eISSN 2255-0569

ORIGINAL

Bone Marrow Aspirate Injection Technique in the Treatment of Scaphoid Fracture Utilizing Percutaneous Screw Fixation

Técnica de inyección de aspirado de médula ósea en el tratamiento de la fractura de escafoides mediante fijación percutánea con tornillos

Rebwar A Hasan[1], Omer A Barawi[2], Jalal A Hasan[3]

1. Department of Surgery, College of Medicine, University of Slemani, Kurdistan Region-Iraq.
2. Orthopedic Surgery Division, Department of Surgery, College of Medicine, University of Slemani, Kurdistan Region-Iraq.
3. Plastic Surgery Division, Department of Surgery, College of Medicine, University of Slemani, Kurdistan Region-Iraq

Corresponding author
Rebwar A Hasan
E-mail: rebwar.hassan@univsul.edu.iq, rebwar.allaf@gmail.com

Received: 19 - IX - 2023
Accepted: 16 - X - 2023

doi: 10.3306/AJHS.2024.39.01.155

Abstract

Background and Objective: Scaphoid fractures are common and can lead to serious complications. Percutaneous screw fixation is a common treatment, and Bone Marrow Aspirate (BMA) injection is an emerging adjunct treatment that may enhance healing. The aim of this study was to investigate the effectiveness of BMA injection in the treatment of scaphoid bone fractures with percutaneous screw fixation.

Methods: Between April 2022 and July 2023, the prospective interventional study was conducted in three hospitals involving 60 patients with scaphoid fractures. The patients were divided into two groups: one group received percutaneous volar screw fixation alone (control group), and the other group received the same fixation along with a intraoperative injection of Bone Marrow Aspirate Concentrate (BMAC) into the fracture site (cases group).

Results: The disparity observed in the reduction of disability scores between the fixation BMAC group and the Fixation alone group highlights the substantial impact of the surgical technique on alleviating disability in the arm, shoulder, and hand of the patients who underwent the procedure. These results suggest that the use of fixation BMAC may lead to a greater reduction in wrist and hand disability compared to fixation alone, indicating the positive impact of the surgical method on reducing disability in the intervened patients.

Conclusions: The results of this study showed that using bone marrow aspirate injection in conjunction with fixation through the skin can lead to a reduction in wrist disability compared to fixation alone in the treatment of scaphoid fractures.

Key words: Bone marrow, fracture fixation, fractures, stem cell.

Resumen

Antecedentes y objetivo: Las fracturas de escafoides son frecuentes y pueden dar lugar a complicaciones graves. La fijación percutánea con tornillos es un tratamiento habitual, y la inyección de aspirado de médula ósea (AMB) es un tratamiento complementario emergente que puede mejorar la curación. El objetivo de este estudio era investigar la eficacia de la inyección de AMB en el tratamiento de las fracturas óseas del escafoides con fijación percutánea con tornillos.

Metodología: Entre abril de 2022 y julio de 2023, se llevó a cabo el estudio prospectivo de intervención en tres hospitales con 60 pacientes con fracturas de escafoides. Los pacientes se dividieron en dos grupos: un grupo recibió fijación percutánea con tornillo volar solo (grupo de control), y el otro grupo recibió la misma fijación junto con una inyección intraoperatoria de concentrado de aspirado de médula ósea (BMAC) en el foco de fractura (grupo de casos).

Resultados: La disparidad observada en la reducción de las puntuaciones de discapacidad entre el grupo de fijación BMAC y el grupo de fijación sola pone de relieve el impacto sustancial de la técnica quirúrgica en el alivio de la discapacidad en el brazo, el hombro y la mano de los pacientes sometidos a la intervención. Estos resultados sugieren que el uso de la fijación BMAC puede conducir a una mayor reducción de la discapacidad en muñeca y mano en comparación con la fijación sola, lo que indica el impacto positivo del método quirúrgico en la reducción de la discapacidad en los pacientes intervenidos.

Conclusiones: Los resultados de este estudio mostraron que el uso de la inyección de aspirado de médula ósea junto con la fijación a través de la piel puede conducir a una reducción de la discapacidad de la muñeca en comparación con la fijación sola en el tratamiento de las fracturas de escafoides.

Palabras clave: Médula ósea, fijación de fracturas, fracturas, células madre.

