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Effects of fast walking on tibiofemoral bone water content in middle-aged adults

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ABSTRACT

Background: Although it is believed that genu varum increases loading on the medial knee during locomotion, the acute effect of increased loading on bone stress has not been determined. This study aimed to examine the effects of locomotion and lower extremity alignment on bone water content in middle-aged adults without knee osteoarthritis.

Methods: Five males and 5 females participated. Lower extremity alignment was defined as the angle between the midpoint of the anterior mid-thigh and the midpoint of the patellar tendon using the center of the patella as the fulcrum. A chemical-shift-encoded water-fat magnetic resonance imaging protocol was used to assess bone water content before and after a 30-minute fast walking session. Bone stress response was determined by quantifying water content within the weight-bearing regions of the medial and lateral compartments of the tibiofemoral joint. Paired t-tests were used to compare bone water content before and after fast walking. Pearson correlation coefficients were used to determine the associations between lower extremity alignment and changes in water content post-walking.

Findings: The paired t-tests revealed no changes in water content after fast walking within medial and lateral femur/tibia ($P > 0.05$). Pearson correlation analyses revealed a significant moderate correlation between increased bone water content of the medial femur and increased varus alignment ($R = 0.688$, $P = 0.028$).

Interpretation: Although there was no significant change in bone water content following locomotion, knee varus was associated with signs of bone stress in the medial femur.

1. Introduction

Lower extremity (LE) alignment has been a topic of much interest regarding the development of osteoarthritis (OA) at the tibiofemoral joint (Amin et al., 2004; Miyazaki et al., 2002; Shelburne et al., 2006). During loading response in gait, LE alignment can determine the medial to lateral load distribution of the tibiofemoral joint (Shelburne et al., 2006). Particularly, as the mechanical axis of tibiofemoral joint passes through the medial compartment of the knee, an adduction moment at the knee naturally transmits force through the medial compartment of the tibiofemoral joint (Miyazaki et al., 2002). Studies have further shown that individuals with an increased knee adduction moment demonstrate a higher compressive force on the medial knee (Miyazaki et al., 2002). Excessive varus alignment is believed to increase the adduction moment of the knee, leading to elevated mechanical loading and accelerated joint degeneration to the medial compartment of the tibiofemoral joint (Amin et al., 2004).

Given the fact that the medial knee joint bears more loading during locomotion, the medial compartment of the tibiofemoral joint has been hypothesized to be the site of initiation and development of bone stress injuries (Felson et al., 2003). Current literature has demonstrated that the medial tibial condyle has a greater amount of subchondral bone marrow edema (i.e., magnetic resonance imaging [MRI]-detected elevated bone water content within focal regions) and bony changes (i.e. osteophytes observed in radiographs) in older adults with OA (Felson et al., 2003). The observed bone marrow edema is thought to be the result of chronic overloading to the subchondral bone (Roemer et al., 2009). However, it remains unclear how locomotion-induced loading contributes to fluid accumulation within the trabecular bone in adults before signs of definitive degeneration of the knee joint (i.e. knee OA) are detected. Additionally, there is little data to support the premise that genu varum alignment is associated with an acute preferential accumulation of bone fluid within the medial compartment of the knee.

The objectives of our study were 1) to investigate tibiofemoral bone stress responses induced by an acute bout of fast walking and 2) to determine the correlation between LE alignment and bone stress response of the tibiofemoral joint. We hypothesized that there would be an increase in bone water content (indicative of bone stress response) of the tibiofemoral joint observed on a chemical-shift-encoded water-fat

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MRI protocol immediately after fast walking. Additionally, MRI-detected elevated bone water content within the medial compartment would be associated with a varus alignment in the LE.

2. Methods

2.1. Subjects

We recruited 10 subjects (5 females and 5 males) between 50 and 65 years of age who were able to walk at brisk pace (1.1 to 1.8 m/s) for at least 30 min. The data from an existing study was used to estimate the sample size for detecting fluid changes after a bout of mechanical loading (Ho et al., 2014b). Using a two-sided paired t-test with 92% power and α value of 0.05, the analysis estimated that 4 individuals would be needed to detect transient changes in bone water content in response to locomotion-induced shock loading using a chemical-shift-encoded water-fat MRI protocol. However, as a larger sample size is critical for establishing correlation relation proposed in our second purpose, a total of 10 subjects were recruited.

Subjects were excluded from participation if they reported having any of the following: 1) medical diagnosis of knee OA, 2) pain, swelling, tenderness, or stiffness of the knee, 3) history of knee surgery, or 4) implanted biological devices that could interact with the magnetic field. This recruitment process was done by a physical therapist with 13 years of experiences. We excluded individuals with diagnosed knee OA to prevent potential bias from existing bone injuries or inflammation. Subjects' physical activity levels were determined based on the World Health Organization's Global Physical Activity Questionnaire (GPAQ) (Bull et al., 2009). Prior to participation, all subjects were informed of the nature of the study and signed a consent form approved by the Institutional Review Board of the University of Nevada, Las Vegas.

2.2. Procedure

Frontal plane LE angle and MRI examination was collected within 1 data collection session. All testing was performed on the dominant side, which was determined by asking the subject which leg they prefer to land on from jumping.

