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1 Title Page

2 Quantitative Knee Cartilage Measurement at MR Imaging of Patients with Anterior
3 Cruciate Ligament Tear

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Abstract

In previous studies, numerous approaches were proposed that assess knee cartilage volume quantitatively by using 3D magnetic resonance (MR) imaging. However, clinical use of these approaches is limited because it is prone to metal artifact in postoperative cases. Our purpose in this study was to validate a method for knee cartilage volume quantification by using conventional MR imaging in patients who underwent anterior cruciate ligament (ACL) reconstruction surgery. The study included 16 patients who underwent MR imaging before and 1 year after ACL reconstruction surgery. Knee cartilage volumes were measured by our computer-based method with use of T1-weighted sagittal images. We classified the cartilage into 8 regions and made comparisons between preoperative and postoperative cartilage volumes in each region. There was a significant difference between preoperative and postoperative cartilage volumes with regard to medial posterior weight-bearing, medial posterior, lateral posterior weight-bearing, and lateral posterior portions ($p=0.006$, $p=0.023$, $p=0.017$ and $p=0.002$, respectively). These results were consistent with the previous studies showing that knee cartilage loss occurs frequently in these portions due to an anterior subluxation

61 of the tibia accompanied by ACL tear. With our method, knee cartilage volumes could
62 be quantitatively measured with conventional MR imaging in patients who underwent
63 ACL reconstruction surgery.

64 Key Words

65 knee cartilage: anterior cruciate ligament: magnetic resonance imaging

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68 Introduction

69 Hyaline cartilage covering the surface of the diarthrodial joint is important for normal
70 joint function and can transmit and distribute pressure without sustaining substantial
71 wear [1,2]. In addition, because articular cartilage provides a nearly frictionless gliding
72 surface, these forces can be transmitted during dynamic joint activity [3–8]. In order to
73 satisfy these complex functional requirements, articular cartilage shows unique
74 morphologic features and biomechanical properties that are unmatched by artificial
75 material [1,2,9,10]. Observing cartilage destruction and loss is important for evaluating
76 osteoarthritis (OA) [11,12].

77 Magnetic resonance (MR) imaging has been in use for cartilage evaluation for
78 many years because it provides high soft-tissue contrast and spatial resolution. MR
79 imaging enables direct qualitative and quantitative visualization and evaluation of the
80 cartilage [13]. In recent years, some investigators have developed computer-based
81 methods to create 3D cartilage reconstruction from magnetic resonance images [12,14–
82 17]. These methods can be used for assessment of cartilage degeneration and cartilage
83 loss quantitatively by evaluation of cartilage volume, while the methods have high
84 susceptibility to metal artifacts due to their sequence design depending on the gradient
85 echo technique, which is not recommended for quantitative analysis of cartilage in

post-operative status.

Anterior cruciate ligament (ACL) tear leads to anterior subluxation of the tibia with engagement of the anterior femoral condyle against the posterior tibial plateau [18–23]. As a result, cartilage loss occurs in the anterior femoral condyle and posterior tibial plateau [19,21]. In addition, 74% of patients who underwent ACL reconstruction surgery displayed some signs of radiographic OA within 7 years post-surgery. Thus, OA is common in ACL-reconstructed knees [24]. Therefore, our purpose in this study was to verify a quantification method for knee cartilage volumes by using conventional MR imaging in patients who had undergone ACL reconstruction surgery.

Materials and methods

Patients

The study included 16 patients who underwent MR imaging before and 1 year after ACL reconstruction surgery (Tables 1,2). This study was conducted in accordance with the Declaration of Helsinki and its updates and was approved by the local ethics committee. Informed consent was obtained from all of the patients.

MR imaging

All patients in this study group underwent MR imaging, with T1-weighted images obtained before (baseline) and 1 year after (follow-up) ACL reconstruction surgery. MR images were performed with the Achieva 1.5T A-series (Philips) and the Achieva 3.0T TX (Philips). Imaging parameters are summarized in Table 3. In follow-up studies, special care was taken so that the slice position was identical to that of the baseline study.

