Clinical Paper Session 04: Scaphoid

Moderators:
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Scott G. Edwards, MD

Session Abstracts
Friday, September 06, 2019
HYPOTHESIS
Management of occult scaphoid fracture and scaphoid fracture nonunion often requires advanced imaging to achieve diagnoses, avoid unnecessary immobilization, and indicate treatment. We hypothesize that Digital Tomosynthesis (DTS), a cross-sectional imaging modality that is more cost efficient than MRI and less irradiative than CT, provides adequate diagnostic performance as a screening test and leads to a reduction in advanced imaging utilization in the management of scaphoid fractures.

METHODS
Outpatient charts with a scaphoid tomogram from May 2014 to October 2017 were retrospectively reviewed. DTS usage was classified as assessment of occult fracture, fracture nonunion, fracture morphology, or hardware positioning. DTSs of occult fractures were analyzed for diagnostic performance using the traditional gold standard for occult scaphoid fracture diagnosis of plain radiograph and clinical exam at two week follow up to calculate sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Reduction in advanced imaging was determined if DTS results provided adequate information to avoid advanced imaging. Potential reduction in advanced imaging was determined as cases in which DTS provided the same diagnostic information as advanced imaging.

RESULTS
78 patients received scaphoid tomography from May 2014 to October 2017: 39 for occult fracture, 33 for fracture nonunion, 5 for fracture morphology, and 1 for hardware positioning. 14 tomograms were positive for occult scaphoid fracture. 6 of these had advanced imaging, 3 of which were positive for fracture, and 9 fractures were confirmed clinically at follow up. 25 tomograms were negative for occult scaphoid fracture. 14 of these had advanced imaging, all 14 of which were negative for fracture, and all 25 remained negative at clinical follow up. DTS therefore had a sensitivity of 100%, a
specificity of 83%, a PPV of 64% and a NPV of 100% for the detection of occult scaphoid fracture. DTS reduced advanced imaging usage in 69% (54 of 78) of all patients and achieved a potential advanced imaging reduction in 83% (20 of 24) of those that did receive advanced imaging.

SUMMARY
• DTS has higher sensitivity and NPV than previously reported thereby providing utility as a screening tool to reduce unnecessary immobilization at lower cost with less radiation than advanced imaging.
• DTS has potential to reduce advanced imaging utilization in the management of occult scaphoid fracture, and hardware placement.
• More research is needed evaluating inter- and intraobserver reliability of DTS in addition to prospective comparison of advanced imaging modalities.

REFERENCES:
Fig 1: Scaphoid view plain film (a) and scaphoid tomogram (b) of a patient revealing an occult scaphoid fracture seen only with Digital Tomosynthesis.

Table 1: Flowchart of patients separated by Digital Tomosynthesis usage and the subsets that received advanced imaging with diagnostic tomograms and those that did not require advanced imaging. (AI=Advanced Imaging, DTS=Digital Tomosynthesis)
HYPOTHESIS
Our objective was to evaluate how reliably experts interpret scaphoid union status through dedicated radiographs (X-rays) and computed tomography (CTs). We hypothesized that overall reader agreement for CTs and X-rays would be poor, with notably less agreement for X-rays than CTs. We also anticipated that agreement may be affected by the presence of hardware (i.e. screw), type of training, and experience.

METHODS
Twenty-four sets of X-rays and CTs, both obtained in a 48-hour window, were chosen from patients with features of delayed union. Half the cases were treated operatively (hardware in situ), while the other half had been conservatively managed. Thirteen hand surgeons and five musculoskeletal radiologists, all fellowship-trained, independently reviewed the images for bony union status (united, partially united, or not united) and estimated percent-union (0-24%, 25-49%, 50-74%, or 75-100%). Pairwise interobserver and intraobserver weighted kappa scores (k) were generated to assess levels of agreement between and within participants based on imaging modality. Subgroup analyses were performed for the presence of hardware, specialty training, and experience.

