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ORIGINAL RESEARCH ARTICLE

Clinical efficacy of Ni-Ti memory alloy four-corner arthrodesis concentrator in the treatment of scaphoid nonunion advanced collapse: a follow-up of over 10 years

Baochuang Qi[a,b#], Minzheng Guo[c,d#], Chen Meng[a,b], Teng wang[b], Chuan Li[b,d] and Yongqing Xu[b]

[a]Graduate School, Kunming Medical University, Kunming, P. R. China; [b]Department of Orthopedics, 920th Hospital of the Joint Logistics Support Force of the Chinese People's Liberation Army, Kunming, P. R. China; [c]Beijing Hospital, National Center of Gerontology, Institute of Geriatric Medicine, Chinese Academy of Medical Sciences & Peking Union Medical College, Beijing, P. R. China; [d]Engineering Laboratory of Peptides of Chinese Academy of Sciences, Key Laboratory of Bioactive Peptides of Yunnan Province, KIZ-CUHK Joint Laboratory of Bioresources and Molecular Research in Common Diseases, National Resource Center for Non-Human Primates, National Research Facility for Phenotypic & Genetic Analysis of Model Animals (Primate Facility), and Sino-African Joint Research Center, New Cornerstone Science Laboratory, Kunming Institute of Zoology, the Chinese Academy of Sciences, Kunming, P. R. China

ABSTRACT

Purpose: Exploring the therapeutic effects of Ni-Ti shape memory alloy four-corner arthrodesis concentrator (NT-FCAC) in treating scaphoid nonunion advanced collapse (SNAC) and providing a decade-long follow-up report. **Materials and methods:** Twenty-six patients with SNAC underwent scaphoidectomy, along with four-corner arthrodesis fusion involving the capitate, lunate, triquetrum, and hamate, using NT-MFCAC. Grip strength was measured using a Jamar dynamometer, while wrist joint mobility was assessed using a goniometer. Preoperative and postoperative assessments were conducted using the Quick Disabilities of the Arm, Shoulder, and Hand (Quick DASH) questionnaire to monitor limb functionality restoration. Pain levels at the wrist joint were evaluated using the visual analog scale (VAS). Postoperative wrist bone fusion status was assessed through anteroposterior and lateral radiographs of the wrist joint. **Results:** After a 3-month postoperative period, all 26 patients exhibited osseous union at the wrist joint. Over a follow-up spanning 10–15 years, no severe postoperative complications were observed in any patient. Grip strength in the affected side of all patients recovered to 81.96% compared to the healthy side, while wrist joint mobility in the affected side reached over 60% of the healthy side's functionality. VAS scores decreased significantly from 5.85 ± 0.73 preoperatively to 0.19 ± 0.40 at the final follow-up; Quick DASH scores reduced from 69.88 ± 5.12 preoperatively to 6.30 ± 1.25 at final follow-up. Statistically significant differences were noted in VAS and Quick DASH scores for all patients ($p < 0.05$). However, beyond 60 months postoperatively, subsequent follow-ups did not yield statistically significant differences in VAS and Quick DASH scores for all patients ($p > 0.05$). **Conclusions:** Utilizing NT-FCAC for SNAC treated with four-corner arthrodesis fusion results in a high rate of wrist bone fusion, preserving a significant portion of wrist joint function and exhibiting favorable long-term outcomes. This approach is suitable for treating patients with SNAC requiring four-corner arthrodesis fusion.

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Wrist joint; wrist collapse; wrist joint arthrodesis

Introduction

Scaphoidectomy combined with four-corner fusion is currently one of the most effective measures for treating scaphoid nonunion advanced collapse (SNAC). Traditional four-corner fusion procedures often involve fixation with Kirschner wires, screws, or metal plates, leading to higher complication rates and suboptimal long-term follow-up outcomes [1,2]. Research indicates that our team-developed Ni-Ti shape memory alloy four-corner arthrodesis concentrator (NT-FCAC) has fewer complications and demonstrates favorable short-term efficacy compared to the aforementioned conventional implants [3]. However, there is a lack of mid- to long-term follow-up reports. This retrospective study analyzes the clinical data of 26 patients treated with the NT-FCAC for scaphoidectomy combined with four-corner fusion due to SNAC at the Department of Orthopedics, 920th Hospital of the Joint Logistics Support Force from July 2008 to July 2013. The study examines the clinical characteristics of these patients and the functional status of the wrist joint before and after surgery, aiming to provide evidence and reference for the clinical treatment outcomes of this method. Ethical approval was obtained from the Medical Ethics Committee of the 920th Hospital of the Joint Logistics Support Force of the Chinese People's Liberation Army (Ethical Approval No: 2011017). All patients provided informed consent by signing an informed consent form.