Image analysis

In this study, we used an original software in which cartilage is manually segmented from MR images taken at baseline and at follow-up, and the interval difference in cartilage volume between baseline and follow-up is displayed with Microsoft Excel and a color map.

The original software was developed with Microsoft Visual C# 2013. The MR images taken at baseline and at follow-up were imported into the software. Then, 3 steps for cartilage segmentation and volumetry were followed.

Step-1: semi-automated bone segmentation for bone area elimination at bone/cartilage interface

The interface between the subchondral bone and its cartilage is a sharp curvilinear line in most cases. Therefore, to eliminate bone pixels from volumetry of the cartilage, all the slices in each MR study were binarized automatically by Otsu's method [25], and fused images of the binary images and the original images were created (Fig.1). Here, the threshold was selected to separate bony structures from the soft tissues including cartilage, a pixel value larger than the threshold was displayed in green, and a pixel value less than the threshold was displayed with that of the original images. The green pixels containing bone area were then automatically extracted from the display. When the bone was not completely displayed in green, we manually eliminated the signal from the bone by mouse dragging operation. Extracting the bone using automatic binarization facilitated easier segmentation of the cartilage boundary for the subsequent processing, thus reducing the time for segmentation without affecting the accuracy of cartilage quantification.

Step-2: manual segmentation of the knee cartilage at its interface to joint space

We manually segmented the articular side of the knee cartilage which we deemed cartilage by mouse dragging operation. The segmented part was displayed in red (Fig.2). During cartilage segmentation, the pixels formally displayed in green were never

repainted as red, so that the bony areas were not added to the knee cartilage volumes. In baseline and follow-up images, we carefully performed this operation only on a slice judged to be the same section by observing between baseline and follow-up slices where articular cartilage is visible. The number of slices used for image analysis therefore resulted in the same for baseline as for follow-up. The total of the measured areas was calculated as volume.

Step-3: automated sub-region (8-regions) segmentation and volume calculation

We divided the segmented cartilage into quarters from the pixel where the cartilage exists at the most anterior position to the pixel at the most posterior position in the slices with the cartilage, and divided these into medial and lateral portions. We defined the 8 regions as lateral anterior, lateral anterior weight-bearing, lateral posterior weight-bearing, lateral posterior, medial anterior, medial anterior weight-bearing, medial posterior weight-bearing, and medial posterior portions (Fig.3.). The way we segmented the cartilage came from the findings of previous studies; ACL tear leads to anterior subluxation of the tibia with impaction of the anterior femoral condyle against the posterior tibial plateau along with cartilage loss in the anterior femoral condyle and posterior tibial plateau [19,21]. The amount of cartilage volume change was obtained by

subtraction of the volume of the baseline from that of the follow-up, and color mapping was performed based on the value of these changes (Fig.4.).

One radiological technologist with three months of experience and enough prior knowledge about the position of the cartilage performed computer-based analysis twice with a half of year interval. In order to examine the validity of the original software, pre- and post-operative knee cartilage was quantified using our software (which includes semi-automatic and manual segmentation) and an image analysis software called ImageJ (National Institutes of Health, Bethesda, MD) in one case (20-year-old, male). In ImageJ, we manually segmented cartilage utilizing the “Polygon selection” tool.

Statistical analysis

SPSS version 22.0 (IBM Corp, New York, NY) for Windows was used for statistical analysis. When we compared the paired samples, normality was tested by the Shapiro-Wilk test and did not find normality; we therefore performed the Wilcoxon signed-rank test, which is a nonparametric test.

Intra-observer agreement was estimated using intra-class correlation coefficients (ICC) employing a one-way random effects model for intra-observer

agreement. ICC values were interpreted as poor agreement for values between 0 and 0.20, fair agreement for values between 0.21 and 0.40, moderate agreement for values between 0.41 and 0.60, substantial agreement for values between 0.61 and 0.80, and almost perfect for values between 0.81 and 1.00 [25]. We compared the time taken per slice between the original software and ImageJ in a Wilcoxon signed-rank test.

