



## ■ WRIST &amp; HAND

# The reliability and clinical utility of a simple MRI based classification tool for acute scaphoid injuries: the OxSMART

**B. J. F. Dean,  
A. Berridge,  
Y. Berkowitz,  
C. Little,  
W. Sheehan,  
N. Riley,  
M. Costa,  
E. Sellon**

*From Oxford University  
Hospitals NHS Trusts,  
Oxford, UK*

## Aims

The evidence demonstrating the superiority of early MRI has led to increased use of MRI in clinical pathways for acute wrist trauma. The aim of this study was to describe the radiological characteristics and the inter-observer reliability of a new MRI based classification system for scaphoid injuries in a consecutive series of patients.

## Methods

We identified 80 consecutive patients with acute scaphoid injuries at one centre who had presented within four weeks of injury. The radiographs and MRI scans were assessed by four observers, two radiologists, and two hand surgeons, using both pre-existing classifications and a new MRI based classification tool, the Oxford Scaphoid MRI Assessment Rating Tool (OxSMART). The OxSMART was used to categorize scaphoid injuries into three grades: contusion (grade 1); unicortical fracture (grade 2); and complete bicortical fracture (grade 3).

## Results

In total there were 13 grade 1 injuries, 11 grade 2 injuries, and 56 grade 3 injuries in the 80 consecutive patients. The inter-observer reliability of the OxSMART was substantial (Kappa = 0.711). The inter-observer reliability of detecting an obvious fracture was moderate for radiographs (Kappa = 0.436) and MRI (Kappa = 0.543). Only 52% (29 of 56) of the grade 3 injuries were detected on plain radiographs. There were two complications of delayed union, both of which occurred in patients with grade 3 injuries, who were promptly treated with cast immobilization. There were no complications in the patients with grade 1 and 2 injuries and the majority of these patients were treated with early mobilization as pain allowed.

## Conclusion

This MRI based classification tool, the OxSMART, is reliable and clinically useful in managing patients with acute scaphoid injuries.

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**Keywords:** Scaphoid, Fracture, MRI, Classification, Injury

## Introduction

Wrist injuries represent a substantial burden to both patients and healthcare services. Around 70,000 patients per year in the UK attend Emergency Departments (EDs) or Minor Injuries Units (MIUs) with post-traumatic wrist pain and tenderness and normal radiological findings.<sup>1</sup> Current guidance from the National Institute of Care and Health Excellence (NICE) advises early MRI for patients with a 'suspected scaphoid fracture'.<sup>2</sup>

Rua et al<sup>3,4</sup> have recently demonstrated cost savings of £266 per patient at six months, while early MRI intervention dominated standard care in the base case and all four deterministic sensitivity scenarios, costing less and achieving more quality adjusted life year (QALY) gains. Furthermore, MRI had a probability of 100% of being cost-effective at six months using the conventional UK willingness to pay (WTP) thresholds of £20,000 to £30,000 per QALY.<sup>3,4</sup> Not only does early

Correspondence should be sent to Benjamin J. F. Dean; email: bendeand1979@gmail.com

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### Grade 3 – complete fracture

T1

STIR

PDFS

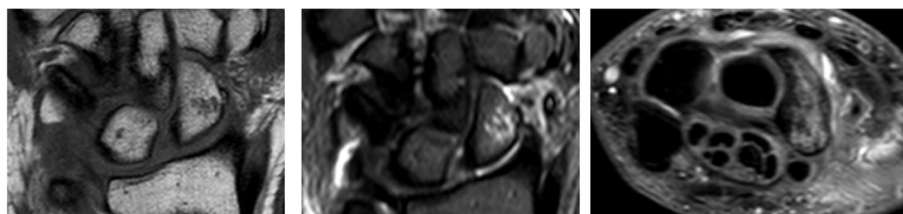


### Grade 2 – unicortical

T1

STIR

PDFS



### Grade 1 – contusion

T1

STIR

PDFS

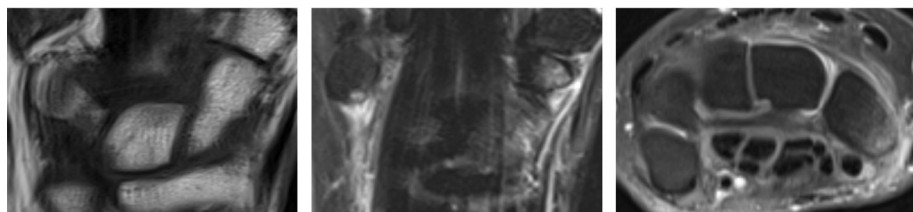


Fig. 1

Examples of MRI grading system. PDFS, Proton density Fat Saturated; STIR, Short Tau Inversion Recovery.

