Nonunions. Surgery and low-intensity ultrasound treatment

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Late results of surgically treated scaphoid nonunion

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Submitted
Abstract

Background Nonunion of the scaphoid is a complex problem for which a number of surgical treatment options are available. The main goals of treatment are to achieve bone healing and, ultimately, good pain-free wrist function. Little is known about the natural course of scaphoid nonunion.

Methods A retrospective review of 88 cases of scaphoid nonunion treated by internal fixation and bone grafting was conducted at an average of 14 years. During follow-up 66 patients were re-examined. The duration of nonunion ranged from 6 months to 17 years. A modified Mayo Wrist Score chart was used to score the degree of postoperative osteoarthritis, and radiographic evaluations were also performed.

Results Union was achieved in 97% (64/66) of patients. Of these 66 patients, 13 patients underwent a total or subtotal arthrodesis mainly for osteoarthritis. The objective of surgical treatment of scaphoid nonunion is not only the elimination of pain but also prevention of osteoarthritis of the wrist. Radiographs revealed an increased incidence of progressive radio-carpal osteoarthritis in all patients. Cooney's clinical score system showed excellent results in 18 patients, a good result in 36, a fair result in 8 and in 4 patients a poor result. In 27 patients anomalies varying from moderate incongruity to severe osteoarthritic changes were seen on the radiographs. Twenty-four percent of patients had symptoms of mild to severe pain.

Conclusion Our conclusions are that freedom from pain is not a reliable prognostic indicator and that patients with a nonunion of the scaphoid are likely to benefit from surgical treatment. However, in time radio-carpal changes occur in all patients.
Introduction

A fractured scaphoid bone is a significant injury that can be difficult both to diagnose and treat. Initially, the fracture may be missed for one of the following reasons: low ranking in physician's index of suspicion, the irregular contour and degree of overlap of the carpal bones on radiographs make the fracture difficult to visualize and the presence of concomitant fractures of the metacarpals or distal radius. Even a healed fracture is no guarantee against wrist pain and loss of movement and strength.\(^1\,^2\) Malunited fractures can be symptomatic and disabling.\(^2\,^3\) Most scaphoid fractures can be diagnosed without difficulty by physical examination and examination of conventional radiographs. Sometimes however, alternative diagnostic modalities may be necessary to aid its diagnosis.\(^4\,^7\) When a fracture is recognised treatment is generally straightforward, but even in those scaphoid fractures treated promptly and adequately, nonunion occurs in 5-12% of cases.\(^1\,^8\,^9\) Scaphoid nonunion, whether due to failure to treat appropriately or due to failure to heal despite appropriate treatment, can cause pain, loss of wrist motion, and loss of grip and strength. Scaphoid nonunion is a complex problem, in which even the aetiology of nonunion is unclear. Some of the potential causes of nonunion that have been put forward are: failure to seek medical attention, delay in diagnosis, displacement of the fracture, a fracture of the proximal pole of the scaphoid and insufficient immobilization.\(^8\,^11\) Diagnosis of a nonunion is established when six months after injury a fracture line is still visible and there may be bone loss, sclerosis, cystic changes or a combination of these factors.\(^11\) Treatment of a delayed union or nonunion of the scaphoid is problematic and cure of symptomatic scaphoid nonunion is generally surgical. The purpose of surgical treatment of a nonunion must be to restore the normal anatomical situation, heal the scaphoid and to attain a well functioning pain-free wrist. Several methods of surgical treatment are currently employed; all with a different outcome.\(^11\,^16\) The fact that there are so many different types of surgical procedure to treat the same problem indicates that there is no general agreement on which is most effective, nor on the indications for these procedures.