Results

There was a significant difference between baseline and follow-up cartilage volumes in the medial posterior weight-bearing, medial posterior, lateral posterior weight-bearing, and lateral posterior portions ($p=0.006$, $p=0.023$, $p=0.017$, and $p=0.002$, respectively). However, there was no significant difference between baseline and follow-up cartilage volumes in the medial anterior, medial anterior weight-bearing, lateral anterior, and lateral anterior weight-bearing portions ($p=0.352$, $p=0.098$, $p=0.642$, and $p=0.602$, respectively), as shown in Table 4. A representative case is shown in Fig.5.

Intra-observer agreement of knee cartilage volume in 8 regions was almost perfect (ICC = 0.955; 95% confidence interval [95% CI], 0.943-0.965). Intra-observer agreement for delta values (difference between the baseline and follow-up) was substantial (ICC = 0.803; 95% CI, 0.732-0.857). The knee cartilage volume in the original software/ImageJ was 2108/2038 mm³ (0.094% difference) and 2108/2110 mm³ (3.4% difference) at the baseline and follow-up, respectively. The mean time ($\pm$ standardized deviation) taken with the original software and ImageJ was 50.9 ($\pm$ 10.1) and 131 ($\pm$ 0.000788) seconds, respectively ($p = 0.00004$).

Discussion

200 In this study, we evaluated cartilage volumes in 16 patients before and 1 year after ACL
201 reconstruction surgery. There was a significant difference between baseline and
202 follow-up cartilage volumes in each of 4 regions (medial posterior weight-bearing,
203 medial posterior, lateral weight-bearing posterior, and lateral posterior portions). In
204 previous studies, quantitative knee cartilage evaluation was conducted using 3D-MR
205 images [12,14–17], but to the best of our knowledge, there were no studies in which
206 there was a quantitative evaluation of postoperative cartilage volume as in this study.
207 T1-weighted images are used routinely for the analysis of anatomic structures.
208 Moreover, they have an advantage over gradient echo sequences and fat suppression
209 images, being free from postoperative metal artifacts. Therefore, this method could be
210 applied immediately to clinical practice.

211 Previous investigations reported that ACL tear leads to anterior subluxation of
212 the tibia with impaction of the anterior femoral condyle against the posterior tibial
213 plateau along with cartilage loss in the anterior femoral condyle and posterior tibial
214 plateau [19,21]. Also, previous studies showed that ACL-reconstructed knees had
215 greater contact along the medial ridge of the medial plateau and the posterior aspect of
216 the lateral plateau, compared to healthy contralateral knees and to the knees of healthy
217 persons during exercise [15]. Furthermore, in another study, 74% of the patients who

218 had undergone ACL reconstruction surgery showed several signs of radiographic OA
219 within 7 years after surgery, indicating that early-onset OA is common in
220 ACL-reconstructed knees [24]. For these reasons, cartilage loss may occur in the
221 anterior femoral condyle and posterior tibial condyle at the time of ACL tear. In this
222 study, the results that there was a significant difference between baseline and follow-up
223 cartilage volumes in the medial posterior weight-bearing, medial posterior, lateral
224 weight-bearing posterior, and lateral posterior portions were consistent with this
225 hypothesis. That may suggest that our newly proposed method could successfully
226 quantify knee cartilage volume.

227 In this study, we showed that there is significant reduction in the reasonable
228 anatomical location of the knee cartilage in patients who underwent ACL reconstruction
229 surgery. Moreover, the knee cartilage volumes can be evaluated by using the
230 conventional MR images with our software. We consider this is due to careful scan
231 planning in terms of stable slice selection and imaging parameter, including slice
232 thickness and slice gap. Together with compatible results from the data using the free
233 software of ImageJ, we considered our cartilage volumetry was to be valid.

234 In our study results, the knee cartilage volumes did not show any significant
235 difference in the anterior and anterior weight-bearing portions of both medial and lateral

sides. This may be attributed to the fact that we could not divide segmented cartilage into the femoral side and the tibial side. In our study population, as ACL tears were caused by trauma, cartilage wear was considered to be localized. For more sensitive detection of the localized cartilage loss, measurement of cartilage volume should be performed on the femoral side and the tibial side separately. However, in this study, it was difficult to separate the cartilage into the femoral side and the tibial side on the T1-weighted sagittal images.

