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Four-corner Arthrodesis: Comparative Analysis of Open Surgery Versus Percutaneous Technique with Arthroscopic Assistance

Artrodesis de cuatro esquinas: Análisis comparativo de técnica abierta versus técnica percutánea con asistencia artroscópica

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Abstract

Introduction Four-corner arthrodesis is a salvage technique for patients with advanced carpal osteoarthritis. This procedure aims to reduce pain and preserve wrist motion. Even though percutaneous techniques with arthroscopic assistance reportedly have favorable outcomes and the advantages of minimal invasiveness, open surgery remains the gold standard for four-corner arthrodesis.

Objective The present study aims to compare the functional and radiological outcomes of patients with scapholunate advanced collapse (SLAC) or scaphoid nonunion advanced collapse (SNAC) submitted to open surgery versus percutaneous surgery with arthroscopic assistance.

Materials and Methods Retrospective case-control study of clinical records and radiological images of patients with advanced carpal osteoarthritis submitted to percutaneous surgery with arthroscopic assistance versus open surgery. Demographic variables, pain score using the visual analog scale (VAS), function ranges of motion, time until consolidation, and correction of the capitolunate angle were analyzed. Both techniques are described.

Results In total, 22 male patients with an average age of 32.5 years were studied, including 13 patients from the case group (percutaneous surgery with arthroscopic assistance) and 9 patients from the control group (open surgery). The VAS score for

Keywords
- four-corner arthrodesis
- SNAC
- SLAC
- wrist arthroscopy
- wrist surgery

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pain at discharge was of 3 for the cases and of 5 for the controls ($p = 0.008$); 30 days postoperatively, it was of 0 and 3 respectively ($p = 0.00$). The ranges of extension and flexion were of 52.6° and 38.7° for the case group, and of 35.7° and 32.4° for the control group ($p = 0.119$ and 0.0016 respectively). The capitolunate angle was of 10° for the controls and of 5° for the cases ($p = 0.0008$). The time until consolidation was of 8.8 weeks for the cases and of 12.5 weeks for the controls ($p = 0.039$).

Discussion Both four-corner arthrodesis techniques are reproducible and effective in achieving consolidation, pain reduction and preservation of wrist motion.

Conclusion The present study demonstrates the superiority of the percutaneous technique with arthroscopic assistance over open surgery. Further prospective studies are required for an adequate recommendation.

Resumen

Introducción La artrodesis de cuatro esquinas es una técnica de salvataje para los pacientes con artrosis avanzada del carpo. Los objetivos quirúrgicos son disminuir el dolor y mantener cierto movimiento de la muñeca. En el último tiempo, se han descrito técnicas percutáneas con asistencia artroscópica que han logrado resultados favorables, a pesar de que la técnica abierta sigue siendo el gold estándar para realizar esa técnica quirúrgica.

Objetivo Comparar resultados funcionales y radiológicos en pacientes con muñecas con colapso avanzado escafolunar (*scapholunate advanced collapse*, SLAC) o colapso avanzado en la pseudoartrosis del escafoides (*scaphoid nonunion advanced collapse*, SNAC) operados con técnica quirúrgica abierta versus técnica percutánea con asistencia artroscópica.

Materiales y Métodos Estudio retrospectivo tipo caso-control, de fichas clínicas e imagenología de pacientes con artrosis avanzada del carpo operados con técnica percutánea y asistencia artroscópica y cirugía abierta. Se estudian variables demográficas, dolor mediante la Escala Visual Analógica (EVA), función en rangos de movilidad, tiempo de consolidación, y corrección del ángulo capitolunar. Se describe la técnica quirúrgica de la cirugía abierta y la cirugía percutánea con asistencia artroscópica.

Resultados Se estudiaron 22 pacientes del sexo masculino con edad promedio de 32,5 años. Había 13 pacientes en el grupo de casos (técnica percutánea con asistencia artroscópica) y 9 pacientes en el grupo de controles (técnica abierta). El dolor en la EVA al momento del egreso hospitalario fue de 3 para los casos y de 5 para los controles ($p = 0{,}008$), y a los 30 días del postoperatorio, fue de 0 y 3 respectivamente ($p = 0{,}00$). Los rangos de extensión y flexión fueron de 52,6° y 38,7° para los casos y de 35,7° y 32,4° para los controles ($p = 0{,}1119$ y 0,0016, respectivamente). El ángulo capitolunar fue de 10° para los controles y de 5° para los casos ($p = 0{,}0008$). El tiempo de consolidación fue de 8,8 semanas para los casos y de 12,5 semanas para los controles ($p = 0{,}039$).

