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■ UPPER LIMB

Sonographic bridging callus at six weeks following displaced midshaft clavicle fracture can accurately predict healing

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Aims
To evaluate if union of clavicle fractures can be predicted at six weeks post-injury by the presence of bridging callus on ultrasound.

Methods
Adult patients managed nonoperatively with a displaced mid-shaft clavicle were recruited prospectively. Ultrasound evaluation of the fracture was undertaken to determine if sonographic bridging callus was present. Clinical risk factors at six weeks were used to stratify patients at high risk of nonunion with a combination of Quick Disabilities of the Arm, Shoulder and Hand questionnaire (QuickDASH) ≥ 40, fracture movement on examination, or absence of callus on radiograph.

Results
A total of 112 patients completed follow-up at six months with a nonunion incidence of 16.7% (n = 18/112). Sonographic bridging callus was detected in 62.5% (n = 70/112) of the cohort at six weeks post-injury. If present, union occurred in 98.6% of the fractures (n = 69/70). If absent, nonunion developed in 40.5% of cases (n = 17/42). The sensitivity to predict union with sonographic bridging callus at six weeks was 73.4% and the specificity was 94.4%. Regression analysis found that failure to detect sonographic bridging callus at six weeks was associated with older age, female sex, simple fracture pattern, smoking, and greater fracture displacement (Nagelkerke R^2 = 0.48). Of the cohort, 30.4% (n = 34/112) had absent sonographic bridging callus in addition to one or more of the clinical risk factors at six weeks that predispose to nonunion. If one was present the nonunion rate was 35%, 60% with two, and 100% when combined with all three.

Conclusion
Ultrasound combined with clinical risk factors can accurately predict fracture healing at six weeks following a displaced midshaft clavicle fracture.

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Keywords: Nonunion, Clavicle, Ultrasound

Article focus
- Nonunion drives morbidity following midshaft clavicle fractures and is difficult to accurately predict.
- The aim of this study was to establish the accuracy of sonographic bridging callus to predict ultimate fracture healing at six months post-injury.

Key messages
- Sonographic bridging callus at six weeks following fracture predicts union in 99% of cases and was detected in approximately two-thirds of all patients.
- When absent, nonunion occurred in 41% of cases at six months.
- Further refinement of nonunion prediction can be achieved when combined with clinical markers of poor recovery at six weeks post-injury.

Strengths and limitations
- This was a large prospective study using a validated ultrasound technique.

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- Conventional ultrasound relies on operator image acquisition and interpretation.

Introduction

There is increasing evidence that acute plate fixation of mid-shaft clavicle fractures does not result in long-term functional advantage over nonoperative management provided that union occurs.[1-5] Early operative fixation for only those patients destined to develop nonunion would reduce the overall intervention rate, minimize prolonged delay to treatment, and potentially be a more cost-effective approach.[6]

The ability to accurately predict nonunion following a displaced mid-shaft clavicle fracture is challenging. Currently, prediction is largely based on patient or fracture characteristics at the time of presentation.[7,8] We have recently evaluated all of the available clinical, functional, and radiological data in the early recovery phase following nonoperative treatment and found this improves nonunion diagnostic accuracy. At six weeks post-injury, a combination of a Quick Disabilities of the Arm, Shoulder and Hand questionnaire (QuickDASH) score of ≥ 40, fracture movement on examination, and absence of callus on radiographs were significant predictors on regression modelling.[9]

Improving the accuracy of this model further is difficult. Radiological callus at six weeks can be found in patients who ultimately go onto nonunion and, conversely, can be absent in patients who progress to union.[10-12] Bridging callus, however, accurately predicts union in long bone fractures but is rarely detected before three months on radiograph.[13-15] Ultrasound may have the ability to evaluate bridging callus at the fracture site prior to radiographs from as early as three to six weeks following injury.[16-18] The application of ultrasound to predict fracture healing has been employed in two studies of tibial fractures to date where it has been shown to detect union prior to radiographs.[19,20]

The use of ultrasound to detect bridging callus at six weeks following a displaced mid-shaft clavicle fracture may further improve the accuracy to predict fracture healing. The primary aim of this study was to establish the accuracy of sonographic bridging callus to predict ultimate fracture healing at six months post-injury.