Nonunion of the scaphoid may present late with the onset of osteoarthritis or generalized wrist osteoarthritis.\(^3\) There are a number of different treatment options for those cases where pain is persistent: prosthetic replacement, excision (radial styloid or proximal row), fusion (limited inter-carpal or wrist arthrodesis) or radial wedge osteotomy.\(^17\,^20\)

The purposes of this study are to evaluate the results of corticocancellous bone grafting with screw fixation and to identify the patterns and sequence of degenerative changes of these wrists over time.
Material and methods

A retrospective study of 88 patients was undertaken. It included a review of records and radiographs of 88 patients with scaphoid nonunion who were seen between 1975 and 1994. At time of follow-up, 66 of the 88 patients were available for re-examination. Of the 22 patients who were not available for follow-up, nine patients were interviewed by telephone because they refused to come to the hospital, five patients had left the country, one patient died and the other seven patients were lost to follow-up.

At follow-up 66 patients were available for re-examination, of these 66 patients, 13 patients had underwent a secondary fusion. All patients underwent physical examination, and standard neutral posteroanterior, lateral and oblique radiographs were performed. The radiographs were examined for the presence and location of osteophytes, osteoarthritis and joint space narrowing. Using the Mayo wrist scoring chart, postoperative osteoarthritis was graded as stage 0 (none), stage 1 (slight incongruency of the wrist joint) stage 2 (moderate incongruency of the wrist joint) stage 3 (severe osteoarthritic changes of the wrist joint). Scaphoid and intercarpal alignment was assessed by measurement of the lateral and posterior/anterior intrascaphoid angles and the scapholunate angle in 53 patients.2

The range of dorsiflexion, palmar flexion, radial and ulnar deviation of both wrists was measured in 53 patients using a protractor and the span was recorded in degrees. Measurements were taken on the non-involved side for comparison purposes. In order to take individual variations into account, the sum of dorsiflexion, palmar flexion, radial and ulnar deviation of the traumatized wrist was expressed as a percentage of that of the opposite wrist. A loss of wrist movement of more than 25% was considered to be significant.

All patients were also asked to give a number on a scale from 0 to 10 how much pain they experienced (0 indicates no pain and 10 extreme pain).

Grip strength of both hands was measured in all 66 patients using a calibrated Jamar dynamometer (Clifton, New Jersey, USA). The mean of three measurements of both hands was recorded. A reduction of grip strength of more than 10% in the traumatized dominant hand or a reduction of more than 20% in the traumatized non-dominant hand were considered to be significant.21,22

A modification of the Mayo Wrist Score Chart7 was used in all 66 patients to assess the results of treatment (Table I). This involved the categories; pain, ability to function in an occupation, range of motion, and grip strength as measured as percentages of the uninvolved side. A perfect score is 100 points. A score of 90 to 100 is considered excellent, 80 to 89 good, 65 to 79 fair, and less than 65 poor.

Analysis of range of motion and the scaphoid and intercarpal alignment was performed in the 53 patients without secondary fusion.
Table 1 Modification of the Mayo Wrist Scoring Chart.

<table>
<thead>
<tr>
<th>Pain</th>
<th>20 - no pain</th>
<th>15 - cold weather symptoms</th>
<th>10 - mild, no effect on activity</th>
<th>5 - moderate, affects activity</th>
<th>0 - severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>(20 points)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Occupation</th>
<th>20 - same as before operation / no job</th>
<th>15 - same as before operation but with limitation</th>
<th>15 - changed to another job</th>
<th>10 - able to work but unemployed</th>
<th>5 - change to lighter work</th>
<th>0 - unable to work because of pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>(20 points)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Range of motion</th>
<th>20 - 140° or more</th>
<th>15 - 100° - 140°</th>
<th>10 - 70° - 100°</th>
<th>5 - 40° - 70°</th>
<th>0 - less than 40°</th>
</tr>
</thead>
<tbody>
<tr>
<td>(20 points)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grip strength</th>
<th>10 - normal</th>
<th>5 - greater than 50% of normal</th>
<th>0 - less than 50% of normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10 points)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radiograph</th>
<th>20 - normal</th>
<th>15 - slight incongruity, malunion, rotation of scaphoid or carpal instability</th>
<th>10 - moderate incongruity, malunion, rotation of scaphoid or carpal instability</th>
<th>5 - severe changes noted above, or nonunion or avascular necrosis, partial arthrodesis</th>
<th>0 - osteoarthritic changes, complete arthrodesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>(20 points)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Satisfaction</th>
<th>10 - satisfied</th>
<th>0 - not satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10 points)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Final result</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>100 - 90</td>
</tr>
<tr>
<td>Good</td>
<td>89 - 80</td>
</tr>
<tr>
<td>Fair</td>
<td>79 - 65</td>
</tr>
<tr>
<td>Poor</td>
<td>&lt; 65</td>
</tr>
</tbody>
</table>

