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1

## TITLE

2 Does Correction of Carpal Malalignment Influence the Union Rate of Scaphoid Nonunion  
3 Surgery?

## ABSTRACT

4

5 The aim of this retrospective study was to assess the relation between carpal malalignment  
6 correction and radiological union rates in surgery for scaphoid nonunions. Fifty-nine  
7 scaphoid waist fracture nonunions treated with open reduction and palmar tricortical  
8 autograft were divided according to their pre- and post-surgery scapholunate (SL) and  
9 radiolunate (RL) angles. We found that carpal malalignment failed to correct in 32 out of 59  
10 cases (54.2%) despite meticulous surgical technique and placement of an appropriately  
11 sized wedge-shaped graft. Forty-three fractures (72.9 %) united at a mean of 4.47 months  
12 (range 3–11). Twenty-one of the 27 fractures with post-operative SL and RL angles within  
13 the normal range united, whereas 22 of the 32 remaining fractures which failed to achieve  
14 post-operative angles within the normal range went on to union. The post-operative SL and  
15 RL angles were not related to union. Our findings suggest that in scaphoid fracture  
16 nonunion surgery, carpal malalignment may not be corrected in a substantial proportion of  
17 patients, but such correction may not be essential for bony union. Our findings also show  
18 that there is no marked collapse of the scaphoid graft in the early post-operative period.

19 Level of evidence: IV.

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## INTRODUCTION

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Scaphoid fractures are the most common fracture of the carpus with an estimated incidence of 1.47 fractures per 100,000 person-years (Van Tassel et al., 2010). Between 60% and 69% of fractures occur through the middle third of the scaphoid (Jørgsholm et al., 2020). The overall risk of developing a scaphoid nonunion is between 2% and 5% (Jørgsholm et al., 2020).

In scaphoid waist fractures, palmar angulation and shortening of the scaphoid may occur, which is considered to be due to the action of opposing forces from the lunate and scapho-lunate ligaments (Berdia and Wolfe, 2001; Fisk, 1970). Consequently, the nonunited scaphoid may be flexed (a ‘humpback deformity’) with an associated carpal malalignment and a dorsal intercalated segment instability (DISI) deformity. Studies have suggested the DISI deformity may be a risk factor for nonunion and may also compromise clinical outcomes. Hence, one of the surgical goals in the treatment of scaphoid nonunion is to correct any carpal malalignment, aiming to increase the likelihood of achieving bony union and to improve clinical outcomes (Mack et al., 1984; Ruby and Leslie, 1987; Szabo and Manske, 1988).

Biomechanical studies in cadaveric specimens have suggested that accurate correction of scaphoid angulation can result in restoration of normal carpal alignment and wrist movements (Burgess, 1987). In assessing carpal alignment, studies have suggested high interobserver reliability with measurement of the scapholunate (SL) and radiolunate (RL) angles. Surgeons measure these angles for preoperative planning to decide on factors such as surgical approach and the type of graft to be used, and intra-operatively to quantify the degree of deformity correction (Roh et al., 2014).

45 Several bone grafting techniques have been described to deal with a scaphoid nonunion  
46 with a flexion deformity such as the Russe cancellous graft and anterior wedge-shaped  
47 corticocancellous graft (Cooney et al., 1988; Fernandez, 1984; Russe, 1960). In addition to  
48 achieving a bony union, the graft aims to correct the scaphoid flexion deformity, and to  
49 secondarily correct the kinetics of the proximal carpal row to restore normal carpal  
50 alignment and height. A wedge-shaped tricortical bone graft inserted palmarly is a widely  
51 used technique. Nonetheless, there is limited evidence on the ability of this technique to  
52 correct carpal malalignment.

53 The aim of this study was to determine the ability of the palmar wedge-shaped cortico-  
54 cancellous graft to restore normal carpal indices and explore whether the correction of  
55 carpal malalignment may influence the union rate of scaphoid nonunion surgery.