Methods

A consecutive series of patients who presented to our trauma unit with a mid-shaft clavicle fracture were recruited over a two-year period. Inclusion criteria included a fully displaced mid-shaft clavicle fracture with no residual cortical contact, with or without comminution (Edinburgh Type 2 fractures),[21] age over 16 years at time of injury, and ability to attend for follow-up.

All patients who met the inclusion criteria were referred to a single specialist clinic during the study. On first clinic review with an orthopaedic specialist, patients were consulted on operative and nonoperative treatment options for displaced mid-shaft fractures. The patients who opted for acute fixation following injury were excluded. The decision to undertake acute fixation was based solely on patient request.

Over the study period 139 fractures eligible for recruitment were identified, of which six patients opted for acute plate fixation (4.3%, n = 6/139). Exclusion criteria are summarized in Figure 1. A total of 125 patients undergoing nonoperative management were recruited into the study, of whom 112 patients completed follow-up at six months and were analyzed (89.6%, n = 112/125).

The nonoperative management protocol was a sling for three weeks post-injury, after which patients received range of motion and strengthening exercises under the supervision of a physiotherapist using a standardized regime.

Functional assessment. Patients underwent a standardized clinical review at six, 12, and 24 weeks using a questionnaire of symptoms and examination findings (Table I). Self-reported QuickDASH and EuroQol five-dimension questionnaire (EQ-5D) were completed.[22]

Radiological assessment. Radiographs of the clavicle were taken at each clinical appointment, in keeping with standard practice with a single erect anteroposterior view. These were graded prospectively for the presence of callus formation at six weeks in comparison to the radiograph at time of injury. Callus was defined as calcified material at the fracture site with or without clear bridging of the fracture. The overall displacement of the fracture was estimated using an erect calibrated radiograph measuring the distance between the ends of the proximal and distal fragment from the centre of the medullary canal using a validated technique.[7]

All patients who had ongoing pain at rest or on movement, palpable movement at the fracture, or absent bridging callus on radiograph at six months underwent a CT scan. Union on CT was defined as bridging callus of more than 50% of the cortical diameter between fracture fragments on 3D reconstruction.[23] Patients who had ongoing symptoms and nonunion on CT at six months were offered operative exploration and plate fixation.

Ultrasound image details and callus interpretation. At each clinic visit, all patients underwent a standardized ultrasound scan performed by an orthopaedic surgeon with training in ultrasound (JAN). A Sonix L14-5 MHz/38 mm ultrasound probe (BK Medical North, Peabody, Massachusetts, USA) was used and set to 3 MHz to 7 MHz and calibrated to 6 cm depth (a standard setting for superficial musculoskeletal ultrasound evaluations).

Ultrasound interpretation was carried out using a validated technique.[24] Sonographic bridging callus was defined as a continuous hyperechoic signal, with a similar echo intensity (EI) to that of the cortical bone, bridging the fracture ends. The fracture site was imaged

