Clinical Imaging 40 (2016) 765–768

Contents lists available at ScienceDirect

Clinical Imaging

journal homepage: http://www.clinicalimaging.org

Original Article

Bone and joint modeling from 3D knee MRI: feasibility and comparison with radiographs and 2D MRI☆

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ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form 11 February 2016
Accepted 17 February 2016

Keywords:
3D
MRI
Knee
Modeling
Joint space

ABSTRACT

Purpose: The purpose was to evaluate feasibility of bone and joint segmentations from three-dimensional magnetic resonance imaging (3D MRI).
Methods: Segmented joint models from 3D MRI data set were obtained for 42 patients. Blinded angular and joint space measurements were performed on 3D MRI model, two-dimensional (2D) MRI, and radiography (XR).
Results: Medial joint space was similar on both XR and 3D MRI (P=.3). The XR measurements were statistically different but closer to 3D MRI for lateral patellar tilt angle, patellar tendon length, and lateral knee joint space, whereas 2D MRI measurements were closer to XR in terms of trochlear depth, sulcal angle, and patellar length.
Conclusion: 3D bone and joint segmentations are feasible from isotropic MRI data sets.

1. Introduction

Magnetic resonance imaging (MRI) is the modality of choice for soft tissue structure visualization in routine knee joint imaging. However, radiographs (XR) and computed tomography (CT) are the current reference standards for evaluation of osseous surface and joint space measurements. Surgeons prefer CT imaging for preoperative planning due to three-dimensional (3D) isotropic capabilities and crisp bony reconstructions that allow improved depiction of the osseous anatomy in joint lesions compared with two-dimensional (2D) imaging modalities [1,2]. High-resolution CT imaging with 3D reconstructions has shown to be a helpful tool in the evaluation of recurrent shoulder dislocation and femoroacetabular impingement [3,4]. Bone segmentation using 3DCT images are needed to quantify the amount of bone loss, guide treatment selection, and help with presurgical planning. 3D MRI reconstructions of the shoulder have been shown to be accurate and effective in measurement of glenoid bone loss [5]. Additional 3D osseous reconstructions from MRI data serve as an advantage for the surgeon as well as the patient. It would help limit the diagnostic costs, with 3D MRI providing both soft tissue and osseous information to the surgeon, thus eliminating the need for additional CT examination. In addition, the patient will not be exposed to radiation that is a part and parcel of CT examination. There is a paucity of literature regarding comparative evaluation of 3D knee MRI bone models with the currently used modalities, such as XR and CT. In this study, the authors evaluated the feasibility of 3D knee joint models derived from isotropic 3D MRI data sets and compared the various joint space and angular measurements to XR and 2D MRI.

2. Materials and methods

Institutional review board approval was obtained and informed consent was waived for this retrospective Health Insurance Portability and Accountability Act-compliant study. A retrospective review was performed of patients who underwent MRI knee examinations with 3D MRI isotropic sequences performed on a 3-T scanner over a 12-month period.

2.1. MRI technique

The examinations were performed on a 3-T MR scanner (Achieva, Philips, Best, the Netherlands) using four-channel knee coil. Isotropic 3D coronal fast spin echo proton density weighted sequence [repetition time (TR)=1500 ms, echo time (TE)=40 ms, voxel=0.65 mm isotropic, time of acquisition=7 min] and 2D coronal fast spin echo proton density weighted sequence were performed as part of the clinical

☆ Disclosures: Vidur Malhotra was a participant in the Dallas Stars program. Avneesh Chhabra serves as a consultant with Siemens for MSK CAD group. He also receives royalties from Jaypee, Wolters, and Elsevier groups of publishers.

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http://dx.doi.org/10.1016/j.clinimag.2016.02.017
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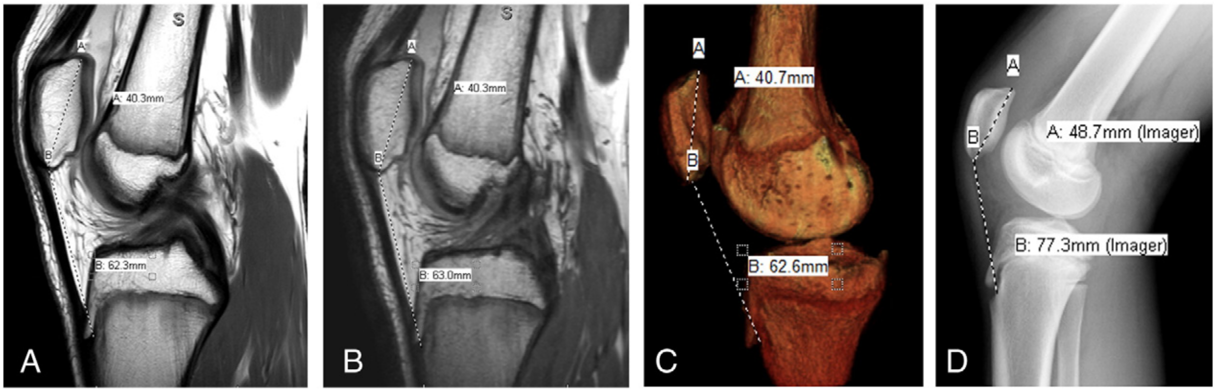

Fig. 1. Insall–Salvati ratio on 2D proton density (PD) (A), 3D PD (B), 3D model (C), and lateral X-ray (D) of knee. Notice that the X-ray measurement is different than the MR and 3D model measurements but ratios are similar (1.53 on 3D model vs. 1.58 on X-ray).

examination (TR = 3500, TE = 35–40 ms, slice thickness = 3.5–4 mm, interslice gap = 10%, time of acquisition = 4 min 30 s).