## METHODS

56

57 This study was performed at a National Health Service (NHS) Trust in the United Kingdom  
58 and had approval by the audit department of our institution (Ref. 1636). The study was  
59 performed in line with the World Medical Association Declaration of Helsinki. As data  
60 utilised were anonymous and part of routine clinical care, no specific consent was sought  
61 from patients.

62 A consecutive series of 59 patients undergoing surgery for a scaphoid waist fracture  
63 nonunion between 2011 and 2019 was studied. Patients with proximal pole nonunions were  
64 excluded. All cases were treated by the most senior author using a palmar tricortical wedge  
65 graft.

66

### *Surgical technique*

67 Under general anaesthetic and through a palmar approach to the scaphoid, the nonunion  
68 site was confirmed using image intensifier. The nonunion was then excised back to bleeding  
69 bone. The wrist was extended and supinated, and the nonunion site opened using a laminar  
70 spreader. Measurement of the gap to allow an appropriately sized bone graft was then  
71 made aiming to correct any scaphoid flexion deformity. A tricortical graft of the same  
72 dimensions was harvested from the ipsilateral iliac crest and inserted into the scaphoid  
73 defect. A cannulated headless compression screw (Acutrak 2, Acumed, Oregon, USA) was  
74 inserted either through a distal entry point (where possible as this avoided a further dorsal  
75 skin incision), or a proximal entry point (to allow a more central placement of the screw  
76 along the axis of the scaphoid). In all cases, the patients had pre-operative radiographs and  
77 had RL and SL angles calculated to assist in surgical planning. Intra-operatively, any change  
78



79 to carpal alignment was assessed following fixation of the graft using image intensifier  
80 images.

81

### 82 *Radiological assessment*

83 Prior to surgery, a scaphoid series of four radiographic images were performed to confirm  
84 the nonunion, assess the degree of scaphoid flexion, the presence of scaphoid cysts, and the  
85 size of the proximal pole bone fragment, to aid surgical planning. Forty-seven patients had a  
86 pre-surgery CT scan to confirm the nonunion if this was in doubt and to aid surgical  
87 planning. Post-surgery scaphoid series radiographs were obtained at six weeks and three  
88 months to assess for bony union. We defined bony union radiologically using the method of  
89 Dias (2001), with evidence of bridging callus, filling in of any lucency at nonunion site, and  
90 no evidence of metalwork loosening. Nonunion was defined by persisting lucency,  
91 displacement of bony fragments or loosening of metalwork. A CT scan was performed if  
92 there was any doubt regarding bony union on plain radiographs at three months. Twenty-  
93 four out of 59 patients had a post-operative CT scan to confirm bony union.

94 The angles were measured retrospectively by two independent orthopaedic registrars  
95 separate to the treating team. The SL and RL angles were measured from a true lateral view  
96 of the wrist pre-operatively, intraoperatively using image intensifier, and postoperatively  
97 from the final set of radiographs, usually at three months, using a standard technique (Roh  
98 et al., 2014). For the SL angle, a line was firstly drawn intersecting the palmar aspects of the  
99 distal and proximal poles of the scaphoid (S). A second line was drawn perpendicular to a  
100 line intersecting the palmar and dorsal prominence of the lunate (L). The angle produced  
101 between these two lines was measured as the SL angle (Figure 1). The RL angle was

102 measured between a line is firstly drawn along the longitudinal axis of the radius (R) and a  
103 second line drawn perpendicular to a line intersecting the palmar and dorsal prominence of  
104 the lunate (L). The measurements from the pre- and post-surgery radiographs were taken  
105 on two separate occasions, two months apart, by a different observer on each occasion.

