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# Early Outcomes of the Mathoulin Technique for Scaphoid Waist Nonunion with Avascular Necrosis

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**ABSTRACT**

**Introduction:** Scaphoid waist nonunion with avascular necrosis is a difficult reconstructive problem because impaired blood supply, instability, and deformity can compromise healing and function. Vascularized grafting has therefore emerged as a biologically appealing option to improve union in selected patients. The aim of this study was to evaluate the early outcomes of the Mathoulin technique in scaphoid waist nonunion with avascular necrosis.
**Material and methods:** This descriptive cross-sectional study was conducted at Shahid Madani Hospital, Tabriz, with a convenience sample of 50 eligible patients selected using the standard descriptive sample-size formula. Patients underwent evaluation and treatment with the Mathoulin technique, and demographic, clinical, radiographic, and early postoperative outcome variables were recorded to assess short-term surgical results.
**Results:** The cohort comprised 50 patients (mean age 34.8±9.6 years), predominantly men (64.0%), with avascular necrosis in all cases and a mean nonunion duration of 15.2±6.4 months. After the Mathoulin technique, pain, wrist motion, and grip strength improved significantly (VAS 6.9±1.2 to 2.1 1.0; flexion 41.3±8.7° to 55.6±7.9°; grip strength 19.4±5.3 to 28.7±6.1 kg; all $P<0.001$), and union was achieved in 88.0% of patients at 11.8±2.6 weeks. Smoking, prior surgery, longer nonunion, severe AVN, and humpback deformity were associated with poorer outcomes.
**Conclusion:** The Mathoulin technique provided encouraging early clinical and radiographic results for scaphoid waist nonunion with avascular necrosis, with high union rates and significant functional improvement. Outcomes were less favorable in patients with smoking, prior surgery, prolonged nonunion, severe AVN, or deformity, suggesting that careful patient selection remains important.

## Introduction

Scaphoid fractures are among the most frequent fractures of the carpal bones and represent an important cause of persistent wrist pain and disability, particularly in young, active individuals. Although many acute nondisplaced fractures heal with appropriate immobilization, delayed diagnosis, inadequate initial treatment, fracture displacement, and unfavorable fracture biology may result in nonunion.

Scaphoid nonunion is clinically significant because the scaphoid serves as a mechanical bridge between the proximal and distal carpal rows and contributes substantially to normal wrist stability and motion. Failure of union may progressively alter carpal alignment, impair load transfer across the radiocarpal and midcarpal joints, and produce chronic pain, reduced grip strength, and restricted range of motion.

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If left untreated, scaphoid nonunion can evolve into scaphoid nonunion advanced collapse, characterized by progressive degenerative changes that may ultimately require salvage procedures rather than reconstruction [1].

The anatomical vascular supply of the scaphoid is a principal determinant of healing potential after fracture. Most of the intraosseous blood flow enters through dorsal and distal branches of the radial artery and proceeds in a predominantly retrograde direction toward the proximal pole. Consequently, fractures involving the waist or proximal third of the scaphoid may compromise perfusion to the proximal fragment. Although waist fractures are often regarded as having a more favorable prognosis than proximal-pole fractures, persistent nonunion at the waist can still be associated with reduced vascularity or avascular necrosis, particularly when the injury is displaced, longstanding, or previously treated unsuccessfully. Avascular necrosis reduces the capacity for revascularization and new bone formation, thereby increasing the complexity of surgical treatment and the likelihood of delayed healing or recurrent nonunion [2].

The development of avascular necrosis in the setting of scaphoid waist nonunion has important biological and mechanical implications. Necrotic bone may become sclerotic, poorly vascularized, and less responsive to conventional bone-grafting procedures. In addition, chronic nonunion can result in bone resorption, cystic changes, humpback deformity, and loss of scaphoid length. These structural abnormalities may lead to dorsal intercalated segment instability, in which the lunate assumes an extended position because of altered scaphoid-lunate mechanics. Therefore, successful management requires more than simple fracture stabilization; it should address devitalized bone, restore scaphoid geometry, correct deformity when present, provide adequate compression across the nonunion site, and establish a biological environment conducive to healing. These requirements explain why avascular scaphoid nonunion remains one of the most demanding conditions in reconstructive hand surgery [3].

