T2 value of high signal line on MRI is related to the conditions around the fragment in osteochondral lesion of talus

[1,2]Tomoyuki Nakasa, MD, PhD, [1]Yasunari Ikuta, MD, PhD, [1]Yuki Ota, MD, [1]Munekazu Kanemitsu, MD, [1]Junichi Sumii, MD, [1]Akinori Nekomoto, MD, [1]Nobuo Adachi, MD, PhD

1. Department of Orthopaedic Surgery, Graduate School of Biomedical and Health Sciences, Hiroshima University

2. Medical center for translational and clinical research, Hiroshima University Hospital

1-2-3 Kasumi, Minamiku, Hiroshima city, Hiroshima, 734-8551, JAPAN

Tel; +81-82-257-5233

FAX; +81-82-257-5234

E-mail; tnakasa0@gmail.com

T2 value of high signal line on MRI is related to the conditions around the fragment in osteochondral lesion of talus

Abstract

Background: MRI is useful for evaluating stability of the lesion in the diagnosis of osteochondral lesion of the talus (OLT). A T2 high signal line between the fragment and its bed on MRI is known as a reliable indicator of an unstable lesion. However, the lesion exhibits various conditions even if a T2 high signal line is observed. The purpose of this study is to evaluate the relationship between the T2 value of a high signal line and the condition of the area between the fragment and its bed in OLT.

Methods: T2 values of the T2 high signal line and those of joint fluid were measured from preoperative MRI images in 46 ankles with OLT. Then, the T2 ratio (high signal line / joint fluid) was calculated. The relationship between the T2 ratio and CT, arthroscopic and histological findings was examined.

Results: The mean T2 ratio was 0.48. T2 ratios of cystic lesions (0.62) or bone absorption (0.67) in the bed were significantly higher than those without a cyst (0.40) or no absorption (0.40). The T2 ratio of an unstable lesion (0.51) was significantly lower than that of a stable lesion (0.29). In histological findings, there were 2 separate patterns: chondral and subchondral bone separations. The T2 ratio of the chondral separation (0.60) was significantly higher than that of bone separation (0.48).

Conclusion: This study showed that the T2 ratio on a high signal line is a predictor of conditions such as stability, cyst and bone absorption in OLT.

Keywords MRI; T2 high; osteochondral lesion; talus; stability

Level of evidence: Level 4

Introduction

Osteochondral lesion of the talus (OLT) is one of the ankle disorders which involves articular cartilage and subchondral bone, which causes ankle disability.[20] The therapeutic strategy is determined by the various factors including the stability of the osteochondral fragment. MRI is useful in the assessment of the stability of the osteochondral fragment, and it shows the characteristic findings on the MRI images for the stability. Several reports have demonstrated that a high signal line on T2-weighted images at the interface between the osteochondral fragment and the underlying bone is a sign of an unstable lesion.[4,5,11] Unstable lesions indicate that osteochondral fragment is not firmly fixed to the underlying bone, and joint fluid tracks though a breach between the osteochondral fragment and the underlying bone, which is depicted as T2 high signal line on MRI images.[7,11,15] Therefore, it has been widely recognized that OLT with a T2 high signal line denotes an unstable lesion and would not heal without surgery. However, it is not always the case that a T2 high signal line on MRI indicates an unstable lesion.[4,11] There are several conditions such as joint fluid, vascular granulation tissue, and adjacent cysts in the interface between the osteochondral fragment and the underlying bone which are also depicted as a T2 high signal line.[4,5,7,19] In cases with a T2 high signal line recognized as an unstable lesion, spontaneous healing of the lesion has been observed.[3,18] Thus, the T2 high signal line is involved in various conditions, which may result in a range of prognoses. It is thought that more details of the lesion can be predicted if a T2 high signal line is quantitatively assessed, not whether a T2 high signal line is present or

not in OLT. We hypothesized that a T2 value at the high signal line from MRI images would reflect the various **conditions** of the lesion in OLT. The purpose of this study is to evaluate the relationship between the T2 value of a high signal line and the condition of the lesion including the stability, underlying bone condition, and histological findings of the lesion in OLT.

Materials and methods

Forty-six ankles in 41 **patients** with OLT treated surgically in our hospital between January 2010 and August 2019 were included in this study. They consisted of 22 males and 19 females, with a mean age of 18.6 years (9 – 56). In five patients, both ankles were involved. They were diagnosed as stage 3 or 4 according to Anderson's classification.[2] Forty-one ankles had a medial lesion, and 5 ankles had a lateral lesion. For these patients, **MRI and CT were taken before surgery to evaluate the condition of articular cartilage, bone contents of the fragment, bone marrow lesion and cystic lesion in the subchondral bone [12,13]**. All patients had arthroscopic surgery after conservative treatment of at least 3 months. This study was approved by the local ethical committee of our university, and informed consent was obtained from all individual participants included in this study.

