MR imaging accuracy in the prediction of bone graft healing potential in scaphoid non-union

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Résumé
Valeur de l’IRM dans l’évaluation du potentiel de guérison des pseudarthroses du scaphoïde traitées par greffe osseuse néonatales.

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Objectifs. Déterminer si l’IRM joue un rôle pronostique dans le traitement par greffe osseuse de la pseudarthrose du scaphoïde.

Matériel et méthodes. Vingt et un cas de pseudarthrose du scaphoïde traitée par greffe osseuse (greffon non vascularisé dans 14 cas et radial vascularisé dans 7 cas) ont été préalablement explorés par IRM avec des séquences frontales en FSE T2 avec Fat Sat et avec des coupes frontales et sagittales obliques dans le grand axe du scaphoïde, en T1 avant et après injection de Gadolinium. L’intensité et l’homogénéité du signal du pôle proximal du scaphoïde étaient analysées sur les différentes séquences par deux radiologues indépendants et corrélés aux résultats thérapeutiques.

Résultats. Le traitement était efficace dans 17 cas. La reproductibilité intra observateur était de 0,92 et 0,86 ; la reproductibilité inter observateur était de 0,88. En pondération T1, le fragment proximal était hypointense dans 1 cas (succès thérapeutique), en hypersignal hétérogène dans 7 cas (7 réussites) et en hypersignal homogène dans 13 cas (9 réussites). En pondération T2, le fragment proximal était hypointense dans 4 cas (3 réussites), en hypersignal homogène dans 5 cas (4 réussites) et en hypersignal hétérogène dans 12 cas (10 réussites). Après injection de Gadolinium, le rehaussement était homogène dans 4 cas (4 réussites), hétérogène dans 8 cas (7 réussites) et absent dans 9 cas (6 réussites). Dans le groupe sans prise de contraste, 5 patients étaient traités avec un greffon radial vascularisé (4 réussites) et 4 avec un greffon non vascularisé (2 réussites).

Conclusion. L’absence de rehaussement du fragment proximal est un facteur péjoratif modéré, devant orienter vers la mise en place d’un greffon vascularisé.


Abstract
Purpose. To determine the accuracy of MR imaging in predicting bone graft healing in patients with scaphoid non-union.

Material and Methods. Twenty-one patients with scaphoid non-union were examined with MR imaging prior to bone grafting (conventional bone graft in 14 cases and vascularized bone graft in 7 cases). The protocol included unenhanced and Gadolinium-enhanced sequences. Signal intensity and homogeneity of the proximal fragment was analysed by two independent radiologists. MRI findings were then correlated to the postoperative rate of union.

Results. Healing occurred in 17 cases and failed in 4 cases with a mean follow up of 14 months. Intraobserver agreement in MR reading was respectively 0.92 and 0.86. Interobserver agreement was 0.88. On T1-wi, the proximal fragment was hyperintense in 1 case (with positive surgical result), heterogeneous low signal intensity in 7 cases (healing in n=7) and homogeneous low signal intensity in 13 cases (healing in n=9). On T2-wi, the proximal fragment was hypointense in 4 cases (healing in n=3), homogeneous high signal in 5 cases (healing in n=4) and heterogeneous high signal intensity in 12 cases (healing in n=10). After Gadolinium injection, enhancement was homogeneous in 4 cases (healing in n=4), heterogeneous in 8 cases (healing in n=7) and absent in 9 cases (healing in n=6). In the group with no enhancement, 5 patients were treated with vascularized bone graft (healing in n=4) and 4 with conventional bone graft (healing in n=2).

Conclusion. The absence of enhancement of the proximal scaphoid fragment leads to poor surgical results except for vascularized bone graft.

Key words: Fracture, scaphoid. Fracture, MR. Fracture, non-union. Fracture, bone grafting. Osteonecrosis. Bone graft, vascularized.


The scaphoid is the most frequently fractured carpal bone (1-3). Five to ten percent progress to non-union and pseudarthrosis (4). Pseudarthrosis of the scaphoid is defined by the persistence of a fracture line at 3 months (1-3). Causes of scaphoid non-union include absence of or inadequate initial treatment, secondary displacement at the fracture site, premature cast removal, and the terminal nature of the vascular supply (1-3). Scaphoid pseudarthrosis is managed surgically to prevent secondary carpal misalignment, degenerative change and scaphoid non-union advanced collapse. Over time, there may be progressive palmar bascule of the distal scaphoid fragment, dorsal bascule of the proximal scaphoid fragment and dorsal rotation of the lunate resulting in dorsal intercalated segment instability (DISI). Degenerative changes usually involve first the radial styloid process and scaphoid, followed by the midcarpal joint. The Alnot classification of scaphoid non-union, based on observation of these findings, is useful for treatment planning (1-3). When degenerative
changes are only minimal, management relies on bone grafting to establish a bony bridge between both portions of the fractured scaphoid and restore height. The scaphoid is vascularized from distal to proximal, and pseudarthrosis reduces vascularization to the proximal pole. Avascular necrosis of the proximal pole may prevent successful bone grafting. The viability of the proximal pole is usually assessed peroperatively by the amount of punctate bleeding (5).