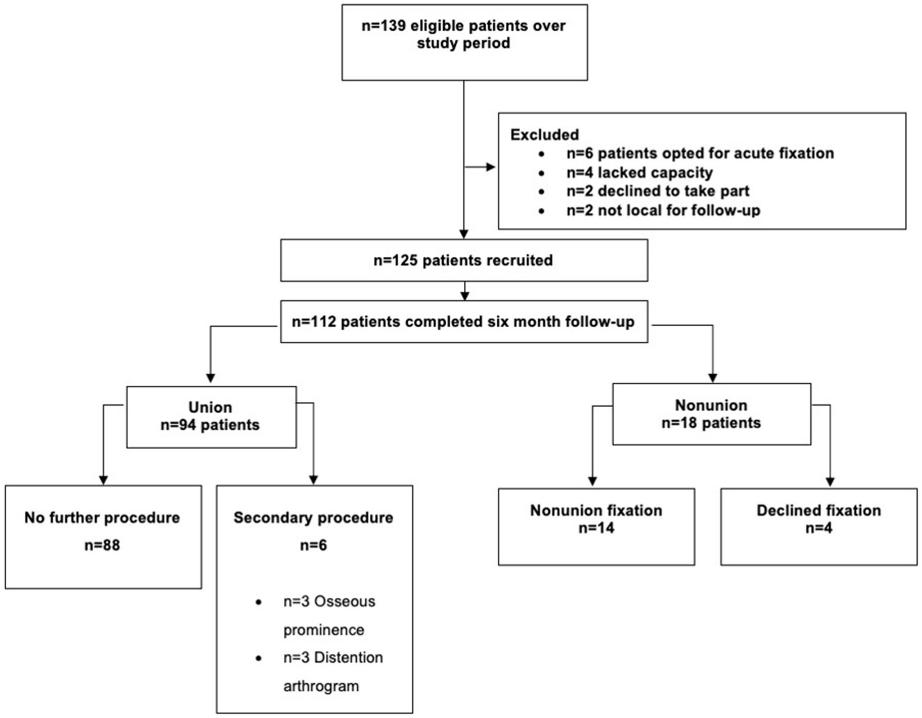

Fig. 1

Flow diagram of patient recruitment and outcome.

Table I. Protocol of patient assessment.

Assessment category	Criterion
History	Night pain at rest in bed
	Unable to dress normally without assistance
	Sling no longer required at any timepoint
	Returned to work with or without adaptation
	Returned to usual activities including hobbies and sport
Examination	Fracture site tenderness (pain on palpation of fracture)
	Hand to head (palm to forehead without assistance)
	Hand to head and elbow to back (active internal rotation of shoulder with elbow on lumbar spine)
	Movement at fracture (crepitus or movement of fracture on palpation with passive movement of the shoulder)
	Abduct shoulder > 90° in scapula plain with elbow extended)
Patient outcome scores	QuickDASH
	EQ-5D
Radiograph	Bridging or non-bridging callus present
Ultrasound	Sonographic bridging callus present

EQ-5D, EuroQol five-dimension questionnaire ; QuickDASH, Quick Disabilities of the Arm, Shoulder and Hand questionnaire.

in both the long and short axis. The probe was carefully rocked, tilted, and rotated at the fracture site to ensure perpendicular visualization of the callus and to avoid anisotropy, which may produce a false anechoic signal (loss of signal) (Figure 2). To avoid confusion with fracture comminution, a complete unbroken view of the bridging callus was required between the fracture fragments without any obvious gapping. For segmental fractures this was required at both fracture sites.

Scans were given a unique code at time of capture. Judgement for the presence of sonographic bridging callus was carried out by the lead author (JAN), who was blinded to the patient's details, radiograph, and clinical union outcome. The repeatability of this technique was established with a series of 20 scans by four independent reviewers (one musculoskeletal radiologist and three orthopaedic surgeons (CMR, WMO, JAN)), which revealed an intraclass correlation of 0.82 (95% confidence interval (CI) 0.68 to 0.91), giving excellent agreement.

Statistical analysis. Statistical analysis was performed using SPSS version 24 (IBM, Armonk, New York, USA). Data were tested for normal distribution with the D'Agostino and Pearson test. Linear variables were assessed using the independent-samples *t*-test for parametric data or the Mann-Whitney U test for nonparametric data. Differences between dichotomous data were assessed by using the chi-squared test and odds ratio (OR). Logistic regression was used to determine the influence of variables present at time of injury on six-week sonographic bridging callus detection. Forward and backward conditional regression was used to ensure stability of predictors. Clinically relevant predictors identified on univariate analysis with a

