Nonunion of the scaphoid: Analysis of the results from bone grafting

Scaphoid nonunion was treated by bone-grafting techniques in 86 patients with 90 scaphoid fractures. The volar inlay (Russel) technique had union in 38 of 44 fractures (86%); the dorsal inlay (Matti) technique in 20 of 22 fractures (91%); the dorsal peg graft (Murray) in nine of 18 fractures (50%); and compression screw osteosynthesis in one of six cases (17%). Fourteen patients had secondary arthritis associated with fracture union. Union was more frequent (85%) in 54 undisplaced nonunions than in 36 displaced nonunions (65%). Complications included avascular necrosis, secondary arthritis, and persistent nonunion. Avascular necrosis in 13 nonunions was treated successfully by inlay grafts in 11, and postoperative avascular necrosis (four nonunions) was resolved after fracture healing in two. The four patients with failed results had the dorsal peg grafting technique. Of 22 persistent nonunions, 16 had secondary arthritis and four had avascular necrosis. The rate of union was increased when Kirschner wire fixation of unstable nonunions was performed. The dorsal and volar inlay techniques had consistently higher rates of union with fewer complications than did the dorsal peg grafting technique.

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Methods and material

The material reviewed in this study comes from a total series of 946 wrist injuries with 435 scaphoid fractures that were seen at our institution between 1961 and 1976. In that group of patients, there were 110 scaphoid nonunions in 106 patients. From this group of 106 patients, we excluded 20 patients who were treated by techniques other than bone grafting. This included arthrodesis (six patients), silicone rubber replacement (four patients), radial styloidectomy (seven patients), and soft-tissue arthroplasty (Bentzon's) (three patients). Patients who had fractures of the scaphoid associated with delayed union or nonunion of less than 6 months in duration often were treated by cast immobilization alone and were not included in the series. Patients with asymptomatic nonunions in whom the diagnosis was made on roentgenographic evidence alone were similarly excluded.

The series involved 86 patients with 90 scaphoid nonunions. Clinical examination and roentgenograms were obtained on 80 of the 86 patients over a median of 5 years (range, 12 to 163 months) from the time of their initial surgical treatment. One patient died, and five were lost to follow-up. These six patients had sufficient clinical information recorded and were seen at least 1 year after the operative procedure and so were included in part of this study. However, they were not included in the long-term results. Twenty of the patients, with
clinical follow-up of less than 18 months, responded to questionnaires and indicated the amount of wrist pain, grip weakness, and range of motion they experienced.

The mean age of the patients in this series was 23 years, with a range of 15 to 72 years. Ninety percent were men; 54% had the dominant hand involved. At diagnosis of the nonunion, from 4 months to 30 years had elapsed from the date of the original injury. Most of the patients, however, presented with symptoms between 6 months and 3 years from the time of injury, and 90% had presented by 5 years. Twenty-seven patients reported no initial treatment of their wrist injury, six had splints applied, 39 had cast support (25 short-arm, nine long-arm, and five thumb-spica casts), and 14 did not remember the initial injury or treatment. The cause of the fracture was a fall in 16 patients, a motor vehicle accident in 17 patients, sports-related injury in 32 patients, and industrial-related injury in five patients; the mechanism was unknown in 16 patients.

The presenting complaint and indication for operation was pain alone in 43 patients (50%), pain associated with loss of motion in 20 patients (23%), and pain, loss of motion, and a weak grip in 14 patients (16%). Six patients (7%) were totally disabled from any work. Three patients (4%) had a median neuropathy at the wrist associated with pain, restricted motion, and reduced grip. Grip strength was 27 kg (median) in the injured wrist and 44.5 kg in the uninjured wrist, and wrist motion was reduced in the injured wrist with a median range of $42^\circ$ of dorsiflexion and $52^\circ$ of volar flexion at the time of initial assessment.

Radiographic study identified the location of the nonunion and the direction of the fracture line and classified the nonunions into two types: stable undisplaced and unstable displaced. The scaphoid view with traction (Fig. 1, A, B, and C), wrist motion series (Fig. 1, D, E, F, and G), and trispiral tomography (Fig. 1, H) assessed the degree of fracture displacement and instability. The fracture was judged to be displaced if there was greater than $45^\circ$ of scapholunate angulation (DISI deformity) on the lateral view (Fig. 1, I). Of the 90 fractures, 32 (36%) were in the proximal one-third, 56 (62%) in the mid one-third, and two (2%) in the distal one-third (Fig. 2). There were 38 displaced fractures, 48 stable undisplaced fractures, and four fracture dislocations—the latter being determined from roentgenograms of the initial injury. The fracture line was horizontal in 43 patients, transverse in 32, spiral in three, and comminuted in eight. The diagnosis of nonunion was made from the plane film in 90%, from motion films (radial and ulnar deviation views) in 6%, and from trispiral tomograms in 4%.

