Evaluation of Mathoulin Surgical Approach in the Treatment of Scaphoid Waist Nonunion with Definite Proximal Avascular Necrosis

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Abstract

Introduction: Avascular necrosis (AVN) is a rather common complication of scaphoid fractures, particularly scaphoid waist nonunion, which may occur even after surgical fixation. In the present investigation we aimed to evaluate the efficacy of Mathoulin technique in the surgical fixation of scaphoid waist nonunion with definite proximal AVN.

Material and Methods: A total of 35 cases of scaphoid waist non-union with definite proximal AVN undergoing surgical fixation in a major tertiary referral orthopaedic hospital in northwestern Iran in 2021 were enrolled. Postoperative pain intensity, grip strength (based on modified mayo wrist score) and carpal range of motion (angles of movements) were evaluated at four time intervals, 1, 4.5, 6 and 9 months following Mathoulin surgical fixation.

Results: A total of 35 patients, 28 (80%) male and 7 (20%) female, with a mean age of 28.96 ± 1.89 were investigated. By the end of the 9th month, no patients complained of severe pain, and 33 (94.28%) participants only reported mild pain. Carpal flexion, extension, supination and pronation angles significantly improved following surgery. Grip strength in 29 patients improved significantly. Wrist function Union as achieved in 33 (97.29%) patients.

Conclusion: Mathoulin method in patients with proximal definite AVN with Scaphoid Waist fusion leads to a reduction in pain intensity, improvement of motor angles, grip strength and satisfaction with surgery to a desirable extent.

Keywords: Mathoulin Surgery, Scaphoid Fracture, Scaphoid Nonunion, Avascular Necrosis, Upper Extremity.

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INTRODUCTION
The human wrist consists of eight carpal bones that are supported by several ligaments on both ventral and dorsal sides. Among these, the scaphoid bone is the most susceptible to fractures, which occurs more frequently in young male adults, and is quite rare in children and the elderly ¹. The most prevalent type of carpal injury, scaphoid fracture accounts for 60 to 90% of all wrist fractures and 11% of all hand fractures ². Scaphoid fracture is most commonly the result of falling on an outstretched hand or having a vehicle accident. This leads to formation of a transverse fracture line across the middle section of the bone, termed waist, dividing it in two portions of relatively equal sizes, namely, the proximal and distal segments. In most of the cases, displacement is limited, nevertheless, it can result in degenerative arthritis if not fixed ³.

Since scaphoid fractures usually result in mild pain, they do not limit individuals in their physical activity to a significantly noticeable extent. Moreover, this type of wrist fracture is not readily identifiable by radiography, as the fracture line can be difficult to detect in both frontal (postero-anterior) and side (lateral) views ⁴. Complications associated with scaphoid fracture include nonunion, delayed union, avascular necrosis (AVN) and osteoarthritis; with the most common being nonunion. AVN may lead to osteoarthritis and permanent disability ⁵. The incidence of AVN in scaphoid fractures can range from 2 to 9% ⁶.

In cases of fracture with displacement, surgical fixation and immobilization of bone with compression screws is indicated. In cases of nonunion or limited range of motion, even when the fractured bone has been maintained immobilized for 4 months, it is recommended to use Herbert compression screws ⁷. As these methods of fixation might predispose the patient to muscular atrophy and carpal joint stiffness ⁸, alternative techniques have been proposed for in-hospital management of scaphoid fracture. One such alternative surgical method is known as Mathoulin...
technique, which has been suggested to yield desirable clinical outcomes \(^7\). Though, the idea needs to be further evaluated by clinical investigations, particularly in cases of scaphoid fracture with AVN.

An investigation by Uerpaisropp et al. in 2000 on 10 patients with Lichtman type I and II nonunion, who had not been surgically treated before, suggested vascularized bone graft (VBG) as the primary procedure in treatment of nonunion regardless of the presence of AVN, as by this technique union was achieved in all cases, 5 of whom had AVN prior to surgery \(^8\).

Considering the profound impact of AVN and nonunion in scaphoid fracture on the quality of life, the present study was aimed at investigating the effectiveness of Mathoulin technique in the treatment of scaphoid waist fracture with proximal AVN in a population of patients from northwestern Iran.

**MATERIAL AND METHODS**

**Patient Selection**

The present investigation was a cross-sectional study on patients with scaphoid fracture admitted to the orthopaedics ward of two institutional referral hospitals in northwest of Iran from 2020 to 2021.