Cite as: Hasan RA, Barawi OA, Hasan JA. Bone Marrow Aspirate Injection Technique in the Treatment of Scaphoid Fracture Utilizing Percutaneous Screw Fixation. *Academic Journal of Health Sciences 2024*; 39(1):155-162 doi: 10.3306/AJHS.2024.39.01.155

Introduction

The scaphoid plays a crucial role in wrist kinematics by articulating with the radius and trapezium and connecting the distal and proximal carpal rows, thereby stabilizing the wrist[1,2]. The scaphoid bone has a complex blood supply with varying perfusion levels, and the proximal portion has the poorest blood flow. This constrained blood supply makes the scaphoid susceptible to nonunion and osteonecrosis when fractured[3,4].

Scaphoid fractures are a prevalent type of wrist injury, comprising 60-70% of all carpal bone fractures, 11% of hand fractures, and 2% of all fractures. These kinds of fractures frequently originate from falls onto an outstretched hand, sports-related mishaps, or direct damage to the wrist [5, 6]. Most cases of scaphoid fractures occur in physically active young adult men. The estimated annual incidence is 5 fractures per 10,000 people[7].

Scaphoid fractures can be divided into three groups according to their position (proximal, middle, and distal), displacement, and angulation[8,9]. Among scaphoid fractures, proximal pole fractures make up around 10% and tend to have a higher risk of complications due to the tenuous blood supply in that area[10,11].

Symptoms of a scaphoid fracture include pain, swelling, tenderness, limited range of motion, and possible bruising. Pain in the wrist, specifically in the anatomical snuffbox, is a common indication. Swelling and tenderness around the scaphoid bone may also be observed, and the fracture may impede the normal range of motion of the wrist[5,12].

To diagnose a scaphoid fracture, a physical examination is done to assess wrist symptoms. Although X-ray imaging is a common diagnostic procedure, specialized views or MRI may be necessary to detect subtle fractures and assess complications. CT scans can provide three-dimensional images for accurate assessment. A combination of these diagnostic methods is used to ensure precise identification and determine the appropriate treatment plan in complex cases[6,13,14].

The treatment of scaphoid fractures is based on factors such as the type of fracture, extent of displacement, and presence of complications. Nonoperative treatment with immobilization is typically preferred for non-displaced or minimally displaced fractures without complications [6, 15]. Surgical options include open reduction and internal fixation (ORIF) and percutaneous screw fixation (PSF). PSF is a minimally invasive surgical method that employs a fluoroscopically guided cannulated screw to stabilize and align broken bone pieces. This method has gained popularity due to reduced surgical complications and improved functional outcomes compared to traditional open treatments[16,17].

Despite advances in fixation methods, nonunion rates for scaphoid fractures treated with screw fixation alone range from 5% to 15% due to a lack of blood supply and difficulties in achieving total stability[18,19]. Adjuvant biologic therapy, such as Bone Marrow Aspirate (BMA), is used to increase scaphoid fracture healing and union rates after screw implantation. BMA provides necessary progenitor cells, growth factors, and osteogenic proteins to accelerate bone repair at the fracture site[20,21]. Several trials of BMA for nonunion fractures have shown high union rates and favorable clinical outcomes with low risk of complications[22,23].

Combining BMA injections with percutaneous screw fixation for scaphoid fractures is a new concept, and more research is necessary to evaluate its safety and efficacy. Since there have been limited studies in this field in the Middle East, the aim of this study is to investigate the effectiveness of bone marrow aspirate injection in the treatment of scaphoid fractures using percutaneous fixation.

Methods and Material

Study design and setting

This prospective interventional study was conducted between April 2022 and July 2023 in three hospitals: Shar Teaching Hospital, Sulaimani Surgical Teaching Hospital, and Anwar Shiekha Medical City.

The target population of this study was patients who had a scaphoid bone fracture in the first six weeks of injury. A total of 60 patients with scaphoid fractures were selected and included in the study using the available sampling method. These patients were divided into two groups:

- 30 patients treated with percutaneous volar screw fixation alone (control group).
- In the case group, a total of 30 patients underwent percutaneous volar screw fixation along with a single intraoperative injection of 1.5 cc of Bone Marrow Aspirate Concentrate (BMAC) directly into the fracture site.

Inclusion and Exclusion Criteria

Inclusion criteria included individuals 18 years or older with non-displaced or minimally displaced unilateral scaphoid fractures located in the middle-third and distal pole, occurring within the first six weeks of the injury and classified as type 3 and 4 according to the MAYO classification. Exclusion criteria consisted of patient refusal to participate in the study, comminuted or displaced scaphoid fractures, fractures associated with other carpal bone fractures or carpal dislocation, and presentation after six weeks.

Study Procedure

The study consisted of three main phases: the preoperative phase, the operative phase, and the postoperative phase.