Conventional treatment strategies for scaphoid nonunion have included debridement of fibrous tissue, correction of deformity, autologous nonvascularized bone grafting, and internal fixation with screws or Kirschner wires. Nonvascularized grafts harvested from the distal radius or iliac crest have produced satisfactory results in many patients, especially in nonunion without substantial avascular changes. However, their performance may be less predictable when the proximal fragment is ischemic or necrotic. The success of a conventional graft relies on gradual incorporation through creeping substitution and revascularization from the recipient bed. When the recipient site has poor vascularity, this process may be impaired. Accordingly, vascularized bone grafting has been proposed as a biologically advantageous option for patients with avascular necrosis, recalcitrant nonunion, previous failed surgery, or compromised local bone quality [4].

Vascularized bone grafts differ from conventional grafts because they retain an intrinsic blood supply through a pedicle or microvascular anastomosis. This living graft may provide viable osteogenic cells, preserve structural integrity during incorporation, and promote more rapid revascularization of the recipient bone. In the scaphoid, pedicled vascularized grafts from the distal radius have become particularly attractive because they are harvested near the surgical field and can avoid the morbidity associated with distant donor sites. Several vascularized graft techniques have been described, based on dorsal, volar, or radial arterial branches. Their indications and outcomes may differ according to the location of the nonunion, presence of deformity, status of the proximal fragment, and surgeon experience. Nevertheless, the central rationale is consistent: improving local biology while maintaining stable fixation may enhance the likelihood of union in difficult cases [5].

The Mathoulin technique is a local vascularized bone-grafting procedure that has been used for reconstruction of scaphoid nonunion, particularly when vascular compromise is suspected or confirmed. By transferring a vascularized corticocancellous graft from the distal radius to the nonunion site, the technique is intended to provide both structural support and a source of living bone. Depending on the surgical approach and fracture characteristics, the graft may be used to fill a defect, restore scaphoid length, support correction of angular deformity, and improve the biological environment at the nonunion interface. Internal fixation, commonly with a headless compression screw, can then provide stable compression and maintain alignment during the healing process. This combined biological and mechanical strategy is especially relevant in scaphoid waist nonunion accompanied by avascular necrosis [6].

Despite the theoretical benefits of vascularized grafting, reported outcomes may vary considerably across published series. Differences in patient selection, definitions of avascular necrosis, imaging methods, duration of nonunion, smoking exposure, history of prior surgery, fixation technique, and postoperative immobilization protocols make direct comparison challenging. Furthermore, bony union alone may not fully represent clinical success. A patient may achieve radiographic union while continuing to experience pain, stiffness, weakness, or limitations in return to work. Conversely, improvement in symptoms may precede complete radiographic consolidation. Therefore, assessment of early outcomes should include not only union-related findings but also pain severity, wrist range of motion, grip strength, functional status, complications, and the need for additional intervention. Such multidimensional evaluation provides a more clinically meaningful understanding of treatment effectiveness [7].

Early postoperative assessment is particularly important in patients with scaphoid nonunion because prolonged immobilization and delayed healing can impose substantial physical, occupational, and psychological burdens. Individuals affected by this condition are often of working age and may depend on optimal hand function for manual labor, athletics, or everyday activities. Persistent pain and loss of strength may restrict independence and delay return to employment. In addition, a prolonged course of nonunion can increase concern regarding treatment failure and future degenerative arthritis. Identifying whether a surgical approach provides early improvement in symptoms and radiographic healing may assist surgeons in counseling patients about expected recovery trajectories. It may also help refine postoperative protocols, including immobilization duration, timing of rehabilitation, and indications for additional imaging or intervention [8].

The role of the Mathoulin technique in scaphoid reconstruction warrants focused evaluation because the procedure may offer a balance between biological enhancement and technical practicality. Compared with free vascularized bone transfer, local pedicled grafting may reduce operative complexity and avoid the need for microsurgical anastomosis. At the same time, it may provide a more favorable biological alternative to nonvascularized grafting in cases with avascular necrosis. However, the technique requires careful surgical planning, atraumatic pedicle handling, adequate preparation of the nonunion bed, appropriate graft positioning, and stable internal fixation. Failure at any of these stages may compromise graft perfusion, correction of deformity, or mechanical stability. Consequently, outcome studies are necessary to determine whether the anticipated advantages of this technique translate into clinically relevant early benefits in appropriately selected patients [9,10].