MRI have this clear cost advantage, but it also has clear benefits in terms of diagnostic accuracy and patient satisfaction.<sup>4</sup>

The increasing use of early MRI has improved our understanding of wrist trauma by describing a variety of pathologies which previously went undetected.<sup>5,6</sup> We have previously demonstrated that a large proportion of scaphoid fractures are not detected by plain radiographs and that the occult undisplaced scaphoid fracture, even if promptly detected and treated, is not necessarily benign in clinical outcome and may progress to nonunion.<sup>5</sup> There is a wealth of literature relating to the reliability of radiographs and CT in assessing acute scaphoid fractures,<sup>7,8</sup> but little has been published relating to the reliability of

MRI in assessing the wider variety of scaphoid injuries that can be detected in modern clinical practice. Given the substantial negative consequences of scaphoid nonunion, it is important that an MRI based classification system of scaphoid injuries is reliable, reproducible, and aids clinical decision-making.

In this context, the aim of this study was to describe the reliability of our MRI based classification system in a consecutive series of patients with a scaphoid injury.

### Methods

This prospective service evaluation project was carried out from the end of September 2019 until the end of September 2020. We collected routine, anonymized

**Table I.** Demographic and basic details of the cohort, broken down as overall diagnostic group.

Group	Total	OxSMART grade		
		3 - full fracture	2 - unicortical	1 - contusion
Number	80	56	11	13
Sex (male/female), n	54/26	38/18	10/1	5/8
Median age, yrs (IQR)	23 (18 to 40)	24 (19 to 42)	19 (16 to 25)	24 (19 to 47)
Median injury to ED, days (IQR)	0 (0 to 1)	0 (0 to 1)	0 (0 to 1)	0 (0 to 1)
Immobilized? (Y/N), n	57/23	50/6	2/9	5/8
Median immobilization, wks (IQR)	6 (0 to 6)	6 (6 to 6)	0 (0 to 1)	0 (0 to 4)
Fracture reported on radiograph (Y/N), n	32/48	29/27	1/10	2/11
Imaging follow-up (CT/radiograph), n	61/19	53/3	5/6	0/13
Complication? (Y/N), n	2/78	2/54	0/11	0/13

ED, emergency department; IQR, interquartile range; OxSMART, Oxford Scaphoid MRI Assessment Rating Tool.

**Table II.** Imaging characteristics in different groups.

Group	Total	OxSMART grade		
		3 - full fracture	2 - unicortical	1 - contusion
<b>Radiograph</b>				
Number	80	56	11	13
Fracture reported on radiograph (Y/N), n	32/48	29/27	1/10	2/11
Obvious fracture present consensus (Y/N), n	38/42	36/20	2/9	0/13
Tubercle fracture present consensus (Y/N), n	14/66	12/44	2/9	0/13
Displacement present consensus (Y/N), n	9/71	9/47	0/11	0/13
<b>MRI</b>				
MRI performed, n	71	47	11	13
Obvious fracture present consensus (Y/N), n	53/18	47/0	5/6	1/12
Tubercle injury present consensus (Y/N), n	36/35	15/32	11/0	10/3
Displacement present consensus (Y/N), n	8/63	8/39	0/11	0/13
STIR/PDFS grade consensus (nil vs partial vs full), n	0/25/46	0/0/46	0/12/0	0/13/0
T1 grade consensus (nil vs partial vs full), n	13/12/46	0/0/46	0/12/0	13/0/0

OxSMART, Oxford Scaphoid MRI Assessment Rating Tool; PDFS, Proton density Fat Saturated; STIR, Short Tau Inversion Recovery.

data without implementing any change to standard clinical care pathways. The study was registered locally as a service evaluation project, and as such no ethical approval was required as stated by the HRA (Health Research Authority).