We believe that as the original software used in this study is accurate, reproducible, and less time-consuming, it can be applied to the comparison among the procedures of ACL reconstruction. In a previous study, the comparison among the procedures of ACL reconstruction was performed, but the investigations evaluated ACL by arthroscopy, whereas a cartilage evaluation was not done [26]. We considered that adding cartilage evaluation to one of the prognostic evaluations might reveal signs of OA, which is considered to occur frequently in ACL-reconstructed knees.

Our study had several limitations. First, the devices used for MR images differ between inter- and intra- patients due to the retrospective design of this study. However, the MR parameters used in this study did not differ greatly between the devices, and the results of this research implied that cartilage volume may be quantified by use of

routine images, independent of the device. The second limitation was the small number of patients included in this study. Further study on more patients is needed for confirmation of the results. Thirdly, although the cartilage region is clearly depicted using 3D imaging methods such as the 3D-FISP sequence, we have no 3D imaging methods available for comparison. However, we believe that it is meaningful to quantitatively evaluate cartilage using 2D-T1w MR images although accuracy for cartilage volumetry may be inferior to 3D sequences due to the slice gap. Finally, because our original software was not free from manual segmentation for the most part, cartilage evaluation could be subjective and time-consuming. Moreover, when conducting similar research in other institutes, there is a possibility that some variation may occur depending on the analyst's skill. Therefore, in order fundamentally to solve these problems, we need to build a new algorithm for automating our original software.

Conclusion

Knee cartilage volumes could be measured quantitatively with conventional MR imaging in patients who underwent ACL reconstruction surgery.

Compliance with ethical standards

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273 Conflict of interest

274 All authors have no conflicts of interest to disclose.

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276 Ethical approval

277 All procedures in studies involving human participants were performed in accordance

278 with the ethical standards of the Faculty of Health Sciences, Hokkaido University, and

279 with the 1964 Helsinki Declaration and its later amendments or comparable ethical

280 standards.

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282 Informed consent

283 Informed consent was waived by the ethical committee of Faculty of Health Sciences,

284 Hokkaido University as this was a retrospective study.

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287 References

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289 1. Mow VC, Holmes MH, Lai WM. Fluid transport and mechanical properties of

290 articular cartilage: a review. J Biomech. 1984;17:377-94.

291 2. Mow VC, Ateshian GA, Spilker RL. Biomechanics of diarthrodial joints: a review of
292 twenty years of progress. J Biomech Eng. 1993;115:460-7.

293 3. Ateshian GA, Wang H. Rolling resistance of articular cartilage due to interstitial fluid
294 flow. Proc Inst Mech Eng H. 1997;211:419-24.

295 4. Jin ZM, Pickard JE, Forster H, Ingham E, Fisher J. Frictional behaviour of bovine
296 articular cartilage. Biorheology. 2000;37:57-63.

297 5. Boschetti F, Pennati G, Gervaso F, Peretti GM, Dubini G. Biomechanical properties
298 of human articular cartilage under compressive loads. Biorheology. 2004;41:159-66.

299 6. Chen AC, Klisch SM, Bae WC, Temple MM, McGowan KB, Gratz KR, et al.
300 Mechanical Characterization of Native and Tissue-Engineered Cartilage. Methods Mol
301 Med. 2004;101:157-90.

302 7. Krishnan R, Kopacz M, Gerard A. Ateshian. EXPERIMENTAL VERIFICATION
303 OF THE ROLE OF INTERSTITIAL. J Orthop Res. 2010;22:565-70.

304 8. Ateshian GA, Hung CT. Patellofemoral joint biomechanics and tissue engineering.
305 Clin Orthop Relat Res. 2005;100:81-90.

306 9. Buckwalter JA, Mankin HJ. Articular cartilage: tissue design and chondrocyte-matrix
307 interactions. Instr Course Lect. 1998;47:477-86.