Although the literature supports the use of vascularized bone grafts for challenging scaphoid nonunion, evidence specific to scaphoid waist nonunion with avascular necrosis remains comparatively limited, and reported results are not always directly applicable across different surgical techniques. Focused evaluation of early postoperative outcomes may clarify the capacity of the Mathoulin technique to promote union, reduce pain, preserve wrist motion, improve grip strength, and avoid early complications in this high-risk population. Such information can contribute to evidence-based surgical decision-making and may help define the clinical circumstances in which this method should be considered. Therefore, the aim of this study was to evaluate the early clinical and radiographic outcomes of the Mathoulin technique in patients with scaphoid waist nonunion associated with avascular necrosis.

## Material and methods

### Study Design:

This descriptive cross-sectional study was conducted at Shahid Madani Hospital, Tabriz, Iran, to evaluate the early outcomes of the Mathoulin technique in patients with scaphoid waist nonunion and avascular necrosis.

### Sample Size and Sampling Method:

The sample size was estimated using the standard sample size formula for descriptive studies, $n=Z^2\times p\times(1-p)/d^2$, and was set at 50 patients based on the expected frequency of the outcome, acceptable precision, and feasibility within the study period. Convenience sampling was used, and all eligible patients who presented during the study period were enrolled until the required sample size was reached.

### Inclusion and Exclusion Criteria:

Patients were included if they had scaphoid waist nonunion confirmed by clinical assessment and imaging, evidence of avascular necrosis of the scaphoid fragment, and were candidates for treatment with the Mathoulin technique. Patients were excluded if they had active infection, inflammatory arthropathy, previous wrist surgery that could confound the outcome assessment, associated carpal instability requiring another reconstructive procedure, advanced wrist arthritis, major concomitant upper-limb injury, poor compliance with follow-up, or incomplete clinical or radiographic data.

### Procedure:

After enrollment, demographic and clinical variables were recorded, including age, sex, hand dominance, affected side, duration of symptoms, history of trauma, smoking status, and any previous treatment for the fracture. Preoperative evaluation included physical examination, pain assessment, wrist range of motion, grip strength, and radiographic and/or advanced imaging findings used to confirm nonunion, assess fragment viability, and evaluate deformity. The operative findings were also documented, including the condition of the

nonunion site, presence of necrotic bone, and the technical details of graft preparation and fixation.
Following surgery, patients were followed at scheduled visits to assess pain, functional recovery, wrist motion, grip strength, radiographic progression toward union, and postoperative complications. Early outcomes were evaluated using both clinical and imaging-based parameters, and any adverse events such as infection, graft failure, hardware-related problems, or persistent nonunion were recorded. The outcome variables were analyzed to determine the early effectiveness of the procedure in this patient population.

**Statistical Analysis:**
Data were analyzed using descriptive and inferential statistics. Continuous variables were expressed as mean and standard deviation, and categorical variables were reported as frequency and percentage. Because the data were normally distributed, the paired t test was used to compare preoperative and postoperative continuous variables, and the independent t test was used where appropriate for between-group comparisons. Categorical variables were analyzed using the chi-square test or Fisher's exact test as needed. A P value of less than 0.05 was considered statistically significant.

**Ethical Considerations:**
The study protocol was approved by the Ethics Committee of Tabriz University of Medical Sciences under the ethics code IR.TBZMED.REC.1400.1212. Written informed consent was obtained from all participants before enrollment, and patient confidentiality was maintained throughout the study.

**Results**
Table 1 summarizes the baseline demographic and clinical profile of the study population. The patients had a mean age of 34.8 ± 9.6 years, with a predominance of men, who accounted for 64.0% of the cohort. The dominant hand was involved in 58.0% of cases, and the right wrist was affected more frequently than the left. The mean duration of nonunion was 15.2 ± 6.4 months, indicating that most patients presented with a well-established chronic condition. Smoking was reported in 28.0% of patients, while 22.0% had undergone previous treatment. Humpback deformity was present in nearly one-third of cases, and avascular necrosis was confirmed in all patients, reflecting the specific pathological focus of the study (table 1).