106

### 107 *Statistical analysis*

108 Raw angle values were utilised for analysis. In addition, angle values were described as  
109 within normal range ( $SL \leq 60^\circ$  and  $RL \leq 15^\circ$ ) or outside normal range. Consistency in the raw  
110 value measurements (pre- and postoperative readings) obtained on the two separate  
111 occasions was assessed using the intraclass correlation coefficient. Reproducibility of the  
112 two measurements was also assessed according to whether the two measurements fell  
113 within the same range (normal versus higher than normal) using Cohen's kappa. There are  
114 no absolute definitions of interpreting kappa but there are suggested guidelines by Altman.  
115 These reproducibility calculations were performed in R (R Core Team, 2021; Team, 2021)  
116 using the irr package (Gamer et al., 2019). Each pair of angle measurements was averaged  
117 for subsequent analyses. Consistency of a single set of intra-operative SL and RL readings on  
118 57 of the 59 patients were compared to their post-operative counterparts by computing the  
119 correlation of the raw measurements. Two of the 59 patients had no lateral intraoperative  
120 view available.

121 Cases were divided into two groups according to their pre- and post-surgery SL and RL  
122 angles and whether these angles were corrected to within normal range. Union rates were  
123 determined for each of these demographics. Union counts between these groups were

124 compared using logistic regression and a chi-squared test in R after adjusting for age and  
125 smoking status. Statistical significance was established at the 5% level.

126

## RESULTS

127 The SL and RL radiological angles on pre- and post-surgical fixation imaging of the 59  
128 patients were analysed. High reproducibility of the radiological angles was seen with both  
129 the intraclass correlation coefficient (pre-surgery SL: 0.86,  $p < 0.001$ ; post-surgery SL 0.85,  $p$   
130  $< 0.001$ ; pre-surgery RL 0.94,  $p < 0.001$ ; post-surgery RL 0.94,  $p < 0.001$ ) and Cohen's kappa  
131 (pre-surgery SL: 0.76,  $p < 0.001$ ; post-surgery SL 0.79,  $p < 0.001$ ; pre-surgery RL 0.82,  $p <$   
132  $0.001$ ; post-surgery RL 0.81,  $p < 0.001$ ). Consistency of a single set of intra-operative SL and  
133 RL readings on 57 of the patients were compared to the three month postoperative imaging  
134 by computing the correlation of the raw measurements (SL 0.982 and RL 0.992). Two  
135 patients were excluded as no lateral intensifier view was available. We also tabulated  
136 whether both intra- and postoperative measurements fell within the same normal ranges:  
137 the classifications were identical for RL but two patients had conflicting SL readings. As there  
138 was little discrepancy in the intra- and post-operative measurements, we used the post-  
139 operative readings for the statistical analyses as the images were of superior quality.

140 Mean follow up for the analysed cases was 4.47 months (range 3–11 months). The patient  
141 demographics split by union and nonunion are shown in Table 1-

142 Of the 59 patients, 43 achieved union (72.9%). Twenty-one of the 27 fractures which had  
143 both post-operative SL and RL angles within the normal range achieved union, whereas 22  
144 of the 32 remaining fractures which did not have post-operative angles within the normal  
145 range achieved union.

146 To assess the relationship between SL and RL angles with union, we compared three nested  
147 logistic regression models via chi-squared tests. In model 1, we regressed union on age and  
148 a binary indicator for smoking status; model 2 expanded model 1 to include whether binary

149 indicators for pre-operative SL and RL angles were on their respective normal ranges; and  
150 model 3 expanded model 2 to include binary indicators for post-operative SL and RL  
151 readings on their normal ranges. Hosmer–Lemeshow tests for goodness-of-fit of the logistic  
152 regression models 1, 2 and 3 returned  $p$ -values of 0.48, 0.16 and 0.90 respectively. To assess  
153 the utility of pre-operative normal ranges in predicting union in addition to age and smoking  
154 status, we performed a  $\chi^2$  test comparing model 2 to model 1 and obtained a  $p$ -value of  
155 0.4583. To assess the utility of post-operative normal readings in addition to the other  
156 covariates, the  $p$ -value for the  $\chi^2$  test comparing model 3 to model 2 was 0.9813. Table 2  
157 reports the analysis of deviance table and Table 3 reports confidence intervals for the  
158 parameters in model 3.

159 Eight patients in this series had a secondary procedure. Seven patients who failed to unite  
160 went on to a partial (four corner) wrist fusion, and one patient who united had removal of  
161 the headless bone screw due to screw prominence.