Potentially eligible patients, i.e., individuals with scaphoid fracture requiring surgical intervention, were identified by an orthopaedics specialist upon admission. The population under study consisted of patients with scaphoid waist nonunion and definite proximal AVN. A set of exclusion criteria was used for dismissal of patients.

**Exclusion Criteria**

**Nonunion-induced Osteoarthritis**

Scaphoid Nonunion Advanced Collapse (SNAC), confirmed with imaging

History of carpal surgery within the last 3 months

History of osteoporosis

History of vascular diseases

Patients at high risk of vascular injury following surgical treatment

A total of 72 patients were deemed eligible for Mathoulin surgery, which was practiced as follows.

**Method of surgery**

All participants were operated following the Mathoulin method. In this method, an incision is made to dissect scaphoid and radius in the area lying under the radial artery and the flexor carpi radialis tendon. Upon carpal extension and ulnar deviation, the anterior capsule overlying scaphoid and the distal margin of radius becomes visible. The fibrotic and devascularized skeletal tissue is then excised. To attain the desirable length in scaphoid, the margins of the two segments forming the nonunion juncture is excised by means of osteotomy. At this stage, simultaneous radiography can be useful to determine the force required for proper traction. If necessary, a temporary traction can be attained by inserting two pins, one penetrating the middle portion of distal scaphoid and projecting into capitate, and the other running through proximal scaphoid well inside the lunate bone.

After the surgery, all patients received analgesics and empirical antibiotic therapy. The participants were followed-up within 1, 4.5, 6 and 9 months from the surgery. The following information were collected from participants: demographics, handedness (dominant and fractured hand), duration of surgery, post-surgical complications, perioperative access to the bone, materials used for fixation, motor force of hand and fingers, pain intensity based on visual analogue scale (VAS), range of motion, extent of union/nonunion, MMWS \(^9\), patient satisfaction with surgery. Pain intensity, based on the 10-score VAS, was categorized in four classes, namely; mild (< 3), moderate (4–6), severe (7–8) and extreme (> 8).

**Statistical Analysis**

Statistical analysis was performed with IBM SPSS 19.0. Normal distribution of data was determined with Kolmogorov–Smirnov test. Qualitative and quantitative data were recorded as integers or percentage, and mean ± standard deviation, respectively. One-way ANOVA test was used for statistical analysis of quantitative data between groups. A p-value < 0.05 was considered statistically significant.

**Ethics statement**

This investigation was approved by the Committee of Ethics in Medical Research, Tabriz University of Medical Sciences, Tabriz, Iran. Informed consent was collected from all patients enrolled in the study.

**RESULTS**

In the present study we investigated a total of 35 patients, 28 (80%) male and 7 (20%) female, with a mean age of 28.96 ± 1.89, and an average body mass index (BMI) of 28.18 ± 3.22. The majority of participants were right-handed (n = 31, 88.75%), and a great proportion of the fractured scaphoids undergoing surgery were of the right hand (n = 28, 80%). Demographic information of the participants are listed in Table 1.
Evaluation of pain intensity, based on VAS, revealed that all patients had severe levels of pain (VAS: 7 – 10) prior to surgery, which significantly declined within a week from operation. The VAS scores recorded for patients at regular time intervals, indicated a downward trend with statistical significance (P-value < 0.001). Severe pain was no longer described by any patients from the third week postoperative onwards (Table 2).

Table 2: Mean pain intensity based on VAS (0 – 10) at different time intervals.

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Quantitative pain intensity (mean ± SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-operative</td>
<td>6.59 ± 1.43</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>First month postoperative</td>
<td>4.65 ± 1.03</td>
<td></td>
</tr>
<tr>
<td>4.5 months postoperative</td>
<td>3.41 ± 0.85</td>
<td></td>
</tr>
<tr>
<td>6th month postoperative</td>
<td>2.95 ± 0.55</td>
<td></td>
</tr>
<tr>
<td>9th month postoperative</td>
<td>1.20 ± 0.21</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Qualitative pain intensity (n =)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-operative</td>
<td>Mild: 2 (5.71%)</td>
<td>Moderate: 6 (17.14%)</td>
</tr>
<tr>
<td>First month postoperative</td>
<td>Mild: 18 (51.42%)</td>
<td>Moderate: 9 (25.71%)</td>
</tr>
<tr>
<td>4.5 months postoperative</td>
<td>Mild: 25 (71.42%)</td>
<td>Moderate: 8 (22.85%)</td>
</tr>
<tr>
<td>6th month postoperative</td>
<td>Mild: 30 (85.71%)</td>
<td>Moderate: 5 (14.28%)</td>
</tr>
<tr>
<td>9th month postoperative</td>
<td>Mild: 33 (94.28%)</td>
<td>Moderate: 2 (5.71%)</td>
</tr>
</tbody>
</table>

