidence about altered ankle kinematics and kinetics in people with CAI compared to healthy controls. In addition to the ankle joint, people with CAI also exhibit alteration of kinematics and kinetics in proximal joints such as the knee joint because lower extremity joints are highly linked during dynamic movements. For example, people with CAI exhibited greater knee flexion angle, knee flexion displacement, and peak knee extension moment during double-leg landing (Li et al., 2018). More interestingly, Terada et al. reported that knee flexion angle was moderately associated with peak anterior tibial shear force during a vertical stop jump (Terada et al., 2014a). Moreover, Terada et al. (2014) reported that people with CAI exhibited increased muscle activation of vastus medialis during double-leg vertical stop-jump tasks (Terada et al., 2014b). These biomechanical and neuromuscular alterations may affect knee joint loads during dynamic movements.

Given that the altered knee joint loads can damage knee joint cartilage, and are greater during dynamic movements than daily activities, it is important to investigate the knee joint loads in people with CAI during dynamic movements. To our knowledge, there is only one study that investigated knee joint contact forces during simulated landing on an inverted force plate and on a flat force plate, where the author found that CAI did not affect knee joint contact forces during landing (Li et al., 2020). However, the tasks in that study were not movements that participants commonly perform in sports. It is important, however, to investigate landing tasks that are commonly performed during sports, such as a forward jump-landing, to better understand knee joint loads in people with CAI.

In addition to the task, it is also important to investigate the contribution of muscle forces to the knee joint loads and compare these between people with and without CAI. This would provide a guide to help healthcare providers target muscles to decrease knee joint injuries.

Another important factor is the association between knee flexion angle and knee joint loads. A previous study revealed an association between knee flexion angle and peak anterior tibial shear force during a vertical stop jump (Terada et al., 2014a). To better understand knee joint

injury risk factors in people with CAI, it is important to examine the associations between knee joint flexion angle and knee joint loads in people with CAI during more dynamic tasks.
Therefore, the purposes of this study were to (1) compare knee joint loads (forces and impulse) in compression and anteroposterior shear directions, (2) compare contribution of muscle forces to the knee joint loads in people with CAI and healthy controls, and (3) examine the associations between knee flexion angle and joint loads during a forward jump-landing task in people with CAI. We hypothesized that (1) people with CAI would exhibit greater knee joint loads, (2) there would be specific muscles associated with greater knee joint loads, and (3) knee joint loads would be associated with knee flexion angle during a forward jump-landing task.

METHODS: Eight people with CAI (male: 4, female: 4, age: 22.3 ± 3.0, mass: 68.2 ± 12.1 kg, height: 1.69 ± 0.13 m) and eight healthy controls (male: 4, female: 4, age: 21.5 ± 2.4, mass: 69.5 ± 10.3 kg, height: 1.68 ± 0.12 m) were recruited. People with CAI were recruited by inclusion criteria using a modified ankle instability instrument (Hale & Hertel, 2005; Kipp & Palmieri-Smith, 2013; McVey et al., 2005) which asks questions regarding the history of ankle history or symptoms. Also, we used the Foot & Ankle Disability Index and Foot & Ankle Disability Index in Sports to evaluate functional ability of the ankle joint in daily life and sports.
The participants performed three trials of a forward jump-landing task with 32 skin markers on bony landmarks, five electromyography (EMG) electrodes on soleus, fibularis longus, tibialis anterior, medial and lateral gastrocnemius, and a force platform. Specifically, each participant performed a double-leg forward jump over a 15 cm-height box and landed on a single leg on a force platform that was located one leg-length away from the participants (CAI leg for people with CAI, a dominant leg for healthy controls). 3D position of skin markers, ground reaction force, and muscle activation were collected by motion capture cameras (240 Hz), a force platform (1200 Hz), and EMGs (1200 Hz).
Ground reaction force data and markers' position data were filtered with a lowpass Butterworth filter (12 Hz). Muscle activation data were filtered with a bandpass Butterworth filter (20-450 Hz) and full-rectified and enveloped with a lowpass Butterworth filter (10 Hz), which were used to validate simulated muscle activations from OpenSim simulation. All data were trimmed from the time of ground contact when the ground reaction force was greater than 10 N to the time of peak knee flexion angle.
OpenSim was used for musculoskeletal modelling and simulation in the current study (Delp et al., 2007). We scaled the generic model using static trial to get a subject-specific model and used Inverse Kinematics to calculate joint angles. Then, we used Static Optimization to estimate muscle forces and used Joint Reaction Analysis to estimate knee joint contact forces and the contribution of individual muscles to the knee joint contact forces. Then, we calculated joint contact impulse by integrating knee joint contact forces.
We used Mann-Whitney U-test to compare the peak knee flexion angle, knee joint contact forces, knee joint contact impulse, and contribution of each muscle to the knee joint contact loads between people with CAI and healthy controls. To test the association between knee joint contact loads and peak knee flexion angle, we used Spearman correlation (≥ 0.70: very strong, 0.40-0.69: strong, 0.30-0.39: moderate, 0.20-0.29: weak, 0.01-0.19: very weak). Alpha values for all analyses were set to 0.05.