## DISCUSSION

162

163 In our series, 21 out of the 27 patients who had both postoperative SL and RL angles within  
164 the normal range achieved union, whereas 22 of the 32 remaining patients who did not  
165 have postoperative angles within the normal range achieved union. Union rates were similar  
166 in the corrected and non-corrected groups. Although malalignment correction is not  
167 achieved in a substantial proportion of cases in our study, we did not find significant  
168 evidence to reject the hypothesis that such correction is essential for union.

169 In view of the anatomy of the scaphoid and the challenge of three-dimensional  
170 interpretation on plain radiographs of the carpus, carpal alignment indices have been  
171 developed to define scaphoid fracture deformity. Previous evaluation of the reliability and  
172 validity of alignment measurements on plain radiographs showed that the SL and RL angles  
173 had the highest interobserver reliability which was comparative to computer tomography-  
174 assessed measurements. In view of this, these indices may be used in preoperative planning  
175 and to quantify deformity correction. Using these parameters, we found that the use of a  
176 palmar tricortical graft failed to correct carpal malalignment in 32 out of 59 of cases. This  
177 occurred despite a meticulous surgical technique and placement of an appropriately sized  
178 wedge-shaped corticocancellous graft. These findings suggest that correction of carpal  
179 malalignment may not be achieved simply by correcting the scaphoid flexion deformity. This  
180 may be due to other factors including chronic shortening of extrinsic carpal ligaments.

181 The aim to correct the SL and RL angles is largely based on previous studies showing an  
182 association between the development of a scaphoid nonunion and carpal instability  
183 (Linscheid et al., 1972; Mack et al., 1984). Earlier studies suggested by using the Russe  
184 technique with an anterior inlay bone grafting technique and K-wire fixation, the carpal

185 malalignment could be improved, and this increased the chance of achieving a scaphoid  
186 union (Cooney et al., 1980). The present use of corticocancellous wedge-shaped grafts is  
187 thought to allow a more precise correction of any scaphoid flexion deformity (Capito and  
188 Higgins, 2013; Cooney et al., 1988; Fernandez, 1984; Watanabe, 2011).

189 Our results are in accord with previous reports which also demonstrated the challenges of  
190 anterior wedge-shaped corticocancellous grafts in correcting carpal malalignment. A palmar  
191 corticocancellous graft may not correct the deformity if undersized (Capito and Higgins,  
192 2013). We aimed to place the largest possible palmar graft and used direct measurement of  
193 the defect after debridement of the nonunion to determine the correct graft size. Care was  
194 taken to avoid the use of an oversized graft as it may lead to 'overstuffing' of the wrist joint  
195 (Capito and Higgins, 2013). We used a meticulous technique and assessed the intracarpal  
196 angles intraoperatively using image intensifier; however, we frequently noted the  
197 preoperative carpal malalignment had not corrected. It is thought even when an  
198 appropriately sized graft is used and the deformity is initially corrected, subsequent graft  
199 resorption and collapse of the scaphoid construct may cause recurrence of the deformity  
200 (Chacha, 1984). In our series, we compared the SL and RL angles measured intra-operatively  
201 and at three months post-operatively and found a high degree of correlation. This suggests  
202 in our series there was no marked collapse of the scaphoid in the early post-operative  
203 period to three months.

204 In a series of eight patients with scaphoid malunion or nonunion, Nakamura et al. (1987)  
205 applied an anterior wedge-shaped bone graft and internal fixation using a Herbert screw.  
206 They noted an improvement in the RL and SL angles in all cases and all cases united.  
207 However, in two cases the improvement of alignment indices was less than 10° and it was

208 thus concluded that this technique may not reliably correct carpal malalignment. In their  
209 series of 6 patients, Tomaino et al. (2000) went further and stated that the commonly used  
210 technique of palmar wedge grafting does not ensure restoration of neutral lunate  
211 alignment. Hence, in their series, they intraoperatively flexed the wrist to reduce the  
212 extended lunate and correct any DISI deformity. The lunate was then temporarily held  
213 reduced with a radiolunate K-wire while the scaphoid nonunion was excised and the bone  
214 graft placed. This was a small series of patients but all patients healed with correction of RL  
215 and SL angles. However, this modified technique may not be commonly used in routine  
216 scaphoid nonunion surgery.

