

DIFFERENCES IN DIAGNOSTIC POWER OF STIR AND T1W SEQUENCES IN MR FINDINGS OF BONE BRUISE OF THE ACUTELY TRAUMATIZED KNEE

Djordje Jelic¹, Dragan Masulovic², Miroslav Milankov³, Branko Ristic^{4,5}, Vladimir Jakovljevic⁴, Radisa Vojinovic^{4,6}

¹College of Health Sciences, Academy of Applied Studies, Belgrade, Serbia

²University of Belgrade, Medical Faculty, Department of Radiology, Belgrade, Serbia

³University of Novi Sad, Medical Faculty, Novi Sad, Serbia

⁴University of Kragujevac, Faculty of Medical Sciences, Kragujevac, Serbia

⁵University Clinical Center Kragujevac, Clinic for Orthopedics and Traumatology, Kragujevac, Serbia

⁶University Clinical Center Kragujevac, Department of Radiology, Kragujevac, Serbia

RAZLIKE U DIJAGNOSTIČKOJ SNAZI STIR I T1W SEKVENCE KOD MR NALAZA KOŠTANE MODRICE AKUTNO TRAUMATIZOVANOG KOLENA

Dorđe Jelić¹, Dragan Mašulović², Miroslav Milankov³, Branko Ristić^{4,5}, Vladimir Jakovljević⁴, Radiša Vojinović^{4,6}

¹Visoka zdravstvena škola Akademije strukovnih studija, Beograd

²Univerzitet u Beogradu, Medicinski fakultet, Katedra za radiologiju, Beograd

³Univerzitet u Novom Sadu, Medicinski fakultet, Novi Sad

⁴Univerzitet u Kragujevcu, Fakultet medicinskih nauka, Kragujevac

⁵Univerzitetski klinički centar Kragujevac, Klinika za ortopediju i traumatologiju, Kragujevac

⁶Univerzitetski klinički centar Kragujevac, Služba za radiološku dijagnostiku, Kragujevac

ABSTRACT

Objective. Increasing use of magnetic resonance imaging (MRI) in acute knee trauma has led to increased awareness of bone bruises (BB). Post-traumatic BB is the only predictor of early osteoarthritis. The aim of our research is to determine the way in which it is possible to observe and precisely determine the localization, size, and number of BBs, by the correct selection of MR imaging sequences.

Methods. MR examinations of the knees performed during 2012-2013 in 100 subjects with an acute knee injury sustained during sports were retrospectively analyzed from the personal archive. All examinations were done in the first month after the trauma. Examinations were performed on an open-type MRI with a power of 0.3T. A standard protocol was used with sequences of spin echo T1-weighted in the sagittal plane, fat suppression T2-weighted in the sagittal, coronal, and axial planes, and Short Tau Inversion Recovery (STIR) in the coronal plane. The presence and arrangement of BB were analyzed. The difference in the frequency of BB findings in STIR compared to the T1W sequence and the assessment of the visibility of BB in both sequences were analyzed.

Results. BB findings were observed in 51% of subjects. BB is, after effusion, the second, most frequent pathological finding on MR examination in acute knee trauma. A significant statistical difference was determined by the Wilcoxon test ($Z = -5.067$, $p = 0.000$) between the T1W and STIR sequence, which indicates that the STIR sequence is convincingly more sensitive than the T1W sequence for the diagnosis of BB.

Conclusion. It was concluded that STIR sequence provides better visibility of BB compared to T1W sequence.

Key words: knee; sports; magnetic resonance imaging.

SAŽETAK

Cilj. Povećanje upotrebe magnetne rezonance (MR) kod akutne traume kolena dovelo je do podizanja nivoa svesti o koštanim modricama (KM). Posttraumatske KM jedini su prediktor ranog osteoartritisisa. Cilj našeg istraživanja bio je da utvrdimo način na koji je moguće uočiti i precizno utvrditi lokalizaciju, veličinu i broj KM pravilnim izborom sekvenci snimanja na MR.

Metode. Retrospektivno su iz lične arhive analizirani MR pregledi kolena obavljani tokom 2012/2013. godine kod 100 ispitanika sa akutnom povredom kolena, zadobijenom pri sportu. Svi su pregledani u prvih mesec dana nakon traume. Pregledi su obavljani na MR otvorenog tipa snage 0,3T. Korišćen je standardni protokol sa sekvencama spin echo T1-weighted u sagitalnoj ravni, fat suppression T2-weighted u sagitalnoj, koronalnoj i aksijalnoj ravni i Short Tau Inversion Recovery (STIR) u koronalnoj ravni. Analizirani su prisustvo i raspored KM. Analizirana je razlika učestalosti nalaza KM u STIR u odnosu na T1W sekvencu i procena vidljivosti KM u obe sekvence.

