Radiography Open

ISSN: 2387-3345 Volum 3, No 1 (2017) http://dx.doi.org/10.7577/radopen.1998

MR imaging of scaphoid fractures. Fat-saturated T2-weighted and Short tau inversion recovery images.

Meincke, Louise[1]; Dimitar, Ivanov Radev[2]; Eriksen Rie Ø.[3]; Lauridsen,Carsten Ammitzbøl[1]

[1] Metropolian University College. Faculty of Health and Technology, Copenhagen, Denmark
[2] Gentofte Hospital. Department of Diagnostic Radiology, Kildegårdsvej 28, 2900 Hellerup, Denmark
[3] Copenhagen University Hospital Rikshospitalet. Department of Diagnostic Radiology, Blegdamsvej 9, Denmark

Corresponding Author: Louise Meincke.
E-mail: louisemeincke@gmail.com

Key words: bone bruise, fat saturation, image quality, magnetic resonance imaging, scaphoid, short tau inversion recovery,

PEER REVIEWED ARTICLE

ABSTRACT

Objective: Traumatic injuries of os scaphoideum are serious, and might lead to two main grades of consequences (*i.e.* osteoarthrosis or avascular necrosis), if a fracture remains undiagnosed. Bone bruise may be the only pathological sign of pain which can last for week or month. Articles describe the importance of early MRI and hereby predict bone bruise with the help of fat suppression sequence; however, only a limited selection articles compares various fat suppression techniques. The purpose of this prospective study was to compare the short tau inversion recovery (STIR) and T2 fat saturation (FAT SAT) sequences, sectional directed along the scaphoid bone axis. In relation to background fat intensity suppression, this study sought the sequence that best evaluated posttraumatic bone marrow edema (bone bruise) on scaphoid injury musculoskeletal magnetic resonance imaging (MRI, 1.5 T extremity scanner).

Materials and methods: Two hundred and fifty-one patients with relevant trauma and positive clinical test for scaphoid bone fractures, exceeding no more than 14 days, underwent MRI examinations. A fast STIR and T2 FAT SAT fast spin echo sequence (FSE) were obtained using a comparable parameter setting (scan time ca. 3 minutes). Three experienced readers (one radiographer and two radiologists) carried out the evaluation blinded to each other’s, based on a quantitative assessment of size (area) and image quality (image contrast, IC and contrast-to-noise ratio, CNR). The study period lasted March 2014-April 2015. Sixty patients met the inclusion criteria and were enrolled. This prospective study was ethically approved by the institutional review board.

Results: There were no significant difference between the bone bruise areas (P=0.45, P=0.44 and P=0.83) or CNR (P=0.31, P=0.38 and P=0.17). However, image contrast showed significant difference in favour of T2 FAT SAT in all three readers' reports ($P<0.05$, $P<0.05$ and $P<0.05$).

Conclusions: The two sequences appear almost identical. An interchangeable usage of the two sequences was found being acceptable for the diagnosis if the protocol is composed appropriately (1.5T). However, the T2 FAT SAT provided a higher image contrast by specific settings (e.g. short TI = 125 ms) compared to STIR.

Introduction

Fat suppression, an essential technique in MR imaging is used to improve depiction of bone marrow edema, determining the lipid content by suppressing the bright fat signal on T2 weighted fast spin echo images, thus improving the contrast resolution for resolving the bright fluid signal of bone marrow edema,[1-4] hereby bone marrow edema appears as a hyper intense area on proton density and T2 weighted sequences.

Bone bruise is a term for a bone marrow edema, caused by a traumatic injury (micro-trabecular fractures) sustained from a forceful impact during sports, accidents or a direct hit. Bone bruise is characterized by severe pain that can last for weeks or months. The best way to help healing is to rest, support, and protect the bone or joint involved, and to apply conventional treatments for trauma.[1-3, 5-14]

Identifying and locating the bone bruise are important for many reasons, knowing that a bone bruise on a T2 fat saturated image in conjunction with a fracture line on a T1 weighted image will set the diagnose for a fracture (however, a fat saturated sequence cannot stand alone for the diagnosis of a fracture).[3,6] Pseudoarthrosis, osteoarthrosis, avascular necrosis and chronic wrist pain, are potential consequences of undiagnosed fractures.[2-6,8] Therefore, a standardized method for diagnostic and treatment purposes is important. Visualization of bone bruise is not only indispensable for identifying a fracture, it may also be the only pathological finding that explains a patient's symptoms. Also, the location and radiation pattern may indicate the point from which the trauma arises.[1-3,5-14]