Discusión Tanto la técnica percutánea con asistencia artroscópica cuanto la cirugía abierta para realizar una artrodesis de cuatro esquinas son técnicas reproducibles y efectivas en lograr consolidación, disminución del dolor, y mantenimiento de rangos de movimiento en la muñeca.

Conclusión En el presente trabajo se demuestran mejores promedios de los parámetros evaluados con la técnica percutánea que con la cirugía abierta; sin embargo, es necesario realizar estudios prospectivos para realizar una recomendación con respecto a la técnica quirúrgica de elección.

Palabras clave
- artrodesis de cuatro esquinas
- SNAC
- SLAC
- artroscopía de muñeca
- cirugía de mano

Introduction

Non-inflammatory osteoarthritis of the carpus is a chronic degenerative disease of the articular cartilage. It may result in structural changes and carpal collapse,[1–3] and most cases have a traumatic etiology.[2] Posttraumatic osteoarthritis secondary to chronic carpal instability usually progresses in a relatively constant sequence.[1] It can cause chronic pain and significant impairment in wrist function. Although it is frequently well-tolerated for years, it is not unusual for symptoms to arise during the early stages of the disease.[2]

The most common form of carpal collapse is the scapholunate advanced collapse (SLAC),[1] resulting from a carpal misalignment due to a chronic change at the scapholunate ligament. A similar degenerative pattern can lead to scaphoid nonunion, causing a carpal collapse known as scaphoid nonunion advanced collapse (SNAC).[3,4]

In both cases, chronic carpal instability generates progressive joint damage with carpal misalignment, leading to advanced carpal collapse and severe panarthritis in subsequent stages.[1,4,5] There are four evolutionary stages. Stage I is characterized by radial styloid involvement. In stage II, the entire radioscaphoid joint is affected; in stage III, there is also degenerative involvement of the midcarpal joint, specifically with joint damage between the lunate and capitate bones. Finally, stage IV is characterized by generalized osteoarthritis with complete involvement of the radiocarpal and midcarpal joints, in addition to potential damage to the distal radioulnar joint.[1,5]

Different therapeutic modalities have been described for each of these stages. In early the stages, the goal is to reduce pain while preserving wrist mobility.[5] In the advanced stages, this is difficult, because of the cartilaginous damage to the carpus, and a total wrist arthrodesis is the procedure of choice.[5]

Four-corner arthrodesis is indicated to patients with stage-II and -III SLAC and SNAC wrists and capitate bone osteoarthritis.[2,4] This technique consists of an arthrodesis of the lunate, capitate, hamate and triquetrum bones associated with a scaphoid excision.[4] Fixation techniques with Kirschner wires, dorsal plates and cannulated screws have been described; the latter are the most frequently used hardware. The procedure can be performed through open surgery or a percutaneous technique with arthroscopic assistance.[4,6,7] The literature reports good medium to long-term outcomes with both techniques,[8] achieving ranges of motion of up to 50% compared to the contralateral wrist,[2] pain reduction of up to 80%, and absence of pain in half of the patients.[2,9] This type of arthrodesis may be unacceptable for some subjects because it prevents the "dart-throwing" movement, and this phenomenon needs to be addressed before surgery.[2]

Although it is demanding and requires training in wrist arthroscopy, the percutaneous technique with arthroscopic assistance has certain advantages over the open surgery because it improves the visualization of the articular cartilage, spares proprioceptive innervation, and better preserves the vascular supply to the carpus, which improves bone consolidation and decreases soft-tissue injury.[7]

The present study aims to compare the functional and radiological outcomes of subjects with SLAC and SNAC wrists and midcarpal osteoarthritis submitted to open surgery or percutaneous surgery with arthroscopic assistance, and to describe the surgical technique performed in both groups of patients.

Materials and Methods

The present is a retrospective case-control study of 22 consecutive patients submitted to four-corner arthrodesis performed in a Level-V Trauma Center by the same surgical team from 2011 to 2016. The control group consisted of patients submitted to open surgery from 2011 to 2013, whereas the case group was formed by patients submitted to percutaneous surgery with arthroscopic assistance from 2014 to 2016.