**Process/pathway.** All patients who attended the ED or MIU following wrist trauma, with radiologically confirmed scaphoid fracture or who were at clinical suspicion of having a scaphoid fracture following normal radiographs, were included. Those admitted into hospital as inpatients with injuries which included a scaphoid fracture were not included. Patients were first assessed by an ED or MIU clinician and plain radiographs (posterior-anterior and lateral of wrist) obtained after clinical examination. Following discussion with a senior ED clinician with specific scaphoid pathway training, scaphoid series radiographs were then obtained for all patients with a suspicious history and at least one positive clinical sign (snuffbox tenderness or scaphoid tubercle tenderness) of scaphoid fracture. The determination of what constituted a 'suspicious history' was subjective and made by the pathway-trained clinician. Those aged 12 years and over

with normal reported radiographs or a scaphoid fracture reported were then immobilized in a wrist splint without thumb extension and referred for a wrist MRI scan, as was pathway guidance at the time of the pandemic. The radiology department has a dedicated daily appointment for a scaphoid MRI involving a 20-minute, four-sequence protocol (coronal T1, coronal Short Tau Inversion Recovery (STIR), axial Proton density Fat Saturated (PDFS), and a gradient echo (GE) 3D isotropic sequence). The MRI scans were all reported by a consultant musculoskeletal radiologist. A team of extended scope physiotherapists (ESPs) working within the ED, MIU, and orthopaedic trauma service managed the pathway beyond this point. MRI scan results were relayed to the patients by the ESP via telephone consultation and personalized letter, and sent to the patient and the GP to document the diagnosis and management plan. The letter also included safety-net advice regarding how to represent if any worrying or persistent symptoms occurred; the management plan was determined for each patient by the MRI scan findings. Those with normal scans or minor abnormalities were discharged with verbal and written advice by