Materials and methods

General data

Inclusion criteria: (1) Complete medical records; (2) Ages between 18 and 65 years; (3) Patients exhibiting clinical symptoms, signs, and imaging findings meeting surgical indications, without apparent surgical contraindications; (4) Ineffectiveness of standardized

CONTACT Yongqing Xu xuyongqing1962@126.com Department of Orthopaedics, 920th Hospital of Joint Logistics Support, Force of Chinese People's Liberation Army, No.212 Daguan Road, Xishan District, Kunming City, Yunnan, 650032, China.

[#]Authors contributed equally to this manuscript.

conservative treatment for 3 months; (5) Treatment involving scaphoidectomy and four-corner fusion using NT-FCAC. Exclusion criteria: (1) Incomplete medical records and less than 120 months of follow-up; (2) Patients with severe peripheral nerve or vascular injuries; (3) Patients with severe osteoporosis; and (4) Poor overall health condition and significant multi-organ dysfunction.

This study included 44 surgeries, with 18 patients lost to follow-up, resulting in a complete follow-up of 26 patients. Among the 26 patients, there were 17 males and 9 females, aged between 20 and 64 years, with disease durations ranging from 18 to 37 months (mean duration: 26.7 months). Clinical presentations mainly comprised wrist joint pain, restricted wrist joint mobility, and decreased grip strength. Based on the classification criteria proposed by Vender and Watson [4,5], preoperative radiological grading revealed 15 cases classified as SNAC stage 2 and 11 cases classified as SNAC stage 3.

Radiological examination

All patients included in this study underwent anteroposterior and lateral X-ray examinations of the wrist joint before surgery, postoperatively, pre-discharge, and during follow-up visits. The cases included exclusively represented SNAC, excluding instances of scapholunate advanced collapse, chronic scapholunate dissociation, or other non-SNAC conditions, as well as patients with severe osteoporosis.

Operation method

In this study, patients underwent anesthesia, positioned supine with abducted limb, used tourniquet, and performed routine disinfection. A 5 cm transverse incision was made on the dorsal side of the wrist at the distal radioulnar joint. The skin and subcutaneous tissue were dissected, followed by blunt dissection of muscles, ensuring protection of the superficial branch of the radial nerve and other important nerve branches. The extensor muscles on the dorsum were incised, and rubber bands aided in traction of the extensor tendons, exposing the dorsal wrist joint capsule for incision. A bone-biting forceps was used to remove the necrotic scaphoid bone, while caution was exercised to avoid damaging the palmar and radial joint capsules. The scaphoid joint surface was debrided, preserving its cancellous bone for autografting. Longitudinal traction was applied to the second, third, and fourth metacarpals to fully expose the radioscaphoid joint, ensuring its normality. Subsequently, the lunate, capitate, triquetrum, and hamate bones and their corresponding joint surfaces were exposed. A bone chisel and bone-biting forceps were employed to remove the cartilaginous layers between these four wrist bones, exposing the subchondral bone, and optimizing their positions. Temporary fixation of these four wrist bones was achieved using 1–2 Kirschner wires of 1.5 mm gauge. Intraoperative fluoroscopy was used to ensure proper alignment of the capitate and lunate bones. The appropriately sized NT-MFCAC was soaked in ice-cold water (0–4°C) for 5 min, and a spreader was used to adjust the arms of the NT-MFCAC to form a 90° angle with its body. The spread NT-MFCAC was positioned at the center of the four wrist bones to determine the insertion points for each arm and mark them. Vertical drilling was performed with 2.0 mm Kirschner wires at each insertion point to create a bone tunnel, followed by the implantation of NT-MFCAC. The previously harvested cancellous scaphoid bone was thoroughly implanted between the four wrist bones, protecting the surrounding soft tissues. The body of the NT-MFCAC was heated to 50°C with sterile saline and subjected to vertical pressure for at least 5 min to restore its original shape, thereby fixing the four wrist bones as a unit. Subsequent wrist joint movement confirmed the stability of the fixation. Fluoroscopy was used to assess the alignment of the wrist bones and the position of the NT-MFCAC implantation, allowing adjustments if necessary. Finally, the soft tissues were sutured, and a plaster splint was applied to stabilize the patient's wrist joint.