Preoperative planning: In the preoperative phase, screening, recruitment, and baseline data collection were conducted. This involved reviewing patient medical records, conducting imaging studies (anteroposterior, lateral, and scaphoid views), MAYO classification, and administering questionnaires (DASH and PRWE scores). Baseline demographic and clinical information, as well as surgical procedure specifics, were carefully documented in a secure electronic database.

Operative technique: The Operative technique involved bone marrow aspiration and scaphoid fracture fixation. For bone marrow aspiration, the patient was positioned in a prone position after receiving general anesthesia. Adequate padding was applied to all bony pressure points and areas of potential nerve compression. After palpating the bony landmarks, the procedural site was sterilely prepared and widely draped to ensure a suitable surgical field. BMAC was harvested from the posterior superior iliac crest region using a trochar and needle inserted percutaneously. 1 mL of Heparin (1000 U/mL) was used to prevent clot formation, and approximately 30 mL of bone marrow was aspirated. A sterile dressing was applied, and the patient was repositioned supine. The harvested BMA was processed using a specialized centrifuge to discard the buffy coat layer and the platelet-poor plasma layer.

In the supine position, the patient's shoulder was abducted, forearm supinated, and wrist gently extended while the ulnar deviated. A longitudinal incision of approximately 5-10 mm was made at the apex, exposing the scaphoid tuberosity. Blunt dissection techniques were used to reveal the scaphotrapezial articulation while preserving the anterior capsule of the wrist joint. A 1.1 mm guidewire was carefully inserted through the scaphoid tubercle, aiming to center it in the proximal pole. The wire was advanced until it reached a suitable position in both views by directing it toward the center of the proximal pole of the fractured scaphoid.

To compensate for the incomplete visibility of the scaphoid on the lateral radiograph, the wire was carefully guided toward the central region of the proximal pole. The goal was to place it precisely at the midpoint between the end surface of the Radius or the Lister tubercle. The required screw length was determined either by using a depth gauge or by comparing the lengths of two parallel pins that were placed at the proximal and distal poles. During the surgical procedure, a specialized cannulated drill bit with a protective sleeve was used to create a hole in the scaphoid bone within 2 mm of the proximal cortex. To guide the screw insertion, a K-wire was utilized. Self-tapping headless compression titanium acutrak screws with a diameter of 3.5 mm and a length range of 16-20 mm were employed in all cases. During screw insertion, around 1.5 ml of concentrated bone marrow was injected through the screw, and drill bit holes were in the proximal fragment to facilitate bone healing. The screw was fully inserted over the K-wire under fluoroscopy control until the fracture was compressed appropriately. Afterward, the end of the screw was buried beneath the distal surface of the scaphoid. Before closing the skin, an additional milliliter of bone marrow concentrate was injected into the fracture site using a syringe under fluoroscopy guidance. The skin was closed using sutures and a sterile dressing.

Postoperative care: Patients were immobilized with a thumb slab for two week, followed by active finger exercises and regular follow-up appointments until a radiological union was established. Sutures were removed after two weeks, and patients underwent physiotherapy for wrist mobilization. Complete loading of the wrist was allowed only after the clinical and radiological union was achieved, and patients were discharged within 24 hours of admission.

Statistical Analysis

Descriptive and inferential statistical analyses were employed to examine the data. Mean and standard deviation were used to summarize continuous variables, whereas frequencies and percentages were utilized for categorical variables. Group comparisons involved t-tests for continuous variables and chi-square tests for categorical variables. Statistical significance was determined with a threshold of $p<0.05$.

Ethical Considerations

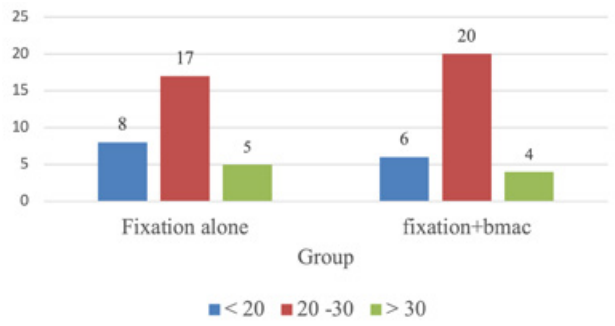
The study adhered to the principles of the Declaration of Helsinki and complied with all relevant ethical guidelines and regulations for clinical research. Informed consent was obtained from all participants, and the study protocol was approved by the Institutional Review Board of the hospital.