Rezultati. Nalaz KM je uočen kod 51% ispitanika. KM je, posle efuzije, drugi po učestalosti patološki nalaz na MR pregledu kod akutne traume kolena. Utvrđena je značajna statistička razlika Vilkoksonovim testom ($Z = -5,067$, $p = 0,000$) između T1W i STIR sekvence, što ukazuje na to da je STIR sekvenca ubedljivo senzitivnija od T1W sekvence za dijagnostiku KM.

Zaključak. Zaključeno je da bolju vidljivost KM daje STIR sekvenca u odnosu na T1W sekvencu.

Ključne reči: koleno, sport, magnetna rezonanca

INTRODUCTION

Magnetic resonance imaging is the only routine examination of the knee that allows non-invasive bone marrow analysis. A bone bruise represents a pathologically altered structure of the bone marrow with findings of microtrabecular fractures, edema, and hemorrhage. Bone marrow edema is seen as the primary MR indicator of bone bruising. On MR examination, it is defined as a zone of low signal in T1W images and medium or high signal intensity in T2W images. In the STIR sequence, bone marrow edema is shown as a zone of flashy hyperintense signal (1). Post-traumatic BBs are the only predictor of the development of early osteoarthritis, injuries to the meniscus or other structures in the knee (2, 3).

The aim of the study is to determine the difference in the degree of sensitivity of STIR compared to T1W sequence in the detection of bone bruises.

PATIENTS AND METHODS

Through a retrospective analysis, MR examinations of the knees performed during 2012-2013 in 100 subjects with acute knee injuries were selected from the personal archive and analyzed. Knee traumas are more common in athletes due to extreme stress, so we analyzed the group of subjects with sports knee trauma. In this way, a group of 100 subjects was selected who underwent an MR examination of the knee with an acute knee injury sustained during sports. All were examined in the first month after the trauma. A standard protocol was used with sequences of spin echo T1-weighted (SE T1W) in the sagittal plane, fat suppression T2-weighted (FS T2W) in the sagittal, coronal, and axial planes and Short Tau Inversion Recovery (STIR) in the coronal plane.

Total of 76 men and 24 women were examined. The age of the patients was from 12 to 46 years, and the average age was 25 ± 5.6 years. Of the total number of patients, 55% were younger than 25 years old, and 77% were younger than 30 years old.

In the MR examination, first of all, the finding of a bone bruise was analyzed, which was represented by an abnormal signal of the bone marrow of the femoral condyles and tibial plateaus, and less often the patella.

Using descriptive statistical methods, the measures of central tendency and the measures of variability, we analyzed the incidence of bone bruises in sports trauma as well as the frequency of localization of bone bruises. The non-parametric Wilcoxon test was used to analyze the difference in the frequency of BB findings in STIR and in relation to T1W sequence, as well as the assessment of visibility in STIR and T1W sequence.

RESULTS

We analyzed bone bruises according to various parameters:

- number of BBs in acute knee trauma;
- size of BB;
- assessment of visibility (resolution and signal intensity) of BB in STIR concerning T1W sequence.

Out of 100 subjects from the sample, one to three bone bruises were identified in 51 (51%) subjects. Out of 51 subjects, 2 BBs were observed in 27 and even 3 BBs in 7 subjects. When analyzing the size of the BB, we measured the width of the base of the BB along the cortex and the depth of the extension of the BB into the subcortical bone. We introduced the size of the spread of BB in the depth below the bone cortex in the direction towards the bone marrow as the main parameter for the analysis of visibility. We observed that during the analysis of BB in the STIR sequence, we have significantly better visibility and better resolution if the intensity of the BB signal is higher, i.e. more hyperintense, and therefore the contrast and resolution concerning the surrounding tissue are more pronounced. Also, the visibility, contrast, and resolution of BB in T1W sequence were better if BB signal intensity was lower. That is why we combined those parameters, which mark better visibility, into one and named it visibility. So, we created our visibility scale based on the resolution and intensity of the signal, where it was rated as 0 - not visible, 1 - very poorly visible, 2 - visible, and 3 - excellent visibility.

In Table 1, we show the depth and visibility of the BB on the lateral condyle of the femur in the STIR sequence. From this table, it can be seen that BB whose intensity is lower has a lower depth, and with the increase in depth, the intensity of the signal measured by the STIR sequence also increases.