Therapeutic evaluation methods

Postoperatively, all patients received routine orthopedic care, prophylactic antibiotics within 24 h after surgery, and suture removal approximately 2 weeks post-surgery. A plaster splint was applied to maintain the wrist joint in a functional position for 3 weeks. Patients were instructed to engage in both active and passive exercises, and at the 6-week mark, wrist joint X-rays were conducted. If signs of wrist bone healing were evident on the X-rays, patients were encouraged to further intensify their exercises. Regular follow-ups were conducted postoperatively. Clinical assessment criteria included: (1) surgical duration and blood loss; (2) postoperative complications such as significant nerve or vascular injury, infection, nonunion, or loosening or breakage of the fusion device; (3) objective assessments encompassing grip strength of the affected hand before and after surgery, range of motion of the affected wrist joint, and subjective evaluations of pain levels in the affected wrist joint during rest and weight-bearing. Grip strength was measured using a Jamar dynamometer with the elbow flexed at 90°, wrist in a neutral position, and the patient exerting maximum force, with an average of three measurements taken, each 5 min apart. Pain levels in the wrist joint were assessed using the visual analogue scale (VAS), with 0 denoting no pain and 10 representing the most severe pain [6]. A goniometer was employed to measure the range of motion of the wrist joint, including palmar flexion, dorsal extension, ulnar deviation, and radial deviation. The Quick Disabilities of the Arm, Shoulder, and Hand (Quick DASH) score was used for preoperative and postoperative assessments to evaluate patients' quality of life [7]. Radiographic evaluations encompassed preoperative and postoperative anteroposterior and lateral X-rays of the affected wrist joint and wrist joint CT scans to confirm wrist bone fusion status.

Statistical analysis

Statistical analysis was performed using SPSS 20.0 software. The Shapiro–Wilk test was employed to assess the normality of the data. Normally distributed and homoscedastic metric data were presented as $\bar{x} \pm S$ and analyzed using repeated measures ANOVA. Post-hoc pairwise comparisons were conducted using the LSD-t test. All tests were two tailed, and statistical significance was set at a p-value < 0.05 to denote differences of statistical significance.

Result

Surgical parameters and complications

In this study, surgeries were performed on a total of 26 patients involving 26 wrist joints. The surgical duration ranged from 30 to 45 min, with blood loss consistently below 60 mL. None of the patients experienced significant nerve or vascular injuries, bone nonunion, or occurrences of fusion device loosening or breakage.

Grip strength and range of motion of the wrist joint

Wrist joint grip strength: Preoperatively, the grip strength on the affected side was (8.19 ± 2.28) kg, while at the last follow-up after surgery, it was (30.42 ± 2.17) kg, and on the healthy side, it measured (37.12 ± 2.81) kg. The postoperative grip strength on the affected side

Table 3. Comparison of quick disabilities of the arm, shoulder and hand, and VAS before and after four-corner arthrodesis with NT-MFCAC($\bar{x}$ ± S).

Time	VAS score	Quick DASH score
Preoperative	5.85 ± 0.73	69.88 ± 5.12
Postoperative 3-month	4.35 ± 0.75**	46.89 ± 5.02**
Postoperative 12-month	2.27 ± 0.60**	23.65 ± 4.19**
Postoperative 60-month	0.54 ± 0.51**	6.61 ± 1.53**
Postoperative 120-month	0.27 ± 0.45**	6.54 ± 1.33**
Last follow-up	0.19 ± 0.40**	6.30 ± 1.25**

Note: VAS is visual analogue score. Comparison with preoperative: *$p < 0.05$; **$p < 0.0$. VAS: Visual Analog Scale.

recovered to 81.96% of that on the healthy side. There was a significant improvement in grip strength on the affected side postoperatively compared to preoperative measurements, demonstrating statistical significance ($p < 0.05$) (Tables 1 and 2).

Range of motion of the wrist joint: For extension, preoperative measurements were (30.81 ± 4.42) °, at the last follow-up post-surgery, it was (32.96 ± 2.25) °, and on the healthy side, it measured (51.69 ± 4.69) °. For flexion, preoperative measures were (34.85 ± 4.31) °, postoperatively it measured (38.57 ± 2.98) °, and on the healthy side, it was (58.65 ± 4.72) °. Radial deviation measured (9.34 ± 1.76) ° preoperatively, (11.08 ± 1.52) ° postoperatively, and (18.42 ± 1.94) ° on the healthy side. Ulnar deviation measured (20.08 ± 4.07) ° preoperatively, (22.15 ± 3.23) ° postoperatively, and (30.54 ± 1.82) ° on the healthy side. The postoperative last follow-up wrist joint range of motion (extension, flexion, radial deviation, ulnar deviation) compared to the healthy side was 63.76, 65.78, 72.53, and 60.15%, respectively. At the last follow-up, there was a significant decrease in the wrist joint range of motion on the affected side compared to the healthy side, showing statistical significance ($p < 0.05$). Comparing the postoperative last follow-up wrist joint range of motion to preoperative measurements, there was a significant improvement, indicating statistical significance ($p < 0.05$) (Tables 1 and 2).