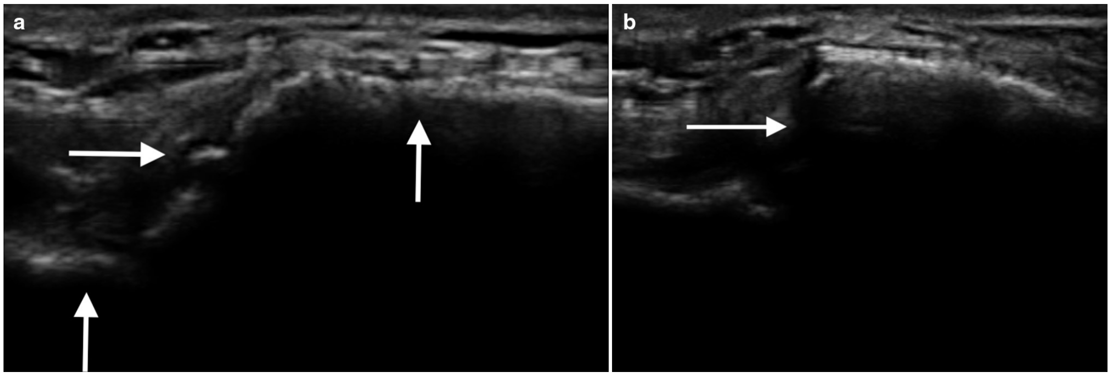

Fig. 2

a) Ultrasound example of six week bridging callus. Cortical surface of bone (vertical arrows), bridging callus (horizontal arrow). Note acoustic shadow below surface of bone. b) Example of anisotropy or loss of ultrasound signal during the same scan sequence. Orientation of the probe that is not perpendicular to the callus results in loss of signal of callus, as shown by the horizontal arrow.

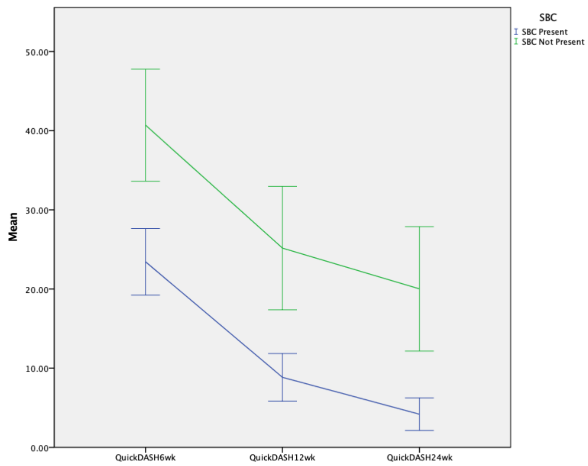

Fig. 3

Line diagram of sonographic bridging callus (SBC) present and not present and influence on Quick Disabilities of the Arm, Shoulder and Hand questionnaire (QuickDASH).

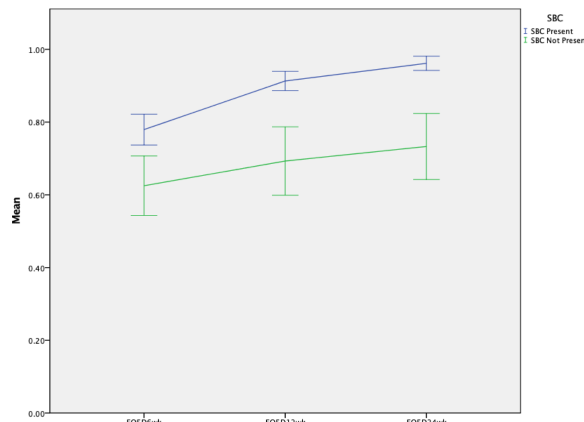

Fig. 4

Line diagram of sonographic bridging callus (SBC) present and not present and influence on EuroQol five-dimension questionnaire (EQ-5D).

p-value of < 0.1 were inserted into a single unadjusted model.

The absence of sonographic bridging callus was modelled with clinical risk factors for nonunion at six weeks post-injury from a published regression model; QuickDASH ≥ 40, fracture movement on examination, and no callus on six-week radiograph.[9] This was used to determine if the accuracy of nonunion prediction was improved when combining sonographic callus findings with clinical recovery.

Ethics and source of funding. Ethical approval was prospectively obtained from the local Research Ethics Committee (reference number 06/S1103/51).

Results

The mean age was 41.3 years (SD 17.6, 16 to 73) and 77% were male (n = 86/112). Of the 13 patients lost to follow-up and six patients who chose acute fixation, no evidence of statistically significant differences in demographics (age, sex, smoking status) and fracture characteristics (overall displacement or comminution) were found compared to those who completed the study.

The nonunion incidence was 16.7% in the cohort (n = 18/112) and this was associated with increasing age (p = 0.015, independent-samples *t*-test), fracture displacement (p = 0.006, independent-samples *t*-test) and smoking (p = 0.002, chi-squared test) on univariate analysis (Table II). The functional outcome scores were significantly better at six months for patients that united their fractures compared to those that developed nonunion; six-month QuickDASH (6.4 vs 29.7, p < 0.001, independent-samples *t*-test) and EQ-5D (0.92 vs 0.64, p < 0.001, independent-samples *t*-test).