We also analyzed the visibility of BB on the lateral femoral condyle in STIR and T1W sequences (Table 2). A total of 38 BBs were found on the lateral condyle of the femur (26 anterior and 12 medial).

Using the same methods of descriptive statistics, we processed data on bone bruises on other bone structures of the knee. The results did not differ from the findings on the lateral femoral condyle.

The size of the BB is shown in mm^2 , and their visibility in T1W and STIR sequences is shown in Figure 1. We presented the size by the area of the BB obtained as the product of the width and depth of the BB.

Using the same statistical methods, we analyzed and compared the findings of the "second" and "third" bone bruises diagnosed using STIR and T1W sequences. When we looked at the test subjects with two and three bone bruises, we got the same picture as in the previous case.

Table 1. Depth and visibility of the BB on the lateral condyle of the femur measured in the STIR sequence.

| Depth BB | STIR signal intensity | | | | | | | | Total | |
|------------|-----------------------|-----|---|-----|---|------|----|------|-------|------|
| | 0 | | 1 | | 2 | | 3 | | | |
| | N | % | N | % | N | % | N | % | N | % |
| To 10 mm | 1 | 2.6 | 2 | 5.3 | 1 | 2.6 | - | - | 4 | 10.5 |
| To 20 mm | - | - | - | - | 7 | 18.4 | 12 | 31.6 | 19 | 50.0 |
| Over 20 mm | - | - | - | - | 1 | 2.6 | 14 | 36.8 | 15 | 39.5 |

Table 2. Visibility of BB assessed in T1W and STIR sequences on the lateral femoral condyle.

| Variable | | STIR | | | |
|----------|---|------|---|---|----|
| | | 0 | 1 | 2 | 3 |
| T1W | 0 | - | 2 | 3 | - |
| | 1 | - | - | 1 | - |
| | 2 | 1 | - | 5 | 18 |
| | 3 | - | - | - | 8 |

Both in patients with the second and third BB, a statistically significant difference was determined by the Wilcoxon test, for the second ($Z=-3.810, p=0.000$), for the third BB ($Z=-2.333, p=0.020$) between T1W and STIR sequences. The STIR sequence provides better visibility of the bone bruise.

In the analysis of the depth of the BB extending into the trabecular subcortical bone, we made the following division into three groups: depths up to 10 mm, up to 20 mm and over 20 mm (Table 3). It can be seen that a total of 15.7% of BBs were up to 10 mm in size, and that 5 out of 8 BBs up to 10 mm in size (9.8% of the total number of BBs) are not shown in the T1W sequence, or have very poor visibility. From this group, no BB has a visibility of 3 in the T1W sequence. A total of 51% of BBs were up to 20 mm in size, and 7 out of 26 BBs (13.8% of the total number of BBs) are not displayed or have very poor visibility in the T1W sequence. Only 2 BBs from this largest group have visibility grade 3 in the T1W sequence, but 17 of them have good visibility. BBs larger than 20 mm make up 33.3% of the total number of BBs, and only 1 out of 17 BBs has very poor visibility (2% of the total number of BBs), while the other 16 have good or excellent visibility in the T1W sequence. A total of 19.6% of BBs are not seen in T1W sequence, and 6% of them are seen very poorly in T1W sequence.

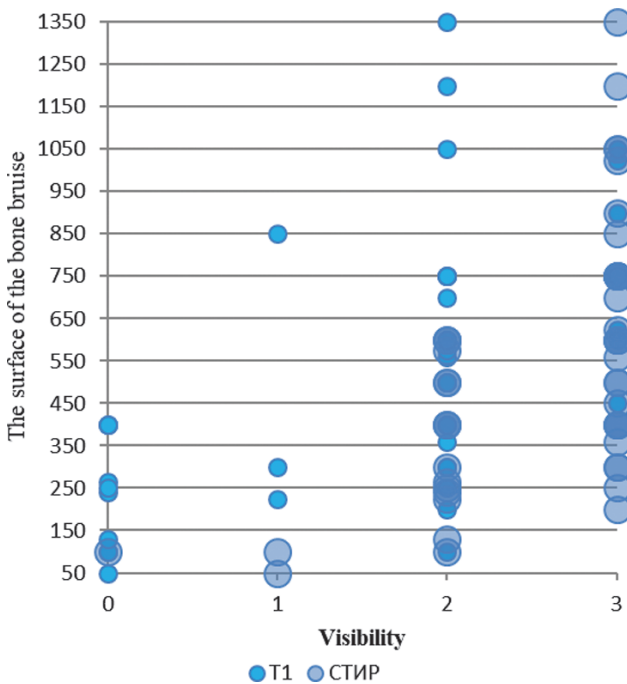


Figure 1: The size of the "first" bruise (by size) in mm² and its visibility in T1 and STIR sequences.