VAS score and quick DASH score

Preoperatively, VAS scores ranged from 5 to 7 points, with an average of (5.85 ± 0.73) points. At 3 months postoperatively, it decreased to (4.35 ± 0.75) points; at 12 months, it was (2.27 ± 0.60) points; at 60 months, it was (0.54 ± 0.51) points, and at 120 months postoperatively, it was (0.27 ± 0.45). At the last follow-up, scores ranged from 0 to 1 point, averaging (0.19 ± 0.40) points. Comparing 3 months, 12 months, 60 months, 120 months postoperatively, and the last follow-up with preoperative scores, all differences were statistically significant (Z = -4.584, p = 0.000; Z = -4.551, p = 0.000; Z = -4.527, p = 0.000; Z = -4.512, p = 0.000; Z = -4.523, p = 0.000). However, there were no statistically significant differences between the VAS scores at 60 months postoperatively compared to 120 months postoperatively and at the last follow-up ($p > 0.05$) (Table 3). Preoperatively, the Quick DASH score ranged from 61 to 79 points, with an average of (69.88 ± 5.12) points. At 3 months postoperatively, it decreased to (46.89 ± 5.02) points; at 12 months, it was (23.65 ± 4.19) points; at 60 months, it was (6.61 ± 1.53) points; and at 120 months, it was (6.54 ± 1.33) points. At the last follow-up, scores ranged from 4 to 8 points, with an average of (6.30 ± 1.25) points. Comparing 3 months, 12 months, 60 months, 120 months postoperatively, and the last follow-up with preoperative scores for Quick DASH, all differences were statistically significant (Z = -4.465, p = 0.000; Z = -4.463, p = 0.000; Z = -4.461, p = 0.000; Z = -4.461, p = 0.000; Z = -4.460, p = 0.000). However, there were no statistically significant differences between the Quick DASH scores at 60 months postoperatively compared to 120 months postoperatively and at the last follow-up ($p > 0.05$) (Table 3).

Imaging examinations

At the 3-month postoperative follow-up, all patients exhibited excellent alignment of the wrist bones, with a fusion rate of 100%. With the follow-up period in this study ranging from 10 to 15 years, with an average of 12.3 years, at the last follow-up, all patients demonstrated well-maintained positioning of the fused wrist bones, without occurrences of radiocarpal arthritis or related conditions.

Typical case

Case 1

The patient, a 25-year-old male, was admitted due to right wrist pain and restricted motion for 2 years following a fall-related injury. X-ray imaging of the right wrist in anteroposterior and lateral views revealed an old scaphoid fracture and right-sided wrist collapse (Figure A1 and A2). Wrist joint CT scan indicated an old scaphoid fracture on the right side, with sclerosis at the fracture ends, increased density at the distant fracture end, SNAC stage 2, and no apparent signs of degeneration in the radiocarpal joint (Figure A3). After comprehensive preoperative assessments, the patient underwent right wrist scaphoid excision combined with wrist arthrodesis. A transverse incision was made at the dorsal aspect of the right wrist, sequentially dissecting through various tissue layers, using a rubber strip to retract tendons and expose the joint capsule and wrist bones (Figures A4 and A5). Necrotic scaphoid bone was excised, cartilage between the wrist bones requiring fusion was cleared, and proper alignment was maintained. Temporary fixation was achieved using Kirschner wires; drilling was performed at the center of the four wrist bones requiring fusion, followed by the implantation of NT-MFCAC and autologous bone grafting (Figures A6 and A7). Postoperative X-ray examination in anteroposterior and lateral views demonstrated the good alignment of the right scaphoid, lunate, hamate, and triquetrum bones, well-placed NT-MFCAC, and the excision of the scaphoid bone (Figures A8 and A9). Fourteen years postoperatively, X-ray examination in anteroposterior and lateral views revealed successful fusion of the right scaphoid, lunate, hamate, and triquetrum bones, absence of joint space, removal of internal fixation, proper alignment of all wrist bones, and no evident radiocarpal joint degeneration (Figures A10 and A11). Fourteen years post right wrist four-corner fusion surgery, the patient exhibited excellent flexion-extension functionality of the wrist joint (Figures A12 and A13).