MRI offers a variety of sequences that are appropriate for examining a bone bruise,[4] STIR, FAT SAT, Hybrid and Dixon are some of the most commonly used fat suppression techniques. The use of high-field-strength MRI in musculoskeletal imaging has become increasingly more common, resulting in higher Signal-to-Noise Ratio (SNR) and wider chemical shifts between fat and water signals. According to theory, the benefits related to a high field-strength scanner (>1.5T, and 3 Tesla in particular); T2 FAT SAT has improved SNR, but increased susceptibility to local field inhomogeneity, limit its value around metallic implants or when imaging is off-center. Hence, this could be an interesting alternative to the recognized STIR sequence.[4,15]

After widespread use of MRI, it is now recognized that the diagnosis of the skeleton is rather more complex than just the presence of fracture. Articles states the importance of an early MRI and hereby predict bone bruise with help from a fat suppression sequence.[1-3,5,7-11,14] To ensure the best composition for diagnosis, medical professionals should be aware of the advantages and clinical considerations of the various sequences. However, only a limited selection of published articles that compare the various fat suppression techniques, were found.[4,16] The purpose of this prospective study was (by specific physical settings) to compare the fast STIR and T2 FAT SAT fast spin echo sequences in the sectional direction along the scaphoid mid-plane axis. STIR and T2 FAT SAT were compared in terms of the diagnostic quality of the area of the bone bruise; image contrast (C) and the contrast-to-noise ratio (CNR), to find which sequence is the best for the evaluation of bone bruise on MRI (1.5 T) of the scaphoid bone.

Materials and methods

Literature search

An initial systematic search in PubMed (October 2014) inspired by the patient/ intervention/ comparison/ outcome (PICO) method [17-19] was undertaken. The initial search included the terms "magnetic resonance imaging" and "bone bruise". After applying four filters "English", "humans", "5 years" and "full text", 81 hits were returned. Articles that did not clearly state sequence used (22 articles) were excluded, revealing 55 articles that met the criterion. The search revealed that most articles described the standard method for such examinations as musculoskeletal MRI fat suppression, comprising short tau inversion recovery (STIR) or T2 Fat saturation (FAT SAT) (also known as chemical shift selective) sequence. However, no unified guideline was found.

Patient inclusion criteria

A total of 251 patients with relevant trauma exceeding no more than 14 days, during time period March 28th 2014- April 13th 2015, having positive clinical tests for scaphoid bone fractures and negative x-rays, underwent MRI examinations. Sixty patients met the criteria, and participated in the study. Age was 21y, average. Genders counted for 45 males and 15 females. Patients were included as bone bruise was diagnosed by the radiologist

Exclusion criteria

Images showing fracture lines were not of interest for this project. Patients with no identified bone bruise of the scaphoid, despite the clinical suspicion were excluded. Patients younger than 10 years old were excluded, since the scaphoid bone in this age group has not yet fully ossified. In addition, patients with degenerative disease of the wrist were excluded (by a radiologist) to avoid any uncertainties.

Patients whose MRI scans showed inadequate diagnostic quality were also excluded *e.g.* overriding artifacts in the region of interest or clearly stated movement artifacts on either the STIR or T2 FAT SAT sequences. Also, the absence of either the STIR or T2 FAT SAT sequence would exclude the patient. Any changing parameters or the placement of the slices, resulted in exclusion of the patient.

Ethics

The incorporation of this study in normal clinical working environment/procedure led to a consecutive, randomly chosen group of patients. This study did not affect or lead to any consequences for the patients; in addition, sensitive data were anonymized before registered in the study. This study was approved by an Institutional Review Board; The Danish Research Ethics Committee System (Videnskabsetisk Komité, DK) and The Danish Data Protection Agency (Datatilsynet, DK) in accordance with the Declaration of Helsinki.