- 308 10. Hunziker EB, Quinn TM, Häuselmann HJ. Quantitative structural organization of
309 normal adult human articular cartilage. *Osteoarthr Cartil.* 2002;10:564-72.
- 310 11. Lawrence JS, Bremner JM, Bier F. Osteo-arthritis. Prevalence in the population and
311 relationship between symptoms and x-ray changes. *Ann Rheum Dis.* 1966;25:1-24.
- 312 12. Raynauld JP, Kauffmann C, Beaudoin G, Berthiaume MJ, de Guise JA, Bloch DA,
313 et al. Reliability of a quantification imaging system using magnetic resonance images to
314 measure cartilage thickness and volume in human normal and osteoarthritic knees.
315 *Osteoarthr Cartil.* 2003;11:351-60.
- 316 13. Conaghan PG, Felson D, Gold G, Lohmander S, Totterman S, Altman R. MRI and
317 non-cartilaginous structures in knee osteoarthritis. *Osteoarthr Cartil.* 2006;14:87-94.
- 318 14. Dam EB, Folkesson J, Pettersen PC, Christiansen C. Automatic morphometric
319 cartilage quantification in the medial tibial plateau from MRI for osteoarthritis grading.
320 *Osteoarthr Cartil.* 2007;15:808-18.
- 321 15. Kaiser J, Vignos MF, Liu F, Kijowski R, Thelen DG. American Society of
322 Biomechanics Clinical Biomechanics Award 2015: MRI assessments of cartilage
323 mechanics, morphology and composition following reconstruction of the anterior
324 cruciate ligament. *Clin Biomech.* 2016;34:38-44.
- 325 16. Koo S, Gold GE, Andriacchi TP. Considerations in measuring cartilage thickness

326 using MRI: Factors influencing reproducibility and accuracy. *Osteoarthr Cartil.*
327 2005;13:782-9.

328 17. Waterton JC, Solloway S, Foster JE, Keen MC, Gandy S, Middleton BJ, et al.
329 Diurnal variation in the femoral articular cartilage of the knee in young adult humans.
330 *Magn Reson Med.* 2000;43:126-32.

331 18. Dimond PM, Fadale PD, Hulstyn MJ, Tung GA, Greisberg J. A comparison of MRI
332 findings in patients with acute and chronic ACL tears. *Am J Knee Surg.* 1998;11:153-9.

333 19. Spindler KP, Schils JP, Bergfeld JA, Andrish JT, Weiker GG, Anderson TE, et al.
334 Prospective study of osseous, articular, and meniscal lesions in recent anterior cruciate
335 ligament tears by magnetic resonance imaging and arthroscopy. *Am J Sports Med.*
336 1993;21:551-7.

337 20. Speer KP, Spritzer CE, Bassett FH, Feagin JA, Garrett WE. Osseous injury
338 associated with acute tears of the anterior cruciate ligament. *Am J Sports Med.*
339 1992;20:382-9.

340 21. Vellet AD, Marks PH, Fowler PJ, Munro TG. Occult posttraumatic osteochondral
341 lesions of the knee: prevalence, classification, and short-term sequelae evaluated with
342 MR imaging. *Radiology.* 1991;178:271-6.

343 22. Kaplan PA, Walker CW, Kilcoyne RF, Brown DE, Tusek D, Dussault RG. Occult

344 fracture patterns of the knee associated with anterior cruciate ligament tears: assessment
 345 with MR imaging. Radiology. 1992;183:835-8.

346 23. Graf BK, Cook DA, De Smet AA, Keene JS. "Bone bruises" on magnetic resonance
 347 imaging evaluation of anterior cruciate ligament injuries. Am J Sports Med.
 348 1993;21:220-3.

349 24. Lidén M, Sernert N, Rostgård-Christensen L, Kartus C, Ejerhed L. Osteoarthritic
 350 Changes After Anterior Cruciate Ligament Reconstruction Using Bone-Patellar
 351 Tendon-Bone or Hamstring Tendon Autografts: A Retrospective, 7-Year Radiographic
 352 and Clinical Follow-up Study. Arthroscopy. 2008;24:899-908.

353 25. Landis JR, Koch GG. The measurement of observer agreement for categorical data.
 354 Biometrics. 1977;33:159-74.

355 26. Kondo E, Yasuda K, Onodera J, Kawaguchi Y, Kitamura N. Effects of Remnant
 356 Tissue Preservation on Clinical and Arthroscopic Results After Anatomic
 357 Double-Bundle Anterior Cruciate Ligament Reconstruction. Am J Sports Med.
 358 2015;43:1882-92.