Table 1. Wrist joint function before and at last follow-up after four-corner arthrodesis with NT-MFCAC ($\bar{x}$ ± S).

Group	Grip strength(kg)	The range of motion of the wrist joint (°)			
		Extension	Flexion	Ulnar deviation	Radial deviation
Preoperative	8.19 ± 2.28	30.81 ± 4.42	34.85 ± 4.31	20.08 ± 4.07	9.34 ± 1.76
Last follow-up	30.42 ± 2.17	32.96 ± 2.25	38.58 ± 2.98	22.15 ± 3.23	11.08 ± 1.52
T value	–67.45	2.498	–8.436	4.478	3.59
P value	< 0.05	0.019	0.000	0.000	< 0.01

Table 2. Comparison of the function of the affected wrist with that of the healthy wrist at the last follow-up after four-corner arthrodesis with NT-MFCAC ($\bar{x} \pm S$).

Group	Cases	Grip strength(kg)	The range of motion of the wrist joint (°)			
			Extension	Flexion	Ulnar deviation	Radial deviation
The last follow-up	26	30.42 ± 2.17	32.96 ± 2.25	38.58 ± 2.98	22.15 ± 3.23	11.08 ± 1.52
Healthy wrist	26	37.12 ± 2.81	51.69 ± 4.69	58.65 ± 4.72	30.54 ± 1.82	18.42 ± 1.94
T value	-	−24.75	−32.12	−27.15	−12.30	−44.29
P value	-	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Case 2

The patient, a 50-year-old male, admitted due to right wrist joint pain and restricted movement for 2.5 years following a fall. Anterior-posterior and lateral X-ray examination of the right wrist joint revealed an old scaphoid fracture with wrist collapse (Figures B1 and B2). Wrist joint CT scan indicated an old scaphoid fracture with sclerosis at the fracture ends, increased density at the proximal fracture end, SNAC stage 3, with no apparent signs of radiocarpal joint degeneration (Figure B3). Following comprehensive preoperative assessments, the patient underwent right wrist scaphoid excision and four-corner fusion surgery. A transverse incision was made at the dorsal aspect of the right wrist, sequentially dissecting through various tissue layers, using a rubber strip to retract tendons and expose the joint capsule and wrist bones (Figure B4). Necrotic scaphoid bone was excised, cartilage between the wrist bones requiring fusion was cleared, and proper alignment was maintained. Temporary fixation was achieved using Kirschner wires, drilling was performed at the center of the four wrist bones requiring fusion, followed by the implantation of NT-FCAC and autologous bone grafting (Figure B5). Postoperatively at 11 years, X-rays revealed fusion of the scaphoid, lunate, triquetrum, and pisiform bones, obliteration of joint spaces between the wrist bones, good alignment, and no evident radiocarpal joint degeneration (Figures B6 and B7). At 11 years postoperatively, the range of motion for wrist flexion and extension reached 70% compared to the healthy side (Figures B8 and B9). Ulnar and radial deviation of the wrist at 11 years postoperatively was at 70% compared to the healthy side (Figures B10 and B11). The grip strength of the right hand at 11