Imaging Technique

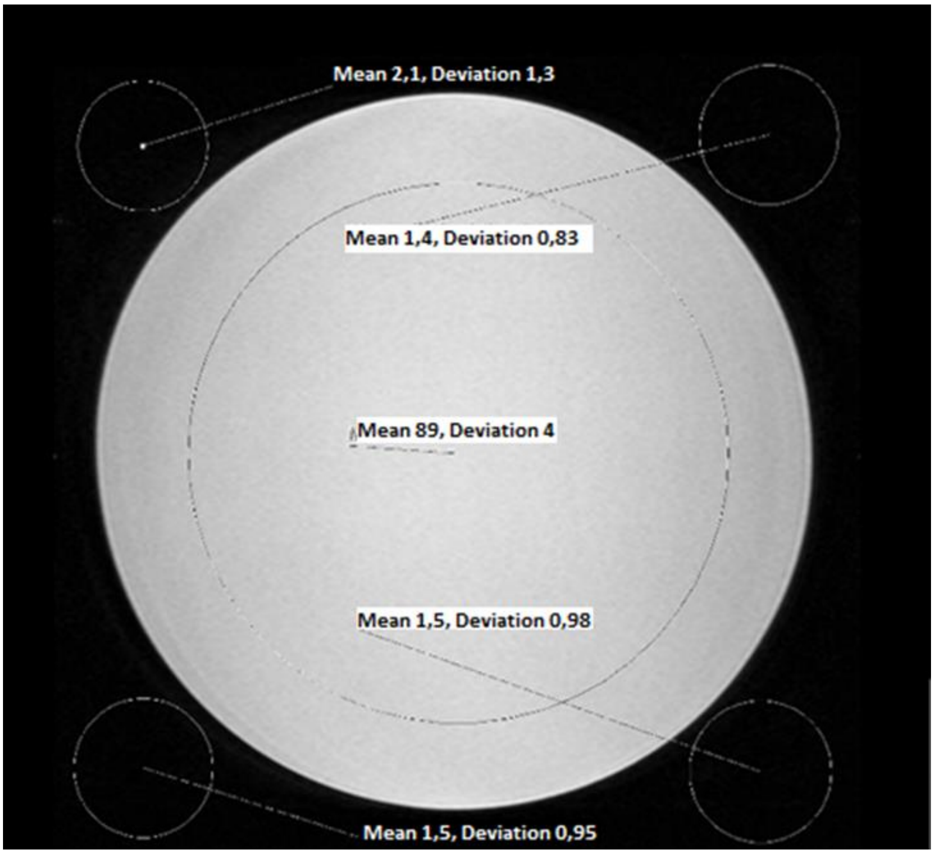
Patients with a positive sign for bone bruise on a sagittal T2 FAT SAT scan and on a coronal STIR scan underwent an additional sagittal STIR scan in the sagittal sectional direction through the mid plane axis of the scaphoid bone (coronal plane). The additional sagittal fast STIR scan was then compared with the sagittal T2 FAT SAT fast spin echo (FSE) scan. A positive finding on the sagittal STIR scan was not necessarily required.

The MRI scans were all performed on the same 1.5 T extremity scanner (GE Healthcare Systems, ©Optima MR430s, 4.02 software release, Milwaukee, WI, USA). The extremity MRI allowed central placement of the hand relative to the magnetic field.

The use of a 123mm quadrature coil on all patients ensured an improved image quality as compared with that obtained with off-centered scan.[20,21] The patient's hand was placed in the anterior-posterior position. Scans along the scaphoid midplane axis were obtained using the following parameters: Fast STIR: Slices 11, slice thickness 2.0 mm, Gap 0.5 mm, NEX 4, field of view 100x100 mm, receiver band width 25, TR 2000 ms, TE 35 ms, TI 125 ms, frequency 192, phase 192, and echo train 8. SNR were 25.11 at scan-time 3 min 12 sec.

T2 FAT SAT fast spin echo: Slices 11, slice thickness 2.0 mm, Gap 0.5 mm, NEX 4, field of view 100x100 mm, receiver band width 25, TR 3100 ms, TE 100 ms, frequency 320, phase 224, and echo train 14. SNR were 59.62 at scan-time 3 min 22 sec.

The two sequences were set to obtain the best and most comparable image quality based on a Signal-to-Noise Ratio estimated phantom, single acquisition technique (Figure 1); Raylength 0.66 x average signal/ average (SD) air within a scan time of a maximum of 5 minutes per sequence. This scan time is acceptable for clinical use, which explains some of the nonequivalence in the parameter settings.



Figur 1. The Signal Noise Resolution phantom, for single acquisition technique. The SNR was calculated with the following equation: SNR = 0.66 (Rayleigh) x average signal (ROI min. 70%) / average SD air. The ROI of the average signal must be at least 70 percent of the field of view.

The MRI scans were performed by experienced MRI technologist (minimum 5 years of MRI experience). Their main assignment was to ensure uniform and consistent execution of the protocol within the specified limitations. Changing the parameters or the placement of the slices resulted in exclusion of the patient.

Image Evaluation

One radiographer (L.M. with 3 years of experience in MRI scans and image interpretation) and two experienced MR radiologists (D.I.R. and H.E.C., with 10 and 8 years of experience in musculoskeletal MRI, respectively), continuously assessed the image material throughout the empirical data collection period. The evaluation was based on the size and image quality, comprising an assessment of the area of edema, image contrast (C) and the CNR. All images were interpreted on identical picture archiving and communications system monitors to ensure an equal, ideal generating of the images.

The three readers performed all the measurements on the same slices independently while blinded to each other's results and type of sequence (STIR or T2 FAT SAT). The initial selection of the representative index slice was performed by a radiologist and based on the following criteria: The biggest area of bone bruise, few or no artifacts, and a scaphoid bone with bone bruise and an area with "normal" signals (without pathological changes) from the bone marrow. After these criteria were applied to the STIR and T2 FAT SAT, the same slice on both sequences was chosen (not necessarily the same index slice number on every patient).

Method 1 - Area: The suspected area of bone bruise was measured quantitatively as illustrated in figure 2. The measurement was performed per reader, three times free-hand drawing the contours on the bruised area of scaphoideum; on each slice for both T2 FAT SAT and STIR sequences, and after which the average area was calculated (mm^2). If zoom was required, it was equally used on both the STIR and the FAT SAT slice.