MRI evaluation

MRI scans were performed using a Signa 1.5-T device or a Signa HDxT 3.0-T device (GE Yokogawa Medical Systems Ltd.) with a wraparound surface coil designed for the ankle joint. Proton density SE and T2-weighted SE images were collected. The conditions for the T2 weighed images were repetition time, 2600 ms; echo time, 98 ms; section

thickness, 4.0 mm. The conditions for proton weighted images were repetition time, 2000 ms; echo time, 20 ms; section thickness, 4.0 mm. In the sagittal section of T2 weighted images, the region of interest (ROI)s at 1.56 mm^2 circle **was** set at joint fluid and high signal line in the same slice, and T2 values were measured (Figure 1). Then, the T2 ratio (high signal line / joint fluid) was calculated to standardize T2 values. **The ROI was set where the T2 high signal line was able to best be confirmed in a lesion.**

CT evaluation

A CT scan for the involved ankle was performed within 1 week before surgery. With the patient placed in a supine position, images of the coronal, sagittal, and axial planes were obtained from a multi-detector row CT scanner (LightSpeed QX/I; General Electric Medical Systems). The scan parameter included a 512 × 512 matrix, 0-degree gantry tilt, 1.25-mm prospective slice thickness, 3.75mm per rotation table speed (multi helical pitch of 3), 0.8-s gantry rotation, 120kV (peak), and 120-200 mA. After this, 2-dimensional images were reconstructed with a 25-cm field of volume, a 1.25-mm retrospective slice thickness, and 0.63-mm overlap. The total table motion was 30-40 cm, and finally 350-450 slices were obtained. On the sagittal images including OLT which matched the same slice on MRI, the entity of bone absorption or adjacent cyst on the underlying bone in the OLT was evaluated according to the previous report.[12] The T2 ratio with or without an adjacent cyst and bone absorption were compared.

Arthroscopic evaluation

All patients underwent arthroscopic surgery. They were placed in a supine position, and standard anterolateral and anteromedial portals were established under joint

distraction using an Ankle Distractor (Smith & Nephew, Memphis, TN). A 2.7 mm 30° oblique arthroscope was used, and the stability of the osteochondral fragment was evaluated from probing to the lesion. The mobility of the osteochondral fragment by probing was defined as an unstable lesion. The relationship between the stability of the osteochondral fragment and the T2 ratio was analyzed.

Histological evaluation

Needle biopsy specimens were obtained from 22 ankles in 21 patients during fixation of the osteochondral fragment. At the time of fixation of the osteochondral fragment, needle biopsy was performed using a 14 gauge biopsy needle (Ostycut; Angiomed/Bard, Karlsruhe, Germany), and a poly-L-lactide (PLLA) 2mm diameter pin was inserted into the hole which was created by the needle biopsy according to previous reports.[12,14] Specimens were fixed in 10% formalin for one day. Then, they were decalcified with 0.25 methylenediaminetetra acetic acid in phosphate buffered saline. After dehydration in graded ethanol, specimens were embedded in paraffin wax. They were cut sagittally into 5 μm thick pieces, and stained with hematoxylin & eosin and Safranin O/Fast Green. The relationship between the histological findings of the lesion and the T2 ratio was examined.

Statistical analysis

Statistical differences between the 2 groups were calculated using the unpaired t test. A P-value of less than 0.05 was considered significant.

Results

The mean T2 ratio was 0.47 (ranging from 0.18 to 0.91). Sixteen ankles with cystic

lesion (Figure 2B) exhibited results of 0.62 (ranging from 0.28 to 0.91), and those of 30 ankles without a cyst were 0.40 (ranging from 0.18 to 0.86) (Figure 2A). There was a significant difference between ankles with and without a cystic lesion ($p<0.01$) (Figure 3A). Thirteen ankles with bone absorption (Figure 2C) in the underlying bone exhibited results of 0.67 (ranging from 0.44 to 0.91), and those of 33 ankles without bone absorption were 0.40 (ranging from 0.18 to 0.86), with a significant difference between ankles with and without cystic lesion ($p<0.01$) (Figure 3B). The T2 ratio of 30 ankles without both bone absorption and cystic lesion exhibited results of 0.39 (ranging from 0.18 to 0.86), and those of 4 ankles with cystic lesion but without bone absorption were 0.48 (ranging from 0.28 to 0.76). One ankle had bone absorption but no cystic lesion and its T2 ratio was 0.62. The T2 ratio of 12 ankles with both cystic lesion and bone absorption exhibited results of 0.66 (ranging from 0.44 to 0.91) (Figure 4).

In arthroscopic findings, a significant difference was found between the results of 39 ankles with instability of fragment (0.51 ; ranging from 0.18 to 0.91), and those of 7 ankles with a stable fragment (0.29 ; ranging from 0.18 to 0.41) ($p<0.05$) (Figure 3C, **Figure 5**). Although the T2 ratio in the unstable lesion was significantly higher than that in the stable lesion, **there were several cases with a low T2 ratio in the unstable lesion those T2 ratio was lower than the mean value – standard deviation of the unstable lesion.** These cases were likely to have a cupped shape lesion, which had good congruency between the osteochondral frpagment and its underlying bone (Figure **6**).