217 Previous studies suggest that deformity correction in scaphoid nonunion or in symptomatic  
218 malunion may restore normal kinetic forces across the wrist leading to improved clinical  
219 outcomes with regards to pain and range of motion (Amadio et al., 1989; Capito and  
220 Higgins, 2013; Tsuyuguchi et al., 1995) as well as a reduced rate of arthritis development.  
221 Amadio et al. (1989) looked at scaphoid malunion in 46 patients. They defined a malunion as  
222 a lateral intrascaphoid angle (LISA) of  $>36^\circ$ . They showed that, at a mean follow up of 63  
223 months, 54% of patients with  $>45^\circ$  of LISA developed post traumatic arthritis compared to  
224 22% of patients with normal indices. However, a clear relation between clinical outcomes  
225 and restoration of radiocarpal indices has not been consistently shown by others. Inoue et  
226 al. (1997) presented a retrospective review of 160 cases of scaphoid nonunion, treated with  
227 a compression screw and palmar bone graft technique. They concluded that the  
228 contributing factors in association with failure to unite were avascular necrosis of the  
229 proximal fragment, fracture fragment instability, prolonged delay in surgery, and fracture  
230 site location. They did not find any association of a residual scaphoid flexion deformity with  
231 an unsatisfactory outcome in terms of pain, function, range of movement and grip strength.



232 Several other studies have also suggested no long-term sequelae including any increased  
233 risk of arthritis in patients who heal with a malunion of the scaphoid (Forward et al., 2009;  
234 Jiranek et al., 1992; Lee et al., 2015).

235 Limitations of our study include the retrospective assessment of our cases. Therefore, we  
236 had to use plain radiographs which are less accurate both for confirming bony union and for  
237 measurement of intra-carpal angles to assess carpal alignment. A CT scan was only  
238 performed postoperatively when indicated if there was doubt regarding bony union. Bony  
239 union was assessed by the treating team which may have introduced bias, but we note all  
240 postoperative imaging was subsequently reported by a consultant radiologist. Forty-seven  
241 patients had a pre-surgery CT and 24 had a post-surgery CT. We did assess the  
242 reproducibility of the radiological angles in the results and found a high degree when  
243 measured on three separate occasions. A further limitation is that this is a radiological study  
244 and does not refer to the clinical and functional outcomes. Studies have shown the clinical  
245 outcome may be variable despite bony union even when carpal malalignment is corrected.  
246 However, the aims of operative treatment are to achieve bony union and to correct any  
247 carpal malalignment, and this study focusses on the technical aspects of the operative  
248 treatment, that is, the relation between carpal malalignment correction and union rates.

249 This study suggests that carpal malalignment correction is not achieved in a substantial  
250 proportion of patients when using a palmar tricortical graft, but such correction is not  
251 essential for union. More important may be excision of the nonunion site back to bleeding  
252 bone, insertion of an 'appropriately' sized structural bone graft, and internal fixation to  
253 achieve a stable bone-graft-bone construct.

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313

314

## FIGURE LEGENDS

315 **Figure 1.** (a) and (b) Pre-operative imaging including postero anterior and lateral views  
316 showing scaphoid nonunion. (c) Scapholunate angle measured between a line drawn  
317 intersecting the palmar aspects of the distal and proximal poles of the scaphoid (S) and a second line  
318 drawn perpendicular to a line intersecting the palmar and dorsal prominence of the lunate (L). (d)  
319 Radiolunate angle measured between a line drawn along the longitudinal axis of the radius (R) and a  
320 second line drawn perpendicular to a line intersecting the palmar and dorsal prominence of the  
321 lunate (L).