Results

The study included a total of 60 patients with scaphoid fractures, divided into two groups of 30 patients each. The mean age of patients in the Fixation alone group was 24.933±5.476 years, while in the fixation BMAC group, it was 25±4.683 years. In the Fixation alone group, 8(26.7%) patients were younger than 20 years old, whereas, in the fixation BMAC group, 6 (20%) patients fell under this age group. Among the patients aged between 20 to 30 years, 17 (56.7%) patients were in the fixation bone group, and 20 (66.7%) patients were in the fixation BMAC group. Furthermore, 5 patients (16.7%) in the fixation bone group and 4 patients (13.3%) in the fixation BMAC group were older than 30 years old. These age groups were illustrated in **Figure 1**.

The study revealed a notable distinction in the employment status of patients between the two groups. In the Fixation alone group, 14 patients (46.7%) were engaged in manual work occupations, whereas 16 patients (53.3%) held office-based employment. Conversely, in the fixation BMAC group, 11 patients (36.7%) were involved in manual work occupations, while 19 patients (63.3%) were employed in office-based roles. The demographic information of the patients is presented in **Table I**.

Figure 1: Age group in patients of two treatment groups.



The clinical characteristics of the patients are shown in **Table II**. Variable analysis of clinical characteristics showed that most patients in both fixation alone and BMAC fixation groups had involvement in their right hand. Specifically, 23 patients (76.7%) in the Fixation alone group and 27 patients (90%) in the fixation BMAC group had involvement in their right hand. The study found a significant difference between the two groups of patients in terms of the dominant hand ($P \leq 0.05$). In the Fixation alone group, 25 patients (83.3%) were right-handed, while in the fixation BMAC group, all patients (100%) were right-handed. The remaining patients in both groups were right-handed (**Figure 2**).

The most common location of fractures in both groups was the waist region, with 28 patients (93.3%) in each group having fractures in this area. Fractures in the distal pole region were observed in only 2 patients (6.7%) in both groups, indicating that this location is less commonly affected in scaphoid fractures.

The study analyzed the mechanism of scaphoid injury in both the Fixation alone group and the fixation BMAC group. The results showed that the most common mechanism of injury in both groups was "Falling down." Specifically, 26 patients (86.7%) in the Fixation alone group and 21 patients (70%) in the fixation BMAC group experienced injuries due to falling down. In the Fixation alone group, 3 patients (10%) had injuries as a result of direct trauma, while in the fixation BMAC group, 8 patients (26.7%) had injuries due to direct trauma. Only 1 patient (3.3%) in both groups had injuries due to traffic accidents.

The results of examining the Union time in weeks as checked by using plain radiograph variable revealed significant differences between the two groups. In the Fixation alone group, none of the patients achieved a Union time of 8 weeks. Instead, 9 patients (30%) attained a Union time of 10 weeks, 18 patients (60%) reached 12 weeks, and 3 patients (10%) required 16 weeks for Union. In contrast, in the fixation BMAC group, 9 patients (30%) had a Union time of 8 weeks, 17 patients (56.7%) had a Union time of 10 weeks, and 4 patients (13.3%) had a Union time of 16 weeks. These findings suggest that the use of fixation BMAC may lead to a shorter Union time compared to fixation alone. Significantly, the statistical analysis indicated a substantial difference in Union time in weeks between the two treatment groups ($P \leq 0.001$). A visual representation of the Union time in weeks for both groups can be observed in **Figure 3**, which vividly illustrates the contrasting Union time durations observed in the two groups.

The analysis of the mean duration of fracture in the two groups of patients showed that the mean duration of fracture in the Fixation alone group was 3±1.661 weeks, while the mean duration of fracture in the fixation BMAC group was 2.8±1.424 weeks. There was no significant difference in the duration of fracture between the two groups.

The initial assessment before surgery was performed using QDASH-KU and PRWHE-KU to determine the degree of initial disability and then repeated in the eighth and sixteenth weeks using the same tools. The mean disability score based on QDASH-KU before intervention was 54.316±5.596 in the Fixation alone group and 56.81±4.719 in the fixation BMAC group, with no significant difference between the two treatment groups. The mean disability score in the eighth week after intervention based on QDASH-KU was 29.54±3.036

Table I: Demographics characteristics of fractured patients in two treatment groups.

