TITLE

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

ABSTRACT

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

Level of evidence: IV.

INTRODUCTION

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).

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

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

METHODS

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

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

Surgical technique

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

Radiological assessment

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

The angles were measured retrospectively by two independent orthopaedic registrars separate to the treating team. The SL and RL angles were measured from a true lateral view of the wrist pre-operatively, intraoperatively using image intensifier, and postoperatively from the final set of radiographs, usually at three months, using a standard technique (Roh et al., 2014). For the SL angle, a line was firstly drawn intersecting the palmar aspects of the distal and proximal poles of the scaphoid (S). A second line was drawn perpendicular to a line intersecting the palmar and dorsal prominence of the lunate (L). The angle produced between these two lines was measured as the SL angle (Figure 1). The RL angle was measured between a line is firstly drawn along the longitudinal axis of the radius (R) and a second line drawn perpendicular to a line intersecting the palmar and dorsal prominence of the lunate (L). The measurements from the pre- and post-surgery radiographs were taken on two separate occasions, two months apart, by a different observer on each occasion.

Statistical analysis

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

Cases were divided into two groups according to their pre- and post-surgery SL and RL angles and whether these angles were corrected to within normal range. Union rates were determined for each of these demographics. Union counts between these groups were compared using logistic regression and a chi-squared test in R after adjusting for age and smoking status. Statistical significance was established at the 5% level.

RESULTS

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

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

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

To assess the relationship between SL and RL angles with union, we compared three nested logistic regression models via chi-squared tests. In model 1, we regressed union on age and a binary indicator for smoking status; model 2 expanded model 1 to include whether binary indicators for pre-operative SL and RL angles were on their respective normal ranges; and model 3 expanded model 2 to include binary indicators for post-operative SL and RL readings on their normal ranges. Hosmer–Lemeshow tests for goodness-of-fit of the logistic regression models 1, 2 and 3 returned *p*-values of 0.48, 0.16 and 0.90 respectively. To assess the utility of pre-operative normal ranges in predicting union in addition to age and smoking status, we performed a χ^2 test comparing model 2 to model 1 and obtained a *p*-value of 0.4583. To assess the utility of post-operative normal readings in addition to the other covariates, the *p*-value for the χ^2 test comparing model 3 to model 2 was 0.9813. Table 2 reports the analysis of deviance table and Table 3 reports confidence intervals for the parameters in model 3.

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

DISCUSSION

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

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

The aim to correct the SL and RL angles is largely based on previous studies showing an association between the development of a scaphoid nonunion and carpal instability (Linscheid et al., 1972; Mack et al., 1984). Earlier studies suggested by using the Russe technique with an anterior inlay bone grafting technique and K-wire fixation, the carpal malalignment could be improved, and this increased the chance of achieving a scaphoid union (Cooney et al., 1980). The present use of corticocancellous wedge-shaped grafts is thought to allow a more precise correction of any scaphoid flexion deformity (Capito and Higgins, 2013; Cooney et al., 1988; Fernandez, 1984; Watanabe, 2011).

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

In a series of eight patients with scaphoid malunion or nonunion, Nakamura et al. (1987) applied an anterior wedge-shaped bone graft and internal fixation using a Herbert screw. They noted an improvement in the RL and SL angles in all cases and all cases united. However, in two cases the improvement of alignment indices was less than 10° and it was thus concluded that this technique may not reliably correct carpal malalignment. In their series of 6 patients, Tomaino et al. (2000) went further and stated that the commonly used technique of palmar wedge grafting does not ensure restoration of neutral lunate alignment. Hence, in their series, they intraoperatively flexed the wrist to reduce the extended lunate and correct any DISI deformity. The lunate was then temporarily held reduced with a radiolunate K-wire while the scaphoid nonunion was excised and the bone graft placed. This was a small series of patients but all patients healed with correction of RL and SL angles. However, this modified technique may not be commonly used in routine scaphoid nonunion surgery.

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

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

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

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

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FIGURE LEGENDS

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