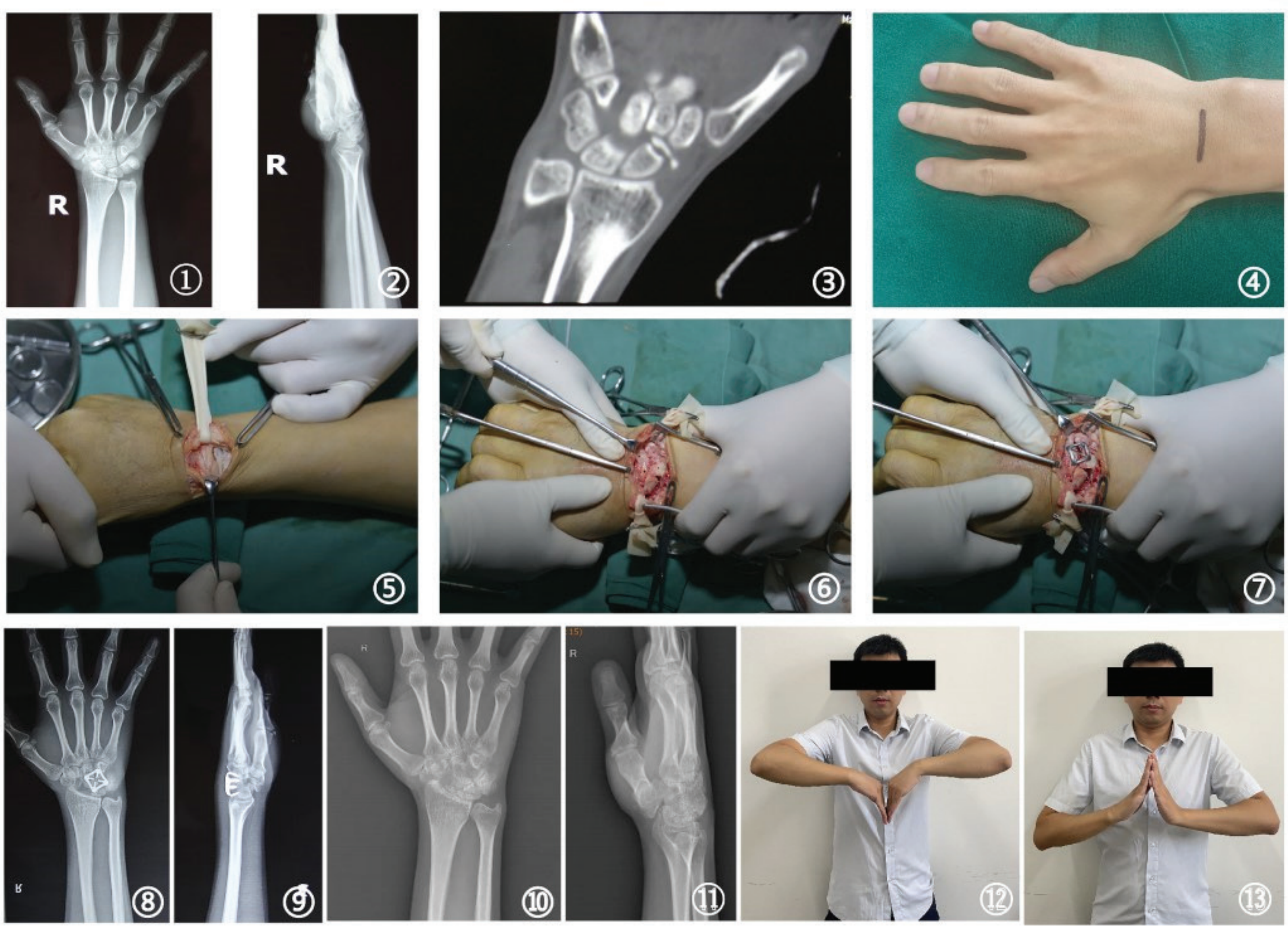

Figure A1: Preoperative right wrist joint anterior-posterior X-ray. Figure 2: Preoperative right wrist joint lateral X-ray. Figure 3: Preoperative right wrist joint CT scan. Figure 4: Transverse incision at the dorsal aspect of the right wrist. Figure 5: Exposure of the joint capsule and wrist bones. Figure 6: Removal of the scaphoid bone and drilling at the center of the wrist bones requiring fusion. Figure 7: Implantation of NT-FCAC. Figure 8: Postoperative 1-month right wrist joint anterior-posterior X-ray. Figure 9: Postoperative 1-month right wrist joint lateral X-ray. Figure 10: Postoperative 14-year right wrist joint anterior-posterior X-ray. Figure 11: Postoperative 14-year right wrist joint lateral X-ray. Apologies for the confusion earlier. Figure 12: Image of patient's right wrist joint flexion function 14 years postoperation. Figure 13: Image of patient's right wrist joint extension function 14 years postoperation.

