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ORIGINAL RESEARCH

Upright Magnetic Resonance Imaging Tasks in the Knee Osteoarthritis Population: Relationships Between Knee Flexion Angle, Self-Reported Pain, and Performance

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Abstract

Objective: To characterize the ability of patients with symptomatic knee osteoarthritis (OA) to perform a weight-bearing activity compatible with upright magnetic resonance imaging (MRI) scanning and how this ability is affected by knee pain symptoms and flexion angles.

Design: Cross-sectional observational study assessing effects of knee flexion angle, pain level, and study sequence on accuracy and duration of performing a task used in weight-bearing MRI evaluation. Visual feedback of knee position from an MRI compatible sensor was provided. Pain levels were self-reported on a standardized scale.

Setting: Simulated MRI setup in a research laboratory.

Participants: Convenience sample of individuals (N=14; 9 women, 5 men; mean, 69±14y) with symptomatic knee OA.

Interventions: Not applicable.

Main Outcome Measures: Averaged absolute and signed angle error from target knee flexion for each minute of trial and duration tolerance (the duration that subjects maintained position within a prescribed error threshold).

Results: Absolute targeting error increased at longer trial durations ($P<.001$). Duration tolerance decreased with increasing pain (mean ± SE, no pain: 3min 19s±11s; severe pain: 1min 49s±23s; $P=.008$). Study sequence affected duration tolerance (first knee: 3min 5s±9.1s; second knee: 2min 19s±9.7s; $P=.015$).

Conclusions: The study provided evidence that weight-bearing MRI evaluations based on imaging protocols in the range of 2 to 3 minutes are compatible with patients reporting mild to moderate knee OA-related pain.

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Osteoarthritis (OA) is the most common form of arthritis[1,2]; it is associated with the degeneration of a joint's load-bearing soft tissues and symptoms of pain and joint stiffness.[3] It is very common in weight-bearing joints, with knee OA being more common than hip OA[4] and leading to prevalent and severe loss of function and mobility.[2,5,6] Approximately 6% of adults >30 years old and 10% to 15% of those >60 years old have symptomatic knee OA.[7-9] The prevalence is projected to increase markedly in the future with the aging of the population.[2,10,11] Therefore, diminishing the rates of incidence and improving the prognosis for knee OA is of pressing health care importance.

Many studies have sought to examine links between OA development and changes in joint loading.[12-17] To elucidate these biomechanical etiologies, precise measurements of joint positioning and cartilage contact are necessary. Plane-film radiography has been used to assess OA progression in clinical research,[18,19] but it provides limited information on contact conditions. Volumetric magnetic resonance scanning, however, provides

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3-dimensional information on bone and soft tissues and hence allows for more detailed assessment of joint positioning and cartilage contact. As has long been recognized,[20,21] compressive force and muscle activation strongly influence joint positioning; therefore, it is important to observe the knee in conditions similar to those experienced in function. Several previous studies have used magnetic resonance imaging (MRI) to study in vivo contact mechanics in the loaded knee. For example, weight-bearing patellofemoral contact area was evaluated by an MRI technique while participants reclined 25° from vertical,[22] whereas a hybrid fluoroscopic/MRI registration method has been used to study cartilage contact[23,24] and joint kinematics.[25] The latter method has the significant advantage of allowing dynamic activities to be studied; however, cartilage surface deformation and interaction is modeled rather than imaged directly.

Subject movement significantly degrades images in MRI scanning.[26] Various techniques have been developed to reduce or correct motion artifact from periodic events (eg, respiration, blood circulation[27,28]), but they are not effective in removing artifact caused by skeletal movement. Such motions are likely to increase with the scan duration and when voluntary muscle contraction is required to maintain a weight-bearing position. Fatigue-related increases in movement may be expected with longer scans, but if motion can be minimized, increased scan times allow for clearer visualization of structures. We have developed methodology using MRI-compatible sensing technology to provide visual position feedback to assist in maintaining a stationary posture during fully upright weight-bearing scanning. Pain and impaired proprioception associated with the knee OA patient population[29] might add to the challenge of maintaining weight-bearing postures with minimal movement. Understanding the tolerability of weight-bearing postures for this group of individuals will provide insight to the feasibility of this method in evaluation of knee OA.

