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Original article

Tibial cartilage volume measurement in knee osteoarthritis using magnetic resonance imaging

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Background: Cartilage degeneration is considered as the initial defect in osteoarthritis. Measurement of cartilage volume is important to monitor disease progression and therapeutic response.

Objectives: To measure tibial cartilage volume using magnetic resonance imaging (MRI), and to evaluate the accuracy and interobserver reliability of tibial cartilage volume measurement using MRI.

Methods: The outline boundaries of the medial and lateral tibial cartilage were drawn manually on 1 mm slices using a track-ball to calculate the volume of each slice. Total calculated MRI-derived tibial cartilage volume was determined by summation of the slice volumes. The calculated tibial cartilage volume was compared to the actual tibial cartilage volume.

Results: There was a strong correlation between the calculated and actual tibial cartilage volumes determined by a radiologist and a researcher (98% and 89% agreement in medial tibial cartilage, 99% and 97% agreement in lateral tibial cartilage, respectively). High observer reliability was identified (92% agreement in medial tibial cartilage and 97% agreement in lateral tibial cartilage).

Conclusion: Tibial cartilage volume measurement using MRI can be easily performed by well-trained personnel such as radiologists or residents, and can be used to estimate tibial cartilage volume preoperatively in total knee arthroplasty, and to monitor disease progression and response to therapy.

Keywords: magnetic resonance imaging, MRI, measurement, tibial cartilage volume

Osteoarthritis (OA) is a common chronic disease of the elderly and has a medical, psychological, and socioeconomic impact [1]. OA is a group of disorders featuring hyaline cartilage and subchondral bone reaction [2, 3]. Cartilage degeneration is commonly considered to be the initial pathology in OA [4]. The assessment of cartilage volume is helpful for monitoring disease progression and therapeutic responses [5, 6].

Development of treatments for OA is limited by the lack of a noninvasive method for measuring disease progression accurately [4].

The width of the femorotibial joint space shown in plain radiographs may not represent the thickness of articular cartilage of the femoral condyle and tibial plateau. Meniscal abnormality or joint effusion can affect the width of the joint space. Moreover, the position of patient when taking the radiograph will also affect the width of the joint space [7-10].

Magnetic resonance imaging (MRI) is the only imaging modality that can directly delineate articular cartilage. MRI is a simple, safe, and noninvasively technique for measuring knee cartilage thickness and volume in vivo. There has been increasing use of MRI in the measurement of knee cartilage volume to detect disease progression and assess the results of treatment for arthritis [11-14].

Monitoring the tibial cartilage volume after some procedures can be helpful in therapeutic strategies and structure-modifying treatments of cartilage disorders. Some operations such as homologous or autologous cartilage transplants (mosaicplasty) [15], or osteochondral grafts or transplantation, require the cartilage thickness and volume to be monitored [16]. In the present study, we measured cartilage volume using MRI and evaluated the accuracy of MRI compared with the actual tibial cartilage volume, which was measured by replacing it with water.

Materials and methods

Patient population

This study was approved by the Institutional

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Review Board of the Faculty of Medicine, Chulalongkorn University (IRB No. 241/55) and received a Certificate of Approval (COA No. 474/ 2012).

Between March 2012 and July 2013, 22 consecutive patients, previously diagnosed with osteoarthritis, who underwent knee MRI studies before having total knee joint arthroplasty were recruited. Inclusion criteria for the OA patients were 50–85 years old, severe symptoms in 1 knee and no prior knee surgery. Patients were excluded from the study if they had prior knee surgery or were diagnosed with rheumatoid arthritis, pulmonary embolism, knee osteonecrosis, or infected knee arthritis. All patients gave their written study-specific informed consent to participate.

The basic characteristics of the 22 patient participants are shown in **Table 1**.

Table 1. Basic characteristics of 22 patient participants

Characteristic	Mean	Range
Age (y)	70.7	58–85
Body weight (kg)	69.2	53–92
Height (cm)	153.7	143–162
Body mass index (kg/cm^2)	29.3	21.6–35.9

MR imaging

All patient participants were prospectively examined using MRI at the Department of Radiology, King Chulalongkorn Memorial Hospital, before total knee joint arthroplasty with bilateral resurfacing prosthesis. The MRI examinations were performed with the 3-dimensional (3D) Zimmer knee scan protocol using a 3.0 T MRI system (Phillips Medical Systems, Best, The Netherlands).

