2-dimensial measures and do not use automated software. To address this we developed and validated a semi-automated software method to rapidly characterize the meniscus volume on knee MRI scans.

Methods: Forty-one subjects from the Osteoarthritis Initiative (OAI) were assessed. Thirty subjects were randomly selected from the Control Cohort (no radiographic knee OA) at baseline and 12 months. An additional 11 subjects from the Incidence Cohort were assesed, also free of radiographic OA at baseline but with known meniscus maceration (based on semiquantitative MOAKS scoring) or meniscus body extrusion (from manual quantitative measures). The 11 scans were evaluated for volume changes from the baseline to 48-month time points. The scans were analyzed using a new semi-automated software tool on the same sequence (Coronal 3D T1-weighted Fast Low Angle Shot Water Excitation (FLASH WE) (0.313 x 0.313 x 1.5 mm, TR 20 ms, TE 7.5 ms)), obtained on a 3-T Siemens Trio MR system. Meniscal body volume and extrusions measures were taken from the central 5 slices. The central slice (+/−2 slices) was halfway between the anterior and posterior tibial limits (first/last image in which the tibial cartilages were identified).

Semi-automated image analysis software was used to delineate the meniscus margins on each of the five slices. Segmentation was initiated by the placement of a seed point over the meniscus on the center slice. The software then attempted to outline the margins of the medial compartment meniscus on each of the five slices. Tools to manually correct the computer-generated contours were also used.

Twenty Control Cohort scans were read at baseline and follow-up for repositioning reliability by one reader (CR), blinded to time point. Ten separate baseline scans were read two times by the same reader for intra-rater reliability. A second reader (JD) also read these scans for inter-rater reliability. Both readers were blinded to each others readings, subject identifiers, and previous readings. For the 11 subjects with known meniscal changes, the extrusion ratio (proportion of the total medial meniscus volume located external to the medial edge of the tibial plateau) was determined, depicted by the red line in Figure 1.

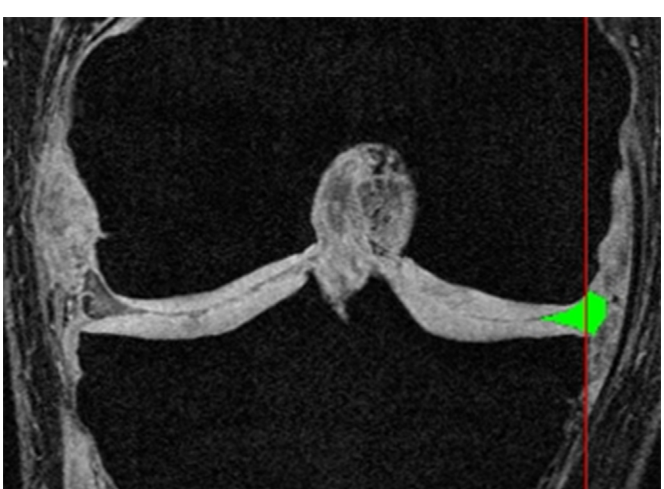
Descriptive statistics for the sample, total meniscal body volume, extrusion ratio and reader times were calculated. ICC's and 95% CI (2-way mixed model - subjects random, raters fixed) were determined for the reliability of patient repositioning by comparing the baseline and 12 month scans, and for inter and intra reader reliability. Responsiveness for the extrusion metric was assessed using the standardized response means (SRMs) comparing baseline to 48 month extrusion volume fraction

Results: The mean age of the subjects at baseline was 54.4 years, 24 (59%) were women, and 35 (85%) were Caucasian. All knees had baseline Kellgren and Lawrence scores of 0 or 1. Average baseline and 12 mo Control Cohort menuscus volumes (SD) were 131.0 (37.0) mm3 and 130.3 (26.6) mm3.

The average (SD) baseline and 48mo meniscus extrusinon ratios for the 11 knes from the Incidence cohortwere 0.43 (0.16) and 0.50 (0.21).

The ICCs (95% CI) for meniscal volume were as follows: Intra-rater Reliablity 0.95 (0.79–0.99), Inter-rater Reliability: 0.90 (0.58, 0.97) Repositioning Reliability: 0.86 (0.63, 0.94). The SRM value for responsiveness was −0.31. The reader time was approximately 3 minutes per scan.

Conclusions: We provide evidence that a new rapid semi-automated software method to quantify medial meniscal body volume is responsive and reproducible. This method is potentially practical for use in large longitudinal cohort studies of knee OA.



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FINITE ELEMENT MODELING OF PROXIMAL TIBIAL STIFFNESS IN NORMAL AND OSTEOARTHRITIC KNEES: IN VIVO PRECISION AND PRELIMINARY COMPARISONS

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Purpose: Osteoarthritis (OA) related subchondral bone alterations are thought to increase local structural stiffness of subchondral bone (i.e., stiffness directly at the subchondral bone surface), thereby altering load and stress distributions in cartilage, resulting in cartilage degeneration and OA development. Current theories regarding the role of subchondral bone in OA rely on evidence from animal studies (which may not be applicable to the human OA process) or ex vivo cadaveric studies (which are questionable given that clinical OA status or pain symptoms are often unknown). To help clarify the role of subchondral bone in OA, accurate in vivo methods are needed to monitor subchondral bone mechanical property variations in people living with OA.