Characteristic		Group		P-value
		Fixation alone	Fixation+BMAC	
Age		24.933±5.476#	25±4.683	0.96**
Age group	< 20 20 - 30 > 30	8 (26.7%) & 17 (56.7%) 5 (16.7%)	6 (20%) 20 (66.7%) 4 (13.3%)	0.5*
Sex	Male Female	28 (93.3%) 2 (6.7%)	29 (96.7%) 1 (3.3%)	0.5*
Residency	Inside City Outside city	22 (73.3%) 8 (26.7%)	23 (76.67%) 7 (23.3%)	1
Education	Yes No	29 (96.7%) 1 (3.3%)	28 (93.3%) 2 (6.7%)	1
Job	Manual work Office employ	14 (46.7%) 16 (53.3%)	11 (36.7%) 19 (63.3%)	0.6*

*P-value Chi-Square, **t-test, & Frequency (%), #Mean ± SD

in the Fixation alone group and 18.866±3.55 in the fixation BMAC group, showing a significant difference in the mean disability score between the two groups (P ≤ 0.001). The mean disability score in the sixteenth week after intervention based on QDASH-KU was 8.93±4.348 in the Fixation alone group and 5.36±2.02 in the fixation BMAC group, indicating a significant difference in the mean disability score between the two groups (P ≤ 0.001). The disparity observed in the reduction of disability scores between the fixation BMAC group and the Fixation alone group highlights the substantial impact of the surgical technique on alleviating disability in the arm, shoulder, and hand of the patients who underwent the procedure.

Figure 2: Involved limb in patients of two treatment groups.

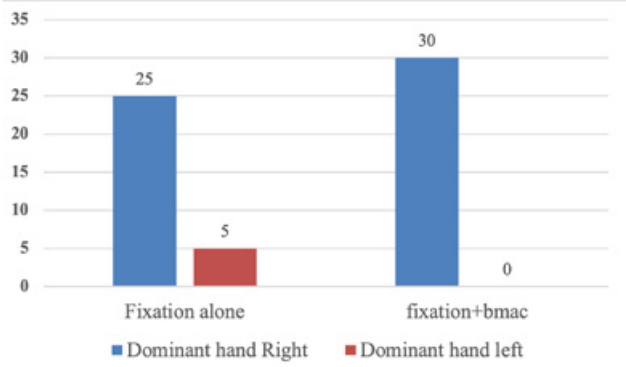


Figure 3: Union time in weeks in patients of two treatment groups.

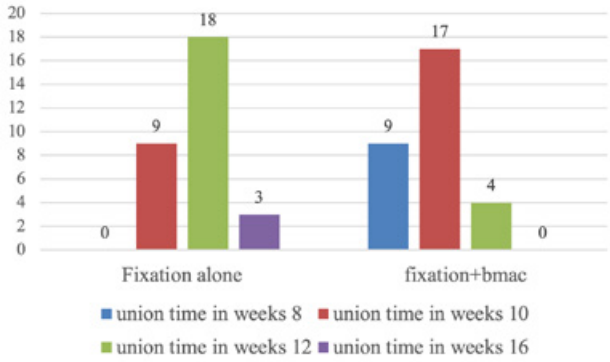


Table II: Clinical characteristics of fractured patients in two treatment groups.

Characteristic		Group		P-value
		Fixation alone	Fixation+BMAC	
Involved limb	Right Left	23 (76.7%)& 7 (23.3%)	27 (90%) 3 (10%)	0.299*
Dominant hand	Right Left	25 (83.3%) 5 (16.7%)	30 (100%) 0	**0.05***
Concomitant illness	Yes No	1 (3.3%) 29 (96.7%)	1 (3.3%) 29 (96.7%)	1
Mechanism of injury	Falling down Direct trauma Road traffic	26 (86.7%) 3 (10%) 1 (3.3%)	21 (70%) 8 (26.7%) 1 (3.3%)	0.313*
Union time in weeks	8 10 12 16	0 9 (30%) 18 (60%) 3 (10%)	9 (30%) 17 (56.7%) 4 (13.3%) 0	**0.001***
Duration (weeks)		3±1.661#	2.8±1.424	0.619**

*P-value Chi-Square, **t-test, & Frequency (%), #Mean ± SD

Table III: Assessment of disability using DASH-KU and PRWHE-KU tools in two treatment groups.