In the pathological findings, there were 2 separate patterns; chondral and subchondral bone separations. Chondral separation showed whole hyaline cartilage with little fibrous tissue at the separation site, and subchondral bone separation exhibited that hyaline cartilage was on the subchondral bone plate and that the separation site was at the

subchondral bone. The T2 ratio of the chondral separation was 0.60, and that of the bone separation was 0.48. There was a significant difference in the T2 ratio between the 2 separation types ($p<0.05$). The underlying bone in specimens with a high T ratio showed that thin trabecular bone with a high number of lining osteoblasts and broad marrow cavity contained loose fibrous tissue with abundant blood vessels (Figure 7A). On the other hand, specimens with a low T2 ratio showed that thick trabecular bone and a narrow marrow cavity (Figure 7B).

Discussion

This study revealed that a T2 high signal line has various intensities, and the stability and condition of the lesion, including the underlying bone, affect the T2 ratio. A T2 high signal line between the osteochondral fragment and the underlying bone has been recognized as a reliable indicator for an unstable lesion in the knee and ankle.[4,5,11] As for the OLT, DeSmet et al.'s study of 14 patients demonstrated that the presence and extent of attachment of the fragment to the talus can be accurately predicted by preoperative MRI.[4] In another study, a T2 high signal line could be observed on T2-weighted MRI in 72% of all unstable lesions.[6] Other studies showed that spontaneous healing is possible, even if a high signal line on a T2-weighted image is evident, because this high signal line may present vascular granulation tissue.[6,9] Thus, a T2 high signal line has various points of significance, which suggests that a T2 high signal line can reflect various conditions in the lesion. Therefore, we assessed a T2 high signal line quantitatively as a T2 ratio and the relationship between its value and lesion condition. **Overall, OLTs with low volume of bone content in the lesion such as chondral separation type, cyst and bone absorption in underlying bone showed higher T2 ratio because joint fluid may enter**

to the space between osteochondral fragment and its underlying bone. However, even an unstable lesion included a low T2 ratio. In those cases, CT showed a cup-shaped form, which may have almost no space for joint fluid to enter. These lesions might obtain good clinical results in surgery or in spontaneous healing in juvenile patients because of the advantage of bone volume, shape for bone union, and no space of joint fluid to enter even if the lesion is unstable. On the other hand, a high T2 ratio, especially with a T2 ratio close to 1, means that much of the joint fluid exists between the osteochondral fragment and the underlying bone, which might comprise an unstable lesion with a low bone volume. A previous report showed that prognostic factors such as depth of the lesion and subchondral bone cyst on MRI correlate with clinical outcomes.[10] These lesions might exhibit a high T2 ratio which suggests that a T2 ratio is a potential predictor of clinical outcomes. As a clinical significance, T2 high signal line has various condition, and the therapeutic strategy can be determined by the T2 ratio. Patients with a higher T2 ratio would be considered to have surgical treatment due to unstable lesion and cystic or absorbed subchondral bone, and conversely, lower T2 ratio lesions would make us continue conservative treatment.

When evaluating the relationship between the T2 ratio and lesion condition, the pathogenesis of OLT should be kept in mind. After the subchondral bone in the talar dome is damaged by factors such as micro-fracture and bone bruise caused by trauma, impaired healing may result in an intermittent flow of high-pressure fluid through the damaged subchondral bone plate into the subchondral bone. Continuous high fluid pressure can lead to osteonecrosis and bone resorption, subsequently forming a lytic lesion and osteochondral fragment.[9,16,17] When the fluid pressure flow decreases, bone resorption stops and bone remodeling around the lytic lesion occurs, leading to osteogenesis. This

193 excessive osteogenesis (sclerotic change) renders spontaneous bone union between the
194 osteochondral fragment and the underlying bone impossible. In this process, bone
195 absorption including cystic lesion in underlying bone occurs as a result of the high fluid
196 pressure, which suggests that a T2 ratio should be high. Thus, OLTs with bone absorption
197 and cystic lesion in our series exhibited high T2 ratio. In histological findings, high T2
198 ratio was observed in the chondral separate type, which has little fibrous tissue at the
199 separation site. This may allow joint fluid to extend between the osteochondral fragment
200 and underlying bone.[18] The underlying bone in these ankles had thin trabecular bone with
201 a high number of lining osteoblasts and a broad marrow cavity containing loose fibrous
202 tissue with abundant blood vessels. A previous report showed these histological findings
203 exhibited a high level of T2.[13]

204 We set ROI of a 1.56 mm^2 circle, which included the surrounding tissue of a T2 high
205 signal line **because the amount of fluid is quite small.** The T2 ratio might be reflected
206 by the surrounding tissue of the separation site **including bone granulation tissue or the**
207 **pressurized fluid into the bone**, which indicates an important significance besides the
208 stability of the lesion. It is reported that the bone condition in the osteochondral fragment
209 and underlying bone affects articular cartilage degeneration of the lesion. This should be
210 one of the indicators for determining the treatment strategy and its prognosis.[13,18]
211 Predicting the condition of the underlying bone from the T2 ratio is considered to be
212 useful in determining the treatment strategy. Recently, conservative treatment combined
213 with biologics such as PRP has performed.[8] If the condition of the lesion can be properly
214 predicted by the T2 ratio, there may be more opportunities for these treatments.