Subject-specific finite element (FE) modeling has potential to clarify the role of subchondral bone alterations in knee osteoarthritis (OA) initiation, progression and pain initiation. These models can be evaluated computationally (and noninvasively) to assess local structural stiffness, stress and strain distributions, and various other mechanical parameters in vivo which cannot currently be measured experimentally. However, associated precision errors of FE-derived mechanical properties are not known.

The objectives of this study were to assess the in vivo precision (Primary Objective) and explore differences (Secondary Objective) in FE-derived proximal tibial subchondral bone stiffness in normal and OA knees.

Methods: Subjects: Fourteen participants (2 men, 12 women; mean age 51.4, SD 11.8 years, 7 normal, 7 with radiographic OA with Kellgren-Lawrence grade ≥1) were scanned using clinical quantitative CT (QCT) 3 times over 2 days.

FE Modeling: The distal femur, proximal tibia and fibula were segmented (via ANALYZE). A surface was generated from each bone (via GEOMAGIC) and converted to volumes with smooth surfaces. The volumes were imported into a commercial FE software (ABAQUS) and meshed with parabolic tetrahedral elements. All bones were surrounded by an incompressible cylindrical medium to simulate soft tissues in the knee (e.g., cartilage, menisci). A custom code (MATLAB) was used to map QCT-derived bone mineral density (BMD) to bone's elastic modulus (E) for the proximal tibia and fibula. Elastic moduli ranged from ~1 MPa (trabecular bone/marrow) to ~16 GPa (cortical bone). Material properties for the proximal tibia and fibula were modeled as linear elastic and isotropic with a Poisson's ratio=0.3. To reduce computational time, the femur was modeled as a rigid structure. For surrounding soft tissues, homogeneous, incompressible, isotropic material properties were applied (E=10 MPa; Poisson's ratio=0.495). A unit displacement along the axis of femur was applied to all of the nodes at the femur's most proximal section. Nodes at the most distal sections of tibia and fibula were constrained in all directions. Mechanical measures of load applied to the elements and also nodal displacements were acquired for the proximal tibia (via MATLAB, ABAQUS). Structural stiffness (load/displacement) was calculated for the medial and lateral compartments of the proximal tibia.

Analysis: Root mean square coefficients of variation (CV%) were used to assess repeatability of FE-derived stiffness. Maximum stiffness (of either the medial or lateral compartment) was compared between OA and normal knees as a percentage difference (relative to normal).

Results: CV% for FE-derived proximal tibial subchondral bone stiffness ranged between 5.7–5.8 % (normal: 4.7–5.6%; OA: 6.1–6.6%). Average FE-derived maximum stiffness was 3284 N/mm (SD: 1064 N/mm) in normal knees and 4850 N/mm (SD: 3225 N/mm) in OA knees (32% difference).

Conclusions: FE-derived estimates of proximal tibial subchondral bone stiffness demonstrated in vivo precision errors <5.8%. Differences in stiffness between OA and normal knees, expressed in relation to precision errors, were ~5.5x greater than CV% error. Our results suggest that FE modeling has potential to precisely quantify and differentiate mechanical property variations in normal and OA knees, in vivo.

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T1RHO RELAXATION MAPPING WITH MRI AS A MEASURE OF THE THERAPEUTIC EFFECT OF CONSERVATIVE TREATMENTS FOR OSTEOARTHRITIS OF THE KNEE