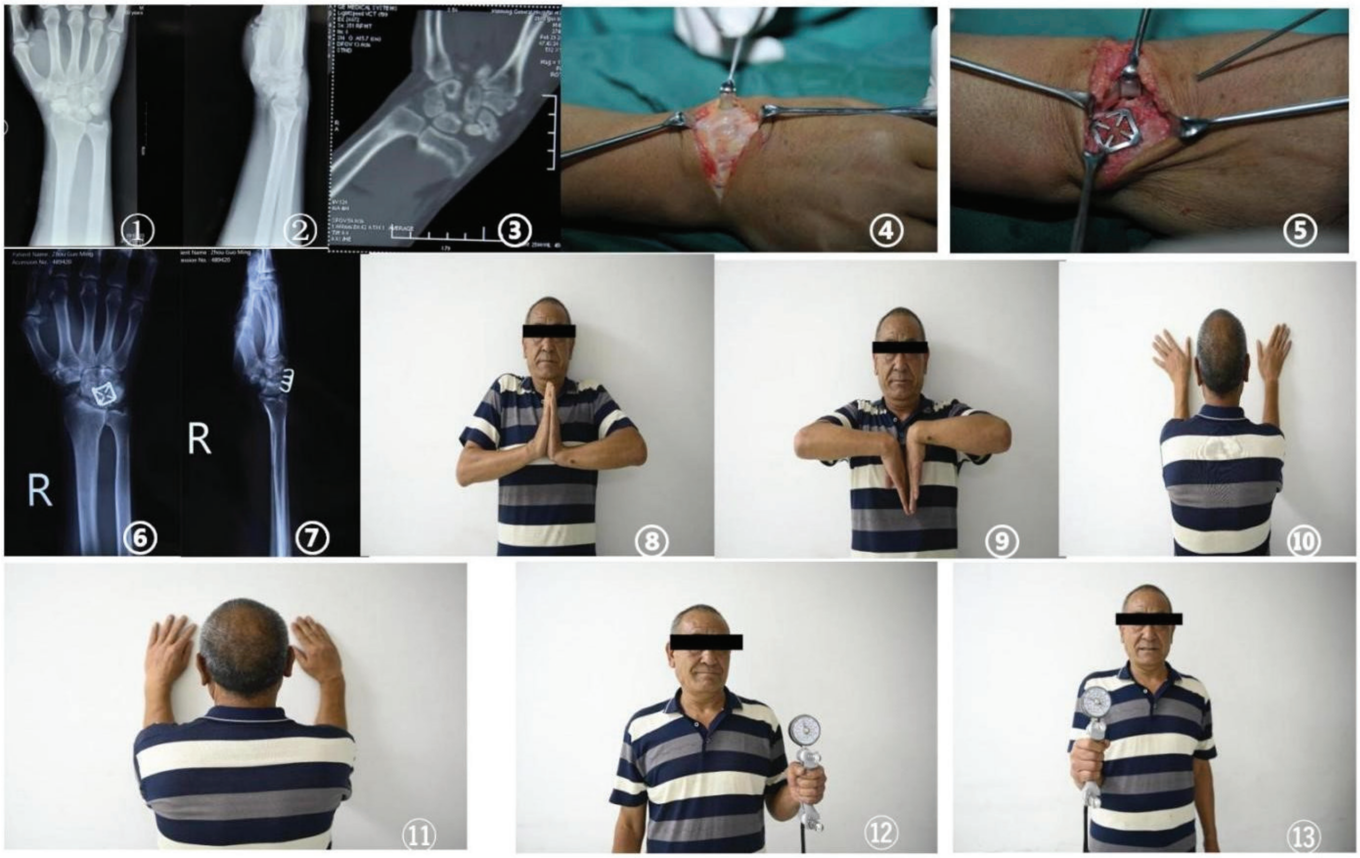

Figure B1: Preoperative right wrist joint anterior-posterior X-ray. Figure 2: Preoperative right wrist joint lateral X-ray. Figure 3: Preoperative right wrist joint CT scan. Figure 4: Exposure of the joint capsule and wrist bones through a transverse incision at the dorsal aspect of the right wrist. Figure 5: Implantation of NT-FCAC. Figure 6: Postoperative 11-year right wrist joint anterior-posterior X-ray. Figure 7: Postoperative 11-year right wrist joint lateral X-ray. Apologies for the misunderstanding earlier. Figure 8: Image of the patient's right wrist joint flexion function 11 years postoperation. Figure 9: Image of the patient's right wrist joint extension function 11 years postoperation. Figure 10: Image of the patient's right wrist joint ulnar deviation function 11 years post-operation. Figure 11: Image of the patient's right wrist joint radial deviation function 11 years postoperation. Figure 12: Schematic representation of grip strength in the healthy hand. Figure 13: Schematic representation of grip strength in the patient's right hand 11 years postoperatively.

years postoperatively reached 81% compared to the healthy side (Figures B12 and B13).