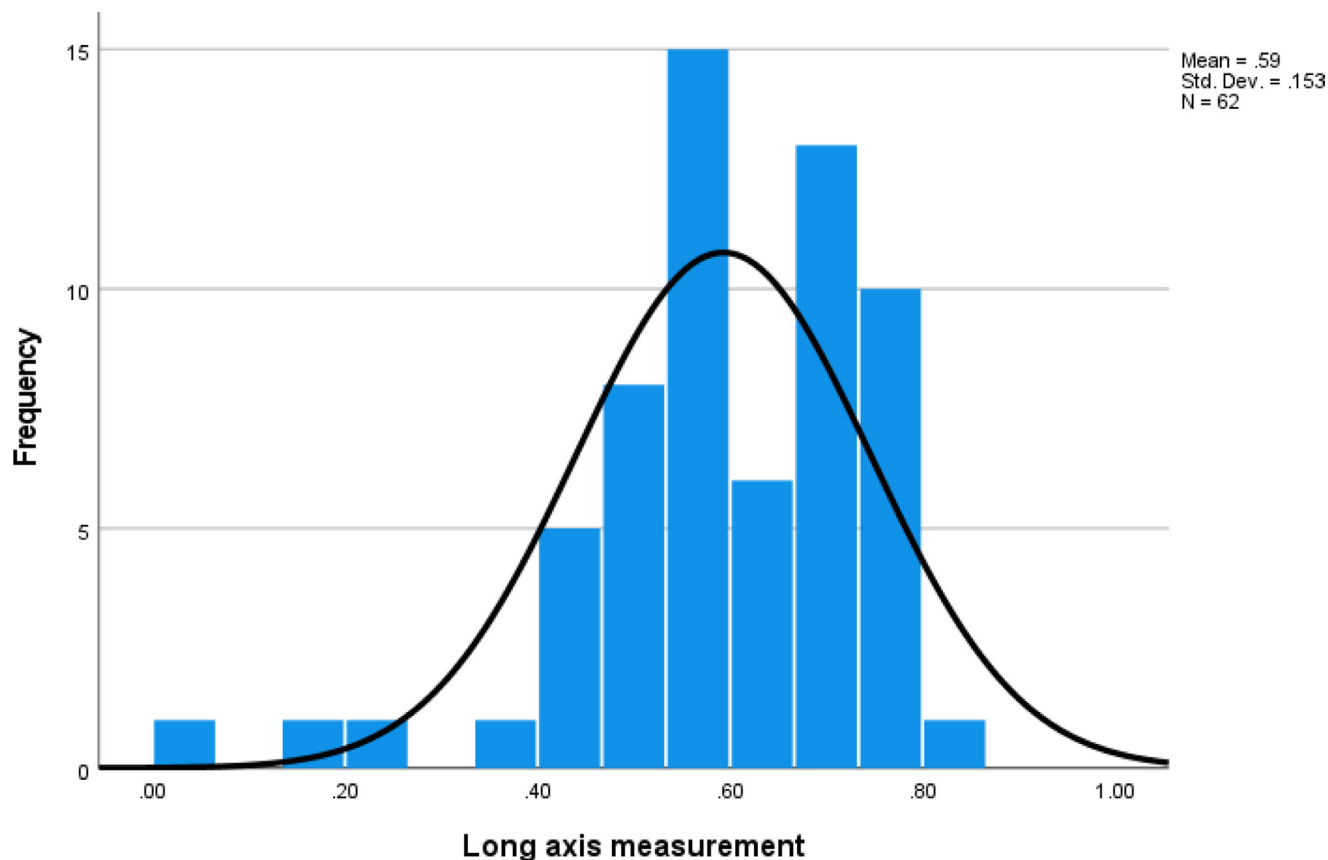


Fig. 2

Histogram of frequencies of scaphoid fracture location as measured by long axis technique.

**Table III.** Inter-observer reliability.

Imaging characteristic	Overall reliability (95% CI)
<b>Radiograph-based</b>	
Presence of obvious fracture (Y/N)	0.436 (0.437 to 0.525)
Fracture location (proximal/middle/distal)	0.509 (0.445 to 0.572)
Presence of tubercle fracture (Y/N)	0.709 (0.620 to 0.798)
Long axis measurement	0.788 (0.646 to 0.894)
Displacement (< 1 mm/1 to 2 mm/> 2 mm)	0.357 (0.281 to 0.433)
<b>MRI-based</b>	
Presence of obvious fracture (Y/N)	0.543 (0.447 to 0.638)
Fracture location (proximal/middle/distal)	0.444 (0.378 to 0.510)
Presence of tubercle injury (Y/N)	0.594 (0.499 to 0.690)
Long axis measurement	0.778 (0.679 to 0.859)
Displacement (< 1 mm/1 to 2 mm/> 2 mm)	0.568 (0.491 to 0.644)
STIR/PDFS grade (partial radial/partial ulnar/full)	0.789 (0.687 to 0.890)
T1 grade (partial radial/partial ulnar/full)	0.708 (0.633 to 0.784)
Overall OxSMART MRI grading (full fracture vs unicortical vs contusion)	0.711 (0.640 to 0.782)

CI, confidence interval; OxSMART, Oxford Scaphoid MRI Assessment Rating Tool; PDFS, Proton density Fat Saturated; STIR, Short Tau Inversion Recovery.

the ESP without further clinical assessment. All patients with scaphoid fractures on radiographs or MRI-detected scaphoid fractures were followed up in a specialist hand trauma clinic and immobilized in a cast. Patients whose scans had demonstrated other abnormalities were

discussed with the specialist hand surgical team to determine the optimal immobilization (none, removable splint, or cast) and clinical follow-up (none, general trauma clinic, hand trauma clinic, or hand therapy), and actioned by the ESP. Details of further treatment, including