The data of pain experience, grip strength and Mayo wrist score chart was recorded in the 66 patients.

Operative technique
A dorsal approach was used in 29 cases, a volar approach in 14 cases and a radial approach in 23 cases. In 54 patients, the scaphoid nonunion was treated by an AO/ASIF screw osteosynthesis and in 12 patients, with a Herbert screw. In all these patients a
corticocancellous bone graft and free cancellous bone from the iliac crest were also used (Fig. 1). All patients were treated postoperatively with a plastercast with for a mean of 5.4 weeks ± 1.2 (range 3 – 8 weeks).

The data were statistically analysed using the Mann Whitney U test, analysis of variance or chi squared test. P-values of less than 0.05 were considered statistically significant.

Results

Of the 66 patients, 58 were men and eight women, with a mean age at examination of 40.9 ± 9.67 years (range 20 – 66 years). The average time from injury to examination was 14 ± 6.53 years (range 4 – 31 years). The ages of the patients at time of surgery ranged from 15 to 45 years, average 26.8 ± 7.09 years. The time interval between surgery and follow-up was 11.6 years ± 5.1 (range 4 to 24 years).

The time interval between injury and initial surgical treatment ranged from six months to 204 months with an average of 37.7 months. Both the right and left hands were involved in 40 and 26 cases, respectively. Thirty-seven cases involved the dominant hand and 29 the non-dominant hand. In 31 cases the fracture was located in the waist of the scaphoid, 28 in the proximal third, and seven in the distal third. In only seven patients the scaphoid fracture was diagnosed at the time of injury, however even after a proper period of immobilization these fractures did not unite. In 41% of cases the cause of injury was a fall, in 32% sports activities, a traffic accident in 19% and in 8% a work related accident.

Nonunion was successfully treated in all but two of the 66 patients. In 13 of the 66 patients an arthrodesis had been performed, seven patients having undergone a total arthrodesis of the wrist. In nine of these 13 patients the nonunion was treated with an AO-screw and in four patients a Herbert screw was used. In two of these 13 patients, the arthrodesis was performed because of persistent nonunion of the scaphoid. In the other 11 patients, pain due to osteoarthritis was the main reason for performing a total or subtotal arthrodesis of the wrist.
Analysis of the patients (n=53) without a secondary fusion

The range of motion showed a significant difference in radial abduction, extension (p<0.01) and in flexion (p<0.05) on the injured side compared with the non-injured side (Table II). There was no statistical difference in the other movements. Postoperatively both the intrascaphoid and scapholunate angles were significantly decreased, p< 0.01 and p<0.05 respectively (Table III).

Radiographic and functional analysis (n=66)

In the whole patient group, grip strength was comparable in both wrists. The analysis of the Mayo wrist score chart showed that of the 66 patients, 50 (76%) had either no pain or pain only during specific activities (Fig. 2A). The overall score showed 54 patients (82%) with good or excellent results (Fig. 2B).

At follow-up, the radiographs of only four patients were normal. There was a slight
incongruency of the wrist in 35 patients, seven patients showed moderate incongruency, 13 patients severe incongruency and seven patients had osteoarthritic changes in the wrist. There was no relationship between pain symptoms, the result of the radiograph and the final result (Table IV a-c). No relationship could be established between the duration of follow-up or the age of the patient and the functional and radiographic results.

