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Chapter

5

Predictors of fracture following suspected injury to the scaphoid

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J Bone Joint Surg Br., in press.

Abstract

Aim The aim of our prospective study was to develop a clinical prediction rule that incorporated demographic and clinical factors predictive of an acute scaphoid fracture.

Methods Of 260 consecutive patients with a clinically suspected or radiographically confirmed scaphoid fracture, 223 returned for evaluation two weeks after injury and formed the basis of our analysis. Patients were evaluated within 72 hours of injury and at approximately two and six weeks post injury using clinical assessment and standard scaphoid radiographs. Demographic data and the results of seven clinical examination manoeuvres were recorded.

Results There were 116 (52%) men and the mean age was 33 years (range, 13-95; SD, 17.9). Sixty-two (28%) patients had a confirmed scaphoid fracture. A logistic regression model identified male sex ($p=0.002$), sports injury ($p=0.004$), ASB pain on ulnar deviation of the wrist within 72 hours of injury ($p<0.001$), and day 14 scaphoid tubercle tenderness ($p<0.001$) as independent predictors of fracture among the entire cohort. No subjects with negative ASB pain on ulnar deviation of the wrist within 72 hours had a fracture ($n=72$, 32%). With four independently significant factors positive the risk of fracture was 91%.

Conclusion Our study has demonstrated that clinical prediction rules have a substantial and meaningful influence on the probability of a suspected scaphoid fracture. This will help improve the diagnostic performance characteristics of radiological tests, whilst in turn better inform the healthcare provider and patient regarding imaging and treatment.

Introduction

The suspected scaphoid fracture continues to present a diagnostic challenge despite extensive literature examining the sophisticated diagnostic modalities currently available¹⁻³. Up to 40% of patients with a scaphoid fracture have normal primary radiographs, and the clinical signs used for detecting a fracture are known to be overly sensitive and have poor specificity⁴⁻¹¹. These issues result in the vast majority of suspected scaphoid fractures being managed with primary immobilisation, given that a missed diagnosis can potentially lead to significant complications¹²⁻¹⁴. However, this policy leads to a high rate of overtreatment and places restrictions on work and recreational activities in a predominantly young and active population¹⁵⁻¹⁷.

Emphasis has been placed on sophisticated imaging, with MRI the most frequently recommended given the documented diagnostic performance characteristics and cost effectiveness associated with its early use¹⁸⁻²¹. However, there are limitations to the current literature. Firstly, the low prevalence of true scaphoid fractures among suspected fractures is often not accounted for through Bayesian statistics^{22,23}. Secondly, given the absence of an agreed consensus reference standard for a true fracture, conventional analysis may not be accurate in determining diagnostic performance characteristics and it may be preferable to use latent class analysis (LCA)^{22,23}. Finally, it is now recognized that sophisticated imaging demonstrated signal abnormalities in injured and uninjured scaphoids that can be misinterpreted as a fracture^{24,25}. In essence, it is inappropriate to consider radiological tests as able to diagnose a fracture with certainty. Both clinical and radiological assessments serve only to refine the probability of having a fracture, and the value of clinical assessment merits increased attention.

An important step to improve the diagnostic performance characteristics of the imaging modalities available would be to increase the prevalence of the true scaphoid fracture amongst suspected fractures through the development of clinical prediction rules. Therefore, our aim was to develop a clinical prediction rule for a true acute scaphoid fracture that incorporated demographic and clinical factors predictive of a fracture. Our secondary aim was to determine the diagnostic performance characteristics of the clinical signs tested using LCA and Bayesian statistical methods.

Patients and Methods

Over a one year period from January 2010 to December 2010 we performed a prospective cohort study of adult patients (≥ 13 years) presenting to our trauma centre with a suspected or confirmed injury to the scaphoid. Inclusion criteria included a clinically suspected or radiographically confirmed scaphoid fracture with no other



major fracture or soft tissue injury affecting the ipsilateral limb and within 72 hours of the time of injury. Patients with a confirmed ipsilateral upper limb injury on radiographs that could explain their symptoms e.g. carpal fracture other than scaphoid were excluded. Patients were also excluded if they were unwilling or unable to co-operate with follow-up assessment. The primary outcome measure for each patient was the presence of a scaphoid fracture, which was defined as a fracture that was confirmed on radiological imaging (radiographs, CT, MRI) by six weeks after the date of injury^{7,20,22,23,26}. If patients had no clinical symptoms or signs at two weeks post injury and all radiographs were negative this was defined as no fracture²⁷⁻²⁹. This study was approved by the local research ethics committee and governance framework.