The objective of this study was therefore to characterize the ability of patients with symptomatic knee OA to perform a weight-bearing activity compatible with upright MRI scanning and how this ability is affected by knee pain symptoms and flexion angles. We studied performance in both knees of participants as they performed the activity at 3 levels of knee flexion in an offline laboratory-based study. We hypothesized that motion levels would be higher, and therefore durations of periods with low motion levels would be shorter, with increasing levels of self-reported knee pain. We also hypothesized that motion would be greater at higher knee flexion angles. Finally, as a result of fatigue effects, we hypothesized that motion levels would increase over time and be larger in the trials of the second knee tested than the first.

Methods

Participants

Fourteen individuals (9 women, 5 men; age range, 47−92y; mean age, 69±14y) with symptomatic knee OA as identified from self-reported symptoms and physical examination were enrolled in the study. All subjects were required to be able to walk without an assistive device, and any individuals with significant cardiovascular, neurologic, or systemic problems, weakness in any lower-extremity muscle group, signs of infection, or body mass index >35kg/m^2 were excluded. The study was approved by the Institutional Review Board of the Kessler Foundation Research Center, and all the participants gave informed consent prior to testing.

List of abbreviations:

ANOVA	**analysis of variance**
MRI	**magnetic resonance imaging**
OA	**osteoarthritis**

Physical evaluation and questionnaire

A physical evaluation was conducted to verify the presence of knee OA signs and to measure lower-extremity range of motion. The presence of ≥1 positive findings (abnormal knee flexion and extension ranges, laxity of any of the major ligaments as documented by measured medial-lateral and/or anterior-posterior drawer signs, tenderness along the joint lines, effusions, positive patellofemoral grind compression, positive McMurray or Apley signs, etc) that were consistently reproducible and correlated to the clinical complaints was considered sufficient confirmation of knee OA in ≥1 of the 3 compartments. Besides the detailed knee examination, the hip and ankle joint ranges of motion were measured and examined to rule out any potential biomechanical interactions that could affect the gait, weight-bearing tolerance, and/or confuse the knee findings. Knee OA was confirmed bilaterally in all but 1 participant; this participant exhibited OA findings in the right knee only, which were in the anterior chamber.

Subjects completed the Western Ontario and McMaster Universities Osteoarthritis Index[30] to record self-reported knee pain and disability. The pain measure used in this study was in response to the item describing pain in each knee in the 48 hours preceding the survey as per the following scale: 1 (no pain), 2 (mild), 3 (moderate), 4 (moderately severe), and 5 (severe pain). Subjects whose symptoms were being managed with medications were permitted to use them as usual during their participation. The pain measure was therefore representative of the managed habitual pain level that might be predictive of their ability to perform the study tasks.

Instrumentation/setup

The study was performed in our laboratory using a setup that simulated the environment for scanning in a 0.6-T vertically open MRI scanner[a] (fig 1). An electric tilt table[b] reproduced the scanner's patient table. The side-to-side dimension of the MRI patient space was reproduced by attaching melamine-covered boards to the table, and a safety harness was used to prevent falls. An MRI compatible knee sensor[c] was attached using adhesive tape spanning the knee joint and was used to provide real-time feedback of the knee angle to the subject during scanning. A custom portable, MRI-compatible dual-force platform was used to measure and display weight distribution between the left and right limbs. The signals from both devices were passed to a data acquisition device and subsequently to a custom LabVIEW[d] application for feedback display and data logging. As found in the MRI environment, both the knee angle and weight distribution were displayed on a large screen television in front of the subject (fig 2), and the MRI receiving coil was fastened around the knee and positioned to allow knee flexion.

Simulated scanning procedure

The tilt table was set to 5° inclined back from the vertical to match the angle available in the scanner. The subject was asked to step