Treatment of scaphoid nonunions by bone grafting alone or combined with internal fixation (Fig. 3) was performed using four techniques by eight surgeons. Subdivided into the four categories, they were (1) volar bone graft (Russe\textsuperscript{18} technique), 44 fractures; (2) dorsal peg graft (Murray\textsuperscript{10} technique), 18 fractures; (3) dorsal inlay graft (Matti,\textsuperscript{9} Barnard-Stubbins\textsuperscript{6} technique, as modified by Lipscomb and Dobyns\textsuperscript{14}), 22 fractures; and (4) compression osteosynthesis (McLaughlin technique\textsuperscript{15, 16}), six fractures. No patient was treated by drilling of the fracture nonunion alone. Of the Russe procedures, internal fixation was performed in 20 of the
Fig. 1, cont’d. Radioulnar deviation views can indicate a stable nonunion without motion at the nonunion site (D and E), whereas an unstable nonunion will have motion (F and G) at the nonunion site. A tomogram (H) of the nonunion site may show displacement, and the lateral view (I) will demonstrate dorsal rotation of lunate [lunocapitate angulation of greater than 10° and scapholunate (S-L) angle of greater than 45°] in the unstable nonunion.

Table 1. Location and Displacement of Fractures and Success of Bone Grafting

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of Fractures</th>
<th>% Union</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal 1/3</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>Middle 1/3</td>
<td>56</td>
<td>80</td>
</tr>
<tr>
<td>Proximal 1/3</td>
<td>32</td>
<td>64</td>
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</table>

<table>
<thead>
<tr>
<th>Displacement</th>
<th>Number of Fractures</th>
<th>% Union</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stable</td>
<td>48</td>
<td>85</td>
</tr>
<tr>
<td>Unstable</td>
<td>42</td>
<td>65</td>
</tr>
</tbody>
</table>

Fig. 2. Union of the scaphoid after bone grafting is influenced significantly by both the location of the fracture and the amount of displacement.
Fig. 3. Scaphoid nonunions were treated by four operative techniques utilizing cortical or corticocancellous bone grafts with internal fixation for unstable nonunions: A, volar inlay (Russe); B, dorsal peg (Murray); C, dorsal inlay and radiostyloidectomy; D, compression screw and matchstick graft.

Table I. Results of bone grafting of initial scaphoid nonunions

<table>
<thead>
<tr>
<th>Grafting technique</th>
<th>No. of cases</th>
<th>Union</th>
<th>Non-union</th>
<th>Uncertain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volar inlay (Russe)</td>
<td>44</td>
<td>38</td>
<td>86%</td>
<td>4</td>
</tr>
<tr>
<td>Dorsal inlay (Matti, Barnard-Stubbins modification)*</td>
<td>22</td>
<td>20</td>
<td>91%</td>
<td>2</td>
</tr>
<tr>
<td>Peg graft (Murray)</td>
<td>18</td>
<td>9</td>
<td>50%</td>
<td>6</td>
</tr>
<tr>
<td>ASIF screw osteosynthesis</td>
<td>6</td>
<td>1</td>
<td>17%</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>68</td>
<td>76%</td>
<td>17</td>
</tr>
</tbody>
</table>

*Unilateral approach modified by Lipscomb and Dobyns by using radiostyloidectomy and inlay-grafting technique of Matti.

Table II. Complications associated with scaphoid nonunion

<table>
<thead>
<tr>
<th>Technique</th>
<th>No. of cases</th>
<th>Avascular necrosis</th>
<th>Arthritis with union</th>
<th>Non-union</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volar inlay (Russe)</td>
<td>44</td>
<td>1*</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Dorsal inlay (Barnard-Stubbins modification)</td>
<td>22</td>
<td>1*</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Peg graft (Murray)</td>
<td>18</td>
<td>2†</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>ASIF screw osteosynthesis</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
<td>4</td>
<td>14</td>
<td>22</td>
</tr>
</tbody>
</table>

*Union occurred after inlay graft and the avascular necrosis resolved.
†Nonunion and avascular necrosis after two dorsal peg grafts.
Nonunion of scaphoid

Results

The union rate of the 90 scaphoid nonunions was 76% (Table I). The volar inlay (Russe) technique resulted in union in 38 (86%) of 44 cases, with four united and two uncertain. The dorsal inlay technique with radial styloidecomy had union in 20 of 22 cases (91%). The dorsal peg graft (Murray technique) had union in nine of 18 cases (50%), with six definite ununions and three uncertain unions. Five of the six fractures treated by compression screw osteosynthesis were ununited. All initially provided excellent scaphoid stability; but by 2, 2.5, and 4 years of follow-up, screw loosening and backing out were noted. Three of the five patients (four of the six fractures) subsequently, two of these patients had instability with pain and were treated by dorsal inlay bone graft. The other two fractures (both in one patient) were not clinically symptomatic.