Initial assessment

Those patients that fit the above criteria were included and assessed. As per protocol, eleven Emergency Department (ED) doctors and emergency nurse practitioners (ENPs) assessed all patients. All had specific training on the assessment of patients with a suspected scaphoid injury. To reinforce this, a detailed information sheet was presented to these healthcare providers prior to the study commencing. Patient demographics and injury details including age, gender, occupation, wrist affected, hand dominance, mechanism of injury, associated injuries, previous injury to the affected limb and past medical history were recorded. Seven clinical signs were chosen on the basis of previously published data (Table 1)^{4,5,9-11,30}.

| Table 1: The description of the seven clinical signs assessed for (present or absent). | |
|--|--|
| Clinical Sign | Description |
| Anatomical snuff box (ASB) tenderness | Pain when digital pressure is applied over the region of the ASB, defined as the area of indentation at the level of the carpus on the radial aspect of the wrist between the tendons of extensor pollicis longus on the ulnar aspect and extensor pollicis brevis and abductor pollicis longus on the radial aspect |
| Pain on thumb-index finger pinch | ASB pain on ipsilateral thumb and index finger opposition |
| Scaphoid tubercle tenderness | Pain when digital pressure is applied over the prominence of the scaphoid found in region of the distal flexor crease in the extended and radially deviated wrist |
| Pain on axial compression of thumb | ASB pain on axial loading of the scaphoid using an extended mid-abducted thumb |
| Decreased range of thumb movement | Reduced ranged of movement of the thumb in all directions tested (extension, flexion, abduction, adduction, opposition) |
| ASB pain in ulnar deviation/pronation | ASB pain on active ulnar deviation of the wrist in a pronated forearm |
| ASB pain in radial deviation/pronation | ASB pain on active radial deviation of the wrist in a pronated forearm |

Presence (positive or negative) of a fracture on standard scaphoid radiographs (posteroanterior, lateral, radial/ulnar oblique, Ziter's) was initially determined by ED staff and the appropriate treatment was instituted. When a fracture was confirmed the patient was immobilized in a cast. When a fracture was suspected the patient was managed using a thumb spica wrist splint.

Follow-up evaluation

Of the 260 patients initially reviewed in the ED, 223 (86%) attended for their two-week review and these patients made up the cohort of patients analysed (Figure 1). The two week evaluation occurred between 10 and 18 days after the initial injury. Patients were assessed at two weeks post injury for the presence of the above clinical signs and for repeat standard four view scaphoid radiographs to determine the presence of a suspected fracture or to check the position of a confirmed fracture. Analysis of clinical signs on day 14 involved 205 patients as the remaining 18, all who had a confirmed fracture on initial assessment, had either already undergone surgical fixation (n=12 of 16) or definitive treatment in a cast (n=6) that they did not want removed for assessment. Sixty (27%) patients were discharged at the two-week point as all symptoms and signs were negative and radiographs were normal, leaving 163 (73%) returning for review at six weeks post injury.

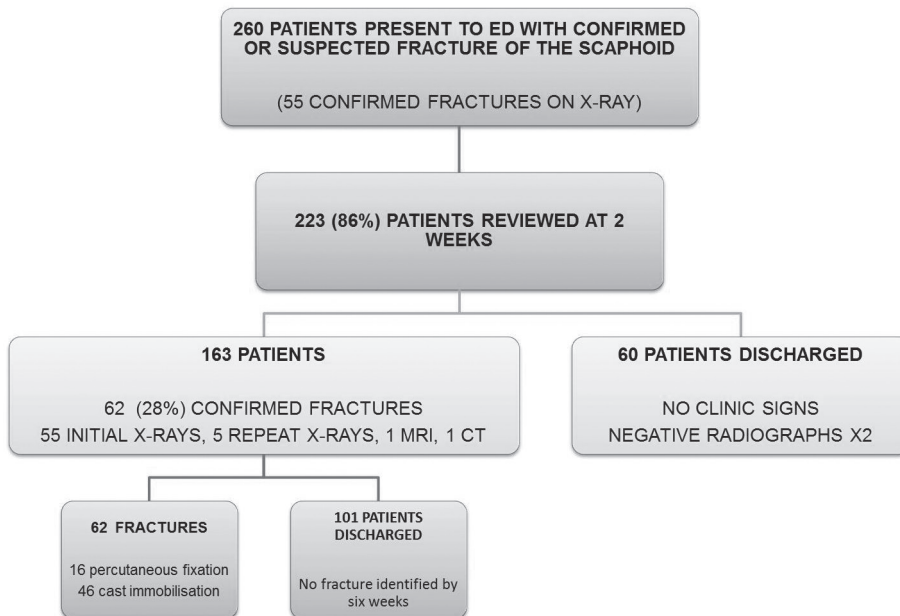


Figure 1. A flow chart of the initial 260 patients initially seen in the Emergency Department (ED), through to review, diagnosis, treatment and discharge.