All patients exhibited subnormal range of flexion at wrist, which significantly improved following surgery (P-value < 0.001). Similar results were observed with carpal range of extension, that showed a remarkable increase following surgical fixation (P-value < 0.001). Pronation and supination of forearm were subject to statistically significant improvement after surgery, as well (P-value < 0.001). Corresponding information are listed in Table 3.

Hand grip strength markedly improved in 29 (38.6%) patients following surgery. Three participants did not show any statistically significant rate of improvement in their grip strength. From the first month onwards, following surgery, range of motion was accompanied by significant increase in all participants with a p-value of 0.003 (Table 4).

Table 3: Angles of flexion, extension, supination and pronation of the operated wrist

<table>
<thead>
<tr>
<th>Angle (degree, mean ± SD)</th>
<th>Pre-operative</th>
<th>1st month postoperative</th>
<th>4.5 months postoperative</th>
<th>6th month postoperative</th>
<th>9th month postoperative</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>50.1 ± 4.9</td>
<td>54.15 ± 5.2</td>
<td>55.41 ± 5.29</td>
<td>58.6 ± 5.9</td>
<td>66.4 ± 5.9</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Extension</td>
<td>50.4 ± 5.6</td>
<td>54.5 ± 5.9</td>
<td>62.1 ± 6.3</td>
<td>65.9 ± 3.5</td>
<td>67.4 ± 3.9</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Supination</td>
<td>80.5 ± 8.6</td>
<td>84.6 ± 10.5</td>
<td>86.5 ± 10.9</td>
<td>88.5 ± 12.6</td>
<td>90.5 ± 5.3</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Pronation</td>
<td>48.9 ± 1.6</td>
<td>52.6 ± 2.9</td>
<td>55.9 ± 3.2</td>
<td>58.5 ± 1.9</td>
<td>59.7 ± 1.6</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
Of the 35 participants undergoing Mathoulin-based surgical fixation, only 2 continued to show non-union, with the remaining 33 having achieved union, indicating a union rate of 97.29%. Limited supination and pronation were only observed in 2 (2.71%) patients. One patient (1.36%) developed degenerative joint disease (DJD) due to unsuccessful grafting. The mean length of incision made at the wrist was 3.35 ± 0.12 cm.

**DISCUSSION**

AVN is a relatively common complication of scaphoid fracture, which is mostly due to the specific anatomy and vasculature of this particular carpal bone. AVN often results in impaired union, and despite the recently developed methods for correction of scaphoid fracture, nonunion occurs as frequently as 10%. Failure of treatment in the case of nonunion can lead to chronic pain and progressive osteoarthritis of the wrist. In such instances, the therapeutic goal is to stabilize the wrist by promoting scaphoid union. VBG is a promising therapeutic intervention in the presence of AVN.

The surgical technique proposed by Mathoulin is based on combined transplantation of bone and vasculature, the latter of which is particularly important for preventing AVN, which occurs due to disruption of blood supply. Consistently, the results of our clinical trial indicated that the Mathoulin method can be quite effective in the treatment of nonunion scaphoid fracture with proximal AVN. A meta-analysis in 2016 by Ferguson et al. reported union rates of 74 and 62 percent for vascularized and non-vascularized bone grafts in the surgical fixation of scaphoid fracture, further confirming the promising clinical outcome that can be achieved by vascularization.

As of recent, in 2022, two clinical investigations on scaphoid fracture were published. The first, by Polat et al., was conducted on 39 patients with proximal scaphoid nonunion, suggesting distal radial bone graft based on intercompartmental supraretinacular artery pedicle as a suitable method for fixation of scaphoid fracture, with a mean duration of 100 min and a union rate of 90%. The other study, led by Ecker et al., reported 29 successful iliac crest cancellous bone grafts in 30 patients with scaphoid nonunion. Consistent with these findings, we achieved a union rate of 97.29% with our patients.