# Scaphoid fracture pathway

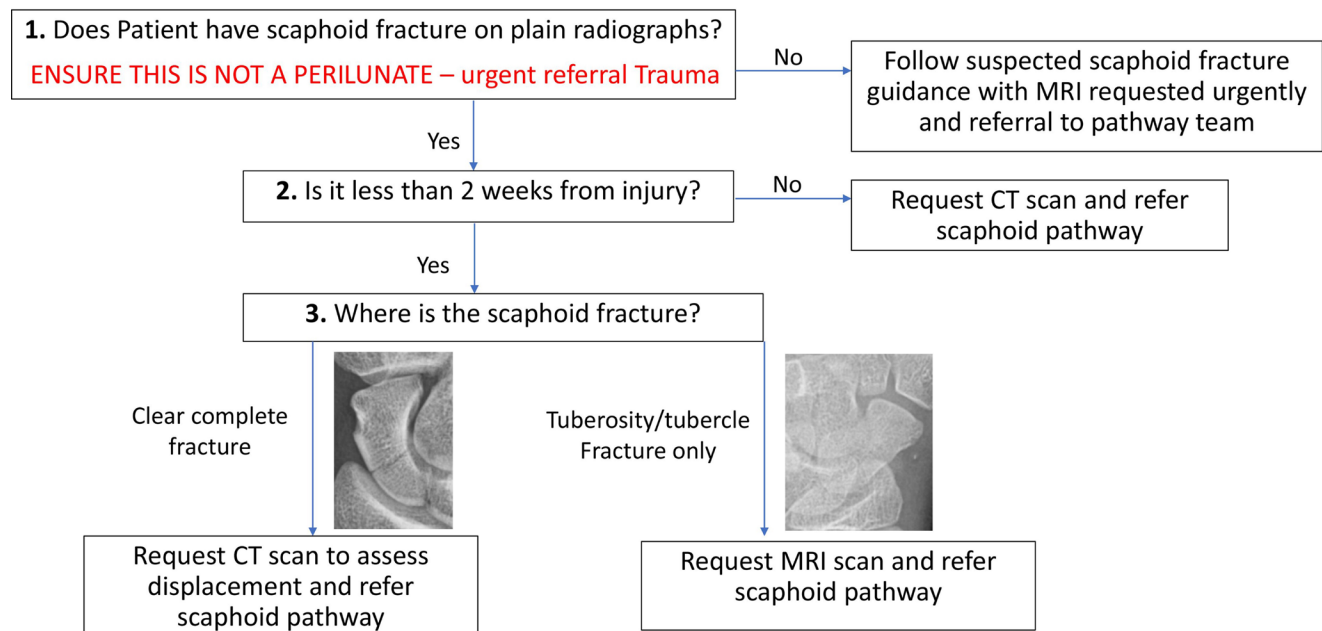


Fig. 3

Our latest clinical algorithm for the management of acute scaphoid injuries.

surgical intervention, were recorded. Electronic patient records were searched in January 2022 to ensure that all representations to our services were captured.

**Imaging.** Two consultant musculoskeletal radiologists (ES and YB) (each with over five years of subspecialist consultant experience) and two consultant hand surgeons (BJFD and AB) retrospectively analyzed the plain radiographs and MRI scans. The four observers met prior to reviewing the imaging and agreed on the structured approach. The observers were briefed on the recent literature, which describes the long axis passing from the proximal point through the centre of the waist to the most distal point, with the most distal point being very close to the centre of the tubercle just radial to its apex.<sup>7</sup> The observers recorded the following outputs for radiographs: presence of an obvious fracture (Y/N); Mayo classification for full fracture (proximal/middle/distal); presence of a tubercle fracture (Y/N); long axis measurement for full fractures (range from 0 to 1); and degree of displacement (< 1 mm, 1 to 2 mm, > 2 mm). The observers recorded the following outputs for MRI: presence of an obvious fracture (Y/N); Mayo classification for full fracture (proximal/middle/distal); presence of a tubercle fracture (Y/N); long axis measurement for full fractures (range from 0 to 1); degree of displacement (< 1 mm, 1 to 2 mm, > 2 mm); T1 appearance (no abnormality, unicortical radial, unicortical ulnar, or bicortical); fluid sensitive sequence appearance (no abnormality, unicortical radial, unicortical ulnar, or full width); and overall

classification (complete fracture, unicortical fracture, or contusion). A complete bicortical fracture was defined as a fracture across the whole scaphoid, from the radiocarpal joint to the midcarpal joint, as opposed to a tubercle fracture which was defined as a fracture extending from the radiocarpal joint exiting in the scaphotrapeziotrapezoid (STT) joint. The OxSMART was based upon our group's shared experience of these injuries, which has evolved naturally as part of routine clinical practice. Figure 1 shows examples of the imaging findings in the different OxSMART grades. The consensus gradings were determined by a majority or a group discussion for cases in which there was no majority decision.

**Statistical analysis.** The study is reported according to the STROBE guidelines for observational studies, and a STROBE checklist has been included in the Supplementary Material.<sup>5</sup> Statistical analysis was carried out using IBM SPSS Statistics for Windows, (version 27.0; IBM, USA). Unless otherwise stated in the characteristics description, numbers represent median (interquartile range (IQR)) for continuous variables and number (percentage) for categorical variables. Histograms for all datasets were analyzed to assess for normality. The interpretation of the degree of agreement determined by the Kappa and intraclass correlation coefficient (ICC) is generally graded as slight (0.01 to 0.2), fair (0.21 to 0.40), moderate (0.41 to 0.60), substantial (0.61 to 0.80), and almost perfect (>0.81).<sup>9</sup> We did not carry out a formal power calculation, as this is not standard practice for reliability studies.<sup>10</sup> Our sample size and number of observers

was, however, comparable with the best practice described within the literature.<sup>10</sup>