The presence of sonographic bridging callus at six weeks was strongly associated with superior patient-reported outcome measures at each timepoint over the six months post-injury when compared against those patients who lacked it (Figures 3 and 4, Table III).

Table II. Patient demographics of the study and six week clinical findings.

Parameter	Union (n = 94)	Nonunion (n = 18)	p-value	OR	95% CI
Patient demographic					
Mean age, yrs (95% CI)	39.6 (35.9 to 43.3)	50.6 (44.2 to 56.9)	0.015*	N/A	N/A
Male, n (%)	75 (79.8)	11 (61.1)	0.086†	2.5	0.9 to 7.3
Smoker, n (%)	13 (13.8)	8 (44.4)	0.002†	5	1.7 to 15.0
Right side, n (%)	42 (44.7)	9 (50)	0.706†	0.8	0.3 to 2.3
Dominant side, n (%)	44 (46.8)	10 (55.6)	0.496†	0.7	0.3 to 1.9
Injury mechanism, n (%)					
High-energy	14 (14.9)	3 (16.7)	0.848†	1.1	0.3 to 4.5
Fracture findings					
Comminution, Edinburgh 2B, n (%)	25 (26.6)	3 (16.7)	0.373†	0.5	0.1 to 2.1
Mean fracture displacement, mm (95% confidence interval)	23.0 (21.6 to 24.4)	28.0 (24.6 to 31.3)	0.006*	N/A	N/A
History, n (%)					
Night pain	44 (46.8)	15 (83.3)	0.004†	5.7	1.5 to 20.9
Unable to dress normally	14 (14.9)	7 (38.9)	0.017†	3.6	1.2 to 11.0
Sling still required	7 (7.4)	5 (27.8)	0.011†	4.8	1.3 to 17.3
Have not returned to work	26 (27.7)	11 (61.1)	0.006†	4.1	1.4 to 11.7
Have not returned to usual activities	70 (74.5)	15 (83.3)	0.420†	1.7	0.5 to 6.4
Examination, n (%)					
Fracture site tenderness	21 (22.3)	11 (61.1)	0.001†	5.5	1.9 to 15.8
Inability to reach hand to head	5 (5.3)	5 (27.8)	0.002†	6.8	1.7 to 26.9
Inability to reach hand to head and elbow to back	7 (7.4)	4 (22.2)	0.054†	3.5	0.9 to 13.7
Movement at fracture	8 (8.5)	5 (27.8)	0.019†	4.1	1.2 to 14.6
Inability to abduct shoulder beyond 90°	10 (10.6)	9 (50)	< 0.001†	8.4	2.7 to 26.1
QuickDASH ≥ 40	22 (23.4)	11 (61.1)	0.001†	5.1	1.8 to 14.9
Patient outcome scores					
Mean QuickDASH (95% CI)	27.2 (23.1 to 31.3)	44.2 (32.9 to 55.5)	0.002*	N/A	N/A
Mean EQ-5D (95% CI)	0.74 (0.71 to 0.78)	0.61 (0.46 to 0.76)	0.020*	N/A	N/A
Radiograph, n (%)					
Callus 6-wk radiograph	59 (62.8)	6 (33.3)	0.020†	3.4	1.2 to 9.8
Callus 12-wk radiograph	92 (97.9)	9 (50)	< 0.001†	9.2	4.6 to 18.2
Callus 24-wk radiograph	94 (100)	10 (55.6)	< 0.001†	10.4	5.8 to 18.7
Ultrasound, n (%)					
Sonographic briding callus 6 wks	69 (73.4)	1 (5.6)	< 0.001†	46.9	5.9 to 371.1
Sonographic briding callus 12 wks	82 (87.2)	1 (5.6)	< 0.001†	116.2	14.1 to 954.2
Sonographic briding callus 24 wks	94 (100)	1 (5.6)	< 0.001†	N/A	N/A

*Independent-samples *t*-test.
†Chi-squared test.
CI, confidence interval; EQ-5D, EuroQol five-dimension questionnaire; N/A, not applicable; OR, odds ratio; QuickDASH, Quick Disabilities of the Arm, Shoulder and Hand questionnaire.

