EFFECT OF KNEE ROTATIONS ON ARTICULAR CARTILAGE COMPRESSION DURING KNEE FLEXION EXERCISE

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INTRODUCTION

Many occupations involve long-term standing in order to perform various tasks. Surgeons, retail clerks, hairdressers, and manufacturing processors, to name a few, required a large range of motion to operate tools and machinery safely and efficiently [1]. Prolonged standing, however, results in discomfort in the lower extremities [2]. One potential estimate of discomfort is cartilage deformation [3], which can be estimated as the distance between the tibia and the femur, or the gap distance (Figure 1).

Figure 1. Illustration of the articular cartilage gap distance in an X-ray of the knee

Dynamic stereo x-ray reconstructions have been used in prior studies to estimate gap distance [4]. Under the assumption that a decreased gap distance is due to cartilage compression, evidence has shown that gap distance follows an exponential decay in vivo when exposed to 50% bodyweight at full extension for 20 minutes [5]. However, these findings do not accurately account for the short-term changes that arise due to joint rotations through weight shifting during standing [6]. Thus, more accurate methods for evaluating the cartilage compression during standing are necessary.

The aim of this study is to determine the effect knee angles and rotations have on cartilage compression in the knee during an in vivo knee flexion exercise. Through characterizing how knee rotations about the ML and AP axes affect calculated gap distance, we may be able to differentiate cartilage compression due to force as a result of standing, and due to knee rotations during long-term standing.

OBJECTIVE

The primary objective of this study was to accurately measure changes in knee metrics: specifically, flexion/extension, ab/adduction, and average gap distance of the tibia with respect to the femur. The secondary objective is to identify any trends among the knee metrics.

HYPOTHESIS

It is hypothesized that knee abduction and adduction angles will have a minimal effect on cartilage compression when compared with flexion and extension, but that it will still contribute in minor ways.

METHODS

Four participants, ages $21 - 35$ years, were recruited for this study. Subjects were screened for exclusionary criteria including recent musculoskeletal and orthopedic problems, cardiovascular issues and diseases, and dizziness problems. Each subject participated in two standing visits spaced at least a week apart to compare results between standing on a hard floor and an anti-fatigue mat. Subjects were consented following IRB protocol and provided the same brand shoes and socks for the standing duration. Subjects were instructed to stand for two hours following a 30 minute seated rest to relax the cartilage in the knee. During standing, subjects were allowed to weight shift but were instructed to maintain ground contact with both feet. A standing desk was provided for subjects to perform desk work, eat, and drink.

At $t = 0, 1$, and 2 hours the subject performed a knee flexion exercise that required a slight flexion of the knee (approximately 15 degrees flexion) while their feet remained fixed. X-rays of the exercise were taken 100 Hz, for 0.5 seconds. On a separate day, a CT scan was taken of the subject's right knee.

The CT slices were reconstructed into a 3D model and matched to the kinematics data resulting from the X-rays using the same methods as a previous study that also executed 3D bone reconstruction [4]. From this matched CT/X-ray model, the average gap distance throughout the medial tibial plateau, flexion/extension angle, and ab/adduction angles between the femur and tibia were calculated using a code in MATLAB.

RESULTS

Results are given for one representative subject. Abduction and flexion angles were plotted as a change from the angle at the beginning of the squat. A comparison between changes in flexion angle, abduction angle, and the average gap distance suggests that there may be interactions between rotations and gap distance. Overall, Fig 2 suggests that an increase in flexion angle is related to a decrease in gap distance, which is displayed in Fig 3. As flexion and abduction increase, gap distance tends to follow a smooth decreasing progression. When the tibia begins to adduct at approximately 0.4 seconds, gap distance increases slightly despite a continual increase in flexion.
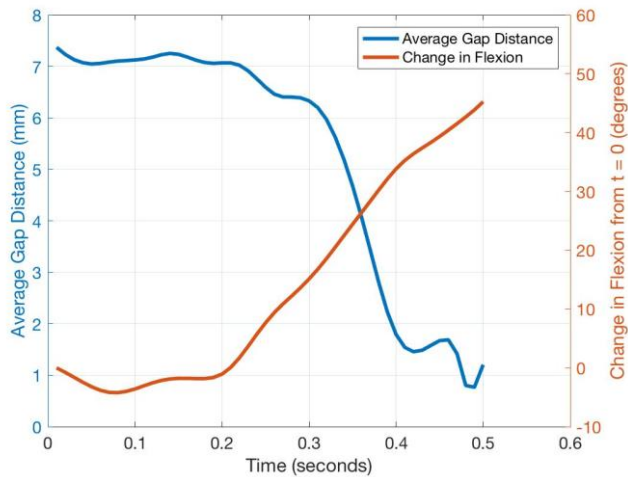
Figure 2. Average gap distance and change in flexion angles for the duration of the flexion exercise.
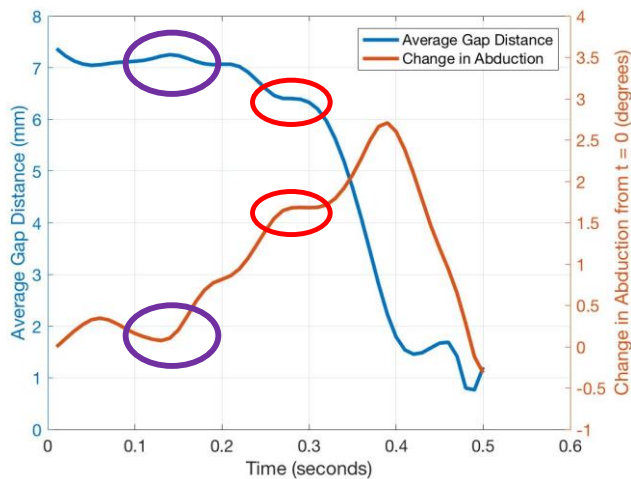

Figure 3. Average gap distance and change in abduction angles for the duration of the flexion exercise.

DISCUSSION

Based on the graphs displayed in Fig 2 and 3, it is clear that there is an interaction between gap distance, flexion angle, and abduction angle. A major limiting factor is our small sample size. However, some patterns can be observed with our limited data. Increasing flexion angle rolls the condyles of the femur over the tibial plateaus, which compresses the menisci [7]. This would be expected to decrease the average gap distance, which is shown in Fig 2. However, the increase in flexion is a relatively smooth rise, and the change in gap distance has a more rippled decrease that does not readily correlate with the rise in flexion. The ripples in average gap distance could be explained by the more variable rise in abduction as noted by the circles in Fig 3.

This effect of abduction angle on gap distance has implications on long-term standing. Those who stand tend to weight shift in an attempt to return synovial fluid to the cartilage in the knee, which may be more or less successful depending on the strategy used. Furthermore, if a person has posture that involves an abnormal amount of abduction or flexion, this could affect cartilage compression in the medial plateau contributing to discomfort.

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