It has been stated that pre-operative MR evaluation of the marrow signal intensity of the proximal pole of the scaphoid may enable assessment of its viability (6-13). However, conflicting results have been published, especially with regards to T1W and T2W sequences (14, 15). Post-contrast MR sequences may be more reliable (15, 16). The purpose of our study was to determine if pre-operative MRI, especially contrast material enhanced T1W sequences, may predict the outcome of bone grafting in patients with non-union and pseudarthrosis of the scaphoid and help in the selection of a specific treatment.

Materials and Methods

From our imaging database (Xplore, EDL), we identified 40 patients who underwent MR imaging for pseudarthrosis of the scaphoid between February 1995 and January 2002. Bone grafting was performed in 21 patients; only these 21 patients were included in our study. The other 19 patients were distributed as follows: 5 underwent palliative scaphoidectomy and partial arthrodesis because of advanced degenerative change, 3 declined surgical intervention because their profession did not allow for a prolonged period of immobilization, 3 had already undergone grafting, 2 showed union in spite of radiographic and MRI findings (one of which had undergone several surgeries already), and 6 were lost to follow-up.

Our patient population of 21 included 18 males and 3 females with a mean age of 31 (range: 21 to 47) (Table I). The right scaphoid was involved in 14 cases and the left in 7 cases. The fracture was located at the proximal third in 17 cases and at the mid third in 4 cases. The time interval between initial trauma and imaging ranged between 6 months and 30 years (mean

<table>
<thead>
<tr>
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<th>STAGE*</th>
<th>GRAFT</th>
<th>RESULT</th>
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<td>FAILURE</td>
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<td>2a</td>
<td>ULNAIRE</td>
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<td>SUCCESS</td>
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<td>PROXIMAL 1/3</td>
<td>2a</td>
<td>ILIAQUE</td>
<td>SUCCESS</td>
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</table>
Based on the classification by Alnot (2) (table II), 9 patients were grade IIa, 3 patients were grade IIb, 4 patients were grade IIIa, and 5 patients were grade IIIb. A vascularized radial graft was used in 7 cases and a non-vascularized cancellous bone graft was used in 14 cases (10 iliac, 3 radial, and 1 ulnar). Postsurgical management included wrist immobilization for 3 months, followed by removal of the fixation wires when the outcome was favorable, and physical therapy.

The MRI examinations were performed on a 1.5 Tesla Signa Horizon (General Electric Medical Systems) using a dedicated wrist coil. The imaging protocol included coronal and oblique sagittal (axis of the scaphoid) SE T1W images, coronal fat suppressed FSE T2W images, and coronal and oblique sagittal (axis of the scaphoid) postcontrast fat suppressed SE T1W images. For T1W images, the slice thickness was 3mm with an interslice gap of 0.2mm. The FOV was between 8 and 12cm with a matrix size of 256x192. The signal of the proximal pole of the scaphoid was evaluated for its homogeneity and intensity relative to other normal carpal bones. The signal was described as heterogeneous. On T1W images, the signal was classified as homogeneously hypointense, heterogeneously hypointense, or isointense to other carpal bones (i.e. hypointense). On T2W images, the signal was classified as homogeneously hyperintense, heterogeneously hyperintense, or isointense to other carpal bones (i.e. hypointense). On postcontrast images, the signal was classified as homogeneously enhancing, heterogeneously enhancing, or non-enhancing (fig. 1-4).

All examinations were reviewed independently by both reviewers (SC, SI) on two separate occasions for evaluation of inter-observer and intra-observer agreement. All available images were reviewed. Both reviewers were blinded to the results of surgery.

### Results

Bone grafting was successful in 17 cases and failed in 4 cases after a follow-up of 6 to 24 months (mean of 14 months). Graft healing was confirmed on clinical findings (symptomatic improvement), radiographic findings (bony union, incorporation of the graft to the native bone) and MRI in 2 cases because plain radiographs were indeterminate. Three of four surgical failures involved non-vascularized bone grafts. Three of four surgical failures underwent secondary scaphoidectomy and arthrodesis, while the fourth patient was lost to follow-up. The radiographic grade of failed surgical management was Ia in one case, IIb in one case, and IIIb in 2 cases.

The degree of intra-observer agreement for preoperative MRI interpretation was 0.92 for one reader and 0.86 for the other reader. The degree of inter-observer agreement was 0.88. Because of this excellent degree of agreement, the results from only one review are presented here (table III).