Two senior consultant orthopaedic trauma surgeons independently reviewed radiographs to determine if a scaphoid fracture was visible by six weeks post injury. The use of further imaging was determined independently by the supervising trauma consultant.

Further imaging

Five fractures were diagnosed on radiographs obtained two weeks following injury that were not present on initial radiographs. Further imaging in the form of MRI (n=10) or CT (n=2) was employed in 12 patients. The indication for further imaging in all cases was to determine the presence of an occult fracture due to persisting symptoms and/or signs at the six week review. Nine MRIs were negative and one was positive for the presence of an occult scaphoid fracture. Of the two CT scans performed, one confirmed an occult fracture and one was unremarkable. Of the 161 patients with normal radiographs in the ED, 15 had an injury to a bone other than the scaphoid diagnosed on radiographs obtained 2 weeks after injury. Thirteen were nondisplaced distal radius fractures, one trapezium fracture and one trapezoid fracture.

Definitive management

Sixteen patients who sustained a fracture underwent percutaneous fixation of the scaphoid using a standard Acutrak screw (Acumed, Alton, United Kingdom). The operation was carried out within 14 days of injury in all cases. The remaining 46 patients were immobilized in a below elbow cast or splint for 6-8 weeks.

Statistical methods

As there is no consensus reference standard for a true scaphoid fracture, we used two methods to calculate the diagnostic performance characteristics. Firstly, we applied conventional Bayesian calculations using the most commonly used reference standard for a true scaphoid fracture, an abnormal lucent line within the scaphoid on radiographs obtained at 6-week follow-up^{7,20,22,23,26}. As this reference standard is debated, we additionally applied latent class analysis to the data set. Latent class analysis identifies unobserved (latent) groups of underlying clinical factors and test results that correspond with specific disease states. In this cohort, we did not expect any of the seven clinical test results to be unrelated (i.e. independent) of the others because the examiner knew the result of each test. Thus the data could violate the assumption of test independence conditional on disease status, commonly assumed in latent class analysis. Therefore, we used a recently developed latent class analysis model based on Bayesian methods that allows for conditional dependence among multiple test results^{31,32}. This is a proven methodology that has been used within the orthopaedic literature²⁴. In particular, we allowed for pairwise dependence among

non-fractured individuals, where initial model fits showed marked dependence. In contrast, there was little evidence of test dependence among individuals with a scaphoid fracture, or dependence across the two time points.

Independent t-tests were performed on continuous data, with categorical data analysed using the chi-square test. When the observed frequency of cases in a cell of the contingency table was less than five, the Fisher's exact test was used. Demographic and clinical signs at presentation and at two weeks were the variables examined on univariable analysis to determine predictors of a true scaphoid fracture.

Factors with $p < 0.10$ on univariable analysis were incorporated in a forward stepwise multivariate binary logistic regression analysis to determine independent predictors of fracture. Models were then generated for the suspected scaphoid fracture at presentation, at two weeks post injury with prior assessment at presentation and at two weeks post injury without prior assessment at presentation. Significance was determined as a p value of < 0.05 . In most cases the coefficients for different independently significant factors in the multiple logistic regressions were of similar magnitude to one another, and it was therefore decided to create prognostic scores using a simple count of the number of factors rather than a more complex score weighted by the exact coefficient values. This is easier to implement and understand within clinical practice, and also gave predicted probabilities that did not differ greatly from those derived from the more complex scores. For each prognostic score, sensitivity and specificity were reported for the cut-off level that maximised the sum of these two values.

Results

Of the 223 patients analysed, 116 (52%) were male and the mean age was 33 years (range, 13-95; SD, 17.9). Sixty-two (28%) patients were diagnosed with a scaphoid fracture within six weeks of injury (Figure 1). Fifty-five were diagnosed at the initial evaluation in the ED (25% of all patients; 89% of all scaphoid fractures). A total of seven fractures (11% of scaphoid fractures; 3% of all patients; 4% of patients with initially normal radiographs) were initially radiographically occult: five were diagnosed on repeat radiographs at two weeks, one on MRI, and one on CT. The prevalence of true occult fractures amongst suspected occult fractures was only 4% (7/168).