215 There are several limitations of this study. First, the number of patients was small.
216 The cutoff value of the T2 ratio in various conditions could not be determined. Analyzing

a large number of patients will make these possible. Second, the high signal line of the T2 ratio was set at only one point, and that did not reflect all lesions of the OLT. **Analysis in more points on high signal line or three dimensions may be useful if possible.** Moreover, the T2 ratio, CT and histological findings did not match completely. It seems to be quite difficult to make all of them match completely. Finally, not all ankles were evaluated from the same MRI in this study. Therefore, the T2 value of the ratio of joint fluid to high signal line was examined. However, there is the possibility that the results may be slightly different depending on MRI such as 3 or 1.5 tesla. Further investigation is needed.

In conclusion, this study revealed that a high signal line in OLT can involve various conditions which higher T2 ratio showed that unstable lesion, underlying bone with cystic lesion or bone absorption, and lower T2 ratio exhibited stable or unstable lesion with cup-shape form. The lesion condition of OLT can be predicted by T2 ratio of high signal line and the appropriate treatment will be determined.

References

1. Adam G, Buhne M, Prescher A et al. Stability of osteochondral fragments of the femoral condyle: Magnetic resonance imaging with histopathologic correlation in an animal model. *Skeletal Radiol* 1991;20:601-606.
2. Anderson BF, Crichton KJ, Grattan-Smith T, Cooper RA, Brazier D. Osteochondral fractures of the dome of the talus. *J Bone Joint Surg Am* 1989 Sep;71(8):1143-1152.
3. Bohndorf K. Osteochondritis (osteochondrosis) dissecans: a review and new MRI classification. *Eur Radiol* 1998;8:103-12.
4. DeSmet AA, Fisher DR, Burnstein MI et al. Value of MR inaging in staging

241 osteochondral lesions of the talus (osteochondritis dissecans): Results in 14 patients.
242 *AJR Am J Roentgenol* 1990;154:555-558.
243 5. DeSmet AA, Fisher DR, Graf BK et al. Osteochondritis dissecans of the knee: Value
244 of MR imaging in determing lesion stability and the presence of articular cartilage
245 defects. *AJR Am J Roentgenol* 1990;155:549-553.
246 6. DeSmet AA, Ihahi OA, Graf BK. Reassessment of the MR criteria for stability of
247 osteochondritis dissecans in the knee and ankle. *Skeletal Radiol* 1996;25:159-63.
248 7. Dipaola J, Nelson DW, Colville MR. Characterising osteochondral lesions by
249 magnetic resonance imaging. *Arthroscopy* 1991;7:101-4.
250 8. Dombrowski ME, Yasui Y, Murawski CD et al. Conservative management and
251 biological treatment strategies: proceedings of the international consensus meeting
252 on cartilage repair of the ankle. *Foot Ankle Int* 2018;39(15):9S-15S.
253 9. Johansson L, Edlund U, Fahlgren A, Aspenberg P. Bone resorption induced by fluid
254 flow. *J Biomech Eng* 2009;131:094505.
255 10. Klammer G, Maquieira GJ, Spahn S, Vigfusson V, Zanetti M,Espinosa N. Natural
256 history of nonoperatively treated osteochondral lesions of the talus. *Foot Ankle Int*
257 2015;36(1):24-31
258 11. Mesgarzadeh M, Sapega AA, Bonakdarpour A et al. Osteochondritis dissecans:
259 Analysis of mechanical stability with radiography, scintigraphy, and MR imaging.
260 *Radiology* 1987;165:775-780.
261 12. Naksa T, Ikuta Y, Yoshikawa M, Sawa M, Tsuyuguchi Y, Adachi N. Added value of
262 preoperative computed tomography for determining cartilage degeneration in
263 patients with osteochondral lesions of the talar dome. *Am J Sports Med*
264 2018;46(1):208-216.