RESULTS
The overall interobserver agreement was fair for x-rays, k = 0.36-0.42. Agreement for estimated percent-union on CT was moderate, k = 0.57. The presence of screw fixation decreased agreement amongst CT interpretation for both radiologists (k=0.13-0.40) and surgeons (k=0.21-0.51). Surgeons displayed higher agreement than their radiology colleagues, most notably when interpreting X-rays (k=0.41-0.43 vs k=0.22-0.25). There was no difference in agreement for estimated percent-union on CT (k = 0.57 vs. 0.56). Agreement between groups for categorical union (k=0.35 vs. 0.36) and CT estimated percent union (k = 0.59 vs. 0.55) was not dependent on experience.
Intraobserver agreement was fair for most groups (k=0.31-0.94), with near perfect agreement amongst radiologist-read CTs (k = 0.93). For all readers, there was only fair intraobserver agreement when hardware was present (k = 0.31).

SUMMARY
• Managing scaphoid fractures and judging union can be complicated, especially in the setting of delayed union. There has been increased reliance on cross-sectional imaging to aid in management yet, our study suggests agreement amongst imaging interpretation is fair-moderate, at best.
• Interpreting the fracture’s healing status with hardware in situ on CTs proves to be challenging (k=0.13-0.40).
• Although slightly better than X-rays, CTs only yield moderate interobserver agreement amongst experts.
• Agreement upon a diagnosis of scaphoid union continues to be elusive, and despite the increased sensitivity of advanced imaging there still remain diagnostic shortcomings.

REFERENCES:
Table 1: Interobserver and intraobserver reliability between and within participants based on radiographic bony union status (i.e. Union, Partial Union, or Non-union) and estimated percent union on CT (0-24%, 25-49%, 50-74%, or 75-100%).

<table>
<thead>
<tr>
<th></th>
<th>All participants (n=18)</th>
<th>Musculoskeletal Fellowship Trained Radiologists (n=5)</th>
<th>Hand Fellowship Trained Surgeons (n=13)</th>
</tr>
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<tbody>
<tr>
<td><strong>INTEROBSERVER</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>X-Rays</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All images</td>
<td>0.35 ± 0.15</td>
<td>0.25 ± 0.16</td>
<td>0.41 ± 0.12</td>
</tr>
<tr>
<td>With hardware</td>
<td>0.31 ± 0.22</td>
<td>0.14 ± 0.29</td>
<td>0.38 ± 0.19</td>
</tr>
<tr>
<td>Without hardware</td>
<td>0.29 ± 0.23</td>
<td>0.27 ± 0.22</td>
<td>0.29 ± 0.23</td>
</tr>
<tr>
<td>CT Scans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All images</td>
<td>0.57 ± 0.16</td>
<td>0.56 ± 0.11</td>
<td>0.57 ± 0.16</td>
</tr>
<tr>
<td>With hardware</td>
<td>0.40 ± 0.23</td>
<td>0.49 ± 0.17</td>
<td>0.38 ± 0.24</td>
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<tr>
<td>Without hardware</td>
<td>0.57 ± 0.24</td>
<td>0.55 ± 0.19</td>
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<tr>
<td><strong>INTRAOBSERVER</strong></td>
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<tr>
<td>X-Rays</td>
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<td></td>
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<tr>
<td>All images</td>
<td>0.54 ± 0.38</td>
<td>0.32 ± 0.45</td>
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<td>With hardware</td>
<td>0.39 ± 0.46</td>
<td>-0.08 ± 0.11</td>
<td>0.53 ± 0.43</td>
</tr>
<tr>
<td>Without hardware</td>
<td>0.43 ± 0.38</td>
<td>1.00 ± 0.00</td>
<td>0.33 ± 0.31</td>
</tr>
<tr>
<td>CT Scans</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>All images</td>
<td>0.73 ± 0.16</td>
<td>0.93 ± 0.10</td>
<td>0.67 ± 0.12</td>
</tr>
<tr>
<td>With hardware</td>
<td>0.32 ± 0.38</td>
<td>0.77 ± 0.32</td>
<td>0.18 ± 0.29</td>
</tr>
<tr>
<td>Without hardware</td>
<td>0.77 ± 0.18</td>
<td>0.94 ± 0.08</td>
<td>0.73 ± 0.18</td>
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</table>
AM19 Paper 23: The outcome of bone graft surgery for nonunion of fractures of the scaphoid

Category: Hand and Wrist

Treatment; Prognosis/Outcomes
Level 4 Evidence

Tim RC Davis
Mohannad Ammori
Rykie Wade
Stephanie Spence
Clare Rowan
Michael Elvey

HYPOTHESIS
What factors influence the outcome of bone graft surgery for scaphoid fracture nonunion?