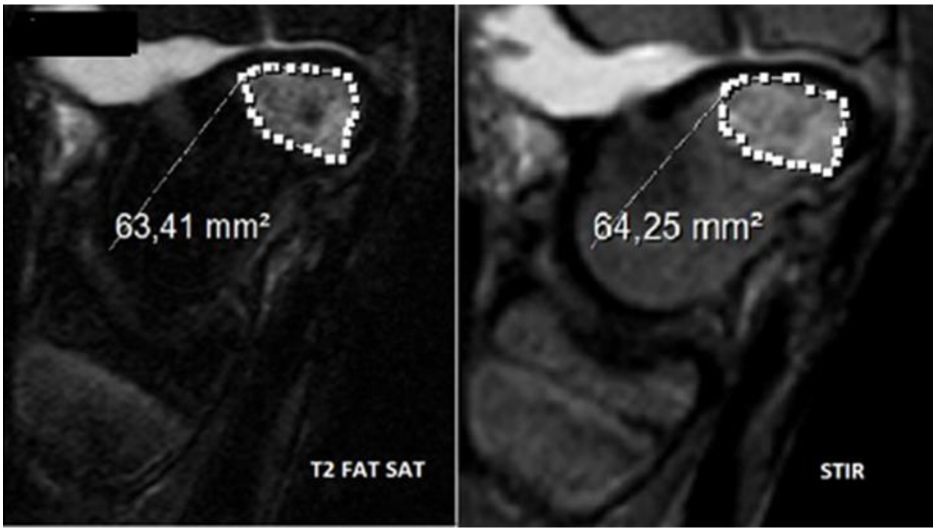


Figure 2. MRI scan of a 25y male's scaphoideum, respectively at T2 FAT SAT (left) and STIR sequences (right), showing the sagittal sectional direction through the axis of the scaphoid bone. Quantitative measurement of the bone bruises (area). The counters are made by a free-hand drawing tool used to limit the region of interest on both scans. The measurements were performed on equal slices, three times on each slice per reader.
The area on T2 FAT SAT is 63,41 mm^2. (left) and 64,25 mm^2 on the STIR (right). The areas seems almost equal but it would be difficult to interpret if the small difference is due to the measurement uncertainty (+/- 1m.m.) or an actually difference in the two sequence.

Method 2 – Measures on pixel values; Image contrast (C), and ***Method 3 – Measures on pixel values; contrast-to-noise ratio (CNR)***: The signal intensity (SI) of the bone bruise and the non-affected bone was quantitatively measured by placing a region of interest (ROI) in both types of tissues.

In addition, the SI and the standard deviation (SD) of the air outside the image anatomy were measured without the inclusion of any artifacts, as illustrated in figure 3.