<table>
<thead>
<tr>
<th></th>
<th>None</th>
<th>Sometimes</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO-screw</td>
<td>18 (46%)</td>
<td>12 (30%)</td>
<td>8 (21%)</td>
<td>0</td>
<td>1 (3%)</td>
<td>39</td>
</tr>
<tr>
<td>Herbert screw</td>
<td>6 (43%)</td>
<td>4 (28%)</td>
<td>3 (21%)</td>
<td>1 (4%)</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>(Partial) arthrodesis</td>
<td>6 (46%)</td>
<td>4 (31%)</td>
<td>2 (15%)</td>
<td>0</td>
<td>1 (8%)</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>20</td>
<td>13</td>
<td>1</td>
<td>2</td>
<td>66</td>
</tr>
</tbody>
</table>

Table IV-a Result of the pain score

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Slight incongruency</th>
<th>Moderate incongruency</th>
<th>Severe changes</th>
<th>Arthritic changes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO-screw</td>
<td>2 (5%)</td>
<td>30 (77%)</td>
<td>1 (3%)</td>
<td>4 (10%)</td>
<td>2 (5%)</td>
<td>39</td>
</tr>
<tr>
<td>Herbert screw</td>
<td>2 (14%)</td>
<td>5 (36%)</td>
<td>6 (43%)</td>
<td>1 (7%)</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
<td>35</td>
<td>7</td>
<td>5</td>
<td>2</td>
<td>53</td>
</tr>
</tbody>
</table>

Table IV - b Results of the radiographs of 53 patients

<table>
<thead>
<tr>
<th></th>
<th>Excellent</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO-screw</td>
<td>13 (33%)</td>
<td>21 (54%)</td>
<td>3 (8%)</td>
<td>2 (5%)</td>
<td>39</td>
</tr>
<tr>
<td>Herbert screw</td>
<td>4 (28%)</td>
<td>5 (36%)</td>
<td>4 (28%)</td>
<td>1 (8%)</td>
<td>14</td>
</tr>
<tr>
<td>(Partial) arthrodesis</td>
<td>1 (8%)</td>
<td>10 (75%)</td>
<td>1 (8%)</td>
<td>1 (8%)</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>18</td>
<td>36</td>
<td>8</td>
<td>6</td>
<td>66</td>
</tr>
</tbody>
</table>

Table IV-c Final patient results
Figure 3
A. The pre-operative antero-posterior radiograph of the wrist of a 42 year-old male patient is shown. The patient suffered a direct injury of his left wrist during a soccer game. The scaphoid fracture was not recognized. Fifteen years post-fracture a scaphoid pseudarthrosis developed and nonunion repair was considered necessary.

B. Ten years after operative treatment with a graft and AO screw fixation a slight incongruency and some arthrotic changes of the wrist are shown. The patient is satisfied, has good wrist function and equal grip strength in both hands.

One patient was operated on 15 years after the initial trauma and made an excellent recovery; the radiograph shows only a slight incongruency of the wrist (Fig. 3A, B).

Discussion
Studies have shown longstanding untreated scaphoid nonunion to be associated with progressive degenerative changes in the wrist. These studies however are all cross sectional. Kerluke and McCabe concluded that they overestimated the incidence of development of osteoarthritic changes. A prospective longitudinal study showed that after 10 to 17 years, osteoarthritis is present in all cases of untreated scaphoid nonunion and subsequent to its development symptoms of wrist pain to increase. In a long term study, the development of osteoarthritis 36 years after non-operative treatment of a scaphoid fracture is shown to be significantly increased in patients with a scaphoid nonunion compared to patients with a united scaphoid fracture (5/9 versus 2/47). Osteoarthritis seems to be correlated with dorsiflexed intercalated segment instability (DISI). If the scaphoid nonunion is located in the proximal and middle thirds, degenerative changes
begin in the radioscapoid joint, whereas if it is located in the distal third, degenerative changes begin in the lunocapitate joint, suggesting a different mechanism of pathology.\textsuperscript{30} Ligamentous injury is often present in scaphoid nonunion and is considered a causal factor.\textsuperscript{29} It is generally agreed that a painful scaphoid nonunion needs to be treated operatively. In some cases scaphoid nonunion is not accompanied by pain.\textsuperscript{31-33} It should be explained to these patients that painful osteoarthritis is likely to develop within ten years.