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Purpose: Osteoarthritis (OA) of the knee is the joint disease that is most commonly encountered in clinical practice. Because the articular cartilage is difficult to regenerate, artificial knee replacement is often performed in patients who have end-stage knee OA and thus have relatively severe symptoms such as pain, instability and limited range of motion. However, to reduce the economic burden on the healthcare system and on patients, it would be desirable to establish conservative therapy that could alleviate symptoms and prevent progression of OA which is increasing in aging society. As T1ρ (or T1 relaxation time in rotating frame)-weighted MRI has recently been proposed as a promising biomarker for cartilage degeneration, it should be useful for evaluating conservative treatments for OA of the knee. The purpose of this study was to determine what characteristics are associated with improvement in OA of the knee in patients who underwent T1ρ mapping at different points in time while receiving conservative treatment.
Methods: The subjects were 47 patients who underwent T1ρ mapping before and after treatment. Thirteen were men, the mean age was 57.6 years, and the follow-up duration ranged from 2 to 36 months with an average duration of 13.2 months. As treatment, 32 were receiving intra-articular hyaluronic acid injections, 3 were receiving oral glucosamine, and 12 were receiving physical therapy. T1ρ relaxation times of articular cartilage were measured using 3.0T MRI. 3D T1ρ-weighted fast field echo imaging was performed for T1ρ quantification. After direct segmentation by referring to the proton density weighted (PDW) images, six regions of interest (ROI) were selected in the medial femorotibial articular cartilage in the coronal plane. Changes of 10% or greater in T1ρ values in at least 4 ROI were considered notable, with a decrease of this magnitude indicating improvement and an increase of this magnitude indicating worsening of the pathological condition. No change in OA was considered if any other result was noted. The duration of symptoms, the Kellgren-Lawrence (KL) grade on plain X-ray images, the slope angles of the articular surface of the tibia, and tears in the posterior segment and posterior horn of the meniscus on normal MRI images were compared.
Results: Of the 47 patients, 8 showed improvement, 11 worsened, and 28 showed no change. Though some cases worsened in as little as 2 months, it took at least 6 months to see improvement in all improved cases. Of the 20 patients who received intra-articular hyaluronic acid injections continuously for at least 6 months (every 2 weeks or every 4 weeks), 7 showed improvement on T1ρ mapping (88% of patients that showed improvement), 4 worsened, and 9 showed no change. Of the patients who received exercise therapy continuously for at least 6 months, 1 showed improvement, 3 worsened, and 5 showed no change. All patients that showed improvement were women with a difference of 5° or less between the slope angles of the medial and lateral tibial plateaus. Age, duration of symptoms, KL grade, and tears in the posterior segment and posterior horn of the meniscus did not differ from patients whose condition worsened.
Conclusions: This study was not a randomized controlled trial, but the results demonstrated that conservative treatment lasting at least 6 months can reduce cartilage degeneration on T1ρ mapping. Though there was no significant difference, the majority of patients that showed improvement were receiving intra-articular hyaluronic acid injections for a long time. This topic must be examined further in a prospective comparative study.

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ADVANCES IN VISUALIZATION OF KNEE CARTILAGE AND MENISCAL MORPHOLOGY WITH STANDING COMPUTED TOMOGRAPHY

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Purpose: The accepted standard for non-invasive visualization of cartilage and menisci is MRI. While there are a number of strengths of MRI, the absence of routine weight bearing limits evaluation of the functional position and configuration of these structures. In contrast, recent advances in standing CT (SCT) have allowed 3D imaging of the knees while challenged by weight bearing, in a manner analogous to fixed-flexed or semi-flexed radiograph protocols. In contrast to those accepted standards for measuring the progression of knee OA, which capture a 2-dimensional projection of a 3-dimensional (3D) structure, SCT permits 3D imaging unemcumbered by overlapping anatomy. The purpose of this study was to develop a protocol for use of SCT arthrography (SCTa) to evaluate weight-bearing cartilage and menisci and evaluate potential advantages over non-weight-bearing MRI.
Methods: A 35ml mixture was injected into the left knee of a healthy 42-year-old male (12ml of Isovue 300, 0.15ml of gadolinium, 18ml of saline and 4.85ml of 0.5% ropivacaine). Following 2–3 minutes of unloaded knee flexion and extension, a low-dose SCT scan {CurveBeam, Warrington, PA, USA} was acquired utilizing cone beam reconstruction, with the following protocol. The participant was positioned with the tips of the great toes, patellae, and the anterior superior iliac spines coplanar to each other, resulting in a knee flexion angle of approximately 20° and the feet 10°externally rotated. A coronal bar was adjusted to make contact with the anterior pelvis and parasagittal bars were adjusted on either side of the participant to stabilize the proximal lateral hips, maintaining comfort and balance as well as preventing motion during the scan. SCT scans were acquired with a 0.3mm isotropic voxel size (20cm height x 35cm width x 35cm depth; 533 slices over 360°), using the manufacturer's standard settings (120 kVp, 5 mA). The total estimated effective radiation dose for each scan was approximately 0.1 mSv, equivalent to the average environmental radiation experienced by a person living at sea level for one week. Ten minutes following completion of SCT arthrography, MR arthrography was acquired using the following settings: NEX=1, ETL=3, Slice thickness=2 mm, Slice spacing 2 mm, Matrix= 240 x 320, FOV=140 mm with axial T1 fat-sat (TR=712 msec, TE=12 msec); coronal T1 fat sat (TR=730 msec, TE=10 msec); and sagittal T1 fat sat (TR=796 msec, TE=10 msec) {Siemens TrioTim, Washington, DC, USA}.
Results: Use of SCTa may play an important role in the assessment of cartilage thickness and volume. Both menisci are well visualized on SCTa and MRA. Bone architecture is better depicted on the SCTa while bone marrow lesions, when present, can be assessed only on MRI.

Figure 1. Coronal and sagittal reformatted and axial SCTa and their corresponding MR arthrography (MRA) demonstrated outstanding delineation of articular cartilage with better differentiation between the cartilage and subchondral bone on SCTa. Visualization of the boundaries of the medial and lateral menisci was achieved to a similar degree on SCTa and MRA.