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Table 1. Characteristics of patients

	Value
Total no. of subjects included	16
Age. mean (range) in years	30.1 (13-58)
Sex. female/male	7/9
Knee. right/left	5/11

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Table 2. Athletic activity or situation associated with the injury, and period from injury to surgery

Case number	Situation	Days	Sex	Age [years]
1	tumble	756	M	36
2	rugby	92	M	19
3	ski	85	M	55
4	soccer	3626	M	32
5	basketball	136	F	13
6	badminton	0	M	19
7	tumble	139	F	45
8	gym vault	111	M	18
9	gym vault	15706	F	58
10	volleyball	57	F	15
11	volleyball	1461	F	51
12	volleyball	100	M	49
13	volleyball	85	F	16
14	triathlon	110	M	20
15	rugby	93	M	19
16	soccer	24	F	17

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Table 3. Acquisition parameters of MR imaging

Magnetic Field Strength [T]	1.5	3
Sequence	SE T1WI	
Section	sagittal	
Slice Thickness [mm]	3	
FA [degree]	90	
NEX	2	
Slice Gap [mm]	0.3	
TR [msec]	500 or 579	700 or 800
TE [msec]	15	10 or 12
ETL	3 or 4	3
BW [Hz]	230 - 259	242 - 255
Pixel Size [mm]	$0.222 \times 0.222 - 0.390 \times$ 0.390	$0.273 \times 0.273 - 0.3125 \times$ 0.3125
No. of Slices	23 or 24	23 or 25

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Table 4. Comparison between baseline and follow-up cartilage volume in each region

Regions		n	Baseline		Follow-up		P value (<0.05)
			Mean [mm ³]	SD [mm ³]	Mean [mm ³]	SD [mm ³]	
Medial	Anterior	16	31.8	29.0	31.2	43.1	0.352
	Anterior weight-bearing	16	203	54.6	171	65.4	0.098
	Posterior weight-bearing	16	309	69.2	252	82.4	0.006
	Posterior	16	321	105	310	86.2	0.023
Lateral	Anterior	16	115	96.4	89.8	50.3	0.642
	Anterior weight-bearing	16	164	74.5	153	84.6	0.605
	Posterior weight-bearing	16	376	96.8	320	113	0.017
	Posterior	16	351	107	278	71.7	0.002

371 SD = standard deviation

372

Fig.1. Original image (A) and fused image (B)

Fig.2. Segmentation of cartilage at fused image

Fig.3. Cartilage classification into 8 regions.

(A) Sagittal MR image of the lateral side of the knee (B) Sagittal MR image of the medial side of the knee. (a) Lateral anterior portion (b) Lateral anterior weight-bearing portion (c) Lateral posterior weight-bearing portion (d) Lateral posterior portion (e) Medial anterior portion (f) Medial anterior weight-bearing portion (g) Medial posterior weight-bearing portion (h) Medial posterior portion

Fig.4. Cartilage volume map in a 36-year-old man's right knee

The closer to red, the larger the difference between the follow-up and baseline is to the positive value. The closer to blue, the larger the difference between the follow-up and baseline is to the negative value. Green indicates almost unchanged.

- (a) Lateral anterior portion (b) Lateral anterior weight-bearing portion (c) Lateral posterior weight-bearing portion (d) Lateral posterior portion (e) Medial anterior portion (f) Medial anterior weight-bearing portion (g) Medial posterior weight-bearing portion (h) Medial posterior portion

Fig.5. Example of a case with significant cartilage volume loss at multiple cartilage regions.

Sagittal T1-w MR images of knee in 36-year-old man before and 1 year after ACL reconstruction surgery. (A) baseline image. (B) is colored cartilage of (A). (c) is followup image. (D) is colored cartilage of (C). The cartilage volume at baseline (followup) was 70.9 (37.6), 131.3 (43.8), 484.9 (314.0) and 458.0 (313.0) mm³ in anterior, anterior weight-bearing, posterior weight-bearing and posterior at baseline, respectively. These interval changes are difficult to recognize using conventional visual assessment.