2.2. 3D postprocessing

Segmented knee joint models were obtained in all cases by a trained student on stand-alone software (TeraRecon, Aquarius, Foster City, CA, USA). A semiautomated method was employed using a stylus to draw the bone contours on a touch-screen Wacom monitor (Kazo, Saitama, Japan). Following mask refinement, bone segmentations were performed to create 3D models for the measurements.

2.3. Image evaluation

Another independent reader performed angular and joint space measurements on 3D MRI segmented model and respective 2D MRI and XR images, blinded on measurements on different modalities. The measurements included tibial tuberosity trochlear groove (TTTG) distance, lateral patellofemoral distance, trochlear depth, sulcal angle, lateral trochlear inclination, lateral patellar tilt, patellar tendon length/patellar length ratio, and medial and lateral joint spaces, measured using criteria defined in literature [6–10]. All data were stored in Excel 2013 (Microsoft Inc., Seattle, WA, USA).

2.4. Statistical analysis

Mean and standard deviation were calculated for all measurements. Paired *t* tests were performed for each pair (XR vs. 2D, XR vs. 3D, and 2D vs. 3D) within each parameter. *P* values less than .05 were considered statistically significant, and box plots were generated.

3. Results

A total of 69 patients had knee MR studies with 3D reconstructions from MR data set, and measurements were performed on all available images. Twenty-seven patients were excluded from the study due to unavailable XRs, and 42 patients with complete measurements of all three modalities, i.e., XR, 2DMRI, and 3DMRI, were finally included in the study (Figs. 1–3).

3D segmentations were successfully obtained in all cases within 20 ± 5 min. The TTTG distance, lateral patellofemoral angle, and lateral trochlear inclination were not statistically significant among all measurements. Medial knee joint space was similar on both XR and 3D MRI ($P = .3$). The XR measurements were statistically different but closer to 3D measurements in assessing lateral patellar tilt angle, patellar tendon length, and lateral knee joint space, whereas 2D measurements were closer to XR in terms of trochlear depth, sulcal angle, and patellar length parameters (Fig. 4).

4. Discussion

MRI of the knee is an important imaging modality for workup of a patient presenting with symptoms suggesting knee pathology, such as pain or locking. 3D MRI has been used in musculoskeletal examinations for many years. These acquisitions obtain thin contiguous slices that can be reformatted into different planes. 3D fast spin echo acquisitions can be performed with isotropic voxel dimensions and have been validated to be used to evaluate cartilage, menisci, ligaments, and bone marrow edema [11]. However, for evaluation of osseous surface and bony anatomy, surgeons prefer XRs and 3D CT reconstructions. 3D knee anatomy model with accurate segmentation is critical for any subsequent knee surgery planning as well as surgical navigation. It provides exquisite

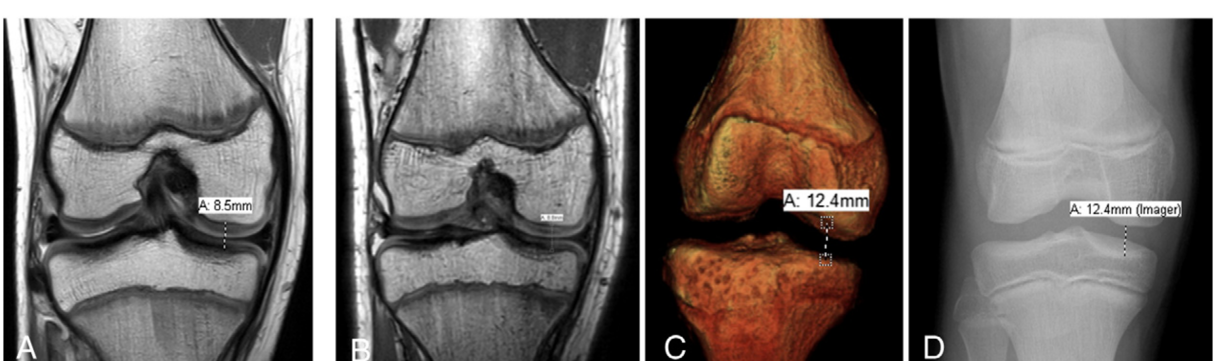

Fig. 2. Medial joint space measurements on 2D PD (A), 3D PD (B), 3D model (C), and lateral X-ray (D) of knee. Notice the similar measurements on 3D model and lateral X-ray (12.4 mm) vs 2D and 3D MRI (8.5 mm).