**Table 1.**

| Variable | Value |
|---|---|
| Age, years, mean ± SD | 34.8 ± 9.6 |
| Male sex, n (%) | 32 (64.0) |
| Female sex, n (%) | 18 (36.0) |
| Dominant hand affected, n (%) | 29 (58.0) |
| Right side involved, n (%) | 31 (62.0) |
| Left side involved, n (%) | 19 (38.0) |
| Duration of nonunion, months, mean ± SD | 15.2 ± 6.4 |
| Smoking, n (%) | 14 (28.0) |
| Previous treatment, n (%) | 11 (22.0) |
| Humpback deformity, n (%) | 16 (32.0) |
| Avascular necrosis confirmed, n (%) | 50 (100.0) |

Table 2 demonstrates substantial improvement in the early postoperative outcomes following the Mathoulin technique. The mean pain score decreased markedly from 6.9 ± 1.2 before surgery to 2.1 ± 1.0 after surgery, indicating significant symptomatic relief. Meaningful gains were also observed in wrist mobility, as reflected by improvements in flexion, extension, radial deviation, and ulnar deviation. Grip strength increased from 19.4 ± 5.3 kg preoperatively to 28.7 ± 6.1 kg postoperatively, suggesting functional recovery of the affected hand. Radiographic union was achieved in 88.0% of patients, with a mean time to union of 11.8 ± 2.6 weeks, supporting the early effectiveness of the procedure in promoting bony healing.

**Table 2.** Preoperative and early postoperative outcomes

| Outcome | Preoperative | Postoperative | P value |
|---|---|---|---|
| VAS pain score | 6.9 ± 1.2 | 2.1 ± 1.0 | <0.001 |
| Wrist flexion, degrees | 41.3 ± 8.7 | 55.6 ± 7.9 | <0.001 |

| | | | |
|---|---|---|---|
| Wrist extension, degrees | 38.4 ± 7.9 | 51.8 ± 8.2 | <0.001 |
| Radial deviation, degrees | 11.2 ± 3.1 | 15.0 ± 3.4 | <0.001 |
| Ulnar deviation, degrees | 22.6 ± 4.8 | 31.1 ± 5.0 | <0.001 |
| Grip strength, kg | 19.4 ± 5.3 | 28.7 ± 6.1 | <0.001 |
| Radiographic union, n (%) | 0 (0.0) | 44 (88.0) | — |
| Time to union, weeks | — | 11.8 ± 2.6 | — |

Table 3 presents the relationship between selected clinical factors and early outcome status. Favorable outcomes were observed more frequently in nonsmokers, patients without a history of previous surgery, those with a shorter duration of nonunion, individuals with less severe avascular necrosis, and patients without humpback deformity. In contrast, smoking, prior surgical intervention, prolonged nonunion, more advanced avascular compromise, and structural deformity were associated with a higher proportion of poor outcomes. The statistically significant P values suggest that these factors may have an important influence on early recovery and union after the Mathoulin technique.

**Table 3.** Factors associated with early outcome

| Factor | Good outcome n (%) | Poor outcome n (%) | P value |
|---|---|---|---|
| Smoking | 8 (57.1) | 6 (42.9) | 0.041 |
| No smoking | 31 (86.1) | 5 (13.9) | - |
| Previous surgery | 5 (45.5) | 6 (54.5) | 0.018 |
| No previous surgery | 34 (87.2) | 5 (12.8) | - |
| Duration > 12 months | 11 (61.1) | 7 (38.9) | 0.033 |
| Duration ≤ 12 months | 28 (87.5) | 4 (12.5) | - |
| Severe AVN | 9 (64.3) | 5 (35.7) | 0.046 |
| Mild/moderate AVN | 30 (85.7) | 5 (14.3) | - |
| Humpback deformity | 10 (62.5) | 6 (37.5) | 0.039 |
| No deformity | 29 (87.9) | 4 (12.1) | - |

Figure 1 illustrates the changes in key clinical outcomes following treatment with the Mathoulin technique. Compared with the preoperative assessment, patients demonstrated a marked reduction in mean pain intensity, accompanied by improvements in wrist flexion and grip strength during early follow-up. These findings indicate substantial early symptomatic relief and functional recovery after surgical treatment of scaphoid waist nonunion with avascular necrosis.