Discussion

Limitations of traditional four-corner fusion procedures

SNAC is among the most common types of wrist collapses [8]. Scaphoid excision combined with four-corner fusion is a classical surgical approach for treating SNAC [1,3,8,9]. Conventional internal fixation materials for wrist four-corner fusion include Kirschner wires, hollow screws, locking plates, etc. [10]. Although Kirschner wires offer simplicity and were initially used, they present drawbacks in clinical application such as loosening and tendon wear leading to pain [11]. Moreover, their ability to adequately compress the fused wrist bones is disputable. The use of hollow screws or combined cable fixation provides compression but involves complex procedures and significant damage to surrounding soft tissues, limiting their widespread application [1,12]. Researchers employing polyether ether ketone plates with locking screws reported improved postoperative grip strength and mobility; however, a 20% rate of internal fixation device fracture was noted during short-term follow-ups [13]. Hence, improvements in the strength of these polyether ether ketone plates are essential for their further clinical adoption. Long-term postoperative follow-up after wrist four-corner fusion remains a concern for many scholars. Reigstad et al. retrospectively studied 42 wrist joints (36 patients) undergoing FCA surgery with Kirschner wires and autogenous bone grafting. With an average follow-up of 11 (4–19) years, about 88% of patients showed degenerative changes on CT scans. Thirteen patients (30%) underwent procedures like total wrist fusion (5 cases) or wrist joint replacement (8 cases) due to nonunion, painful arthritis, etc. [2]. FCA surgery appears to alleviate pain and improve limb function for most patients; however, long-term follow-ups reveal degenerative changes and the need for revision surgeries, warranting attention.

Advantages of NT-FCAC

To overcome the limitations of conventional internal fixation materials, our team developed and applied NT-MFCAC in wrist collapse patients, demonstrating favorable long-term clinical outcomes over 10 years. No severe surgical complications were observed, with postoperative grip strength recovering to 81.96% of the unaffected side and wrist joint mobility exceeding 60% of the unaffected side. Both VAS and quick DASH scores significantly decreased compared to preoperative values. No cases required total wrist fusion or wrist joint replacement. The advantages of our NT-MFCAC design include: (1) Biomechanical testing showed that the fusion device fully meets the mechanical requirements for normal wrist joint activity. We reinforced the nail–body interface of the fusion device, and no instances of device fracture or loosening were observed in short- and long-term follow-ups [3,14]. The superior biomechanical performance of this fusion device was notably better than previously reported shape-memory alloy fusion devices [15]; (2) Simple surgical operation with minimal secondary injuries, avoiding significant vascular damage; (3) Leveraging the shape memory function of nickel-titanium shape-memory alloy, continuous compression on the fused wrist bones is achievable postsurgery, promoting fusion healing. In our study, long-term follow-up patients achieved a 100% wrist bone fusion rate, significantly higher than traditional internal fixation materials [16].

Surgical Insights

This surgical method is straightforward, and the learning curve for using NT-FCAC in four-corner fusion surgery is short. NT-FCAC overcomes the disadvantages of traditional internal fixation materials, demonstrating excellent clinical outcomes. Important considerations during surgery include: (1) Avoiding damage to dorsal wrist tendons and tendon sheath; rubber strips may be used intraoperatively to assist in traction and protect the tendons; (2) Attention to restoring axial alignment between the scaphoid and lunate bones is crucial to prevent postoperative impact between the dorsal radius and scaphoid; (3) While expanding the nail foot of NT-FCAC, angles greater than 90° should be avoided to prevent compromising the fusion device's memory function; (4) Applying a plaster splint for wrist joint immobilization for 3 weeks postoperatively, advising patients to engage in early functional exercises to maximize wrist joint recovery. (5) This four-corner fusion device utilizes nickel-titanium shape-memory alloy materials; however, no specific adverse reactions have been found in the long-term stay in the body. Patients considering removal of internal fixation materials after wrist bone healing should primarily consider convenience in daily life, such as airport security checks, and local customs.

Limitations

This study had a small number of cases and was a single-center retrospective study, lacking comparisons with other internal fixation materials. Subsequent research is needed for a prospective study aimed at assessing these variables and their impact on clinical and joint function.

Ethics approval and consent to participate

All methods were carried out in accordance with the relevant guidelines and provisions of the Helsinki Declaration. The study was approved by the Ethics Committee on Human Research of the 920th Hospital of Joint Logistics Support Force of Chinese People's Liberation Army, and written informed consent was obtained from the participants.

Consent for publication

All participants included in this retrospective study were well informed and provided written consent for publication.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests. No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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Authors' contributions

Baochuang Qi, Yongqing Xu, and Minzheng Guo were responsible for the study design, guiding, performing surgeries, collecting and analyzing data, and drafting the manuscript. Chuan Li and Chen Meng contributed to the study design, performing surgeries, collecting, and analyzing data, and provided critical review of the intellectual content of the manuscript.

Teng Wang participated in performing surgeries and data collection.

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