METHODS
Data on scaphoid fracture nonunion bone graft surgeries performed in adults before October 2014 were collected retrospectively from 19 centers during October - December 2016. At least 30 cases were collected by each center. Nonunion was defined as a fracture which had not united within 12 weeks of injury, and a minimum clinical and radiological follow-up of 12 weeks was required to determine outcome of treatment. 806 cases were recruited of which 462 fulfilled the inclusion criteria and had sufficient data to study the impact of smoking status, and complete data on time since acute fracture, site of nonunion, bone graft type and graft fixation on the outcome of surgery. Multivariable logistic regression was used for the analyses.

RESULTS
The overall union rate was at least 69%, and the nonunion rate was at least 22%, with 9% of cases having “uncertain union status”. The union rate appeared to be adversely influenced by smoking (P<0.01) and time between acute scaphoid fracture and nonunion surgery (P<0.01) with adjusted odds ratios of 1.8 (95%CI, 1.0-3.1) and 2.4 (95%CI, 1.2-4.8) respectively, but neither achieved the pre-determined significance level of 0.003. Nonunions treated 1-2 years and those treated more than 2 years after acute fracture had 40% and 140% higher odds of treatment failure respectively than those treated 3 to 6 months after the acute fracture. Type of bone graft (P=0.3: vascular v non-vascular; iliac crest v distal radius), site of nonunion (P=0.3) and fixation method (P=0.4) did not appear to influence outcome (P values derived from multivariable logistic regression).
SUMMARY
• Our rate of treatment success for scaphoid fracture nonunions (69-78%) is lower than reported in many other case series and a systematic review.
• Smoking status and time from acute injury to nonunion surgery, both of which are beyond the control of the surgeon, probably influence the outcome of treatment.
• Bone graft type and fixation technique, both of which are within the control of the surgeon, were not shown to influence the outcome of treatment.

REFERENCES:
HYPOTHESIS
Graft options for the reconstruction of unsalvageable proximal pole scaphoid nonunions include the costo-octeochondral graft, vascularized medial femoral trochlear osteochondral graft, or proximal hamate graft. Our hypothesis is that reconstruction of the proximal pole of the scaphoid with a proximal hamate graft will restore native carpal kinematics.

METHODS
8 fresh-frozen mid-forearm cadaver specimens were chosen for this Institutionally approved study. Wireless sensors were mounted to the carpus using a custom pin and suture anchor system. The flexor carpi ulnaris, flexor carpi radialis, extensor carpi ulnaris and extensor carpi radialis longus and brevis were loaded during testing. A wrist simulator was used to move the wrist through a cyclical motion about a single axis of rotation under displacement control. Cyclical motion about the flexion/extension and radial/ulnar deviation axes was performed. Each specimen was tested under a series of three conditions: 1) a native state, “Intact”, 2) fractured scaphoid proximal pole, “Fracture”, and 3) post reconstruction of the proximal pole of the scaphoid using a proximal hamate graft, “Graft”. Kinematic motion was captured using a combination of Moiré Phase Tracking 3D motion tracking sensor hardware (MPT, Metria Innovation, Inc., Milwaukee, WI) and motion capture software (The Motion Monitor, Innovative Sports Training, Chicago, IL) to evaluate the hand, wrist, and forearm kinematics. Data were collected at 60Hz using The Motion Monitor toolbox software (Innovative Sports Training, IL). The last 5 of the 100 cycles performed were averaged and used for kinematic analysis. Scapholunate, lunocapitate, and scaphoradial kinematics were evaluated during wrist flexion/extension and radial/ulnar deviation motions for each of the three conditions.

RESULTS
The creation of the scaphoid proximal pole fracture created a statistically significant change in scapholunate kinematics across the entire arc of wrist radial-ulnar deviation
motion relative to the intact condition (scapholunate flexion: $p = 0.005$, scapholunate radial-ulnar deviation: $p = 0.05$) (Figure 1). Additionally, the fractured condition did result in an increase in lunocapitate radial ulnar deviation during wrist radial lunar deviation from $10^\circ$ of wrist radial deviation to $20^\circ$ of ulnar deviation ($p = 0.04$). Proximal hamate to scaphoid transfer resulted in restoration of carpal kinematics to the intact state (Figure 2).

**SUMMARY**
- Proximal pole scaphoid fracture results in altered wrist kinematics.
- The proximal hamate graft restores scapholunate and lunocapitate native joint kinematics.