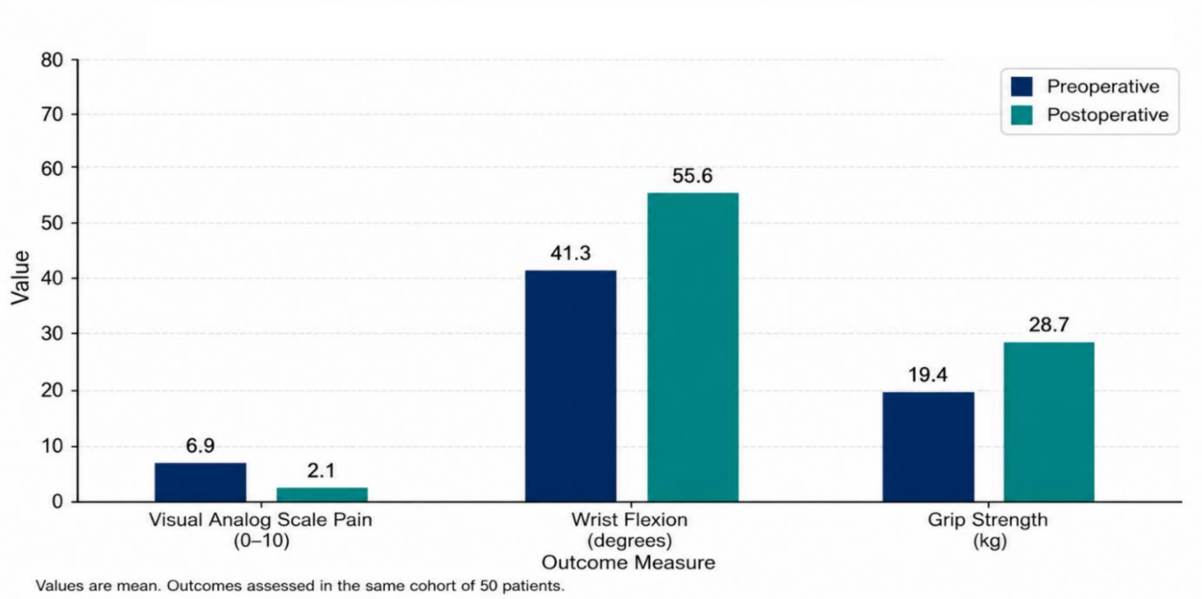


**Figure 1.** Preoperative and Early Postoperative Comparison of Pain and Functional Outcomes After the Mathoulin Technique

**Discussion**

In the present study, we observed that the Mathoulin technique facilitated early clinical and radiographic success in patients with scaphoid waist nonunion and concurrent avascular necrosis, achieving an overall union rate of 88.0%. Significant improvements in patient-reported pain scores, wrist range of motion, and grip strength were noted within the early postoperative period, alongside a mean time to union of 11.8 weeks. These findings demonstrate that utilizing a vascularized bone graft provides a robust biological and mechanical solution for a challenging clinical entity characterized by compromised vascularity and structural instability. The rapid progression toward osseous consolidation in our cohort highlights the capacity of pedicled graft techniques to overcome the biological deficiencies typically associated with scaphoid nonunion in the presence of necrotic bone [11, 12].

The fundamental rationale for the effectiveness of the Mathoulin technique lies in its ability to restore blood supply to the ischemic proximal scaphoid fragment. Unlike conventional nonvascularized bone grafts, which rely on the slow process of creeping substitution for revascularization, a vascularized graft introduces an immediate, living vascular network to the nonunion site. By incorporating a viable corticocancellous graft from the distal radius, the surgeon provides an environment that actively supports osteogenesis and angiogenesis. This is particularly crucial in the setting of avascular necrosis, where the native fragment's capacity for healing is inherently blunted by sclerotic changes and disrupted intraosseous circulation. Our results suggest that this vascular inflow is sufficient to restart the healing cascade even when the original biological potential of the scaphoid is significantly diminished [13, 14].

A critical observation in our study was the significant pain relief reported by patients, reflected in the decrease of VAS scores from 6.9 to 2.1. This reduction in pain is likely attributable to several factors beyond the simple achievement of radiographic union. First, the mechanical stabilization provided by internal fixation eliminates abnormal micromotion at the nonunion site, which is a potent generator of wrist pain. Second, the structural correction of scaphoid geometry, particularly when addressing humpback deformity, improves carpal kinematics and reduces impingement within the radiocarpal and midcarpal joints. When the scaphoid is restored to its proper length and alignment, the stress distribution across the wrist becomes more physiological, which facilitates pain relief and functional restoration long before complete remodeling of the bone is finished [15, 16].