On T1W images, the proximal pole was hyperintense in 1 case (surgical healing), heterogeneously hypointense in 7 cases (surgical healing in 7 cases), and homogeneously hypointense in 13 cases (surgical healing in 9 cases and surgical failure in 4 cases for a surgical success rate of 70%). Of the latter 13 patients, 7 underwent non-vascularized bone grafting (surgical healing in 4 cases and surgical failure in 3 cases for a surgical success rate of 57%) and 6 underwent vascularized radial bone grafting (surgical healing in 5 cases and surgical failure in 1 case for a surgical success rate of 83%).

On fat-suppressed T2W images, the proximal pole was isointense to other carpal bones (i.e. hypointense) in 4 cases (surgical healing in 3 cases and surgical failure in 1 case), homogeneously hyperintense in 5 cases (surgical healing in 4 cases and surgical failure in 1 case), and heterogeneously

### Table III

<table>
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<tr>
<th>Sequence</th>
<th>T1W</th>
<th>Fat suppressed FSE T2W</th>
<th>Postcontrast fat suppressed T1W</th>
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<td>Homogeneously hypointense</td>
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<tr>
<td>Number of patients</td>
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<td>13</td>
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<tr>
<td>Mean success rate</td>
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<td>100%</td>
<td>70%</td>
</tr>
<tr>
<td>Success rate with non-vascularized graft</td>
<td>100%</td>
<td>100%</td>
<td>57%</td>
</tr>
<tr>
<td>Success rate with vascularized graft</td>
<td>100%</td>
<td>100%</td>
<td>83%</td>
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hyperintense in 12 cases (surgical healing in 10 cases and surgical failure in 2 cases). On postcontrast fat-suppressed T1W images, enhancement of the proximal pole was homogeneous in 4 cases (surgical healing in 4 cases), heterogeneous in 8 cases (surgical healing in 7 cases and surgical failure in 1 case), and absent (i.e. non-enhancing) in 9 cases (surgical healing in 6 cases and surgical failure in 3 cases). In the group of patients with homogeneous enhancement (surgical success rate of 100%), 2 patients were treated using a vascularized bone graft and 2 patients were treated using a non-vascularized bone graft. In the group of patients with heterogeneous enhancement (surgical success rate of 88%), all patients were treated using a non-vascularized bone graft. In the group of patients with absence of enhancement (surgical success rate of 67%), 5 patients were treated using a vascularized radial bone graft (surgical healing in 4 cases) and 4 patients were treated using a non-vascularized bone graft (surgical healing in 2 cases).

**Discussion**

Our results further confirm that absence of enhancement of the proximal pole of the scaphoid is a factor of poor prognosis. However, results from bone grafting remained more frequently favorable, irrespective of the MRI findings, especially when using a vascularized radial bone graft.

Pseudarthrosis is the main complication of unsuspected or inadequately treated scaphoid fracture (1-4). Pseudarthrosis frequently is asymptomatic early on, but it is inevitably associated with arthritic changes that become worse over time as seen on standard radiographs and graded using the Alnot classification (2). The prevalence of asymptomatic pseudarthrosis is 0.14% (17). Excluding very advanced cases, the goal of treatment is to restore height, alignment, and stability using a corticocancellous bone graft. Several surgical techniques have been described: iliac or radial bone grafting material packed into the defect from a volar approach (usually for grades I and IIa), iliac bone graft wedged between both scaphoid fragments (for more advanced non-unions), and vascularized bone graft, usually radial in origin (usually performed after failed surgery or suspected avascular necrosis of the proximal pole) (3). Surgery is successful in 47 to 100% of cases (18-23). Failure usually re-
results in fragmentation or lack of incorporation of the bone grafting material to the proximal pole. Prognostic indicators of favorable or poor outcome following surgery remain controversial (20-23). Some authors report that outcome is less favorable when non-union is older than 5 years and in the presence of advanced secondary degenerative changes. In a meta-analysis, Merrel et al. (23) reported that outcome was more favorable when lesions were treated within the first year with a mean success rate of 90% whereas treatment after one year carried a mean success rate of 80% irrespective of time delay between injury and treatment. The site of the pseudarthrosis and the viability of the proximal pole are the most important prognostic factors: the incidence of avascular necrosis, and poor outcome, increases as fractures are located more proximally in poorly vascularized areas. This is due to the particularities of its blood supply. The scaphoid possesses a dual blood supply with small palmar branches at the distal pole providing 20-30% of the total blood supply and dorsal branches at the waist providing the remaining 70-80% of the total blood supply. Fractures proximal to the waist are thus associated with an increased risk of avascular necrosis. The rate of surgical success also depends on the type of bone grafting procedure. For avascular necrosis of the proximal fragment, union is achieved in 88% of those patients with a vascularized graft versus 47% with screw and non-vascular wedge fixation (23).