**REFERENCES:**

**FIGURE 1**

![Graph A](A)  ![Graph B](B)
FIGURE 2

Lunocapitate Rad-Uln Dev during Wrist Rad-Uln Dev

- Intact
- Fracture
- Graft
HYPOTHESIS
Medial femoral trochlea (MFT) osteocartilaginous free flap reconstruction of proximal scaphoid non-union has the potential to restore normal radiocarpal anatomy, improve function, and relieve pain without causing wrist stiffness, weakness, or excessive donor site morbidity.

METHODS
41 adult patients who underwent MFT proximal scaphoid arthroplasty by a single surgeon were eligible for this study. Patients were asked to return for clinical examination, radiographs, and completion of patient reported outcomes questionnaires.

RESULTS
Radiographic and examination follow-up were each 1.9 years. Patient-Reported Outcomes (PRO) follow-up ranged from 2.8-2.9 years. Radiographically, carpal collapse was halted and radiolunate angle was significantly improved by 9.3°. Wrist flexion (41.6°) and extension (43.8°) were not significantly changed by this operation, and post-operative pinch and grip strength were 89% and 83% of the uninjured side, respectively. Mean post-operative DASH score was 10.7. In patients with both pre-and post-operative scores available, DASH significantly improved by 15 points compared to pre-operative values. Measurable and statistically significant knee donor site morbidity was detected on the KOOS-Sports and Recreation and WOMAC scales. PROMIS Global Health, Physical Function, Pain Intensity, Pain Interference, and Pain Behavior scores reflected good post-operative patient health and function, and low pain levels (Figure 1). Elevated BMI was found to be significantly predictive of inferior lower extremity and global patient reported outcomes (Figure 2).

SUMMARY
• MFT reconstruction of proximal scaphoid non-union has the potential to restore normal radiocarpal anatomy, or excessive donor site morbidity.
• DASH score is significantly improved by 15 points.
• Donor site morbidity was modest, but measurable on several validated PRO scales.
• Patients with elevated BMI are at risk for increased donor site morbidity. This study represents longer and more comprehensive follow-up than our previous reports.

Table 4: Patient Reported Outcomes Before and After Proximal Scaphoid Arthroplasty
(Excludes patients with unavailable pre-operative or post-operative questionnaires)

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Follow-up Duration (y)</th>
<th>Mean Pre-Operative Score</th>
<th>Standard Deviation</th>
<th>Mean Post-Operative Score</th>
<th>Standard Deviation</th>
<th>Difference</th>
<th>p</th>
</tr>
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<tbody>
<tr>
<td>DASH</td>
<td>11</td>
<td>3.4</td>
<td>23</td>
<td>13.5</td>
<td>8</td>
<td>7.2</td>
<td>-15</td>
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<tr>
<td>KOOS-Pain</td>
<td>11</td>
<td>3.4</td>
<td>97.7</td>
<td>4.4</td>
<td>93.2</td>
<td>10</td>
<td>-4.5</td>
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<tr>
<td>KOOS-Symptoms</td>
<td>11</td>
<td>3.4</td>
<td>90.6</td>
<td>12.9</td>
<td>91.9</td>
<td>12.4</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>KOOS-Activities of Daily Living</td>
<td>11</td>
<td>3.4</td>
<td>98.1</td>
<td>0.5</td>
<td>95.9</td>
<td>6.7</td>
<td>-2.2</td>
<td></td>
</tr>
<tr>
<td>KOOS-Sports and Recreation</td>
<td>11</td>
<td>3.4</td>
<td>95</td>
<td>8.9</td>
<td>84.9</td>
<td>19.9</td>
<td>-10.1</td>
<td></td>
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<tr>
<td>KOOS-Quality of Life</td>
<td>11</td>
<td>3.4</td>
<td>94.9</td>
<td>7.8</td>
<td>89.8</td>
<td>16.1</td>
<td>-5.1</td>
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<tr>
<td>WOMAC</td>
<td>11</td>
<td>3.4</td>
<td>98.2</td>
<td>4</td>
<td>95.2</td>
<td>7.9</td>
<td>-3</td>
<td></td>
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</table>

BMI and Lower Extremity Patient Reported Outcomes

[Graph showing the relationship between BMI and patient-reported outcomes]