13. Nakasa T, Ikuta Y, Sawa M, Yoshikawa M, Tsuyuguchi Y, Ota Y, Kanemitsu M, Adachi N. Relationship between bone marrow lesions on MRI and cartilage degeneration in osteochondral lesions of the talar dome. *Foot Ankle Int* 2018 Aug 39(8):908-915.
14. Nakasa T, Ikuta Y, Tsuyuguchi Y, Ota Y, Kanemitsu M, Adachi N. MRI tracking of the effect of bioabsorbable pins on bone marrow edema after fixation of the osteochondral fragment in the talus. *Foot Ankle Int* 2019 Mar 40(3):323-329.
15. Nelson DW, Dipaola J, Colville M, Schmidgall J. Osteochondritis dissecans of the talus and knee: prospective comparison of MR and arthroscopic classifications. *J Comp Assist Tomogr* 1990;14:804-8.
16. Radin EL, Rose RM. Role of subchondral bone in the initiation and progression of cartilage damage. *Clin Orthop Relat Res* 1986;213:34-40.
17. van Dijk CN, Reilingh ML, Zengerink M, van Bergen CJ. Osteochondral defects in the ankle: why painful? *Knee Surg Sports Traumatol Arthrosc* 2010;18:570-580.
18. Yoshida S, Ikata T, Takai H et al. Osteochondritis dissecans of the femoral condyle in the growth stage. *Clin Orthop* 1998;346:162-70.
19. Yulish BS, Mulopulos GP, Goodfellow DB et al. MR imaging of osteochondral lesions of the talus. *J Comput Assist Tomogr* 1987;11:296-301.
20. **Zengerink M, Szerb I, Hangody L, Dopirak RM, Ferkel RD, van Dijk CN. Current concepts: treatment of osteochondral ankle defects. *Foot Ankle Clin.* 2006;11:331-359.**

Legends

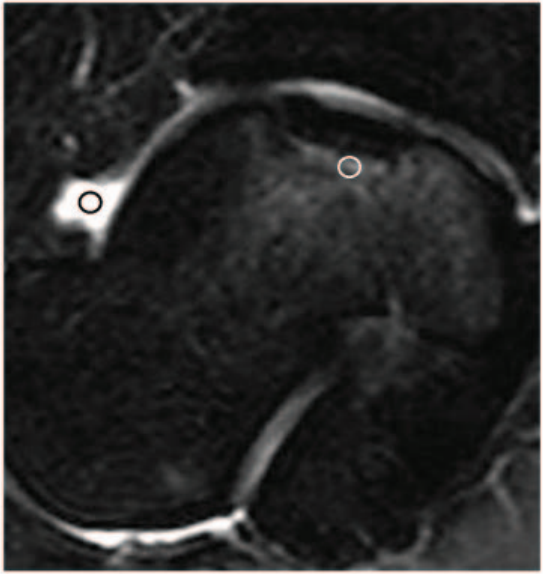
Figure 1.

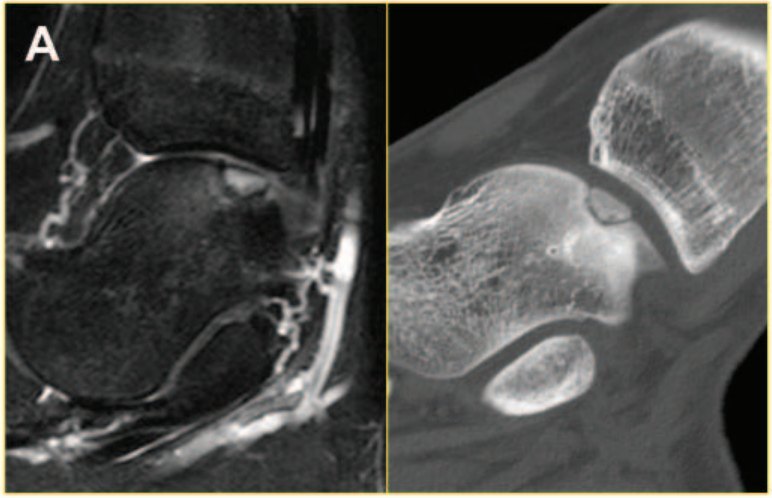
289 Measurement of T2 value on T2 weighted MRI. Circles were set on the joint fluid and T2
290 high signal line at osteochondral lesion of talus (OLT). The circle area is 1.56mm^2.
291
292 Figure 2.
293 Representative images of MRI and CT. (A) OLT without cyst and bone absorption. (B)
294 OLT with cyst. (C) OLT with cyst and bone absorption.
295
296 Figure 3.
297 **Box-whisker plots. T2 ratio of high signal line with or without cyst (A), bone**
298 **absorption (B), and (C) stable or unstable lesion.** *;p<0.05, **;p<0.01.
299
300 Figure 4.
301 Box-whisker plots with or without cyst or bone absorption.
302
303 **Figure 5.**
304 **Representative images of MRI and arthroscopic findings in stable and unstable**
305 **lesion. (A) (B) Stable lesion with low T2 ratio. (C) (D) Unstable lesion with high T2**
306 **ratio.**
307
308 **Figure 6.**
309 **Representative images of cup-shaped OLT. (A) MRI, (B) CT image.**
310
311 **Figure 7.**
312 **Histological findings of underlying bone. (A) Chondral separation type. (B) Bone**