Clinical Prediction Rule 1 (Table 2, Table 3)

Of the 62 patients who sustained a fracture, the mean age was 27 years (range, 13-66; SD, 12.4) and 49 (79%) were male. Of the 161 patients confirmed to have no fracture, 67 (42%) were male and the mean age was 35 years (range, 13-95; SD, 19.1). Patients with a fracture were significantly younger ($p = 0.002$) and were more frequently male



| Table 2: Demographic predictors of an acute scaphoid fracture on univariable analysis for clinical prediction rule 1. | | | |
|---|------------------|------------------|-------------------|
| | NO FRACTURE | FRACTURE | p value |
| Total (n, %) | 161 (72) | 62 (28) | N/A |
| Males/Females | 67/94 | 49/13 | <0.001* |
| Mean age (range, SD) | 35 (13-95, 19.1) | 27 (13-66, 12.4) | 0.002¶ |
| Previous ipsilateral scaphoid fracture | 9 | 1 | 0.29 ^α |
| Mechanism of injury | | | |
| Fall height | 6 | 4 | |
| Fall standing | 99 | 15 | |
| Fight/assault | 7 | 4 | <0.001* |
| RTA | 14 | 5 | |
| Sports | 26 | 32 | |
| Twist | 1 | 0 | |
| Other | 8 | 2 | |

¶ Unpaired t-test; * Chi-squared; ^α Fisher's exact test

($p < 0.001$) than those who did not sustain a fracture. The most common mechanism of injury overall was a fall from standing height onto an outstretched hand (51%), as it was for patients who sustained no fracture (61%). The most frequent mechanism of injury for those who sustained a fracture was a sports injury (52%). Of all the patients who had a sports injury ($n=58$) 55% sustained a fracture, compared to 13% following a fall from standing height (15/114) and 0% following a twisting injury (0/1). Therefore, the demographic predictors of fracture were relative youth, male gender, and a sports mode of injury.

Clinical signs predictive of fracture within 72 hours of injury were pain on thumb-index finger pinch ($p=0.002$), scaphoid tubercle tenderness ($p=0.005$), ASB pain on ulnar deviation of the wrist ($p < 0.001$) and ASB pain on radial deviation of the wrist ($p < 0.001$). Except for ASB pain on axial compression of the thumb, all the clinical signs were predictive of fracture at two weeks post injury ($p < 0.05$ for all).

Using multiple logistic regression incorporating the demographic and clinical signs at presentation alone there were four independent predictors of fracture, which were male gender ($p < 0.001$, 95% confidence interval for adjusted odds ratio (CI) 1.5-7.7), sports injury ($p < 0.001$, CI 1.4-6.7), ASB pain on ulnar deviation of the wrist within 72 hours ($p < 0.001$) and thumb-index finger pinch ($p < 0.05$, CI 1.0-5.6). No patient without ASB tenderness on ulnar deviation of the wrist within 72 hours had a scaphoid fracture ($n=72$, 32%), and hence it was not possible to calculate a confidence interval for the adjusted odds ratio. Therefore, the probability of fracture in this case is 0%.

The probability of fracture in this model is:

Table 3: Clinical signs predictive of an acute scaphoid fracture on univariable analysis for clinical prediction rule 1.

| | NO FRACTURE N (%) | FRACTURE N (%) | p value |
|---------------------------------------|----------------------|-------------------|---------|
| Clinical sign (time point 1, <72hrs) | | | |
| Total | 161 (100) | 62 (100) | |
| ASB tenderness | 155 (96) | 61 (98) | 0.42* |
| Pain on thumb-index finger pinch | 90 (56) | 49 (79) | 0.002* |
| Scaphoid tubercle tenderness | 99 (62) | 51 (82) | 0.005* |
| Pain on axial compression of thumb | 108 (67) | 41 (66) | 0.89* |
| Decreased range of thumb movement | 100 (62) | 40 (65) | 0.74* |
| ASB pain on ulnar deviation | 89 (55) | 62 (100) | <0.001* |
| ASB pain on radial deviation | 94 (58) | 56 (90) | <0.001* |
| Clinical sign (time point 2, ~day 14) | | | |
| Total | 161 (100) | 44 (100) | |
| ASB tenderness | 84 (52) | 36 (82) | 0.001* |
| Pain on thumb-index finger pinch | 43 (27) | 21 (48) | 0.013* |
| Scaphoid tubercle tenderness | 56 (35) | 36 (82) | <0.001* |
| Pain on axial compression of thumb | 52 (32) | 17 (39) | 0.43* |
| Decreased range of thumb movement | 45 (28) | 20 (46) | 0.043* |
| ASB pain on ulnar deviation | 63 (39) | 35 (80) | <0.001* |
| ASB pain on radial deviation | 66 (41) | 31 (71) | 0.001* |