All static sequences were performed using a 128 × 256 imaging matrix, a field of view of 25–50 cm, and a slice thickness of 3.5 mm with a 0–2.5 mm interslice gap. The number of signals averaged was 2.

All MRI evaluations comprised coronal spin-echo T1-weighted imaging [echo time (TE)/repetition time (TR) = 15–22/400–700 ms, coronal gradient echo T2*-weighted image (TE/TR = 10–12/350–600 ms), followed by sagittal, coronal T2-weighted (TE/TR = 70–90/2000–3500 ms) and sagittal, axial proton density-weighted imaging (TE/TR = 15–30/500–700 ms). T2-weighted imaging were always combined with fat suppression.

These static studies were followed by a dynamic study with a gradient-echo, turbofield echo (TFE) sequence (2–3/1–3, 10° flip angle, two excitations, 128 × 256 imaging matrix, 3.5-mm slice thickness, no gap) that incorporated gradient spoiling of the transverse magnetization.

To obtain high-resolution images of the cartilage, the Zimmer knee protocol was added for all patients. The protocol comprises sagittal and coronal 3D T1-weighted gradient-echo TFE imaging (25° flip angle, 128 × 256 imaging matrix, 1 mm slice thickness, no gap, TE/TR = 9/20). The acquisition time for 1 coronal data set for the tibia was 7 min 58 s (field of view 160 mm; matrix 512 × 512 pixels).

The slices selected was on the basis of the 3D T1-weighted gradient-echo image in coronal view, which had sufficient sensitivity to detect a cartilage lesion [17].

Evaluation of MR imaging data

The MRI data were transferred to a work-station (Advantage Workstation version 5.0, GE Healthcare, Little Chalfont, Buckinghamshire, United Kingdom). Volume assessment software (AW VolumeShare 5, AW4.6, GE Healthcare) used the segment cartilage compartment (medial and lateral tibia) for cartilage volume assessment. The boundaries of the medial and lateral tibial cartilage were outlined manually in a coronal 3D gradient-echo T1-weighted image slice-by-slice (1 mm) using a track-ball to exclude the subchondral bone and tibial spine (**Figure 1**). The ROI of the tibial cartilage was determined by delineating the deepest gradient between the hyperintense cartilage and hypointense bone and joint cavity.

Cartilage volume was calculated by summation of the slice volumes, each slice being 1 mm thickness, the slice volume being determined by multiplying the surface area by each slice thickness, using the software to calculating the MRI-derived total cartilage volume in cubic centimeters (**Figure 2**). The tibial cartilage volume was individually measured before the total knee arthroplasty by two observers (a musculoskeletal radiologist and a researcher) blinded to the MRI data.

The accuracy was evaluated by comparing the values obtained with MRI with those obtained from volume displacement of surgically retrieved cartilage tissue. The reference actual cartilage volume was obtained immediately after total knee arthroplasty by volume replacement in a Eureka bath and a 1 cm^3 pipette (**Figure 3**). Measurement of actual cartilage volume was conducted by an orthopedist (fellow, Arthroplasty Unit, Department of Orthopaedics, Faculty of Medicine, Chulalongkorn University) who was blinded to the results of the MRI analysis.