Characteristic		Group		P-value
		Fixation alone	Fixation+BMAC	
QDASH	QDASH 1 Before intervention	54.316±5.596**	56.81±4.719	0.06
	QDASH 2 8th After intervention	29.54±3.036	18.866±3.55	0.001
	QDASH 2 16th After intervention	8.93±4.348	5.36±2.02	0.001
PRWHE	PRWHE 1 Before intervention	62.05±4.43	53.833±7.786	0.001
	PRWHE 2 8th After intervention	35.116±1.501	20.85±3.744	0.001
	PRWHE 3 16th After intervention	10.983±2.283	7.566±1.275	0.001

*P-value t-test** Mean ± SD

The results of the investigation of the disability score variable based on PRWHE-KU showed that the mean disability score before intervention was significantly higher in the Fixation alone group (62.05±4.43) than in the fixation BMAC group (53.833±7.786) (P ≤ 0.001). In the eighth week after intervention, the mean disability score in the Fixation alone group was 35.116±1.501, while in the fixation BMAC group, it was 20.85±3.744, indicating a significant difference between the two groups (P ≤ 0.001). Similarly, in the sixteenth week after intervention, the mean disability score in the Fixation alone group was 10.983±2.283, and in the fixation BMAC group, it was 7.566±1.275, showing a significant difference between the two groups (P ≤ 0.001). These results suggest that the use of fixation BMAC may lead to a greater reduction in wrist and hand disability compared to fixation alone, indicating the positive impact of the surgical method on reducing disability in the intervened patients. (**Table III**).

Discussion

In this study, the effectiveness of bone marrow aspirate injection was examined in the treatment of scaphoid fracture using percutaneous fixation compared to alone fixation. Disability assessment and the impact of injection on reducing disability were evaluated using DASH-KU and PRWHE-KU tools in two treatment groups. Based on these results; it was shown that bone marrow aspirate injection in the treatment of scaphoid fracture using percutaneous fixation led to a reduction in wrist disability compared to fixation alone, indicating the positive impact of the surgical method on reducing disability in the intervention group of patients.

Scaphoid bone fractures are among the most common wrist fractures, often due to a fall on an outstretched hand[24]. Since this fracture is often not diagnosed and improper treatment can lead to complications such as non-union, avascular necrosis, and the development of osteoarthritis, its diagnosis, and treatment are of particular importance[25].

The evaluation of treatment outcomes for improving and enhancing the patient's quality of life is vital. A study conducted in the Netherlands by Cohen et al. (2021) aimed to examine the changes after surgery in scaphoid bone fractures. The PRWHE questionnaire was used to evaluate the treatment interventions in this study. The study demonstrated that the mean PRWHE score decreased from 47 before the surgery to 11 after the surgery, which is consistent with the findings of the current study, indicating that patients can expect improved functional outcomes after scaphoid surgery[26].

In China, Tang et al. (2020) carried out a study to assess the efficacy of percutaneous injection of bone marrow aspirate combined with platelet-rich plasma (PRP) in treating delayed fractures. This prospective study involved 66 patients with fractures, and its outcomes aligned closely with the findings of the present investigation. The results indicated that the percutaneous injection of bone marrow aspirates had a substantial positive effect on the treatment of the condition, facilitating accelerated fracture healing and reducing the overall recovery time[27].

In a recent study conducted by Chanthana et al. (2023) in Thailand, the primary objective was to explore the patterns and preferences of patients with wrist injuries or diseases. In this retrospective study, 183 patients with wrist injuries or diseases who visited the clinic or were hospitalized for surgery between 2017 and 2020 were included in the study. The researchers collected data through the administration of four questionnaires: DASH, MHQ, PRWHE, and EQ-5D. The findings of the study indicated that these questionnaires exhibited satisfactory accuracy and capability in assessing treatment interventions. Notably, the PRWHE questionnaire was deemed more significant to patients compared to the other questionnaires [28]. Based on the similar findings of the current study, it is crucial to employ appropriate tools in evaluating treatment interventions. The use of suitable questionnaires, such as DASH and PRWHE, for assessing surgical interventions is highly important. These questionnaires are effective and reliable and can be extensively utilized[29-31].

Paying attention to changes in functionality and movement of individuals who experience hand fractures is necessary. In a study conducted in the United States by Weinstock-Zlotnick et al. (2015), patient reports and preferences were examined. A total of 60 participants with 74 cases of hand fractures were included in this study. They completed the Disabilities of the Arm, Shoulder, and Hand Questionnaire (DASH), the Michigan Hand Outcomes Questionnaire (MHQ), and the Patient-Rated Wrist/Hand Evaluation (PRWHE) in three trials. The results of these three questionnaires, which align with and validate the findings of the current study, demonstrated that patients showed improved functionality and reduced disability after undergoing treatment interventions. By utilizing these tools, the evaluation of changes in patients' functionality after treatment interventions were effectively conducted[32].