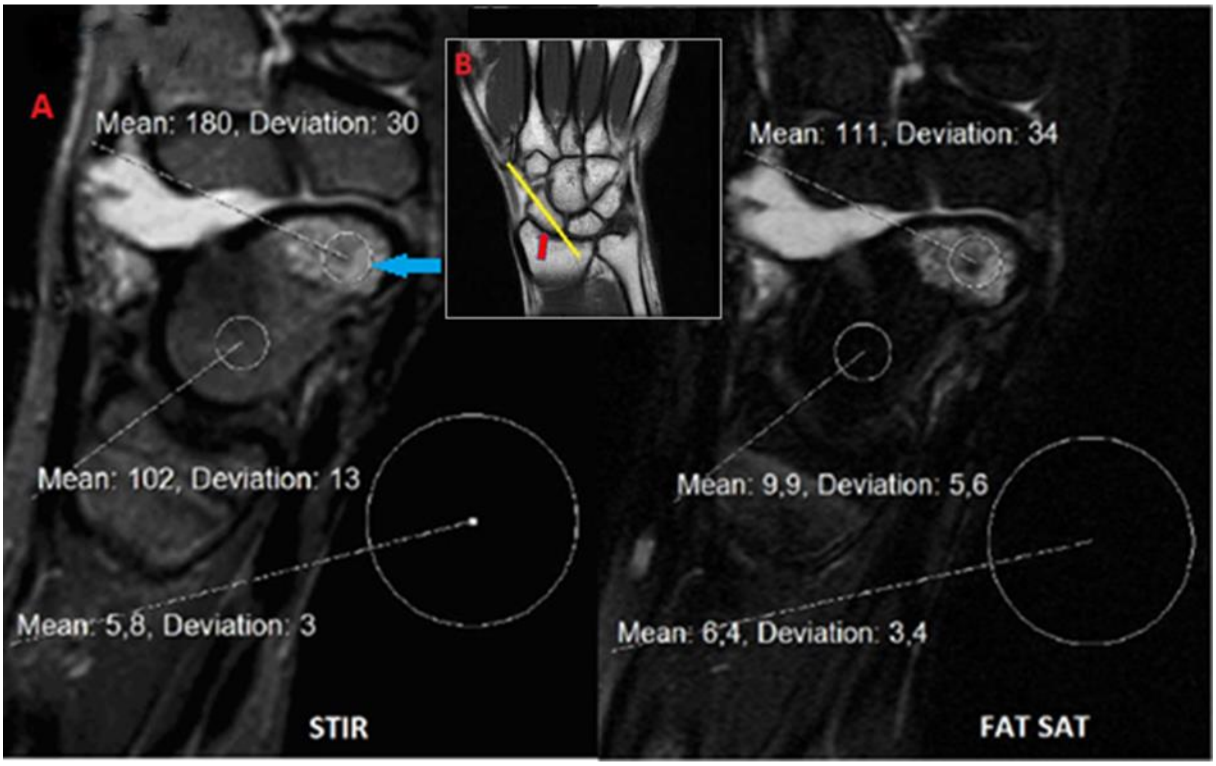


Figure 3. MRI scaphoideum examination of a 19y female, illustrated with both STIR and FAT SAT scan. The sagital scan (A) and the coronal scan (B) goes through the axis of the scaphoid bone. The bone bruise region on the STIR sequence are pointed with a blue arrow (sagittal sectional, situation A) and a red arrow (coronal section, situation B) whereas the yellow line indicates the placement of the slice, in the scaphoid mid-plane axis (situation B).
Region of interest measurements of mean signal intensities value of bone bruise (sa) on the STIR sequence is 180 with a Standard Deviation (SD) of 30 compared to SD 3 in air, compared to mean signal intensities of normal bone (sb) 102 (SD 13).

All three readers set the placement independently and the size and placement of the ROI´s as equal as possible on the two slices. The image contrast and the CNR were calculated with the following equations [21]:

$$\text{Image Contrast} = (Sa-Sb) / (Sa+Sb)$$

$$\text{CNR} = (Sa-Sb) / \text{SD air}$$

The *Sa* represents the mean signal intensities of each ROI in bone bruise. *Sb* represents the mean signal intensities of each ROI in normal bone, and *SD air* represents the *standard deviation* of background noise.

Statistical analysis

The three methods resulted in numerical and categorical data. All analyses were performed using STATA version 13 software (StataCorp LP, College. TX, USA). Student´s T-test was used to compare the data derived from the STIR and FAT SAT images. A value of $P<0.05$ were considered statistically significant.

The intra- and inter-observer correlation was analyzed with the use of *Intra-class correlation coefficient* (ICC), with a value of 1 determining a perfect agreement and a value of 0 determining no agreement between the three readers. It is defined as the ratio of the between-subject variance divided by the sum of the between subject and the within subject variance (total variance). Reproducibility was measured in accordance with the Rosner values.[22]

Results

No patients were assessed to have a visible bone bruise on only one of the two sequences.

There was no significant difference between bone bruise area (respectively p-values as P=0.45, P=0.44 and P=0.83) and the CNR (P=0.31, P=0.38 and P=0.17) on STIR and T2 FAT SAT in the areas drawn by the image readers (Figure 4). However, there was a statistically significant difference in image contrast between STIR and T2 FAT SAT in all three readers' reports (P<0.05, P<0.05 and P<0.05) (Figure 5). The Intra-class correlation coefficient indicated agreement departed for two (≥0.4) out of three levels:

- Excellent reproducibility ≥ 0,75
- Fair-to-good reproducibility 0.75-0.4
- Poor reproductibility 0.4-0