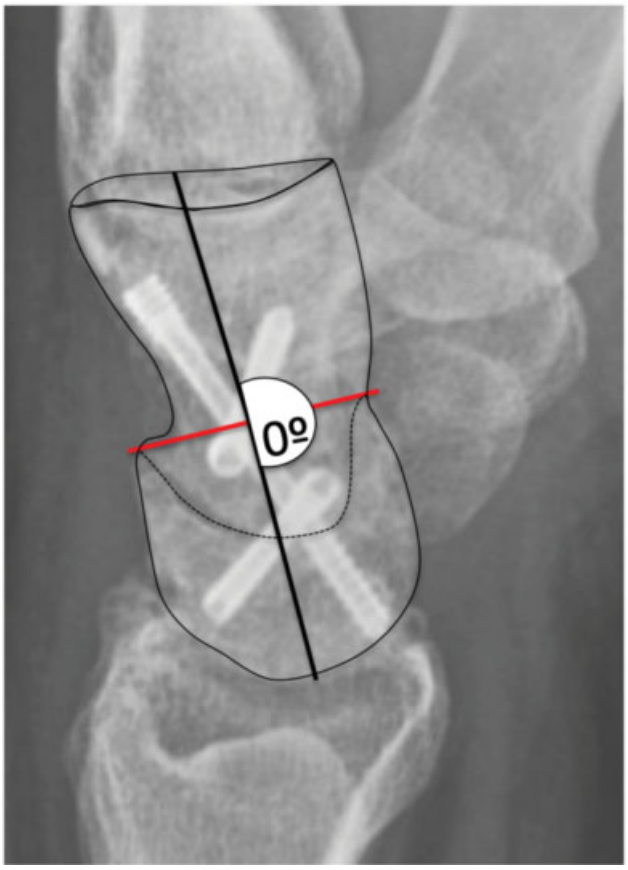

Fig. 1 Lateral wrist radiograph showing the measurement of the capitolunate angle.

The inclusion criteria were patients older than 18 years of age with clinico-radiological diagnosis of SLAC/SNAC in stages II or III and preoperative pain during daily activities greater than 4 according to the visual analog scale (VAS). Patients with SNAC/SLAC in stages I or IV were excluded.The following variables were analyzed in both groups: demographic variables; functional outcomes, that is, flexion and extension ranges of motion measured with a goniometer 6 months after surgery; postoperative pain at rest both at hospital discharge and 30 days after surgery, according to the VAS; radiological consolidation time; and correction of the capitolunate angle (►**Fig. 1**).

Radiological consolidation was evaluated using anteroposterior (AP) and lateral wrist radiographs taken every 15 days starting the fourth week after surgery. The images were reviewed by the two senior surgeons from the study. Consolidation was defined by bony trabeculae between the capitolunate joint, the triquetrum-hamate joint, and the corners of these four bones.

A statistical study was carried out using the Stata (StataCorp, LLC, College Station, TX, US) software, version 15. The Shapiro Wilk test demonstrated variable normality, the

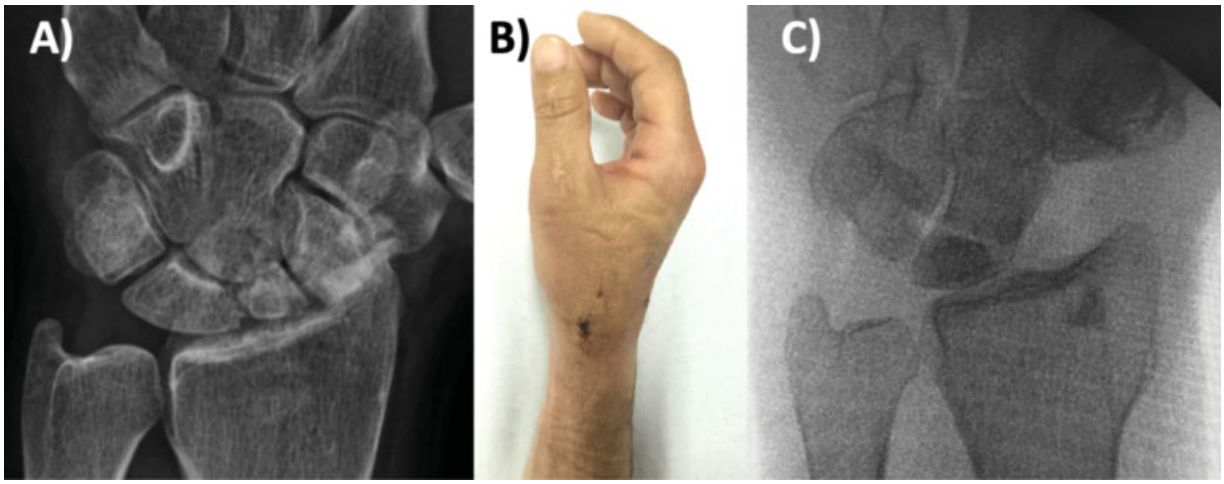

Fig. 2 Scaphoid resection using a mini-open approach. (**A**) Preoperative anteroposterior (AP) wrist radiograph. (**B**) Lateral image of the hand and wrist of a patient submitted to the percutaneous surgery. Note the incision of the mini-open approach. (**C**) Intraoperative AP radioscopy of the wrist showing complete scaphoid resection.