RESULTS: We found that there were no significant differences in peak knee compression and anteroposterior shear forces ($p = 0.96$ and $p = 1.00$, respectively) /impulses ($p = 0.54$ and 0.46, respectively) or in the contribution of muscle forces to the knee joint compression and anteroposterior shear forces/impulses ($p > 0.05$) between groups. In addition, there was no significant difference on peak knee flexion angle between groups ($p > 0.05$).
There was no significant association between peak knee flexion and peak knee compression force ($p > 0.05$). There were significant associations between peak knee flexion and knee compression impulse for healthy control ($r = 0.854$, $p = 0.014$) and all participants ($r = 0.715$, $p = 0.003$), but not for people with CAI ($p = 0.219$). There were significant associations between peak knee flexion angle and peak knee anteroposterior shear force for people with CAI ($r =$

0.744, p = 0.034), healthy controls (r = 0.772, p = 0.042), and all participants (r = 0.734, p = 0.002). Also, we found that there were significant associations between peak knee flexion angle and knee anteroposterior impulse for people with CAI (r = 0.925, p = 0.001), healthy controls (r = 0.982, p = 0.001), and all participants (r = 0.956, p = 0.001).

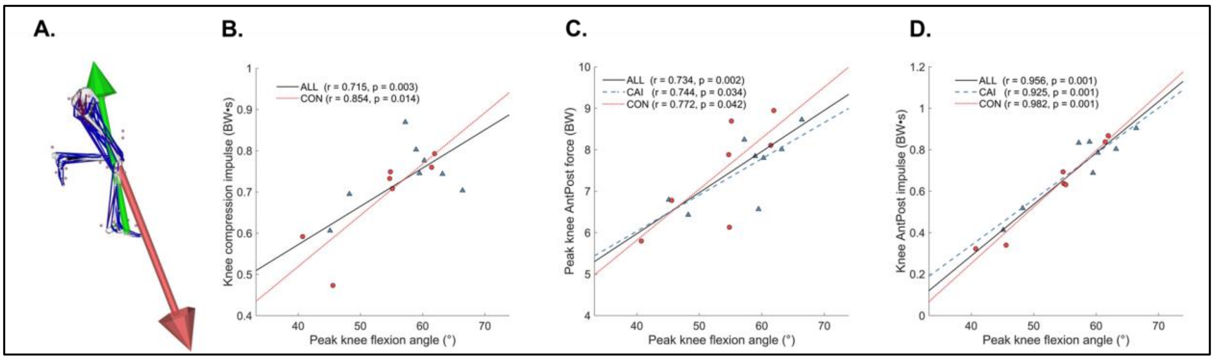

Figure 1: Musculoskeletal modelling (A) and the association between peak knee flexion angle and knee compression impulse (B), peak knee anteroposterior shear force (C), and knee anteroposterior shear impulse (D) during double-leg forward jump single-leg landing.

DISCUSSION: This study aimed to (1) compare the knee joint loads in compression and anteroposterior shear directions, (2) compare the contribution of muscle forces to the knee joint loads, and (3) examine the associations between knee flexion angle and knee joint loads during a forward jump-landing task in people with and without CAI.

The results did not support the first and second hypotheses that people with CAI would exhibit greater knee joint loads or that there would be differences in specific muscle contributions to knee joint loads. However, the results supported the third hypothesis that knee joint loads would be associated with knee flexion angle. Specifically, people with larger knee joint flexion angle exhibited greater peak knee joint anterior shear force and impulse during forward jump-landing tasks regardless of group. Although people with larger knee joint flexion angle exhibited greater knee joint compression impulse, the association was not shown in people with CAI.

This current study is the first to report associations between the knee flexion angle and knee joint anteroposterior shear force during forward jump-landing in people with CAI. The association between greater knee joint anterior shear force and impulse and larger knee flexion angle may be due to (1) the anterior acceleration of the femur segment on a relatively fixed tibia and/or (2) contribution of specific muscles at greater knee flexion angles, which should be examined in the future studies.

Our result that larger peak knee flexion angles are associated with greater knee joint loads is contrary to previous findings, e.g., in the ACL literature (Leppanen et al., 2017; Montgomery et al., 2018). Previous studies reported that smaller knee flexion angles at initial contact were associated with greater risk of non-contact ACL injuries (Montgomery et al., 2018) and that smaller peak knee flexion angle during a vertical drop-jump increased the risk of ACL injuries (Leppanen et al., 2017). However, other studies reported no association between knee flexion angle and ACL injury risk (Boden et al., 2009; Hewett et al., 2005; Numata et al., 2018). Our results may provide new evidence regarding the association between knee flexion angle and injury risk by reporting specific variables directly related to knee joint loads during a sport-related motion. Specifically, while previous studies typically examined the joint moments, our study examined joint contact force/impulse accounting for individual muscle forces. Also, the task in the current study was forward jump-landing that is commonly performed in sports.

CONCLUSION: Our results identify differences in knee joint loads or the contribution of muscle forces to knee joint loads between people with CAI and healthy controls. This indicates that knee joint loads seem to be independent of CAI during the forward jump-landing task. However, this study revealed that people with larger peak knee joint flexion angle exhibited greater peak anterior knee joint force and impulse during forward jump-landing tasks. This may indicate that the knee joint flexion angles are important to decrease knee joint anterior shear forces regardless of the presence of CAI.

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ACKNOWLEDGEMENTS: The authors would like to acknowledge assistance from the National Institutes of Health (T32 HD007422-20) and a Research Stipend from the NIDRR. This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF- RS-2022-00165979).