Logistic regression for sonographic bridging callus detection at six weeks post-injury was modelled on age, sex, smoking, energy, comminution, and fracture displacement. Sonographic callus was less likely to be detected with increasing age (p = 0.004), female sex (p = 0.013), simple fractures (Edinburgh 2B1; p = 0.027), smoking (p = 0.009), and greater overall fracture displacement (p < 0.001) (Forward and Backward Conditional entry, Nagelkerke $R^2 = 0.48$)(Table IV).

Fracture healing and association with six-week sonographic bridging callus. At six weeks following injury, sonographic bridging callus was found in 62.5% of the cohort (n = 70/112), increasing to 74.1% (n = 83/112) by 12 weeks. This was in contrast to radiographs at six weeks, where callus was found in 52.7% of the whole cohort (n = 59/112) but only bridging in 22.3% of patients (n = 25/112).

When sonographic bridging callus was found, 98.6% (n = 69/70) of these patients united their fractures by six months (Figures 5 and 6). Of the patients without sonographic bridging callus at six weeks, 40.5% (n = 17/42) went on to nonunion. One patient who ultimately developed a hypertrophic nonunion was classified incorrectly with sonographic bridging callus. Therefore, when sonographic bridging callus was detected it had a 98.6% positive predictive value (PPV) for union and a 42.9% negative predictive value (NPV) when absent (chi-squared test, p < 0.001, odds ratio

Table III. Comparison of demographics and functional outcomes of those with and without sonographic bridging callus at six weeks post-injury.

Parameter	Bridging callus (n = 70)	No callus (n = 42)	p-value	OR	CI 95%
Patient demographic					
Mean age, yrs (range)	36.7 (32.5 to 40.9)	49.1 (44.6 to 53.7)	< 0.001*	N/A	N/A
Male, n (%)	61 (87.1)	25 (59.5)	0.001†	4.6	1.8 to 11.7
Smoker, n (%)	7 (10)	14 (33.3)	0.002†	4.5	1.6 to 12.4
Union outcome					
Union at six mths, n (%)	69 (98.6)	25 (59.5)	< 0.001†	46.9	5.9 to 371.1
Injury mechanism					
High-energy, n (%)	7 (10)	10 (23.8)	0.049†	2.8	1.0 to 8.1
Fracture findings					
Comminution, Edinburgh 2B, n (%)	22 (31.4)	6 (14.3)	0.043†	0.4	0.1 to 1.0
Mean fracture displacement, mm (range)	21.9 (20.4 to 23.4)	26.9 (24.8 to 29.1)	< 0.001*	N/A	N/A
Callus present on six-wk radiograph, n (%)	24 (34.3)	2 (4.8)	< 0.001†	10.4	2.3 to 47.0
Mean QuickDASH (range)					
6 wks	23.4 (19.2 to 27.6)	40.7 (33.6 to 47.8)	< 0.001*	N/A	N/A
12 wks	8.8 (5.8 to 11.8)	25.2 (17.4 to 33.0)	< 0.001*	N/A	N/A
24 wks	4.2 (2.1 to 6.2)	20.0 (12.2 to 27.9)	< 0.001*	N/A	N/A
Mean EQ-5D (range)					
6 wks	0.78 (0.74 to 0.82)	0.63 (0.54 to 0.71)	< 0.001*	N/A	N/A
12 wks	0.91 (0.89 to 0.94)	0.69 (0.60 to 0.79)	< 0.001*	N/A	N/A
24 wks	0.96 (0.94 to 0.98)	0.73 (0.64 to 0.82)	< 0.001*	N/A	N/A

*Independent-samples *t*-test.
†Chi-squared test.
CI, confidence interval; EQ-5D, EuroQol five-dimension questionnaire; N/A, not applicable; OR, odds ratio; QuickDASH, Quick Disabilities of the Arm, Shoulder and Hand questionnaire.

Table IV. Logistic regression of detection of sonographic bridging callus at six weeks using 'forward conditional' methodology.

Parameter	p-value	OR	95% CI
Age	0.004	1.05	1.01 to 1.08
Female	0.013	4.39	1.37 to 14.08
Simple fracture pattern (Edinburgh 2B1)	0.027	4.05	1.17 to 13.96
Smoker	0.009	5.14	1.50 to 17.63
Fracture displacement	< 0.001	1.16	1.07 to 1.25

Nagelkerke R2 = 0.48 model fit.
CI, confidence interval; OR, odds ratio.