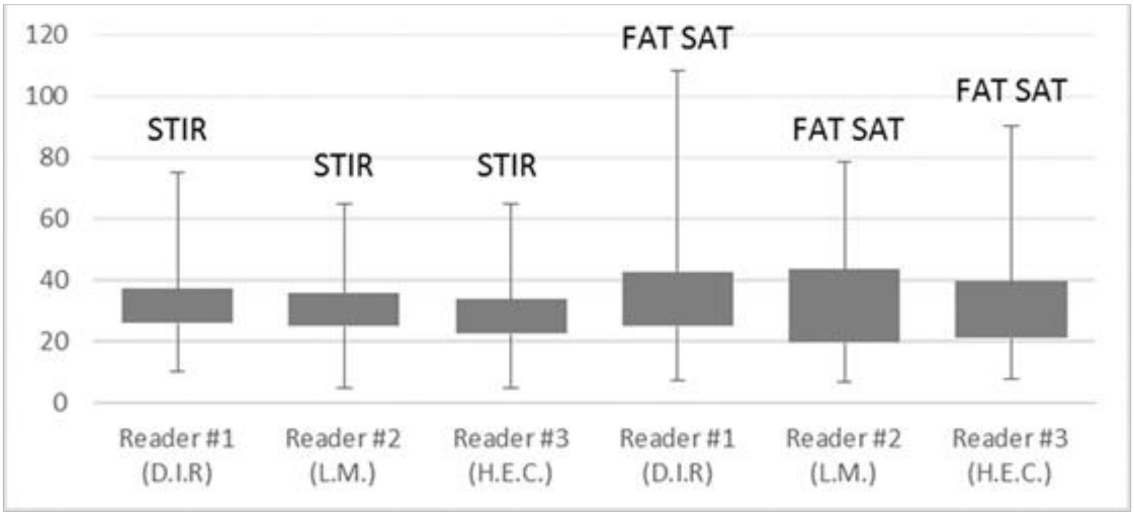


Figure 4. Contrast to noise ratio (CNR). The box-plot shows the CNRs (CNR = y-axis) for respectively the short tau inversion recovery (STIR) and fat suppression (FAT SAT) sequences conducted by all three readers. The measurements for reader 1, 2 and 3 lies respectively between 10.37-75.48, 4.83-65 and 4.81-65.16 on the STIR scan and between 7.5-108.85, 7.19-78.62 and 8.13-90.34 on the FAT SAT scan. The boxes indicate that half of the measurements lies between 26.21-37.38, 25.2-36,37 and 22.8-34.04 on the STIR scan and between 25.13-43.08, 19.84-43,83 and 21.34-39.84 on the FAT SAT scan.
The CNR is close to equal for both the STIR and the FAT SAT sequences, suggesting that interchangeably usage of the two sequences at 1.5-T is acceptable.

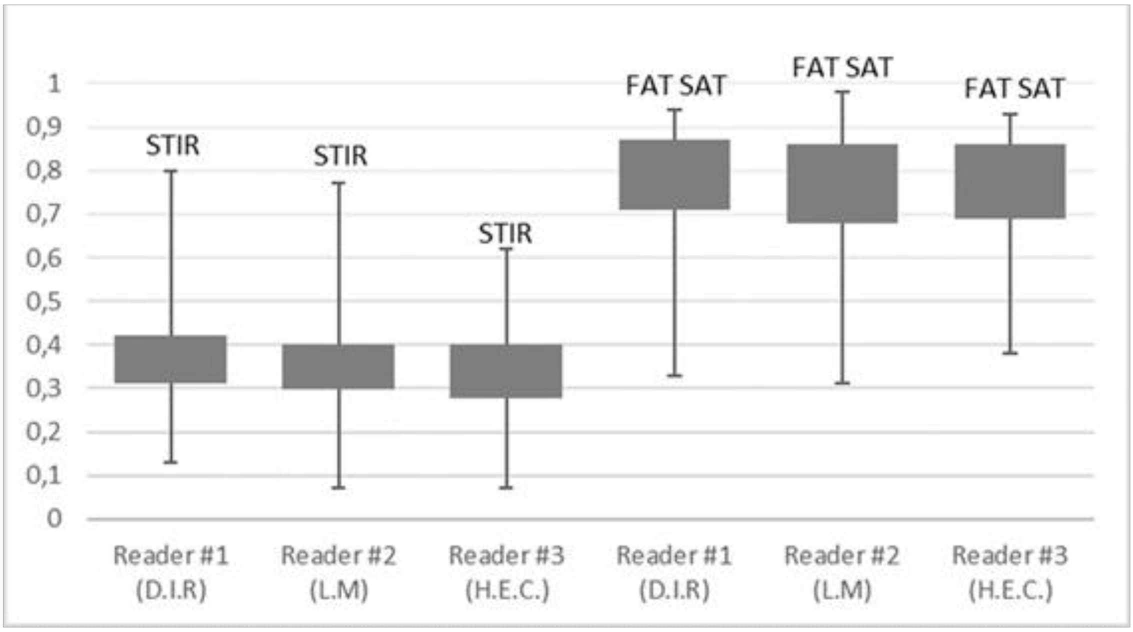


Fig. 5. The box-plot shows the image contrast (C = y-axis) for respectively the STIR and FAT SAT sequences conducted by all three readers. The measurements for reader 1, 2 and 3 lies respectively between 0.13-0.8, 0.07-0.77 and 0.07-0.62 on the STIR scan and between 0.33-0.94, 0.31-0.98 and 0.38-0.93 on the FAT SAT scan. The boxes indicate that half of the measurements lies between 0.31-0.42, 0.30-0.4 and 0.28-0.40 on the STIR scan and between 0.71-0.87, 0.68-0.86 and 0.69-0.86 on the FAT SAT scan.

The image contrast was calculated as higher executing the FAT SAT sequence, suggesting that the FAT SAT sequence should be used if a better image contrast is needed.