Grafting

In 1960, Russe\textsuperscript{34} introduced his grafting technique. Using a volar approach the nonunion is debrided and inlay bone grafting (peg and small chips) is carried out using bone taken from the iliac crest, (a modification of the original technique described by Matti\textsuperscript{35}). Postoperative treatment with a long arm plaster is necessary with this technique. Bone healing is achieved in 73\% to 100\% according to Green's review of 13 reports.\textsuperscript{36} In his own series he reported 75\% healing, with failures usually caused by avascularity of the proximal pole.\textsuperscript{36} In Barton's series, the healing rate was reported to be 65 \%. \textsuperscript{37} A long term review, covering more than 27 years after Matti-Russe operation, revealed mild pain, a moderate loss of function and grip strength with a slow progression of osteoarthrotic changes.\textsuperscript{38} A study on patients following Russe bone grafting \textsuperscript{39} points out that in cases of malunion (humpback deformity) the difference between the poor objective results and the comparable subjective results are comparable to cases where there is no malunion. Comparison between Matti-Russe reconstruction and untreated scaphoid nonunions as a control shows a significant difference in development of arthrosis in favour of the former.\textsuperscript{40} Major drawbacks of the Matti-Russe bone grafting technique are the long periods of follow-up treatment in plaster and the lack of ability of the bone grafting technique to correct a DISI deformity. In all our patients, the bone graft was taken from the iliac crest and not from the distal radius as the latter localization yields weaker cortical bone\textsuperscript{41} that cannot easily be shaped to the desired form. However some authors favor radial bone grafts,\textsuperscript{36,42-44} thus avoiding additional morbidity at the donor site. Two minor wound complications occured at the bone graft donor site. To our knowledge, no comparative studies between grafting procedures and immobilization in a plaster cast have been reported in the literature. Recent studies have laid emphasis on the use of vascularized bone grafts from the radial epiphysis\textsuperscript{45-48} and the iliac crest\textsuperscript{49} or revascularization techniques\textsuperscript{50} for scaphoid nonunion. These relatively difficult and delicate techniques have, in selected cases, had good short-term follow-up results.
Internal fixation

In 1984 Herbert introduced a double threaded bone screw for the treatment of fractures and nonunion of the scaphoid. Herbert used an anterior approach, excision of fibrous tissue from the nonunion, iliac crest grafting (in 75% of cases) and screw fixation, which resulted in 85% union in fibrous nonunion and 59% in sclerotic nonunion. A postoperative plaster cast is not indicated. It is a technically demanding operation. Overall bony union is achieved in 74-100% of cases with an excellent to good functional outcome in 85-87%.

Some explanations that have been proposed by some authors for the worse bone healing results in scaphoid nonunion using this operative technique are: an avascular proximal pole in combination with a scaphoid nonunion is liable to fair bony healing and bad functional outcome. A true avascular necrosis of the scaphoid bone is rare. The most reliable indicator of avascular necrosis is punctate bleeding during operation. An avascular proximal pole is easily established by magnetic resonance imaging (MRI).