Fracture union was determined by both clinical and roentgenographic examination. Fracture union in the uncertain results could not be determined by roentgenograms that included trispiral tomography, and these were considered to be unsuccessful results. The overall time for union averaged 4.4 months in this series, but union depended on the grafting technique and the type of fracture.

Complications from bone grafting of scaphoid nonunions were avascular necrosis (four patients) arthrosis with union (14 patients) and nonunion (22 patients) (Table II). Of the persistent nonunions after treatment (22 fractures), four were associated with avascular necrosis and 16 with secondary radioscaphoid arthritis. Of the nine peg graft failures, five required reoperation (arthrodesis in two, silicone rubber scaphoid in one, and volar inlay graft in two). Four of the six nonunions after volar inlay graft were regrafted (Fig. 5), and two remained untreated. One dorsal inlay graft was regrafted successfully by the same technique. Two screw osteosynthesis failures were treated by a dorsal inlay graft, and union was obtained.

Avascular necrosis identified at the initial treatment
Fig. 6. Matti’s original dorsal inlay approach to scaphoid nonunion was modified by Dobyns and Lipscomb. The technique consists of: (A) a radial approach between the first and second dorsal retinacular compartments; (B) corticocancellous bone graft (20 by 5 mm) from the radial styloid; (C) radial styloideectomy, preparation, and excavation of a dorsoradial trough in proximal and distal fragments with removal of all avascular bone; and (D) inlay of the corticocancellous bone graft, which is countersunk to prevent displacement; internal fixation of the fracture fragments. E, A case illustration of an established nonunion through the mid distal third junction of the scaphoid. F, Treatment by radial styloidectomy, radial inlay bone graft with Kirschner wire fixation of the fracture fragments and radiocarpal joint. G, Fracture union without pain or arthrosis was present 2 years later.
Fig. 7. A and B, Early result (6 months) after compression screw fixation of scaphoid nonunion. Bone grafting was not performed. C, At 18 months screw migration had occurred and there was no evidence of scaphoid union. D, A volar inlay graft was performed, and 3 months later (21 months from the original injury) progression toward scaphoid union was present.

was associated with scaphoid nonunion in 13 fractures. Fracture union was obtained by bone grafting in 11 of the 13. In the two patients with failed union, the fracture was a displaced, proximal pole fracture—one was treated by the peg graft technique and the other was treated by the volar inlay technique. Four other patients developed avascular necrosis after operation. Union occurred in two (both dorsal inlay grafts), with eventual revascularization of the proximal fragment. The two other developed avascular necrosis and nonunion after treatment by the dorsal peg technique. Both involved the proximal third of the scaphoid, and one also was displaced.

Internal fixation was used in 21 of 44 volar inlay bone grafts when motion was present at the fracture site (fracture instability demonstrated). Union resulted in 88% of these fractures. In the dorsal peg technique, internal fixation was performed in only four of the 18 fractures. Ten of the 18 fractures were displaced nonunions. The four that had pin fixation united. The remaining displaced fractures (six) without pin fixation accounted for five of the nine nonunions. All of the fractures treated by the dorsal inlay technique had two or more Kirschner wires, and 20 of the 22 united.

Arthrosis despite fracture union was present to a mild—moderate degree in 14 patients (16%). Occasional pain usually associated with heavy labor was present in four patients (10%) with a united scaphoid nonunion treated by the volar inlay technique, four patients (20%) with united dorsal inlay graft, and five of nine patients with united dorsal peg graft. Roentgenograms revealed that 9% of the wrists with volar inlay grafts and 14% of the dorsal inlay grafted had radioscaphoid arthrosis. Nearly half (44%) of those treated by the dorsal peg method had roentgenographic evidence of radioscaphoid arthrosis.

Grip strength for the entire group was 36 kg after operation—from 27 kg before operation for an increase of 30% in comparison with the uninjured side (average, 45 kg). Wrist motion (preoperative versus postoperative) changed little. Dorsiflexion was unchanged, and volar flexion lost 5° of motion. The volar and dorsal
inlay grafts resulted in more improvement in grip strength than did the dorsal peg technique, and this appeared to be related to the roentgenographic appearance of arthrosis and to the higher incidence of fracture nonunion.