* Chi-squared; ASB: Anatomical snuff box

Zero factors=0%

One factor=2%

Two factors=20%

Three factors=39%

Four factors=74%

and this gave a sensitivity of 77% and a specificity of 73% for a prognosis of fracture with three or more factors.

For the combined demographic factors and clinical signs obtained at initial presentation and two weeks after injury the independent predictors of fracture were male gender ($p=0.002$, CI 1.7-14.0), sports injury ($p=0.004$, CI 1.5-11.6), ASB pain on ulnar deviation of the wrist within 72 hours ($p<0.001$, no CI calculated) and two week scaphoid tubercle tenderness ($p<0.001$, CI 3.9-20.0). The probability of fracture in this model is:

Zero factors=0%

One factor=4%



Two factors=10%

Three factors=34%

Four factors=91%

and this gave a sensitivity of 82% and a specificity of 80% for a prognosis of fracture with three or more factors.

For the combined demographic factors and week 2 clinical signs alone the independent predictors of fracture were male gender ($p=0.002$, CI 1.7-12.6), sports injury ($p=0.004$, CI 1.6-10.5), ASB pain on ulnar deviation of the wrist ($p=0.003$, CI 1.7-13.3) and scaphoid tubercle tenderness ($p<0.001$, CI 2.3-17.0). The probability of fracture in this model is:

Zero factors=0%

One factor=2%

Two factors=15%

Three factors=46%

Four factors=84%

and this gave a sensitivity of 73% and a specificity of 86% for a prognosis of fracture with three or more factors.

Clinical Prediction Rule 2 (Figure 2)

Given that subjects without ASB pain on ulnar deviation of the wrist within 72 hours of injury did not have a fracture ($n=72$, 32%), we developed a second rule in which

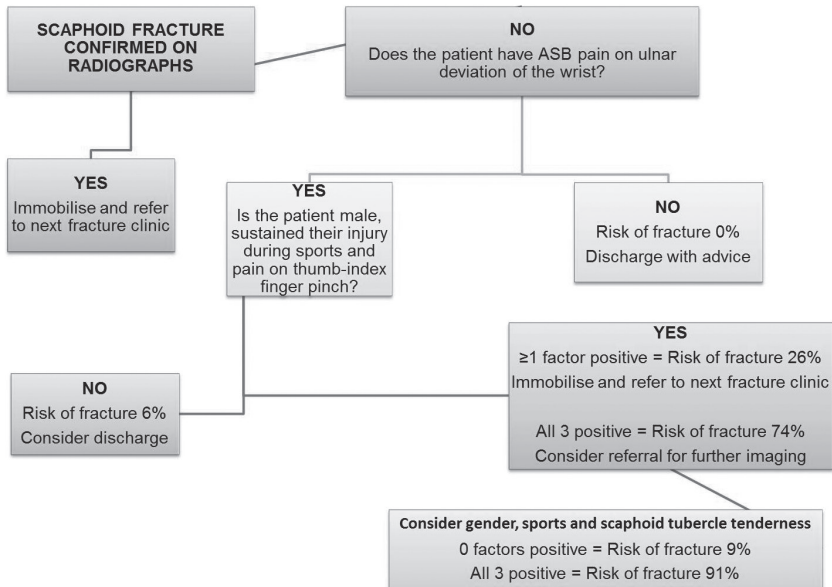


Figure 2: A potential management algorithm based on clinical prediction rule 2.

this was the primary step. Therefore, once the 72 patients with negative ASB pain on ulnar deviation of the wrist (Figure 3) at presentation were excluded, analysis of the remaining 151 patients showed that male gender, youth and thumb-index finger pinch pain were predictive of fracture at presentation on univariate analysis (all $p < 0.05$). Analysis of the week two clinical signs revealed ASB tenderness, thumb-index finger pinch pain, scaphoid tubercle tenderness and ASB pain on radial and ulnar deviation of the wrist were predictive on univariate analysis (all $p < 0.05$).