Discussion

Clinical considerations

The comparable scan time and Signal-to-Noise Ratio were obtained in this study with a STIR sequence with inferior spatial resolution and fat suppression (due to the low TI). A low TI predicts that the SNR would increase, due to a small signal from the fat allowed, but a longer TI (recommended 160-180ms[18,19]) would increase the contrast between edema and bone marrow and this result would differ if the STIR sequence was not optimized to SNR; due to this would influence the result of method 2, and possible also method 3. However, because a bone bruise and non-affected bone are not perceived as two objects with similar signal intensity, very good image contrast and spatial resolution is not of overarching importance for the detection of bone bruise and thus for this project; conversely, a very poor image contrast could result in undiagnosed pathology. In this study a comparison using a standard STIR setting wouldn't therefore be ideal and "fair" for the result.

With MRI, it will always be possible to improve the image quality at the detriment of a longer scan time. However, this may increase the risk of artifacts caused by the patient's movements, and from a clinical perspective, might result in fewer examinations per day. The T2 FAT SAT sequence is a fast and safe method for diagnosing a bone bruise (>1T). This study shows that the STIR sequence can be used equally (at any field strength).

Theoretically, field inhomogeneity and field strength result in some boundaries for the use of the FAT SAT sequence. These boundaries should be tested before considering its use clinically. The average age of the participants in this study (21 years) was shown to be beneficial when considering inhomogeneity, as young people are more easily mobile and thus more likely to be positioned correctly. Also, the FAT SAT sequence is not suitable for patients with metal implants or for a field strength of <1 T.

Limitations of the study

Limitations include the use of a 1.5 T MRI unit, the use of an extremity MRI unit and a small panel of readers with different backgrounds. In addition, the small nonequivalence of the parameter settings could be considered a bias.

The 1.5T extremity MRI was used because the central placement of the patient's hand and the comfortable position decreased the possibility of artifacts,[23] which in this study, was considered more important than higher field strength.

According to the intra-class correlation coefficient, the inter-observer agreement was acceptable for all correlated scores (0.50 – 0.81) which supports the validity of this project. The intra-class correlation coefficient was used to indicate the association among the three readers. It was expected, that the quantitative measurements were unlikely to result in 1 (total positive). An increased number of readers could have limited the uncertainty.

As the area is quantitatively measured, der would be a measurement uncertainty (approximately +/-1 mm). It would be difficult to interpret if a small difference in the area is due to this uncertainty or an actually difference in the two sequence. The difference in the readers' theoretical and clinical experience is beneficial for this study as they ensured that no biased subjective opinion influenced the result. The protocols reflect appropriate parameter settings. Since a T2 FAT SAT has certain image quality advantages, a STIR sequence with identical parameters would not be ideal from a clinical perspective.

It has not been possible to compare the results of this study to other similar studies, as no comparable articles were found during the initial search. However, the results seem to be in accordance with the theory that expects FAT SAT sequences with a higher CNR when executing the STIR sequence with a low TI (125 ms).[4,15-16]

The main advantage of STIR is high contrast. This was however sacrificed for higher SNR in this study.
A complete identical placement of the ROI´s could not be ensured using the quantitative method.

This study did not address the physical basics of the STIR and FAT SAT sequences. The average age was skewed toward younger patients as a result of excluding patients with osteoarthrosis. Likewise bone marrow edema may not be as evident in older patients.GE has released a new version of the fat saturation for the Optima 430s that uses the Dixon technique for a more reliable and homogeneous fat saturation. Incorporation of this new version of fat saturation in a similar study would be commendable.

Conclusion

This study shows an equivalency both in area and CNR when executing the STIR and T2 FAT SAT, suggesting interchangeably usage of the two sequences (1.5-T) are acceptable for diagnostic purposes due to that bone bruise will appear almost identical on both sequences. However, the T2 FAT SAT provided higher image contrast in this study when taken advantages of specific STIR-settings, *e.g.* short TI (125 ms), and could therefore be considered useful when better image contrast is required.

Acknowledgments

We would like to express our sincerest gratitude to MD Helle Elisabeth Christensen and radiographers involved in the data collection, assistance and contribution.

References

1. Deangelis JP, Spindler KP. Traumatic Bone Bruises in the Athlete's Knee. Sports Health. 2010 Sep;2(5):398–402. https://doi.org/10.1177/1941738110377745

2. Geijer M. Diagnosis of scaphoid fracture: optimal imaging techniques. Reports in Medical Imaging. 2013;57–69. https://doi.org/10.2147/RMI.S48951

3. Eustace S, Keogh C, Blake M, Ward RJ, Oder PD, Dimasi M. MR imaging of bone oedema: mechanisms and interpretation. Clinical Radiology. 2001 Jan;56(1):4–12. https://doi.org/10.1053/crad.2000.0585

4. Del Grande F, Santini F, Herzka DA, Aro MR, Dean CW, Gold GE, et al. Fat-Suppression Techniques for 3-T MR Imaging of the Musculoskeletal System. Radiographics. 2014;34(1):1–12. https://doi.org/10.1148/rg.341135130