Discussion

Bone grafting to restore stability and union is the procedure of choice for established scaphoid nonunions. Exceptions to this are generalized and severe posttraumatic arthritis, a small and avascular proximal fragment, and the patient who is asymptomatic or sedentary. The natural history of scaphoid nonunion is that late morbidity from pain, loss of motion, and grip weakness usually will result if the symptomatic patients are not treated.

When bone grafting is elected for established nonunion, the results from this series indicate that a dorsal or volar inlay graft is best. This technique of inlay bone grafting was originally described by Matti in 1932. He recommended a dorsal approach. By this technique, direct inspection of the fracture nonunion was performed; a trough was curetted in the distal and proximal fragments, removing sclerotic bone; and a cancellous iliac crest bone graft was inserted. Russe modified this method by recommending a volar approach. One of us (J.H.D.) used the dorsal inlay technique by modifying the radial styloidectomy approach of Barnard and Stubbs and using the radial styloid as the source of corticocancellous inlay bone graft (as described by Matti) (Fig. 6).

This technique consists of exposing the radial styloid by dissecting off the abductor pollicis longus and extensor pollicis brevis with the first extensor compartment. The radial sensory nerve and the radial artery with its branches to the scaphoid are carefully protected. A sagittal saw is utilized to remove a corticocancellous bone graft (approximately 20 by 5 by 5 mm). The styloid itself is removed using an oblique cut calculated to enter the radial articular surface ulnar to the position of the scaphoid fracture. With the fracture site exposed, an appropriate-size trough is cut into the dorsoradial or radial aspect and deepened by curettage of the distal and proximal fragments. Microscopic examination can help to determine if there is avascular bone. The bone graft, along with cancellous bone chips, is then packed into the trough, and each end is countersunk. Correct reduction of the fracture is checked, and any malunion is reduced. Multiple Kirschner wires are inserted to stabilize first the site of the nonunion and then the radiocarpal joint. With unstable nonunions it is best to realign the dorsiflexed lunate, pin the proximal scaphoid fragment to the reduced lunate, and reduce the distal scaphoid fragment onto the fixed and well-aligned proximal scaphoid. It is important that care should be taken that the fracture fragments are not distracted dorsally and that radiographic malalignment is not present. For comminuted fractures, bone grafting may be necessary to compensate for bone loss in order to achieve an accurate reduction of the malunion. The volar (Russe) approach is performed similarly, with the exception that radial styloidectomy is not necessary and internal fixation is less frequently indicated because the volar bone graft will close the dorsal cortex angulation and provide inherent stability. A large iliac corticocancellous bone graft is preferred for this approach, but care must be taken to maintain anatomic alignment.

These methods were superior, in our hands, to the peg graft technique credited to Murray in 1934. That method had a 50% incidence of nonunion (nine of 18 fractures). It was performed by a number of surgeons for both displaced and undisplaced fractures. A higher incidence of radioscaphoid arthrosis (44%) occurred after this method than after the volar (9%) and dorsal inlay (14%) techniques. Murray reported that 96% of his patients had union, but stressed a large cortical graft, accurate placement through a substantial drill hole, and fracture immobilization until roentgenographic union. In this series immobilization with pins was used in only four of 18 patients, and care was not always taken to differentiate the stable from the unstable group. Others have reported reduced rates of union, similar to our experience with this technique, and the differences in these series from Murray's reports cannot be well explained.

Compression screw osteosynthesis has been recommended by several authors for scaphoid nonunion. McLaughlin and Parker used this method in five patients with pseudarthrosis and found that none had union. (They preferred the Russe volar inlay technique.) Gasser's series of ASIF screw fixation consisted of 20 patients. Two had acute fractures, and five had fractures that were less than 6 months old. All were candidates, in our opinion, for cast immobilization alone. Of the 20 patients with scaphoid screw fixation, he had 11 patients with complete union and nine patients with nonunion. Seven of those with union were in the group that was less than 6 months from the time of injury. In the present series there was only one patient with union of the six with nonunions treated by ASIF compression screw. Four of the six patients with frac-
Fig. 8. Fracture of scaphoid proximal pole with nonunion. A and B. Established nonunion of proximal one-third with displacement evident on the lateral view. C, A tomogram showed viable fragment, and bone grafting was recommended. D and E, A volar Russe approach was performed, with curettement of the entire proximal pole and trough formed for placement of a corticocancellous iliac bone graft. Note the preserved lateral-volar artery (arrow). F and G, Union was observed at 4 months on tomograms and was confirmed at the 5-year follow-up.
Fig. 9. Avascular necrosis of the proximal portion of the scaphoid and nonunion (A). After dorsal inlay bone grafting with internal fixation (B), union resulted (C), and resolution of avascular segment progressed (D) with fracture healing and revascularization.