Using logistic regression analysis incorporating the demographic and clinical signs at presentation alone there were three independent predictors of fracture, which were males ($p = 0.003$, CI 1.5-7.7), sports ($p = 0.005$, CI 1.4-6.7) and pain on thumb-index finger pinch ($p = 0.037$, CI 1.0-5.6). The probability of fracture in this model is:

Zero factors=6%

One factor=26%

Two factors=45%

Three factors=74%

and this gave a sensitivity of 77% and a specificity of 60% for a prognosis of fracture with two or more factors.

For the combined demographic factors and clinical signs obtained at initial presentation and two weeks after injury the independent predictors of fracture were male gender ($p = 0.001$, CI 1.7-14.0), sports injury ($p = 0.003$, CI 1.5-11.6), and two week scaphoid tubercle tenderness ($p < 0.001$, CI 3.9-34.5). The probability of fracture in this model is:

Zero factors=9%

One factor=12%

Two factors=39%



Figure 3: Clinical assesment for ASB pain on ulnar deviation of the wrist. For a positive test, as the patient deviates the wrist in the ulnar direction, they will experience pain in the ASB at some point – this may be at a few degrees or at full ulnar deviation.



Three factors positive=91%

and this gave a sensitivity of 82% and a specificity of 70% for a prognosis of fracture with two or more factors.

For the combined demographic factors and week 2 clinical signs alone the independent predictors of fracture were the same as for those in the previous paragraph, since no clinical signs at initial presentation were independently significant adjusted for demographic factors and two week clinical signs.

Clinical Prediction Rule 3 – The occult fracture

An analysis of 168 patients, including seven occult fractures, was performed with the 55 radiographically confirmed fractures at presentation excluded to resemble the situation of trying to predict the presence of an occult fracture with normal initial radiographs. This revealed the only factor close to being significant as a predictor

Table 4: Diagnostic performance characteristics for the seven clinical signs used to detect the presence of the scaphoid fracture. Values represented include those determined with LCA and conventional analysis, with PPV and NPV determined using Bayes theorem.

| Clinical Sign | Latent Class Analysis | | | |
|--|-----------------------|------------|-----------------|------------|
| | Sensitivity (%) | 95% PI (%) | Specificity (%) | 95% PI (%) |
| Time point 1 (<72 hours) | | | | |
| ASB tenderness | 99 | 96-100 | 10 | 6-28 |
| Pain on thumb-index finger pinch | 82 | 72-90 | 52 | 43-61 |
| Scaphoid tubercle tenderness | 84 | 73-93 | 45 | 38-54 |
| Pain on axial compression of thumb | 88 | 80-95 | 45 | 39-56 |
| Decreased range of thumb movement | 78 | 66-87 | 46 | 37-57 |
| ASB pain in ulnar deviation/pronation | 90 | 81-98 | 50 | 42-58 |
| ASB pain in radial deviation/pronation | 88 | 78-95 | 49 | 41-57 |
| Time point 2 (~day 14) | | | | |
| ASB tenderness | 98 | 92-99 | 66 | 54-77 |
| Pain on thumb-index finger pinch | 70 | 60-82 | 89 | 80-93 |
| Scaphoid tubercle tenderness | 79 | 69-89 | 75 | 66-83 |
| Pain on axial compression of thumb | 73 | 62-82 | 86 | 80-92 |
| Decreased range of thumb movement | 67 | 50-78 | 87 | 80-92 |
| ASB pain in ulnar deviation/pronation | 95 | 87-99 | 79 | 86-86 |
| ASB pain in radial deviation/pronation | 87 | 77-95 | 76 | 67-82 |
| Fracture prevalence | 36.9% | | | |

ASB: Anatomical snuff box; PI: Probability Interval; CI: Confidence Interval; PPV: Bayes prevalence-adjusted positive predictive value (based on prevalence of 28%); NPV: Bayes prevalence-adjusted negative predictive value (based on prevalence of 28%)

of fracture was ASB pain on ulnar deviation of the wrist at presentation ($p=0.05$, CI 1.12- ∞). The probability of fracture in this model with no factor positive is 0%. With one factor positive the probability was 7%.

Given that subjects without ASB pain on ulnar deviation of the wrist within 72 hours of injury did not have a fracture ($n=72$), we analysed a fourth rule in which this was the primary step. Therefore, once the 72 patients with negative ASB pain on ulnar deviation of the wrist at presentation were excluded, analysis of the remaining 96 patients (168-72) showed no factor being significantly predictive of fracture at presentation.