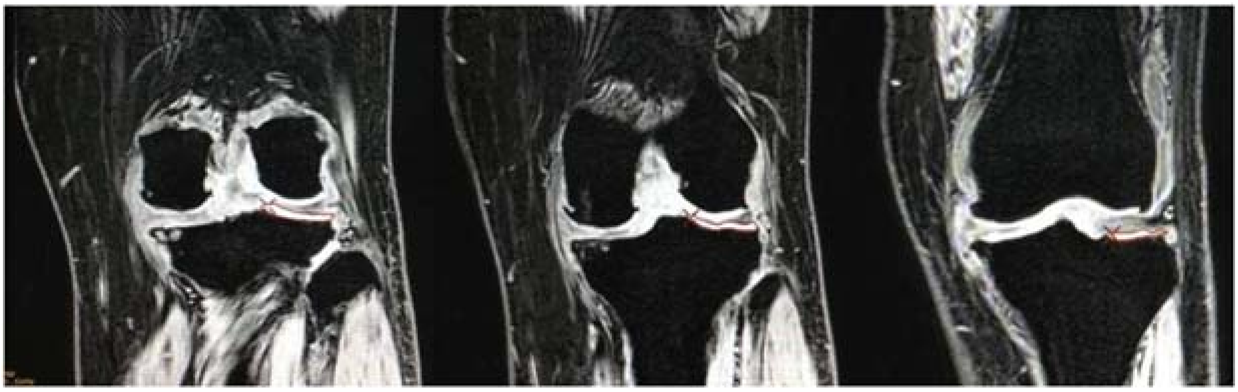

Figure 1. Examples of manual outline border of lateral tibial cartilage in coronal views, shown as red line

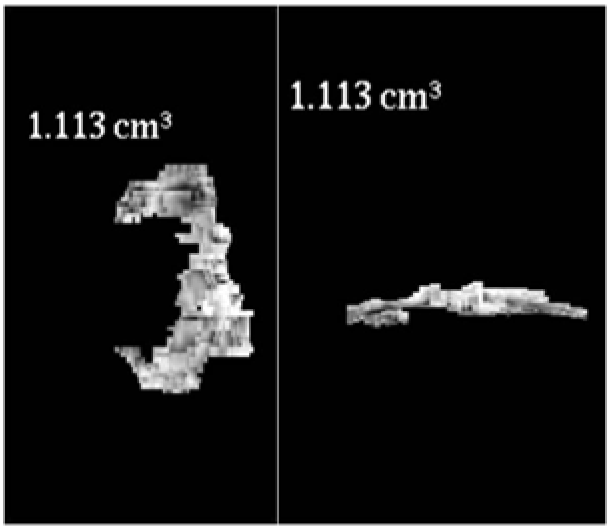

Figure 2. Three-dimensional reconstructions of lateral tibial cartilage

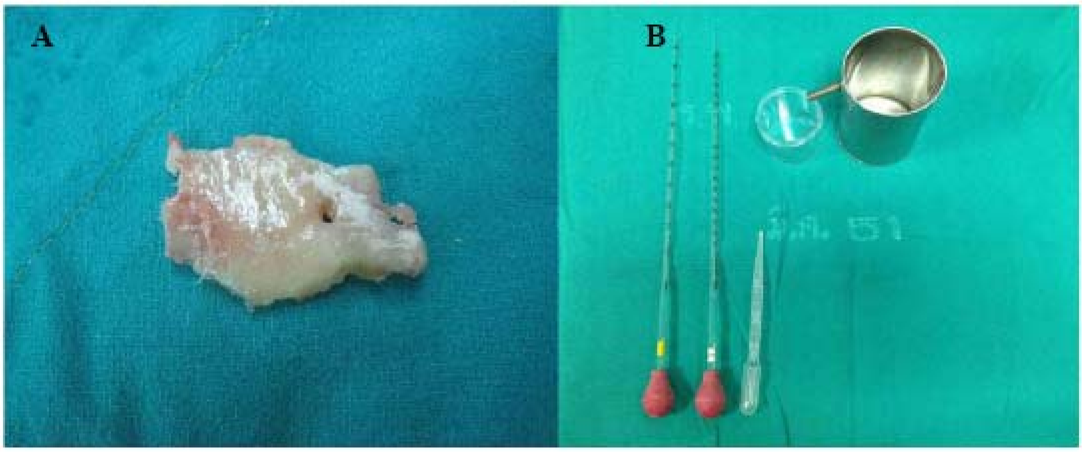

Figure 3. A: Excised lateral tibial cartilage to measure tibial cartilage volume. **B:** Eureka cup and pipette for measured volume actual cartilage.

We then calculated the pairwise differences between volumes obtained with MRI analysis and the surgically removed tibial cartilage.

Statistical analysis

The tibial cartilage volume measurements were compared with the actual tibial cartilage volume using intraclass correlation power analysis (SPSS version 11.5, SPSS, Chicago, IL, USA). An intraclass correlation coefficient close to 1.0 was considered in agreement and a $P < 0.05$ was considered significant.