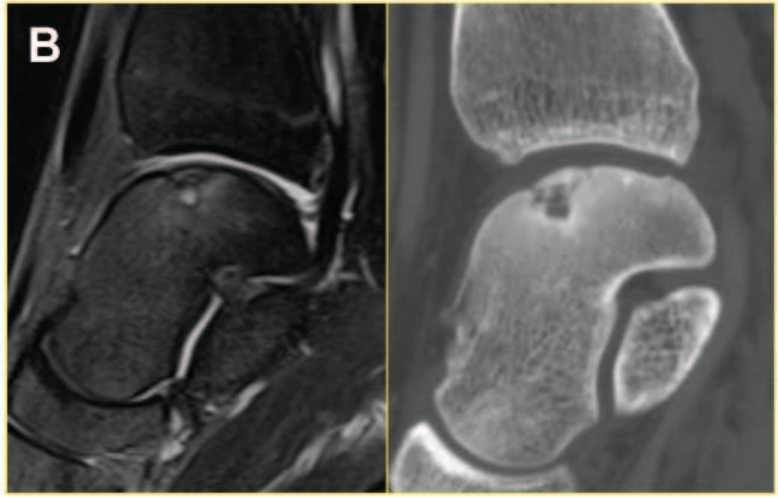
313 **separation type.** Arrows indicate lining osteoblasts. Arrow heads indicate arteries with

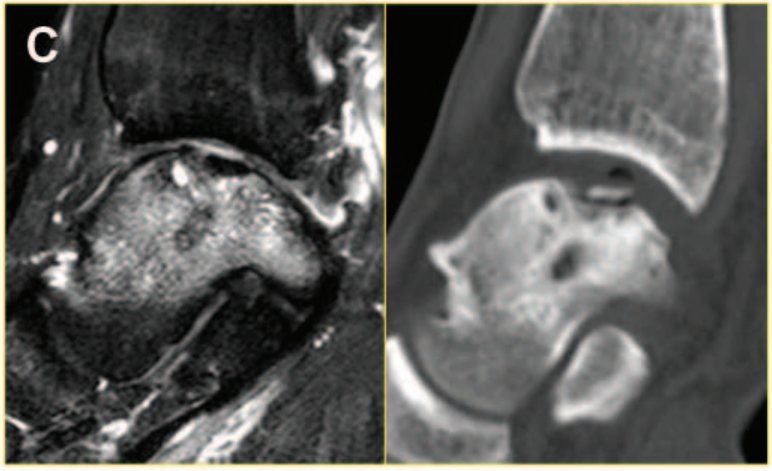
314 thick wall.