Diagnostic performance characteristics of clinical signs (Table 4)

The prevalence of true fractures among suspected fractures according to LCA was 37% compared to 28% in the conventional analysis based on a reference standard.



| Conventional Calculations | | | | | |
|---------------------------|------------|-----------------|------------|---------|---------|
| Sensitivity (%) | 95% CI (%) | Specificity (%) | 95% CI (%) | PPV (%) | NPV (%) |
| 100 | 95-100 | 4 | 2-4 | 25 | 100 |
| 77 | 65-87 | 44 | 41-47 | 30 | 86 |
| 86 | 75-93 | 39 | 35-40 | 31 | 90 |
| 73 | 60-83 | 33 | 30-36 | 25 | 80 |
| 66 | 53-77 | 38 | 34-41 | 25 | 78 |
| 100 | 93-100 | 45 | 34-45 | 36 | 100 |
| 89 | 77-95 | 42 | 39-43 | 32 | 92 |
| 82 | 70-90 | 48 | 45-50 | 33 | 90 |
| 48 | 35-60 | 73 | 70-77 | 36 | 82 |
| 82 | 70-90 | 65 | 62-68 | 42 | 92 |
| 39 | 27-51 | 68 | 65-71 | 28 | 78 |
| 46 | 33-58 | 72 | 69-76 | 34 | 81 |
| 80 | 67-89 | 61 | 58-63 | 39 | 91 |
| 71 | 58-81 | 59 | 56-62 | 35 | 87 |
| 28% | | | | | |

On both LCA and conventional analysis, no one clinical sign was shown to have high sensitivity and specificity at initial presentation of injury. In particular, the PPV and specificity for all clinical signs was low. On conventional analysis, ASB tenderness had 100% sensitivity with a 100% NPV, but with a markedly poor specificity (4%) and PPV (25%). ASB pain on ulnar deviation of the wrist had the highest sensitivity (100%) and specificity (45%) within 72hrs of injury on conventional analysis, with the highest combined sensitivity (90%) and specificity (50%) on LCA. The highest PPV (36%) and NPV (100%) at presentation was also ASB pain on ulnar deviation of the wrist.

At two weeks post injury ASB tenderness had the highest sensitivity on both analyses, with a specificity that had increased on both analyses. However, ASB pain on ulnar deviation of the wrist had the highest combined sensitivity and specificity on LCA, with scaphoid tubercle tenderness the highest on conventional analysis that also had the best PPV and NPV. Pain on axial compression of the thumb and decreased range of thumb movement demonstrated, overall, the poorest diagnostic performance characteristics.

Discussion

In the present study, we have identified a combination of demographic and clinical risk factors associated with a true acute scaphoid fracture, which we have incorporated to develop clinical prediction rules. Implementation of these rules increases the prevalence of true scaphoid fractures among suspected fractures and allows the use of sophisticated imaging to be targeted at high risk patients. When the pre-test probability of a true fracture is around 40% or greater, tests such as MRI, CT or bone scan have better diagnostic performance characteristics, which means that they provide more useful and accurate information to help guide treatment^{23,33}.

Based on our clinical prediction rules, patients with a suspected scaphoid fracture are defined as high-risk if they are male, have sustained a sports injury, have ASB pain on ulnar deviation of the wrist and pain on thumb-index finger pinch at presentation, as well as persistent scaphoid tubercle tenderness at two weeks. We would suggest these patients would benefit from repeat assessment by a senior experienced member of the trauma team and referral for further imaging if radiographs are negative. Lower risk patients would initially either be discharged or splinted, and then re-evaluated two weeks after injury.

Our data demonstrates that even in patients that have as many as three of the four signs determined to be useful for clinical prediction rules the probability of a true fracture is still relatively low, around 40%. This fact, combined with the limitations of even the most sophisticated imaging and the lack of a consensus reference standard for a true scaphoid fracture^{23,33}, means that the diagnosis of scaphoid fracture is best

considered a probability rather than a certainty. If we can accept a small risk of missing a true fracture (e.g. $\leq 1\%$), it would improve the management of scaphoid fractures by limiting unnecessary immobilization and protection, as well as the use of expensive radiological tests.

In a prospective analysis of 78 patients with a suspected scaphoid fracture, a clinical prediction rule was developed incorporating a previous scaphoid fracture, a reduction in extension of $>50\%$ and a loss of supination strength of $\leq 10\%$ as predictive³⁴. This study established the possibility of a clinical prediction rule in the assessment of the suspected scaphoid fracture, although many of the tests are not widely used and are difficult to perform in the clinical setting, making the generalizability of this rule doubtful. We feel the clinical prediction rules we have set out are easy to implement in the clinical setting. In addition, the use of various clinicians in our study to record the clinical signs provides evidence for the generalizability of the rule.