It is important to acknowledge that the open reduction and internal fixation method for scaphoid bone fractures has certain disadvantages and potential risks. These risks include the possibility of damaging the radiocarpal ligament, causing destruction of the scaphotrapezial joint, compromising blood flow to the bone, and the potential development of hypertrophic scars[33]. However, these issues can be mitigated by utilizing the bone marrow aspiration injection technique[21,34].

Overall, the injection treatment method administered through the skin for scaphoid bone fractures was found to be an appropriate and effective approach. It

not only accelerates fracture healing but also improves wrist functionality while reducing the incidence of complications. Given the availability of resources, the injection treatment method can be preferred over other treatment methods for scaphoid bone fractures.

Conclusions

The results of this study demonstrate that bone marrow aspirate injection in conjunction with percutaneous fixation can lead to a reduction in wrist disability compared to fixation alone in the treatment of scaphoid fractures. Furthermore, using DASH-KU and PRWHE-KU questionnaires, it was shown that bone marrow aspirate injection improved patient performance and significantly reduced patient limitations.

Acknowledgments
We would like to express our gratitude to all the participants who took part in this study and made it possible.

Availability of data and materials
The data and materials used in this study are available upon request.

Competing interests
The authors declare no competing interests that could potentially bias the findings or interpretation of this study.

Funding
None

References

1. Green JB, Deveikas C, Ranger H, Draghetti JG, Groat LC, Schumer ED, et al. Hand, wrist, and digit injuries. Pathol Interv Musculoskelet Rehabil. 2015;344.

2. Rainbow MJ, Wolff AL, Crisco JJ, Wolfe SW. Functional kinematics of the wrist. J Hand Surg. European 2016;41 (1):7-21.

3. Wong C, Ho P. Arthroscopic Management of Scaphoid Fractures and Nonunions. Arthrosc Endosc Elbow, Wrist Hand Surg Anat Tech. 2022:865-86.

4. Sabbagh MD, Morsy M, Moran SL. Diagnosis and management of acute scaphoid fractures. Hand Clin. 2019;35 (3):259-69.

5. Hayat Z, Varacallo M. Scaphoid Wrist Fracture. In: Treasure Island (FL); 2023.

6. Clementson M, Björkman A, Thomsen NOB. Acute scaphoid fractures: guidelines for diagnosis and treatment. EFORT open Rev. 2020;5 (2):96-103.

7. Yoon AP, Lee YL, Kane RL, Kuo C-F, Lin C, Chung KC. Development and validation of a deep learning model using convolutional neural networks to identify scaphoid fractures in radiographs. JAMA Netw open. 2021;4 (5):e216096-e216096.

8. Daniels AM, Bevers M, Sassen S, Wyers CE, Van Rietbergen B, Geusens P, et al. Improved detection of scaphoid fractures with high-resolution peripheral quantitative CT compared with conventional CT. JBJS. 2020;102 (24):2138-45.

9. Ten Berg PW, Drijkoningen T, Strackee SD, Buijze GA. Classifications of acute scaphoid fractures: a systematic literature review. J Wrist Surg. 2016:152-59.

10. Xiao C, Wei D, Zhu Z, Chen H, Zhou W, Tang X, et al. Robot-assisted vs traditional percutaneous freehand for the scaphoid fracture treatment: a retrospective study. Int Orthop. 2023;47 (3):839-45.

11. Bezirgan U, Acar E, Özbek EA. Can headless screw used in fixation of the scaphoid proximal pole fracture be broken after wrist trauma? An unreported complication of scaphoid surgery. Jt Dis Relat Surg. 2021;32 (3):779.

12. Winston MJ, Weiland AJ. Scaphoid fractures in the athlete. Curr Rev Musculoskelet Med 2017;10:38-44.

13. Hossein KM, Ashkan S. Comparing the role of physical examination and radiography in diagnosis of scaphoid fracture; superiority or collaboration? Razavi Int J Med. 2016;341 (55):5-6.

14. Glad TH, Melhuus K, Svenningsen S. Use of MRI for diagnosing scaphoid fracture. Tidsskr den Nor Laegeforening Tidsskr Prakt Med ny Raekke. 2010;130 (8):825-28.

15. Rhemrev SJ, Ootes D, Beeres FJP, Meylaerts SAG, Schipper IB. Current methods of diagnosis and treatment of scaphoid fractures. Int J Emerg Med. 2011;4:1-8.

16. Tallman MG, Patel AH, Anderson RC, Medvedev G. Fixation Methods for Replacement Screws in Scaphoid Fractures: A Biomechanical Study. J Hand Surg Glob Online. 2023;5 (2):159-63.