In 2021, several studies were published on the efficacy of VBG in scaphoid fractures with AVN. Çolak et al. demonstrated a union rate of 81% for 68 patients with scaphoid nonunion treated with VBG. Lamon et al. explored 42 cases with scaphoid nonunion of the proximal and middle third without SNAC, reporting a union rate of 83%, significantly improved wrist function and markedly decreased pain intensity following arthroscopic bone grafting. Another study by Saruhan et al. on 4 patients with proximal scaphoid nonunion and AVN reported a union rate of 100%, significant decrease in pain and moderate objective functional results after surgical fixation with hamate bone autograft. Papatheodorou et al. treated 64 patients with established proximal scaphoid nonunion and AVN by means of vascularized distal radius graft, observing a union rate of 86% and markedly improved wrist function within a mean interval of 12 weeks. For their investigation, Cavit et al. enrolled 17 male patients with scaphoid waist and proximal pole fracture, 13 of whom had AVN. After performing intercompartmental supraretinacular artery vascularized graft and compression screw fixation, union was achieved in 88.2% of cases.

Similarly, a significant improvement in MMWS and carpal extension was attained. In the present investigation, our patients displayed significant improvements in their MMWS over the span of 9 months, and a considerably sharp decline in pain intensity, following Mathoulin surgical intervention.

A year earlier, in 2020, Kawasaki et al. incorporated vascularized bone grafting for the fixation of scaphoid nonunion with AVN in 11 patients. Union was achieved in 10 patients, with a mean MMWS of 88 (range, 75–100 points). Although, we did not attain a mean MMWS as high as 88 in our study, the increase in MMWS within the span of three months from surgery was still considerable.

A retrospective clinical study by Ammori et al. in 2019 on 806 patients with scaphoid fracture revealed a union rate of 69% independent of the type of bone graft—vascularized or non-vascularized—along with a 22% prevalence of nonunion even after surgical correction.

Two major studies on scaphoid fractures, in 2018, reported noteworthy findings. Rahimnia et al. achieved a union rate of 73% with 41 patients who were treated with VBG for scaphoid nonunion. Postoperative union was accompanied with significant improvement in MMWS and scaphoid length. Sander et al. investigated a total of 16 patients with scaphoid fracture divided into two groups based on the technique of surgery, reporting a higher MMWS for the group having been treated with bone graft compared with patients who had only received headless compression screws (HCS).

Consistent with the more recently published literature, Wolf et al. in 2014 reported similar findings they had observed with 28 cases of scaphoid nonunion, 75% of whom achieved union, which was characterized by improved grip strength, range of motion and MMWS. Similarly, our participants

### Table 4: Grip strength based on modified Mayo wrist score (MMWS)

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Pre-operative</th>
<th>1st month postoperative</th>
<th>4.5 months postoperative</th>
<th>6th month postoperative</th>
<th>9th month postoperative</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMWS</td>
<td>41.9 ± 2.3</td>
<td>52.6 ± 2.8</td>
<td>56.8 ± 2.9</td>
<td>60.3 ± 2.3</td>
<td>62.8 ± 1.1</td>
<td>&gt; 0.05</td>
</tr>
</tbody>
</table>
exhibited significantly improved wrist function in terms of flexion, extension, supination and pronation.

As we demonstrated in this study, the Mathoulin method of fixation negatively regulated postoperative pain, and improved the hand muscle force and movements.

LIMITATIONS
Orthopaedic surgeons are encouraged to identify novel and practical methods for preventing development of AVN after scaphoid fracture, which is a relatively common complication in the case of this carpal bone. Based on our findings, implantation of vascular grafts along with bone graft, as practiced through the Mathoulin method of surgical fixation, proves to be an effective type of intervention for prevention of postoperative AVN and pain in scaphoid waist nonunion, and enhancing carpal function and grip strength. However, further clinical investigations are warranted to confirm our experimental results, as the scope of the present study was limited in its own right.

ACKNOWLEDGEMENTS
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CONFLICT OF INTEREST
All authors have no potential conflicts of interest to disclose.

ETHICAL APPROVAL
The present study was approved by the Committee of Ethics in Medical Research, Tabriz University of Medical Sciences, Tabriz, Iran.

INFORMED CONSENT
Informed consent was obtained from all individual participants included in the study.

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