Upon arrival to the imaging center, subjects' LE alignment was measured while standing. The LE alignment was assessed using the goniometer method described by Hinman et al. (2006). The LE alignment was defined as the angle between the midpoint of the anterior mid-thigh and the midpoint of the patellar tendon using the center of the patella as the fulcrum (Fig. 1). An angle of 180° is considered neutral alignment, and genu varum was defined as a LE alignment angle greater than 180°. Prior to the study, we tested 2 common goniometer methods for measuring LE alignment, including the current method and the umbilical method by Gibson et al. (2010). This current method was chosen as a higher intra-rater reliability value was derived.

MRI data was collected using a 3.0 Tesla General Electric (GE Healthcare, Milwaukee, WI, USA) scanner with a 16-channel, medium flex coil. Prior to a fast-walking session, 3-dimensional fast gradient echo (FGRE) iterative decomposition of water and fat with echo asymmetry and least-squares estimation (IDEAL) sequence was utilized to quantify bone water content.

Immediately following the first MRI scan, subjects were asked to walk on the treadmill for 30 min. The fast walking speed was defined as the highest speed within 1.1 to 1.8 m/s that a subject achieved without the presence of double limb swing or reported physical discomfort. The subjects were instructed to walk fast but allowed to change the speed as necessary. Immediately following fast walking, subject received a second MRI on the dominant knee using the same MRI protocol. As moderate-intensity cardiorespiratory exercise training for 30 min per day is recommended for maintaining physical fitness and health in general populations (Garber et al., 2011), a 30-minute walking protocol was used in this study. It has been reported that the average walking speed for individuals between 50 and 59 years old is 1.2 (SD: 0.1) m/s (Schimpl et al., 2011). Thus, we set up the lowest target speed as 1.1 m/s (lower limit of the population) and highest target speed as 1.8 m/s (50% increase) for this cohort. In addition, as Arnoldi et al. (1972) reported that experimentally-induced intraosseous fluid accumulations in the femur dissipated after only 30 min, we believe that it is important to detect the changes in water content immediately after loading.

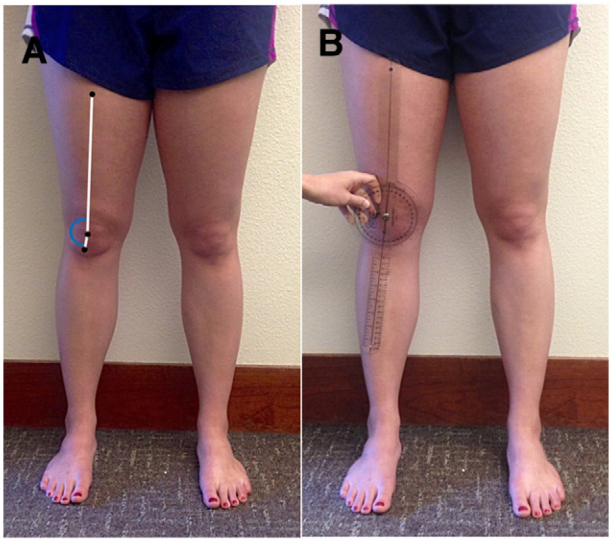

Fig. 1. Measurement of the LE alignment: (A) the measurement landmarks (midpoint of the anterior mid-thigh, center of the patella, and midpoint of the patellar tendon) were demonstrated. The lateral angle was used to describe the LE alignment angle; (B) the placement of goniometer.

2.3. MRI data processing

Bone stress response of the tibiofemoral joint was determined by quantifying the water content within the medial and lateral compartments of the tibiofemoral joint. The default reconstruction software provided by the GE Healthcare returned individual series of water-only and fat-only images (Fig. 2A & B). For the purposes of this study, we performed additional post-processing analysis using ImageJ software (National Institutes of Health, Bethesda, MD, USA) to reconstruct water fraction (water / [fat + water] × 100%) maps (Fig. 2C).

To detect walking-induced content changes within the medial and lateral compartments of the tibiofemoral joint, 4 steps of analysis were performed. First, the image slices that contained weight-bearing regions of the tibia and femur were identified (Blazek et al., 2014). Specifically, the weight-bearing area on each condyle was defined as the region bounded anteriorly by the medio-lateral line intersecting with the lowest point of the cartilage in the trochlea and extending 60% of the distance to the most posterior point of the articular cartilage covering each condyle (Blazek et al., 2014). Once the weight-bearing slices were identified, the lines that defined the 4 regions of subchondral bone (i.e., lateral femur, medial femur, lateral tibia, and medial tibia) were identified on each image slice. Specifically, the epicondyles of the femur and tibia served as the superior and inferior landmarks outlining the subchondral bone (Peterfy et al., 2004). The center of the trochlear groove was used to divide the medial and lateral compartments of the femur and the center of the tibial spine was used to divide the medial and lateral compartments of the tibia (Fig. 3). Third, to quantify the water content within each region of interest, the subchondral bone region on the water fraction maps (defined as the dark region under bright articular cartilage) was manually contoured (Fig. 3). Lastly, the