Results

The medial and lateral tibial cartilage volumes determined by the radiologist and the researcher are shown in **Table 2**.

Figure 4 shows the relationships between the medial (**A, B**) and lateral (**D, E**) tibial cartilage volumes measured using MRI by the radiologist or researcher and the actual medial tibial cartilage volumes. The MRI volumes determined by the radiologist and the researcher agreed well with the actual medial and lateral tibial cartilage volume. The reliability of observers was very good, but higher for the lateral tibia compared with the medial tibia.

Discussion

There has been increasing interest in the use of cartilage volume to assess the development of OA. The knee joint is the main joint that develops OA, and causes pain and genu varus deformity [18]. Total knee arthroplasty is frequently performed in patients with severe OA of the knee. MRI is helpful to evaluate the cartilage and subchondral bone preoperatively [18].

In the present study, we used manual tracing of the tibial cartilage boundary using an electronic trackball on every 1 mm slice. We found that using 1 mm slices provides reliability in tibial cartilage volume estimation when measured by well-trained medical personnel such as radiologists or researchers.

Errors in estimating the cartilage volume tended to be higher for the medial tibia compared with the lateral tibia. This may be due in part to the more advanced stage of OA with larger contact area in the medial femorotibial compartment because the majority of patients with total knee arthroplasty had varus deformity. Similarly two previous studies using unselected cadavers also showed higher between-method deviations in results in the medial tibia compared with the lateral tibia [19-21].

In advanced stages of the OA with high grade chondromalacia, which had severe cartilage loss and narrowing joint space, accurate distinction of tibial cartilage boundary was difficult. Furthermore, the fibroid tissue accompanying OA led to additional difficulties in delineating the tibial cartilage. Therefore, drawing the cartilage contours slice-by-slice is necessary. We used an optimized coronal gradient-echo 3D T1-weighted MRI sequence to obtain high contrast and high-resolution images of the cartilage. However, this sequence requires long acquisition times (7.58 min). A partial volume effect occurs because of motion artifact, causing blurred cartilage boundaries. Moreover, An MRI system produced by only one vendor was used, and the results may not necessarily apply to systems from other manufacturers [22]. The cost for MRI and 3D postprocessing may currently be too high to use them for routine examination of OA patients in clinical practice [15].

Among the potential advantages of MRI as a 3D technique over radiography is that there are less errors resulting from joint malpositioning [15]. Future MRI-based techniques should examine the cartilage tissue loss in a larger number of patients to allow for statistical sample size calculations for clinical trials.

Table 2. Precision of magnetic resonance imaging-based analysis of tibial cartilage in osteoarthritis

Volume (cm^3)	Minimum	Maximum	Mean	SD	CV%
Medial tibia					
Radiologist	0.29	1.63	1.13	0.32	28.13
Researcher	0.29	1.77	1.10	0.34	31.02
Actual volume	0.30	1.72	1.14	0.35	30.23
Lateral tibia					
Radiologist	0.77	3.17	1.84	0.55	30.22
Researcher	0.60	3.24	1.78	0.57	31.91
Actual volume	0.65	3.2	1.85	0.58	31.44