Presurgical evaluation of the viability of the proximal pole is valuable because in the presence of suspected impaired blood supply, the surgeon is more likely to select a vascularized bone graft. It is generally accepted that plain radiographs, CT and bone scintigraphy do not allow adequate evaluation of scaphoid blood supply whereas the role of MRI deserves further evaluation. Plain radiographs frequently show sclerosis of the proximal pole. This appearance is not specific: the relative sclerosis is secondary to the immediate post-fracture ischemia that may only be transient (12, 13). Bone scintigraphy is limited by its lack of spatial resolution and low specificity. CT is probably the best imaging technique to characterize the degree of angulation and size of the fragments and also to detect the presence of fragmentation of the proximal pole but it cannot assess the quality of blood supply (13, 15).

MRI is the best imaging modality to detect avascular necrosis (24) and bone
infarcts. For that reason, it has been used since the late 1980’s to detect possible avascular necrosis of the proximal pole in patients with scaphoid fracture (6-11). Even though sample sizes in the first series were small, initial results were excellent. Perlik et al. (6) reported an accuracy of 100% for MRI diagnosis of avascular necrosis of the proximal pole. Desser et al. (9) reported a specificity of 100% and sensitivity values of 89% and 55% for T1W and T2W sequences respectively. In a more recent study (14) of 32 patients, Guñal et al. reported a large number of discordant results comparing MRI and peroperative results. Recently, Cerezal et al. (15) reported, in a study of 30 patients including 27 patients presumably treated with non-vascularized grafts, that unenhanced T1W and T2W images did not provide an adequate assessment of the proximal pole. Mummification of fat was suggested to explain the lack of sensitivity of T1W images and the presence of inflammatory tissue was suggested to explain the lack of sensitivity of T2W images. On the other hand, results at post-contrast MR imaging correlated well to surgical findings; the degree of enhancement correlated well to the degree of punctate peroperative bleeding; surgical results correlated well to the degree of enhancement. The rate of successful union was 100% in patients showing intense homogeneous enhancement. This rate was 89% when patchy enhancement involved 50-80% of the proximal fragment of the scaphoid, and 75% when patchy enhancement involved 20-50% of the proximal fragment of the scaphoid. The rate was 0% when there was absence of or less than 20% enhancement of the proximal fragment of the scaphoid.

Our results confirm the lower usefulness of T2W images. On T1W images, the presence of homogeneous hypointensity is a factor of poor prognosis with a successful union of 70% compared to 100% when T1W hyperintense areas are present. The rate of union decreases to 57% when a non-vascularized graft is used (versus 83% when a vascularized graft is used). For enhanced T1W images, the rate of successful union was 100% when enhancement was homogeneous and intense, 88% when enhancement was heterogeneous, and 66% when enhancement was absent. There is a correlation between enhancement and union, but the degree of this correlation is less than in the study of Cerezal et al. This difference may be due to the larger number of patients without enhancement in our study and the small sample sizes that result in limitations to statistical analysis. It may also be due to differences in surgical techniques since 5 of our 9 patients without enhancement were treated using a vascularized bone graft, a treatment that provides better results in patients with avascular necrosis. Four of these 5 patients (80%) achieved successful union. Two of the
four patients (50%) treated with non-vascularized bone graft also achieved successful union. Therefore, the absence of enhancement of the proximal pole does not preclude treatment using a bone graft, but a vascularized bone graft should be preferred.

A third difference compared to the study of Cerezal et al. relates to the selection of MR imaging planes. In the study of Cerezal et al., postcontrast images were obtained in the coronal and sagittal planes whereas we obtained coronal and oblique sagittal (axis of the scaphoid) images. This difference may be significant given the small size of these structures and the difficulties related to accurate characterization of the degree of enhancement. The excellent results for intra- and interobserver agreement in our study suggest that our selection of imaging planes is satisfactory.

A limitation of our study is the apparent absence of correlation between MRI findings, peroperative punctuate bleeding, and histology. These data were not available for all patients. However, the purpose of our study was to evaluate the prognostic value of MRI and its usefulness for treatment planning and not to correlate MRI and histological findings. Also, the value of different MR pulse sequences in the evaluation of associated anomalies of the carpus (arthrosis, collapse, angulation, number of fragments, and ligamentous and peri-ligamentous lesions) was not assessed. Therefore, it is not possible to conclude that only pre- and postcontrast T1W images are valuable.

**Conclusion**

Our study further confirms the prognostic value of MRI, even if our results may be a little different than those from previous studies. Postcontrast T1W images show changes of the proximal pole of the fractured scaphoid that have a good degree of correlation with therapeutic results. The absence of enhancement remains a factor of poor prognosis, but maybe not as much so as previously reported, and certainly should favor selection of a vascularized bone graft.

**References**

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