17. Dinkar K, Kapoor R, Verma A, Dwivedi S, Patel J, Verma A. Comparision between functional outcome of scaphoid fracture treated by open reduction internal fixation vs percutaneous fixation. Indian J Orthop. 2021;7:267-72.

18. Nakashian MN, Hughes TB. Scaphoid Fractures. In: Skeletal Trauma of the Upper Extremity. Elsevier; 2022. p. 538-43.

19. Eardley WGP, Page PRJ, Doorgakant A, Parker PJ. Self Assessment in Trauma & Orthopaedics II. BMJ Mil Heal. 2008;154 (4):247.

20. Brozovich A, Sinicrope BJ, Bauza G, Niclot FB, Lintner D, Taraballi F, et al. High variability of mesenchymal stem cells obtained via bone marrow aspirate concentrate compared with traditional bone marrow aspiration technique. Orthop J Sport Med. 2021;9 (12):23259671211058460.

21. Marmor MT, Matz J, McClellan RT, Medam R, Miclau T. Use of osteobiologics for fracture management: the when, what, and how. Injury. 2021;52:S35-43.

22. Modest JM, Lemme NJ, Testa EJ, Evans AR, Reid DBC. Successful Fracture Healing for Femoral Neck Non-union with Bone Marrow Aspirate Concentrate. R I Med J. 2022;105 (2):13-16.

23. Benshabat D, Factor S, Maman E, Khoury A, Krespi R, Ashkenazi I, et al. Addition of bone marrow aspirate concentrate resulted in high rate of healing and good functional outcomes in the treatment of clavicle fracture non-union: A retrospective case series. J Clin Med. 2021;10 (20):4749.

24. Fahy K, Duffaut CJ. Hand and wrist fractures. Curr Sports Med Rep. 2022;21 (10):345-46.

25. Polo Simón F, García Medrano B, Delgado Serrano PJ. Diagnostic and Therapeutic Approach to Acute Scaphoid Fractures. Rev Iberoam Cirugía la Mano. 2020;48 (02):109-18.

26. Cohen A, Hoogendam L, Reijman M, Selles RW, Hovius SER, Colaris JW. Patient-reported physical functioning and pain improve after scaphoid non-union surgery: A Cohort Study. Injury. 2021;52 (10):2952-58.

27. Tang Y, Yang Y, Li H, Xi J, Li W, Yue C, Wang H, Liu Y. [Effectiveness of percutaneous injection of autologous concentrated bone marrow aspirate combined with platelet-rich plasma in treatment of delayed fracture healing]. Zhongguo xiu fu chong jian wai ke za zhi = Zhongguo xiufu chongjian waike zazhi = Chinese J reparative Reconstr Surg. 2020;34 (9):1130-35.

28. Chanthana P, Atthakomol P, Manosroi W, Wongpakaran T, Kraisarin J, Sananpanich K. Comparison of patient preferences and responsiveness among common patient-reported outcome measures for hand/wrist injuries or disorders. J Orthop Traumatol. 2023;24 (1):2.

29. Thorninger R, Wæver D, Tjørnild M, Lind M, Rölfing JD. VOLCON: a randomized controlled trial investigating complications and functional outcome of volar plating vs casting of unstable distal radius fractures in patients older than 65 years. J Orthop Traumatol. 2022;23 (1):54.

30. Kootstra TJM, Keizer J, Bhashyam A, Houwert RM, Verleisdonk E-JMM, van Heijl M, et al. Patient-reported outcomes and complications after surgical fixation of 143 proximal phalanx fractures. J Hand Surg Am. 2020;45 (4):327-34.

31. Van Bussel EM, Houwert RM, Kootstra TJM, van Heijl M, Van der Velde D, Wittich P, et al. Antegrade intramedullary Kirschner-wire fixation of displaced metacarpal shaft fractures. Eur J Trauma Emerg Surg. 2019;45:65-71.

32. Weinstock-Zlotnick G, Page C, Ghomrawi HMK, Wolff AL. Responsiveness of three Patient Report Outcome (PRO) measures in patients with hand fractures: A preliminary cohort study. J Hand Ther. 2015;28 (4):403-11.

33. Renfree KJ. Surface Replacement Arthroplasty of the Proximal Interphalangeal Joint in Border Digits Using a Lateral Approach. Hand (New York, NY). 2016;11 (1 Suppl):1S.

34. Mott A, Mitchell A, McDaid C, Harden M, Grupping R, Dean A, Byrne A, Doherty L, Sharma H. Systematic review assessing the evidence for the use of stem cells in fracture healing. Bone Jt Open. 2020;1 (10):628-38.