We found the demographic factors most predictive of an acute scaphoid fracture are male gender and a sports mode of injury, as one previous study has shown³⁵. Epidemiological studies show a male predominance for fractures of the scaphoid and the most frequently quoted modes of injury are a fall on to the outstretched hand and sports injuries³⁵⁻³⁷. We have shown that the clinical signs most predictive of a true acute scaphoid fracture are ASB pain on ulnar deviation of the wrist at presentation and persistent scaphoid tubercle tenderness at two weeks post injury. With the risk of fracture calculated at 0% if ASB pain on ulnar deviation of the wrist at initial presentation is negative, our data would suggest this clinical sign is the 'key' sign suggestive of an acute scaphoid fracture rather than ASB tenderness. This is reinforced by our results which demonstrate that it is the best performing diagnostic test at presentation using either conventional analysis or LCA. A prospective analysis of 73 patients with a suspected scaphoid fracture found ASB pain on ulnar deviation of the pronated wrist to have a PPV of 52% with a NPV of 100%¹⁰, and suggested, as have we, that patients with a negative sign could be discharged from the ED. However, alternate studies have shown other clinical signs to be optimal in the diagnosis of the suspected scaphoid fracture^{11,34} and it is clear that further work in this area is needed. We have presented one of the largest series examining the clinical signs suggestive of a scaphoid fracture. Using both conventional analysis and LCA, no single sign was found to be adequately sensitive and specific^{4,5,8-11,30,38}. The results are overall comparable but also quite different from the reference standard based calculations, as was the case in a previous study that used latent class analysis to determine the performance characteristics of various diagnostic tests for the suspected scaphoid fracture³⁹. As with previous literature^{4,5,9-11,30}, the sensitivity of all physical tests is consistently greater than specificity, with the specificity of all tests increasing over time (with an associated drop in sensitivity). This emphasises the importance of repeat examination at two weeks post injury⁷. The best combined PPV and NPV was ASB



pain on ulnar deviation of the wrist, further emphasising the usefulness of this clinical sign. Sensitivity of anatomical snuffbox tenderness was greatest, although with poor specificity at both time points. Interestingly, pain on thumb-index finger pinch was most specific at both time points. A recent study concluded this sign and ASB pain on pronation of the forearm were most predictive of fracture when using MRI as the reference standard⁵. The greatest difference observed with LCA was the prevalence of the suspected fracture, which was 37% according to LCA versus 28% in the reference standard based analysis. It is difficult to compare this percentage to the literature as this cohort is not one of suspected scaphoid fractures only, but one combined with confirmed fractures. Other authors have found that 5-20% of patients who attend the ED with a suspected scaphoid fracture are ultimately found to have a true fracture^{2,22,23,34-36,40}.

It could be argued that only patients ≥ 16 years of age should have been included in this study. However, individuals aged ≥ 13 years are seen in many adult trauma centres throughout the UK, including ours, and the clinical scenario of the suspected scaphoid fracture is frequently encountered. Furthermore, there is now good evidence that the characteristics of scaphoid fractures in this age group are not significantly different to adults⁴¹.

A potential weakness of the study is that many healthcare providers administered the initial examinations and there was no attempt to standardize the clinical examination. We tried to minimise this via a detailed information leaflet to ensure members of the trained healthcare team were clear regarding testing for the clinical signs to be elicited. Furthermore, all patients were assessed by one of the senior authors with pre-determined definitions of the clinical signs. However, a low inter-observer variability could be assumed as the signs were based upon the patient's subjective interpretation of pain⁵.

As there is no consensus regarding a reference standard we used six week radiographs as our reference standard for fracture, which is widely used throughout the literature^{7,20,22,23,26}. We acknowledge that it may have been beneficial to perform a six week review on the 60 patients who were discharged at the two week point due to a complete absence of clinical signs and two sets of negative radiological imaging, however, this was stated as part of our reference standard and has been used in previous studies²⁷⁻²⁹. Furthermore, none of these patients have subsequently returned to our institution in the year following the study with recurrent wrist symptoms and we are the only musculoskeletal trauma service for the local adult population.

Although we used the generic term of day 14 or two week follow-up as the second time point, we have documented that patients were reviewed between 10-18 days after injury. This is an unavoidable issue in our centre, as in many institutions, that although it is routine to review patients at two weeks (14 days) post injury, this is not always exactly the case given timing and appointment constraints.

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