## Results

**Patient demographics, characteristics, and imaging findings.** Tables I and II show the patient demographics and characteristics, as well as the imaging findings within the different OxSMART grades. Of the grade 3 injuries 50 of 56 (89%) were cast immobilized, while of the grade 1/2 injuries 17 of 24 (71%) were not cast immobilized. Only 29 (52%) of the grade 3 injuries were detected with radiographs. There were two complications of delayed union which were both in the grade 3 injuries, and both these patients had been treated with prompt cast immobilization within two weeks of injury. Both cases of delayed union were confirmed on CT at six to eight weeks post injury. All 53 patients with grade 3 injuries who resided within our catchment area were followed up with imaging (CT: n = 52; radiographs: n = 1). Of the 11 patients with a grade 2 injury, five were followed up with a CT to confirm union. Figure 2 shows the distribution of fractures as measured using the long-axis measurement, with fractures of the mid-scaphoid being the most common and fractures at either end of the spectrum being relatively rare. Table II shows how 12 of the 14 (86%) tubercle fractures visible on radiographs occurred in the context of an associated complete scaphoid fracture (see the example depicted in Supplementary Figure a).

**Inter-observer reliability of radiograph based results.** Table III demonstrates the inter-observer reliability of the radiograph based results. There was moderate agreement for the presence of an obvious fracture (Kappa = 0.436) and the location of the fracture (Mayo classification) (Kappa = 0.509). There was substantial agreement for the presence of a tubercle fracture (Kappa = 0.709) and substantial agreement for the long axis measurement (ICC = 0.778). There was moderate agreement for the grading of fracture displacement (Kappa = 0.568).

**Inter-observer reliability of MRI based results.** Table III demonstrates the inter-observer reliability of the MRI based results. There was moderate agreement for the presence of an obvious fracture (Kappa = 0.543) and the location of the fracture (Mayo classification) (Kappa = 0.444). There was moderate agreement for the presence of a tubercle injury (Kappa = 0.554) and for the long axis measurement (ICC = 0.788). There was fair agreement for the grading of fracture displacement (Kappa = 0.357). There was substantial agreement for the T1 grading (Kappa = 0.789), T2 grading (Kappa = 0.708), and overall OxSMART grading (Kappa = 0.711).

## Discussion

The key finding of this study is that the OxSMART is highly reliable in classifying acute scaphoid injuries into three grades: 1) contusion; 2) unicortical; and 3) complete fracture. Importantly, this is within a context

of around half of complete scaphoid fractures detected on MRI not being detected by plain radiographs. The OxSMART's clinical utility has also been shown as our study findings support the requirement of cast immobilization for grade 3 injuries, however early mobilization appears safe for grade 1 injuries. Given the lack of published evidence relating to the assessment of scaphoid injuries on MRI, these findings are of use for clinicians in interpreting scans and providing a consistency of language which we feel is useful clinically. The other key finding is that the presence of an obvious scaphoid tubercle fracture on radiographs should alert the clinician to the high likelihood of a complete scaphoid fracture being present on MRI.

The substantial negative impact of scaphoid nonunion has been well described in the literature.<sup>11,12</sup> Consequently, there is a great need to detect and promptly treat any complete scaphoid fractures that have the potential to go on to nonunion, which has driven the development of modern MRI based pathways.<sup>5</sup> There is little debate as to whether complete scaphoid fractures should at minimum be cast immobilized, and this study has demonstrated that the injuries which are complete on T1 and on fluid-sensitive sequences can be reliably classified as grade 3. Our pragmatic approach is to allow patients with grade 1 injuries to mobilize, while we have tended to manage grade 2 injuries more on a case-by-case basis. This seems logical and safe, although it should be noted that our study is not powered to prove clinical safety. It should also be noted that we cannot be sure that no patient who did reattend our services did not sustain a complication, as they may have presented to other services for example. Clearly no classification system is perfectly reliable, and sometimes in real-world clinical practice there may be an element of uncertainty in the decision-making process.