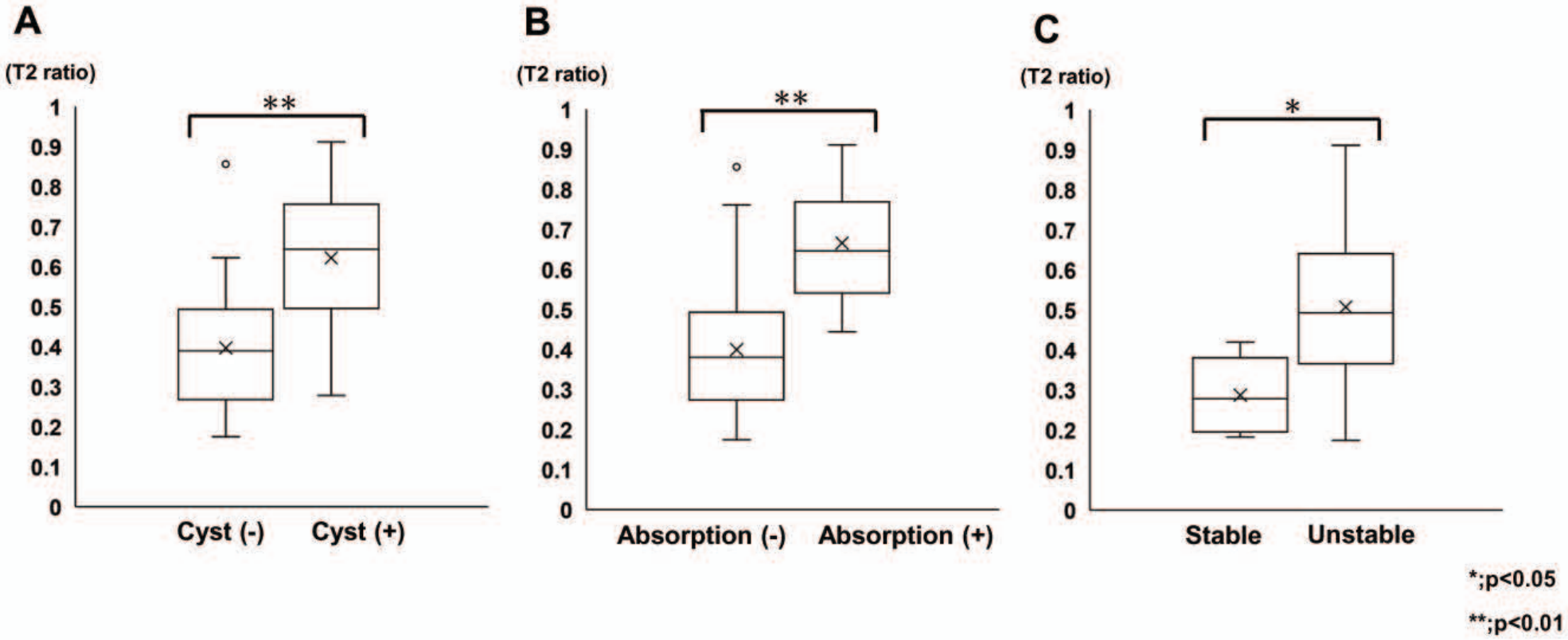
315

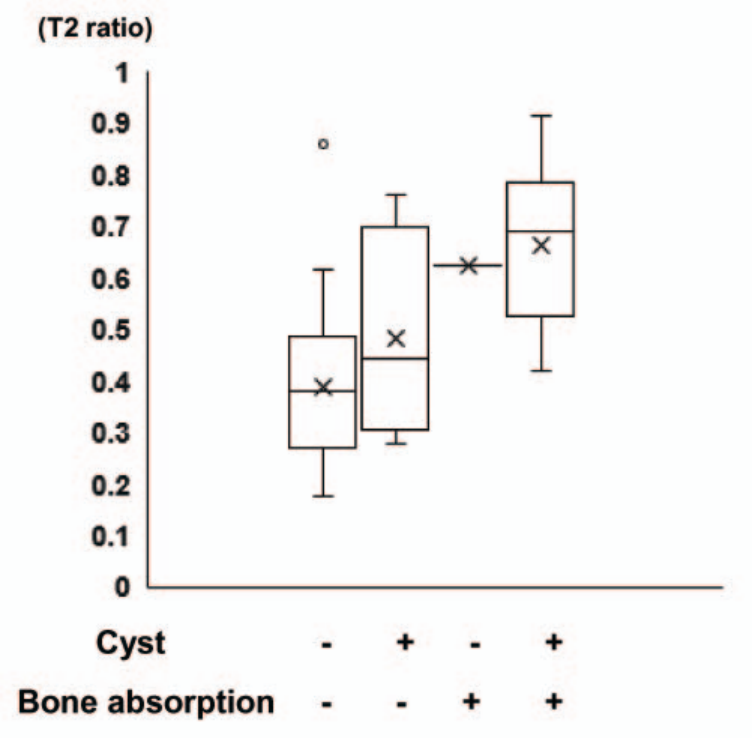


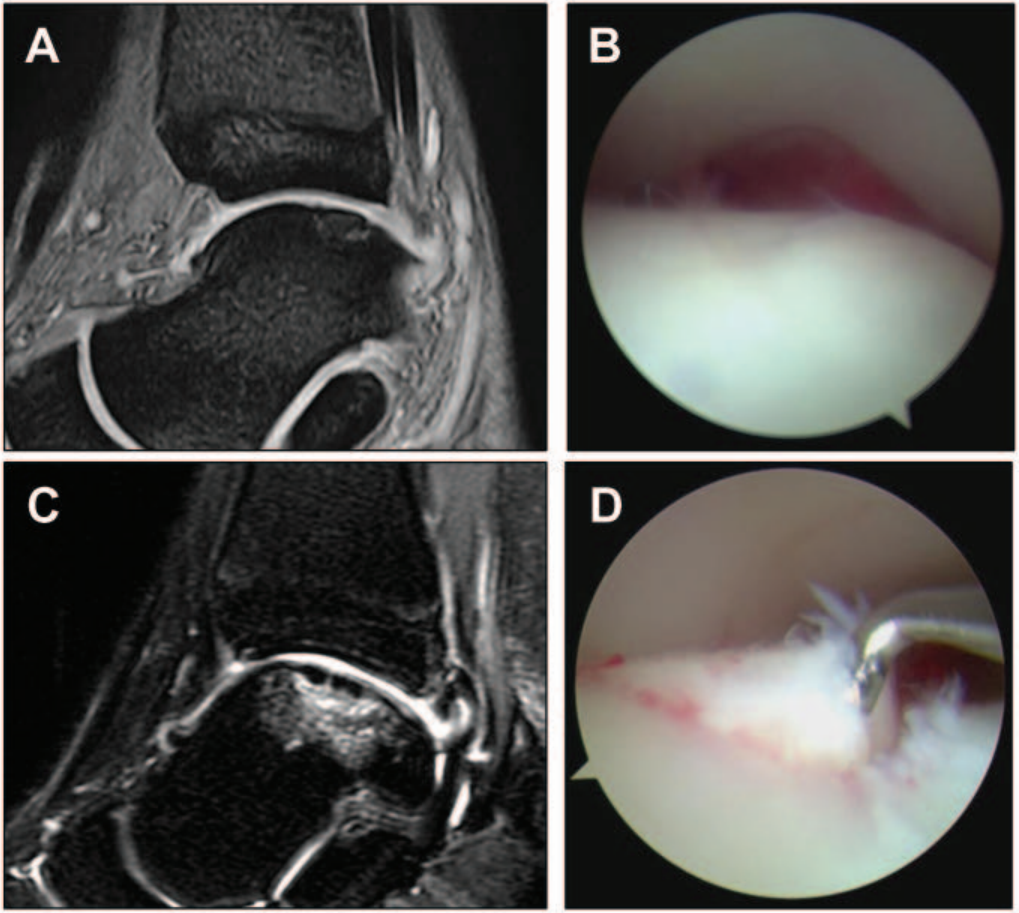

A

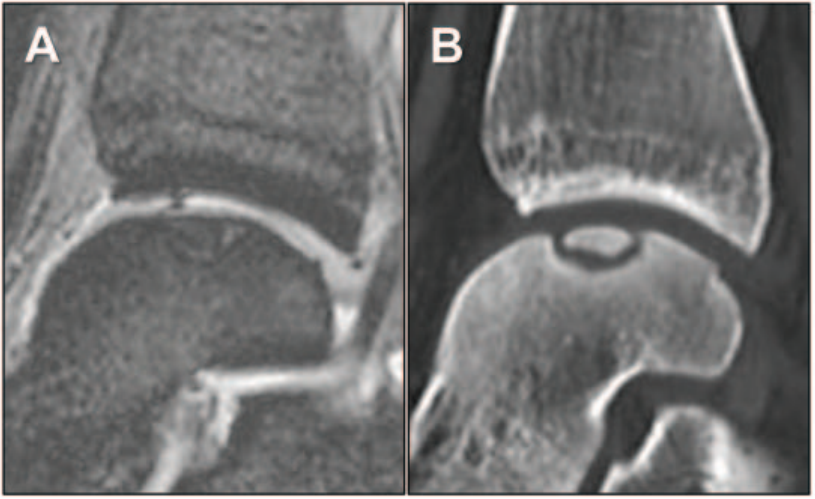

B

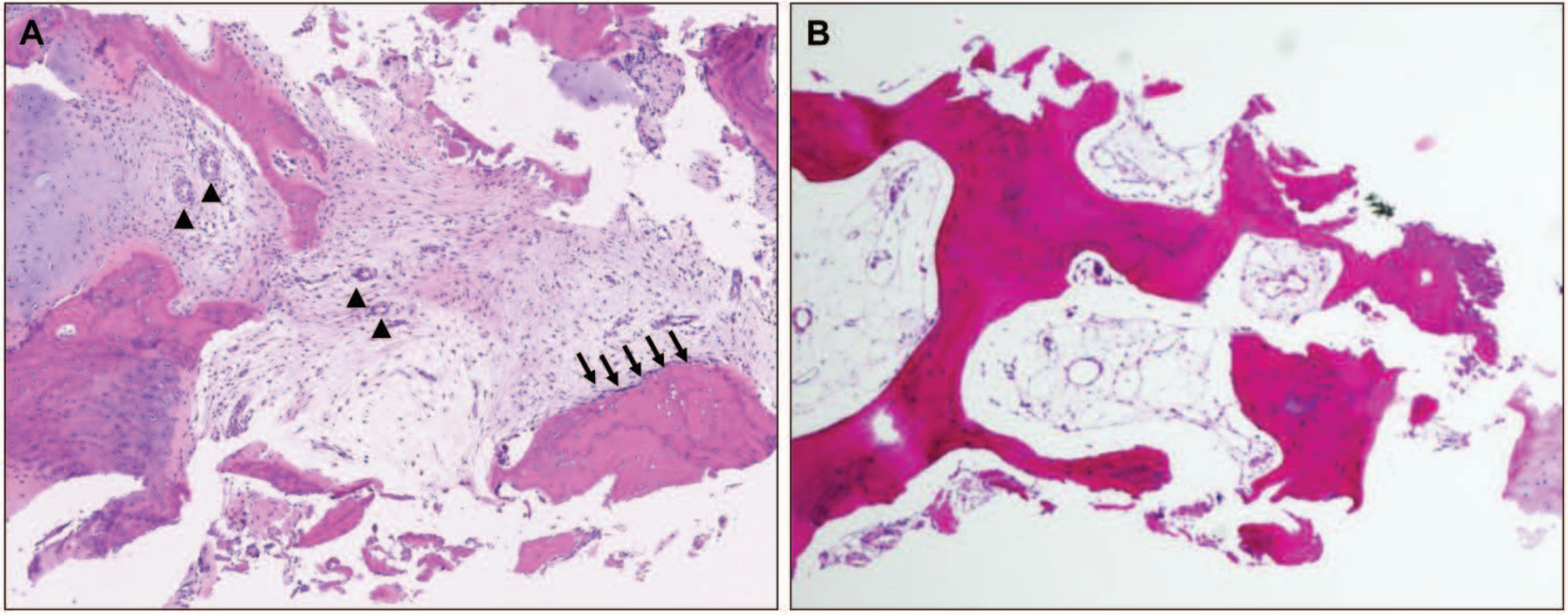

C


A
(T2 ratio)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
**
Cyst (-)
Cyst (+)
B
(T2 ratio)
**
Absorption (-)
Absorption (+)
C
(T2 ratio)
*
Stable
Unstable
*;p<0.05
**;p<0.01


(T2 ratio)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Cyst
- + - +
Bone absorption
- - + +


A
B
C
D


A
B


A
B