DISCUSSION

Conventional radiographic techniques are limited in showing the bone marrow. Thus, the analysis of bone marrow characteristics, especially BB, is based on MR examinations. The normal bone marrow signal on MR is the same as the subcutaneous fat signal, so it is shown as

Table 3. BB visibility in T1W sequence in three groups, up to 10 mm, up to 20 mm and larger than 20 mm.

| Depth BB | T1W visibility | | | | | | | | Total | |
|------------|----------------|------|---|-----|----|------|---|------|-------|------|
| | 0 | | 1 | | 2 | | 3 | | | |
| | N | % | N | % | N | % | N | % | N | % |
| to 10 mm | 4 | 7.8 | 1 | 2.0 | 3 | 5.9 | - | - | 8 | 15.7 |
| to 20 mm | 6 | 11.8 | 1 | 2.0 | 17 | 33.3 | 2 | 3.9 | 26 | 51.0 |
| over 20 mm | - | - | 1 | 2.0 | 10 | 19.6 | 6 | 11.8 | 17 | 33.3 |

high signal intensity on T1W sequence, and medium on T2W sequence. On MR examination, a bone bruise is represented by a focal abnormal bone marrow signal of the femoral condyles or tibial plateaus. It is observed as a decrease in signal intensity in T1W and an increase in signal intensity in T2W sequence. The intensity of the BB signal is higher in the T2W sequence with fat suppression, but it is markedly higher in the inversion sequence, such as STIR, in which there is suppression of the fat signal (4, 5).

Therefore, in the STIR sequence, the intensity of the BB signal is almost brilliantly hyperintense due to the suppression of the fat signal intensity and the enhancement of the water signal intensity, which is found in the edema structure of the post-traumatic microtrabecular fracture-bone bruise. Although the STIR sequence is superior in showing findings of bone marrow edema, one should not neglect the analysis of the T1W sequence, which is superior for showing occult fractures, when analyzing BB. They are shown in the T1W sequence as fracture lines, lesions, of low signal intensity, and on radiographs they are difficult or not visible at all (4-10). To our knowledge, our current study is the first to examine differences in the diagnostic power of STIR and T1W sequences in diagnosing BB. In this way, we tried to increase the degree of reliability of MR findings in the detection of BB. Of all the BBs observed during our examinations on the lateral femoral condyle (38 in total), about 2/3 can be said to have better visibility on the STIR sequence compared to T1W, about 1/3 have the same intensity on both sequences, and only one BB has better visibility on T1W sequence.

We also proved that the visibility of BB on the STIR sequence depends on the depth of the bruise. Namely, the increase in the depth of the BB also increases the intensity of the signal measured in the STIR sequence, and vice versa, BB with a smaller depth have a weaker signal intensity. We determined that 39.5% of BB on the lateral condyle of the femur extended to a depth greater than 20 mm, and a total of 89.5% of BB extended to a depth of more than 10 mm.

Differences in the incidence of bone bruise findings can also be based on the difference in the sensitivity of the selected sequences during the examination of the traumatized knee. In earlier years, the technique of MR examination of the knee was predominantly performed in the T1W sequence (11). In some later studies, the T1W sequence was also the sequence of choice for BB analysis, so the incidence of BB was lower than when analyzed in FS T2W or STIR sequence (8). In the study from 2006, among 664 patients with knee trauma, BB was found in 124 patients, which is 18.7%. We see the reason for the lower percentage of BBs in the fact that BBs were not analyzed in the STIR sequence.

There is not a large number of studies that analyzed the size of the BB in acute knee injury (4, 6, 7, 10). In our study, the difference in the visibility of BB in T1W and STIR sequences exists, so that smaller BBs are less visible or not visible at all in T1W sequence, in contrast to STIR sequence, where this situation does not exist. We, therefore, assume that the reason for the difference in the degree of visibility, which we observed with the Wilcoxon test, can be attributed primarily to small BBs, which are not at all or poorly visible in T1W.

There are very different results regarding the incidence of BB (20% Lynch et al, 27% Terzidis et al, 60% Atkinson et al, 69% Bordoni et al) (12-15). In our previous work, 32.5% of patients with acute knee trauma also had BB of the knee (16). The difference according to the current study (32.5% vs 51% BBs) can be explained by the structure of the subjects in the two studies. The current study is about younger or relatively younger athletes, for whom it is the first injury, in contrast to the previous study, where the consequences of old injuries were also included. In the current study, out of the total number of 85 BBs observed by STIR sequence, 25 of them (29.4%) were not observed on images in T1W sequence. Such a finding convincingly confirms the view that the best differentiation of BB is in the STIR sequence, in which the signal of normal fatty bone marrow is significantly suppressed, and the BB itself is a flash of increased signal intensity.