SD, standard deviation; CV, coefficient of variation

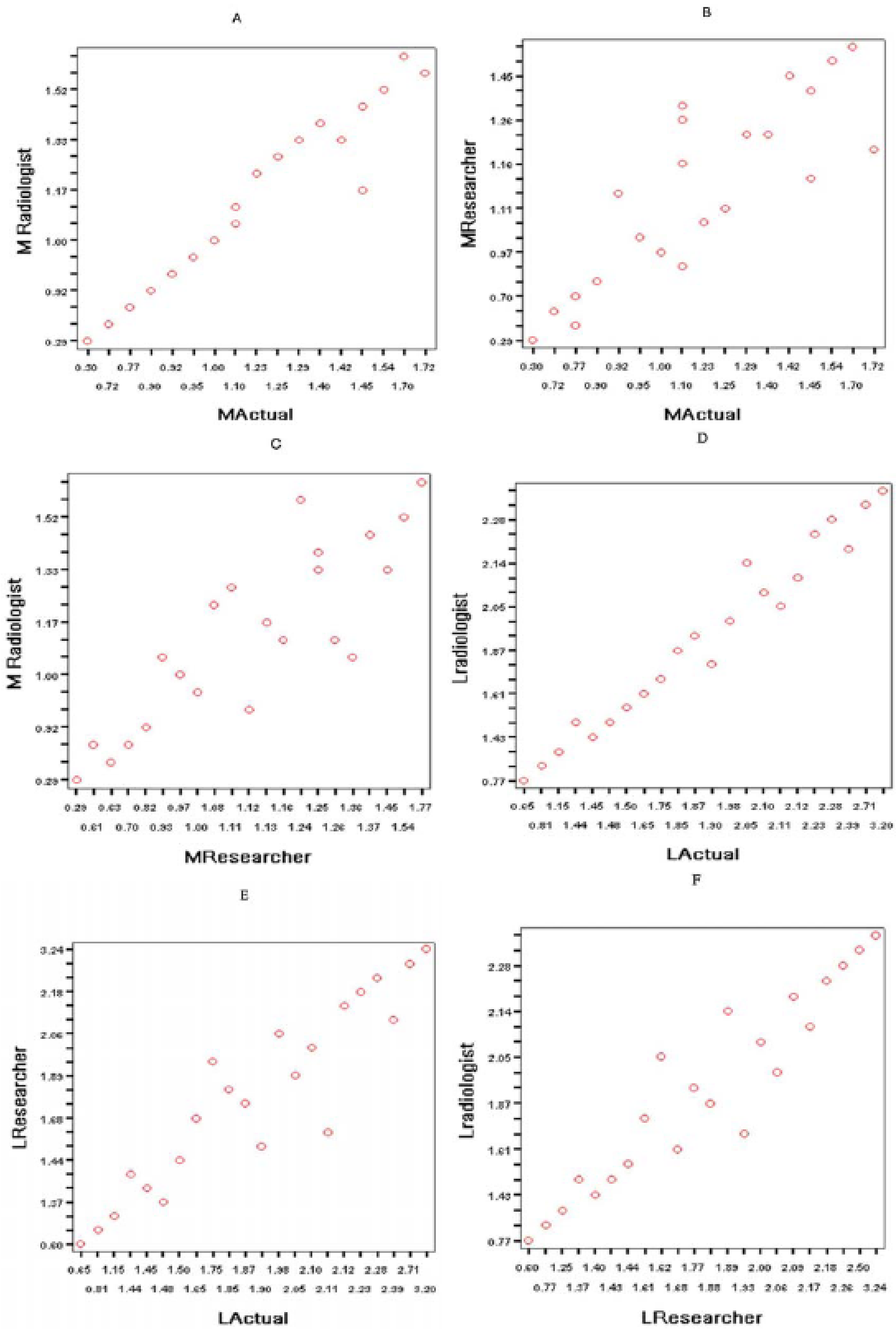

Figure 4. **C**orrelation between MRI medial and lateral tibial cartilage volume measurement and actual medial cartilage volumes, using intraclass correlation power analysis. Medial cartilage volume measurement by a radiologist and the researcher correlated well with actual medial cartilage volume (intraclass correlation coefficient (ICC) = 0.98 and 0.89 in A and B, respectively). The reliability of observers was good (ICC = 0.92 in C). Lateral cartilage volume measurement by a radiologist and a researcher correlated well with actual lateral cartilage volume (ICC = 0.99 and 0.97 in D and E, respectively). The reliability of observers was excellent (ICC = 0.97 in F).

It is important to use MRI to evaluate preoperatively the size, location, and stability of chondral and osteochondral fragments in patients with chondral and osteochondral injury. MRI is the modality of choice to monitor new cartilage development and to evaluate the treatment result after cartilage repair procedures such as autologous chondrocyte transplantation, microfracture, osteochondral allograft, osteochondral autograft transplantation (mosaicplasty).

Conclusion

MRI measurement using manual tracing of every 1 mm slice of tibial cartilage is helpful to estimate the volume of tibial cartilage preoperatively in total knee arthroplasty, and to monitor disease progression and response to therapy. This technique is easily performed by well-trained personnel such as radiologists or residents.

The authors have no conflict of interest to declare.

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