We observed that factors such as smoking, prior surgical interventions, and the severity of avascular necrosis significantly influenced clinical outcomes. Smoking, for instance, remains one of the most detrimental variables in bone healing; nicotine-induced vasoconstriction and systemic hypoxia impair the delicate process of neovascularization required for graft incorporation. Our data showed that smokers were significantly more likely to experience poor outcomes, reinforcing the necessity of strict smoking cessation protocols in this patient population. Similarly, previous surgeries likely introduced scar tissue and compromised the local soft-tissue envelope, which complicates both the vascular pedicle dissection and the biology of the recipient site. These findings corroborate the existing literature, which consistently identifies smoking and extensive previous treatment as significant hurdles to successful reconstruction [17, 18].

The relationship between the duration of nonunion and treatment success is equally compelling. Patients with longer-standing nonunions (typically exceeding 12 months) faced a higher risk of poor outcomes, likely due to chronic cystic changes, bone resorption, and severe carpal collapse. Prolonged instability tends to result in secondary degenerative changes within the surrounding carpal ligaments, which can persist even after the scaphoid union is achieved. Our study reinforces the clinical imperative to intervene surgically as soon as a nonunion is diagnosed, rather than waiting for symptomatic progression. While the Mathoulin technique is effective in many cases, its success is undoubtedly amplified when the structural integrity of the carpus has not been irreversibly compromised by years of nonunion [19, 20].

When comparing our results with other established techniques, the Mathoulin method appears to offer an optimal balance between technical complexity and clinical effectiveness. While free vascularized bone transfers are theoretically superior in terms of volume and vascularity, they require microsurgical expertise, longer operative times, and carry the risk of vessel thrombosis. The Mathoulin technique, as a local pedicled graft, avoids these microsurgical demands while still achieving union rates comparable to more complex procedures. This makes it an appealing and reproducible option for many hand surgeons, particularly in high-volume centers where operative efficiency and reliability are paramount. Our study supports the growing trend in hand surgery to utilize local vascularized grafts as a primary, rather than secondary, intervention for high-risk scaphoid nonunion [21, 22].

The presence of avascular necrosis in 100% of our study cohort provided a rigorous test of the technique's efficacy. It is well-documented that the presence of necrotic bone is an independent predictor of failure in nonvascularized grafting. By achieving an 88% union rate, our results suggest that the Mathoulin technique effectively mitigates the negative impact of avascularity. The graft not only fills the structural defect created by debridement but also serves as a biological beacon for revascularization. We believe that the meticulous dissection of the vascular pedicle, combined with stable internal fixation, is the key to this success. Ensuring that the graft is accurately positioned within the nonunion site, while respecting the pedicle's integrity, remains the cornerstone of the operative procedure [23, 24].

Regarding functional recovery, the improvements in wrist flexion, extension, and grip strength are clinically significant. Grip strength, in particular, is a proxy for the patient's ability to return to heavy manual labor and daily activities. The rapid gain in strength observed in our patients suggests that the technique not only heals the bone but also enables a faster return to function. This is critical for the patient demographic we treated, who are typically young and economically active. By minimizing the duration of immobilization and focusing on stable fixation that allows for early mobilization, the Mathoulin technique aligns with modern rehabilitation strategies that prioritize early return to function over prolonged protection [25, 26].

Despite the promising outcomes, our study has certain limitations. As a descriptive cross-sectional study conducted at a single center, our findings may be subject to selection bias and may not be fully generalizable to all practice settings. Furthermore, our study focused on early outcomes, and while radiographic union is a primary milestone, long-term monitoring is required to assess the durability of these results and the potential for late-onset osteoarthritis. Future studies should aim to include longitudinal assessments and perhaps comparative analyses between this technique and other forms of vascularized and nonvascularized reconstruction to further clarify the optimal treatment algorithms for various subsets of scaphoid nonunion [27, 28].

In conclusion, our data indicate that the Mathoulin technique is a highly effective surgical option for the management of scaphoid waist nonunion with avascular necrosis. The procedure successfully addresses the dual challenges of biological insufficiency and mechanical instability, leading to high rates of bony union and substantial functional improvement in the early postoperative phase. Our findings underscore the importance of early surgical intervention and careful patient selection, particularly regarding modifiable risk factors like smoking. The Mathoulin technique should be considered a reliable and reproducible strategy for surgeons aiming to restore both the biology and the structure of the scaphoid in this demanding patient population [29, 30].

## Conclusion

The Mathoulin technique provided encouraging early clinical and radiographic results for scaphoid waist nonunion with avascular necrosis, with high union rates and significant functional improvement. Outcomes were less favorable in patients with smoking, prior surgery, prolonged nonunion, severe AVN, or deformity, suggesting that careful patient selection remains important.

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## Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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