Table V. Absence of sonographic bridging callus in combination with six week clinical risk factors (Quick Disabilities of the Arm, Shoulder and Hand questionnaire score ≥ 40, no callus on radiograph, and fracture mobility on exam).

Number of risk factors	Observed nonunion, %	Predicted NNT	At risk, %
3	100	1	2.7
2	60	1.7	9.9
1	35	2.9	17.9

NNT, number needed to treat with plate fixation to prevent nonunion.

46.9). Alternatively, 73.4% sensitivity to detect union and 94.4% specificity.

None of the three clinical risk factors for nonunion were present in 38.4% (n = 43/112) of the cohort, of which only 4.7% developed nonunion (n = 2/43). The remainder had one or more risk factor present (n = 69/112), and when combined with absent sonographic bridging callus (n = 34/69) the nonunion prediction could be further refined. If just these patients underwent fixation, and assuming union is successfully achieved following surgery, the numbers needed to treat (NNT) to prevent one nonunion can be estimated. If there was absent sonographic bridging callus with one risk factor the nonunion risk was 35% (NNT 2.9), if two clinical predictors were present this increased to 60% (NNT 1.7), and when all three were present the nonunion incidence was 100% (NNT 1.0) (Table V).

Discussion

Ultrasound evaluation of bridging callus may have a useful role following nonoperative management of clavicle fractures to predict healing. In a prospective cohort of 112 displaced mid-shaft clavicle fractures that underwent nonoperative management, we found that ultrasound detection of bridging callus was strongly predictive of ultimate union. When bridging callus was observed on ultrasound at six weeks post-injury, it predicted union in 99% of cases. In combination with a previously validated model of clinical predictors of nonunion, fracture healing estimation can be

Fig. 5

Nonunion with absence of bridging callus as seen in a 37-year-old male. a) Six-week ultrasound showing absent bridging callus. b) Six-month anteroposterior radiograph with atrophic nonunion.

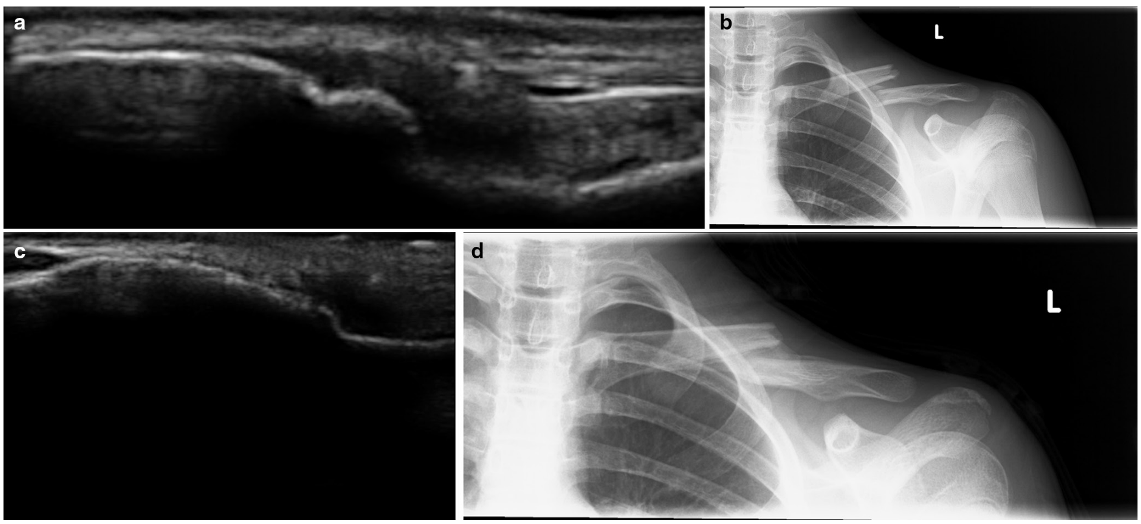

Fig. 6

Remodelling of bridging callus on ultrasound as seen in an 18-year-old male. a) Six-week sonographic bridging callus at fracture site; b) six-week anteroposterior radiograph showing minimal callus formation; c) 12-week ultrasound scan showing remodelling of sonographic bridging callus; d) 12-week anteroposterior radiograph with bridging callus now evident.

further refined. To our knowledge, this is the first study to explore the use of ultrasound to predict nonunion following a clavicle fracture, or indeed any fracture which has been nonoperatively managed.