In sclerotic nonunion, a wedge bone graft and Herbert screw fixation is superior to Russe bone grafting in terms of time to union and function. In our study, 12 patients were treated by bone grafts and a Herbert screw. Two patients had an excellent result, six a good result, three a fair result and one patient had a poor result. In six cases a volar approach was used, in four a radial approach and in two cases a dorsal approach. Both the dorsal and palmar approaches have their disadvantages; the palmar approach being safer in relation to vascularity, but if care is taken to preserve the dorsal proximal ridge of the scaphoid normal vascularity is to be expected as a result of the dorsal approach. The dorsoradial approach is used mainly in proximal pole nonunions.

In our study the AO compression screw in combination with a bone graft was used in 54 cases. The results were excellent in 16 cases, good in 31 cases, fair in four cases and poor in three cases. In 40 cases a dorsal approach was used, a volar approach in 6 cases and in 8 cases a radial approach. Using an AO lag screw in fixation of a scaphoid nonunion gives bony union in 87-90% and improvement in function in 83-90%. The biomechanical strength of both the Herbert and AO screws is the same. However the AO screw has a larger head than the Herbert screw, and its position is therefore sometimes intra-articular and can damage the cortex or cartilage. A secondary operation for screw removal was performed in 23 cases with AO screw fixation and in five cases with the Herbert screw.

Other techniques of fixation include staple fixation and the Ender compression blade and have produced satisfactory results. With a prolonged immobilization time, Kirschner wire fixation can achieve enough stability to promote union. Due to the low costs and ease of insertion this is a good alternative for treatment of scaphoid nonunion in developing countries. The technique of reconstruction of a scaphoid nonunion depends on the surgeon’s preference and does not seem to influence the outcome. A large multicentre
study on prognostic factors influencing the outcome of scaphoid nonunion treatment concluded that only a delay of more than five years between initial trauma and nonunion treatment was significantly associated with poor outcome.64

Stimulation
A pulsed electromagnetic field incorporated into a cast72 and direct current via implanted electrodes73 have been shown to achieve bone healing in 71-80% in non-controlled studies on ununited scaphoid fractures. In two non-controlled studies introducing low-intensity ultrasound as the only new treatment in existing nonunions, 80-100% of the scaphoid nonunions healed in an average of 18-20 weeks.74,75 However, in both non-operative techniques, the scaphoid nonunion should be stabilized and there must be sufficient viable tissue to be stimulated. In this study no additional bone stimulation devices were used.

Secondary solutions
In the presence of arthritis, if reconstruction is not indicated, a soft tissue interposition may initially give satisfying results but in the long term leads to carpal collapse and osteoarthritis.76 A complete or partial replacement arthroplasty using silastic, vitallium or an allograft can give pain relief and a fair hand function, but progressive carpal collapse, osteoarthritis and synovitis cannot be prevented.18 Distal scaphoid resection may be considered in patients with persistent nonunion and associated osteoarthritis of the distal fragment. Although in the short term good follow-up results can be achieved,19 further degeneration of the wrist cannot be prevented. Extensive excision of the radial styloid leads to instability of the wrist.77 Radial open wedge osteotomy can relieve symptoms of a painful scaphoid nonunion and even occasionally promote bone healing.20 The intercarpal or wrist arthrodesis is the ultimate solution if reconstructive techniques have failed and painful osteoarthritis has already developed. In 11 of 13 patients, who underwent a partial or total wrist arthrodesis in our study, the arthrodesis was performed for painful osteoarthritis. Two of 66 patients could be considered as failures of nonunion treatment of the scaphoid, because they had an arthrodesis for their scaphoid nonunion.

In our study, the majority of all patients (75%) experienced either no or only occasional pain during follow-up. From the group of patients with no arthrodesis, osteoarthritic changes could clearly be seen on the radiographs of 14 of them (26%), although, in this group 81% had an excellent or good result. In this analysis no relationship could be found between the osteoarthritic changes on the radiographs and the final clinical result.
Our conclusion is that patients with a nonunion of the scaphoid are likely to benefit from surgical treatment as this prevents progression of osteoarthritis of the wrist. Nevertheless, radiographic deterioration of the wrist will occur in time.

References