In conclusion, in our study, the STIR sequence showed a statistically significant difference in the degree of visibility of bone bruises and is superior in identifying BB compared to the T1W sequence.

ABBREVIATIONS

STIR – *Short Tau Inversion Recovery*

T1W – *T1-weighted*

MRI – magnetic resonance imaging

BB – bone bruise

T – Tesla

SE T1W – *spin echo T1-weighted*

FS T2W – *fat suppression T2-weighted*

REFERENCES

1. Ryu KN, Jin W, Ko YT, et al. Bone bruises: MR characteristics and histological correlation in the young pig. *Clin Imaging* 2000; 24: 371-80.
2. Ward P, Chang P, Radtke L, Brophy RH. Clinical implications of bone bruise patterns accompanying anterior cruciate ligament tears. *Sports Health* 2022; 14: 585-91.

3. Filardo G, Andriolo L, di Laura Frattura G, Napoli F, Zaffagnini S, Candrian C. Bone bruise in anterior cruciate ligament rupture entails a more severe joint damage affecting joint degenerative progression. *Knee Surg Sports Traumatol Arthrosc* 2019; 27: 44-59.
4. Driban JB, Lohmander S, Frobell RB. Posttraumatic bone marrow lesion volume and knee pain within 4 weeks after anterior cruciate ligament injury. *J Athl Train* 2017; 52: 575-80.
5. Arndt 3rd WF, Truax AL, Barnett FM, Simmons GE, Brown DC. MR diagnosis of bone contusions of the knee: comparison of coronal T2-weighted fast spin-echo with fat saturation and fast spin-echo STIR images with conventional STIR images. *AJR Am J Roentgenol* 1996; 166: 119-24.
6. Moran J, Katz LD, Schneble CA, et al. A novel MRI mapping technique for evaluating bone bruising patterns associated with noncontact ACL ruptures. *Orthop J Sports Med* 2022; 10: 23259671221088936.
7. Allen GM. Dark T1 bone marrow. *Semin Musculoskelet Radiol* 2011; 15: 247-56.
8. Vincken PW, Ter Braak BP, van Erkel AR, Coerkamp EG, Mallens WM, Bloem JL. Clinical consequences of bone bruise around the knee. *Eur Radiol* 2006; 16: 97-107.
9. Marot V, Corin B, Reina N, Murgier J, Berard E, Cavaignac E. Femoral and tibial bone bruise volume is not correlated with ALL injury or rotational instability in patients with ACL-deficient knee. *Knee Surg Sports Traumatol Arthrosc* 2021; 29: 900-6.
10. Flury A, Hodel S, Andronic O, et al. Extent of posterolateral tibial plateau impaction fracture correlates with anterolateral complex injury and has an impact on functional outcome after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2023; 31: 2266-73.
11. Mirowitz SA, Apicella P, Reinus WR, Hammerman AM. MR imaging of bone marrow lesions: relative conspicuousness on T1-weighted, fat-suppressed T2-weighted, and STIR images. *AJR Am J Roentgenol* 1994; 162: 215-21.
12. Lynch TC, Crues 3rd JV, Morgan FW, Sheehan WE, Harter LP, Ryu R. Bone abnormalities of the knee: prevalence and significance at MR imaging. *Radiology* 1989; 171: 761-6.
13. Terzidis IP, Christodoulou AG, Ploumis AL, Metsovitis SR, Koimtzis M, Givissis P. The appearance of kissing contusion in the acutely injured knee in the athletes. *Br J Sports Med* 2004; 38: 592-6.
14. Atkinson PJ, Cooper TG, Anseth S, Walter NE, Kargus R, Haut RC. Association of knee bone bruise frequency with time postinjury and type of soft tissue injury. *Orthopedics* 2008; 31: 440.
15. Bordoni V, di Laura Frattura G, Previtali D, et al. Bone bruise and anterior cruciate ligament tears: presence, distribution pattern, and associated lesions in the pediatric population. *Am J Sports Med* 2019; 47: 3181-6.
16. Jelić D, Masulović D. Bone bruise of the knee associated with the lesions of anterior cruciate ligament and menisci on magnetic resonance imaging. *Vojnosanit Pregl* 2011; 68: 762-6.