Union was more frequent as a result of the Russe volar approach than from either the dorsal inlay or the peg graft approach when the fracture was in the proximal pole.

Displaced scaphoid fractures had a union rate of 65% in comparison with the rate of 85% for undisplaced or stable fracture nonunions. McLaughlin and Parkes, Verdan and Narakas, Fisk, and others have emphasized the need to classify scaphoid nonunions into displaced and undisplaced and the importance of the lunate angulation that accompanies fracture displacement. More recently, Dobyns and Linscheid have brought attention to the dorsiflexion collapse deformity that results from displaced scaphoid fractures. Eddeland and associates noted the greater incidence of pseudarthrosis when displacement exceeded 1 mm, and this was true in our series. The importance of the lateral roentgenogram to assess carpal instability cannot be overstressed. Dorsal tilt or rotation of the lunate...
occurs when the scaphoid is displaced. If uncertainty exists, roentgenographic views such as distraction in finger traps, radioulnar deviation views, or firm compressive gripping anteroposterior and lateral views may provide additional information in determining the degree of displacement and instability. Our experience suggests that, when displacement is present, a volar or dorsal graft combined with internal fixation of not only the scaphoid but also the lunate in its reduced position to the distal radius increases the rate of union and reduces the risk of secondary arthrosis. When radios- caphoid arthrosis is evident, we prefer the dorsal ap- proach with radial styloidectomy, direct inspection and reduction of the fracture site, a dorsal inlay bone graft, and internal fixation of the fracture and the carpus.

The role of fracture stabilization by internal fixation by pins should be emphasized, particularly in the dis- placed fractures. In the displaced nonunion group, there were fewer complications and a higher rate of union in the Russe volar graft with pins and the dorsal inlay graft with pin techniques than in those fractures treated without internal fixation. Cast support alone does not appear to provide sufficient immobilization. The length of time in cast support for displaced frac- tures with pins or screw fixation included should be a minimum of 6 weeks, and longer (up to 3 months) for proximal pole fractures. We prefer a long-arm cast that includes the thumb for 6 to 8 weeks, and then a short- arm thumb spica cast until there is roentgenographic evidence of union. The concept that roentgenographic evidence of union occurs after clinical union is not supported by the tomographic results in many of these studies. The single most important factor in the failure of bone grafting was haste in discontinuing the cast support. Vascular supply to the scaphoid has been well de- scribed by Taleisnik and Kelly. We studied the effect of surgical approach on the blood supply in four cadaver hands. Since both the lateral volar and dorsal arterial branches from the radial artery to the scaphoid are similar in size and cross-anastomose in supplying the proximal two-thirds of this bone, it was concluded that neither the dorsal nor the volar approach was superior to the other from a vascular standpoint. Avascular necrosis, which was present in 13 patients before operation, was resolved in 11—six by the volar and five by the dorsal approach. The two patients who had failed to obtain union and who had persistent avascular necrosis had small proximal fragments; one of the two also had displaced fragments. Russe and Verdan have noted that avascular necrosis re- evolves with fracture union, and this was also true in our series (Fig. 9). If the surgical approach decreased vascular- ity to the scaphoid, we would have expected a greater incidence of avascular necrosis and nonunion.

Conclusions

This study of the bone-grafting treatment for scaphoid nonunions revealed that long-term results from the bone grafting of scaphoid nonunions were favorable by both dorsal and volar inlay grafts, but that peg grafts had a higher rate of nonunion and secondary arthritis. Grip strength was improved (inlay grafts greater than peg grafts), but wrist motion was not changed. Scaph- oid fractures should be classified into stable or unstable on the basis of roentgenographic evidence of displace- ment of greater than 1 mm or of instability collapse patterns (dorsal rotation of the lunate) or both. Internal fixation of the unstable nonunion is recommended, and the carpus should be included with reduction of the lunate. Compression screw osteosynthesis provides stability but not union; long-term results are discouraging. The surgical approach did not significantly influence fracture union, and avascular necrosis was rare after these procedures. Nonunions should be immobil- ized until there is roentgenographic evidence of union, and a minimum of 4 months is recommended for stable nonunions.

REFERENCES

14. Lipscomb PR, Dobyns JH: Personal communication

INFORMATION FOR AUTHORS

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