5. Murthy NS. The role of magnetic resonance imaging in scaphoid fractures. Journal of Hand Surgery. 2013 Oct;38(10):2047–54. https://dx.doi.org/10.1016/j.jhsa.2013.03.055

6. Resnick DL, Kang HS, Prefferklieber ML. Internal Derangements of Joints, Vol 1. 2nd Eds. Saunders. 2007

7. Thavarajah D, Syed T, Shah Y, Wetherill M. Does scaphoid bone bruising lead to occult fracture? A prospective study of 50 patients. Injury. 2011;42(11):1303–6. https://doi.org/10.1016/j.injury.2011.02.020

8. Mccullough MP, Smith FW, Cooper JG. Early MRI in the management of the clinical scaphoid fracture. European Journal of Emergency Medicine. 2011 18(3) 133-6. https://doi.org./10.1097/MEJ.0b013e32833edb59

9. Taljanovic MS, Karantanas A, Griffith JS, Desilva GL, Rieke JD, Sheppard JE. Imaging and Treatment of Scaphoid Fractures and Their Complications. Seminars in Musculoskeletal Radiology. 2012;16(2):159–74. https://doi.org/10.1055/s-0032-1311767

10. Rhemrev SJ, Ootes D, Beeres F, Meylaerts S, Schipper IB. Current methods of diagnosis and treatment of scaphoid fractures. International Journal of Emergency Medicine. 2011;4(4). https://doi.org/10.1186/1865-1380-4-4

11. Mallee W, Doornberg JN, Ring D, van Dijk CN, Maas M GJ. Comparison of CT and MRI for diagnosis of suspected scaphoid fractures. Journal of Bone & Joint Surgery. 2011;93(1):20–8. https://doi.org/10.2147/RMI.S48951

12. Sendher R, Ladd AL. The Scaphoid. Orthopedic Clinics of North America. 2013;44(1):107–20. https://doi.org/10.1016/j.ocl.2012.09.003

13. Bergh TH, Lindau T, Soldal LA, Bernardshaw SV, Behzadi M, Steen K BC. Clinical scaphoid score (CSS) to identify scaphoid fracture with MRI in patients with normal x-ray after a wrist trauma. Emergency Medicine Journal. 2014;31(8):659–64. https://doi.org/10.1136/emermed-2012-202219

14. Shetty S, Sidharthan S, Jacob J, Ramesh B. "Clinical scaphoid fracture": Is it time to abolish this phrase? Annals of The Royal College of Surgeons of England. 2011;93(2):146–8. https://doi.org/10.1308/147870811X560886

15. Cameron I. Techniques of Fat Suppression. MR Phys Ottawa Hosp 501 Smyth Rd, Ottawa, ON, Canada. 2009;7 http://cds.ismrm.org/protected/09MProceedings/files/Tues C36_01 Cameron.pdf

16. Kijowski1 R , Farber JM, Medina J, Morrison W, Jyng J, Buckwalder K. Comparison of Fat-Suppressed T2-Weighted Fast Spin-Echo Sequence and Modified STIR Sequence in the Evaluation of the Rotator Cuff Tendon. American Journal of Roentgenology. 2005;185(2):8. https://doi.org/10.2214/ajr.185.2.01850371

17. Dodd JD. Evidence-Based Practice in Radiology: Steps 3 and 4--Appraise and Apply Diagnostic Radiology Literature. Radiological Society of North America. 2007;242(2):342–54. https://doi.org/10.1148/radiol.2422051679

18. Razavi SA, Sadigh G, Kelly AM CP. Comparative effectiveness of imaging modalities for the diagnosis of upper and lower urinary tract malignancy: a critically appraised topic. Academic Radiology. 2012;19(9):1134–40. https://doi.org/10.1016/j.acra.2012.05.004

19. El-Maraghi RH KA. CT colonography versus optical colonoscopy for screening asymptomatic patients for colorectal cancer a patient, intervention, comparison, outcome (PICO) analysis. Academic Radiology. 2009;16(5):564–71. https://doi.org/10.1016/j.acra.2009.01.008

20. GE Healthcare, Milwaukee. ONI Optima 1.5T MR430s Extremity. Magnetic Resonance Imaging. [Cited 2017_April 26] Available from: http://www3.gehealthcare.com/en/support/site_planning

21. Tomura N, Saginoya T, Kokubun M, Tsuchiya M, Yamamoto T. T2-weighted IDEAL fast spin echo imaging of the brachial plexus: comparison with STIR. Acta Radiologica. 2015;0(0):1–6. https://doi.org/10.1177/0284185114552292

22. Rosner B. Fundamentals of biostatistics Belmont, CA:Thomson-Brooks/Cole. 2006.

23. McRobbie DW, Moore EA, Graves MJ, Prince MR. MRI from Picture to Proton. New York: Cambridge University Press; 2003. 359 p.