The role of acute fixation for mid-shaft clavicle fractures is contentious. Despite early trials suggesting a sustained benefit of plate fixation over nonoperative management at one year,[25-27] increasing evidence suggests that functional outcomes are similar if union occurs.[1,2,5,28-30] Therefore, rather than the perceived malunion causing morbidity, it is the development of nonunion that likely accounts for the majority of dissatisfaction and poor function at one year post-injury.[31-33] The ability to target those at high risk of nonunion would decrease the morbidity associated with prolonged delay to treatment and reduce unnecessary intervention in those patients who would likely unite with nonoperative treatment.

We have previously shown that a six-week clinical assessment has superior accuracy to predict fracture healing when compared to estimate at time of injury alone, however the model has limitations and relies on radiological callus detection.[7] Callus on ultrasound is thought to have an increasingly hyperechoic ultrasound signal as it calcifies and reconstitutes into cortical bone, and this does not appear to be based on dense mineralization as required for traditional radiographs.[16,34] The ability to detect callus formation at three weeks following a fracture was first described by Ricciardi et al[35] and Maffuli and Thornton[17] soon after, who described the lack of sonographic callus in a patient with a humeral shaft nonunion. Following this, Moed et al[18,19] reported that ultrasound can predict union prior to radiographs in a series of tibial shaft fractures following intramedullary nailing. They reported that bridging callus could be found at a mean of 6.5 weeks on ultrasound versus 19 weeks on radiographs, with a PPV of 97% to predict union when present. This finding has recently been replicated by an independent group examining a series of tibial fractures postoperatively, where ultrasound was able to detect bridging callus prior to radiographs and this correlated with union.[20]

Our work is the first to evaluate the prognostic use of ultrasound to identify patients at high risk of nonunion following a clavicle fracture. Six-week sonographic bridging callus was more likely to be absent with increasing age, female sex, absence of comminution, smoking, and increasing fracture displacement. When present, the functional recovery was superior over the first six months following injury. We have previously evaluated our 2D scanning technique between observers and found excellent agreement.[24] The detection of bridging callus on six-week ultrasound in that pilot study of 20 patients was 80% sensitive and 100% specific for subsequent union. In this larger cohort of 112 patients, we validated this result with 73.4% sensitivity to detect union and 94.4% specificity. Whether this holds true for other long bone fractures is an interesting premise for future work. The combination of absent bridging callus and clinical risk factors for poor fracture healing at six weeks post-injury enabled further nonunion prediction. Unfortunately, our study was underpowered to evaluate the nonunion predictors specific to this cohort with regression modelling, given the modest number of nonunion events. We therefore used a previously validated model of six-week clinical risk factors for this study.[9]

The main limitation with conventional ultrasound is the reliance on the operator for image acquisition, and orthopaedic surgeons' unfamiliarity with image interpretation. Additionally, there is the risk of loss of signal and incorrect image evaluation if an ultrasound beam is not perpendicular to the site of interest (anisotropy). One surgeon (JAN) performed all of the ultrasound scans and image interpretation. Bias was kept to a minimum by grading the anonymous scans independently of the clinical review of patients to avoid potential interpretation bias.

In this study at least one patient was misinterpreted with bridging callus who was later diagnosed with a hypertrophic nonunion at six months post-injury. In equivocal cases, CT evaluation beyond three months may play a role in detect bridging callus when ultrasound cannot make an adequate judgement.[23] Specific fracture patterns may also affect the ability to detect bridging callus. A more detailed analysis of sonographic bridging callus and fracture patterns using 3D modelling may enable more accurate image interpretation.

In conclusion, ultrasound evaluation of bridging callus following a displaced mid-shaft clavicle fracture has excellent accuracy to predict fracture healing. When combined with clinical risk factors for nonunion at six weeks post-injury, the absence of sonographic bridging callus may enable targeted operative fixation in select patients.

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