In cases where there is clearly a full width abnormality on fluid-sensitive imaging and an equivocal finding regarding the completeness of the T1 cortical abnormality (as might be the case with an incomplete fracture across the trabecular bone that does not visibly involve one or both cortices), our approach has been to err on the side of caution and to immobilize in cast. This reflects the limitation of conventional MRI sequences in the examination of cortical bone. As can be seen from the size of our patient groups, this demographic is a relatively small number of patients per year in our unit. The differentiation between a scaphoid contusion and a unicortical fracture, as seen on MRI, is something which may be of clinical relevance but requires further exploration. We differentiate between the terms only to illustrate different points along the same trabecular injury spectrum. Both terms are defined from the perspective of imaging as a trabecular fracture sufficient to cause

visible haemorrhage. When a discreet fracture line or contour abnormality becomes visible, we prefer the term unicortical fracture.

The findings relating to the moderate and fair agreement respectively relating to the radiograph based assessment of the presence of a fracture and of classifying displacement are consistent with the published literature.<sup>7</sup> The substantial agreement relating to the long axis measurement measured on radiographs and MRI is also consistent with previous work.<sup>7</sup> The reliability of MRI assessed displacement was superior to that of radiographs, which is perhaps unsurprising given the inclusion of an isotropic 3D sequence. Although the reliability of assessing the presence of a tubercle fracture on radiographs was substantial, it is an interesting finding that the majority of patients with only a tubercle fracture detected on radiograph went on to have a complete fracture detected on MRI. This novel finding means that when an isolated tubercle fracture is seen on radiographs, there should be the assumption that a complete fracture is present until proven otherwise. Our latest clinical algorithm considers the learning from this period and is shown in Figure 3.

The strengths of this study are that we have a system in place to prospectively gather data on consecutive patients and its novelty, given the number of scaphoid fractures which have undergone early MRI. Subsequently we have modified our pathway, as outlined in Figure 3, to use CT to further investigate complete fractures that are visible on plain radiographs, as we feel that CT is probably superior for assessing fracture displacement. The limitations include the fact that this study only represents one centre and the absence of patient-reported outcomes, although it is clear that nonunion of scaphoid results in poor clinical outcomes.<sup>13,14</sup>

In conclusion, this MRI based classification tool, the OxSMART, is reliable and clinically useful in managing patients with acute scaphoid injuries.



### Take home message

- The Oxford Scaphoid MRI Assessment Rating Tool (OxSMART) categorizes scaphoid injuries into three grades (contusion (grade 1), unicortical fracture (grade 2), and complete bicortical fracture (grade 3)), and is highly reliable in classifying these injuries.
- Scaphoid tubercle fractures which are obvious on radiographs are frequently accompanied by a full thickness injury on MRI, which was not detected on the initial radiographs.
- Injuries which are clearly partial thickness (grade 1 and some grade 2) can be mobilized early, but further work is necessary to determine if any grade 2 injuries have the potential to go onto delayed union.

### Twitter

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### Supplementary material



Figure showing images depicting a tubercle fracture without a bicortical waist fracture on radiograph, with MRI images demonstrating the bicortical waist fracture in addition. A STROBE checklist is also included to show that the STROBE guidelines were adhered to in this study.

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#### Author information:

- B. J. F. Dean, BM BCH MA BA FRCS PhD, Consultant Hand Surgeon and Senior Research Fellow, Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences (NDORMS), Botnar Research Centre, University of Oxford, Oxford, UK.
- A. Berridge, FRCS, Consultant Hand Surgeon, East Suffolk and North Essex NHS Foundation Trust, Colchester, UK.
- Y. Berkowitz, FRCR, Consultant Musculoskeletal Radiologist
- C. Little, FRCS, Consultant Orthopaedic Surgeon
- N. Riley, FRCS, Consultant Hand Surgeon
- E. Sellon, FRCR, Consultant Musculoskeletal Radiologist Nuffield Orthopaedic Centre, Oxford, UK.
- W. Sheehan, BSc, Senior Physiotherapist, Emergency Department, John Radcliffe Hospital, Oxford, UK.
- M. Costa, FMedSci, Professor of Orthopaedic Trauma Surgery, Trauma Unit, John Radcliffe Hospital, Oxford, UK.

#### Author contributions:

- B. Dean: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing.
- A. Berridge: Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.
- Y. Berkowitz: Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.

- C. Little: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing.
- W. Sheehan: Investigation, Methodology, Writing – original draft, Writing – review & editing.
- N. Riley: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.
- M. Costa: Methodology, Supervision, Writing – original draft, Writing – review & editing.
- E. Sellon: Conceptualization, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing.

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