Student *t*-test compared the mean values, and the Mann-Whitney U test compared the median values. The variables expressed as mean values presented normal distribution, in contrast to those expressed as median values. The significance was set as $p < 0.05$.

Surgical Technique for Percutaneous Surgery with Arthroscopic Assistance

The patient is placed in supine position on the surgical table and the hand table after regional anesthesia with brachial-plexus block. Ischemia is performed with an ischemia cuff inflated 100 mm Hg higher than the patient's diastolic blood pressure.

A mini-open, longitudinal approach is performed at the radial fossa of the wrist, followed by dissection, sparing the dorsal branch of the radial artery. Next, the radial joint capsule is opened to reach the scaphoid, which is divided into two parts with a chisel, and all the ligaments joining to the radius, lunate, capitate, trapezoid and trapezius bones are sectioned with a scalpel. Both scaphoid poles are resected with a Rongeur forceps, and a scaphoid graft is harvested (►**Fig. 2**). Under fluoroscopic view, the dorsal intercalated segment instability (DISI) is reduced with the correct alignment of the radius and lunate bones at the lateral view, and radiolunate fixation with a 1.6-mm Kirschner wire (►**Fig. 3**).

Next, the limb is placed in a 15-lb ACUMED (Hillsboro, OR, US) traction tower, secured by the index and middle fingers, paying special attention to the point of attachment at the level of the arm, and using an ischemia cuff to prevent skin and neurological lesions.

The midcarpal ulnar (MCU) portal and the midcarpal radial (MCR) portal are prepared, and a diagnostic arthroscopy of the midcarpal joint with 2.7-mm optics evaluates the articular cartilage of the carpal bones.

The articular cartilage of the lunate, triquetrum, capitate, and hamate bones is resected with a handpiece motor and burr tip (►**Fig. 4**). The intermittent supply of normal saline solution through a 20-mL syringe connected to the optic

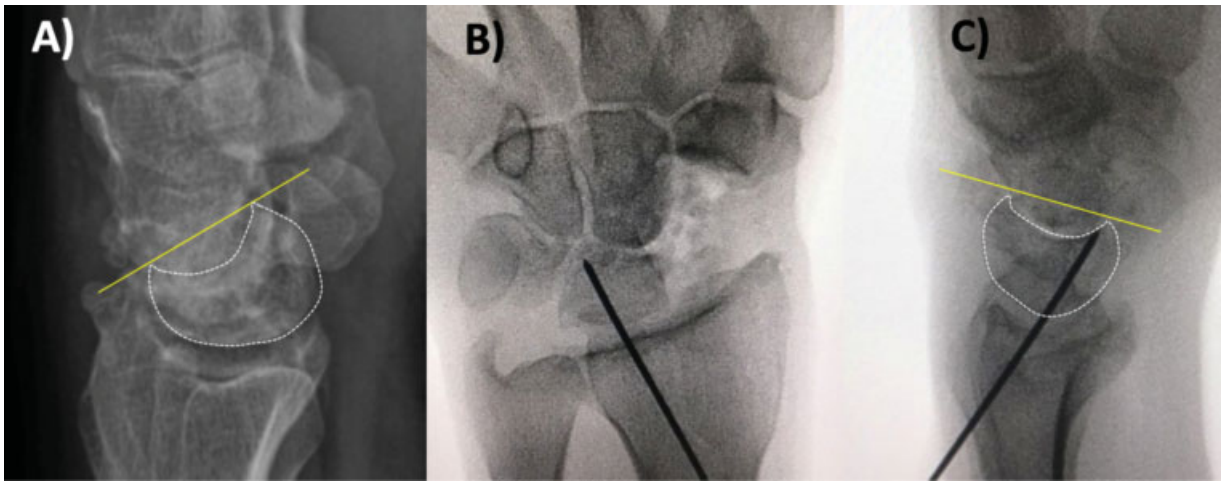

Fig. 3 Reduction of dorsal intercalated segment instability (DISI) through lunate reduction. (**A**) Preoperative lateral wrist radiograph of a patient with DISI. (**B**,**C**) Intraoperative anteroposterior and lateral radioscopy, respectively, of lunate reduction with a radiolunate Kirschner wire.

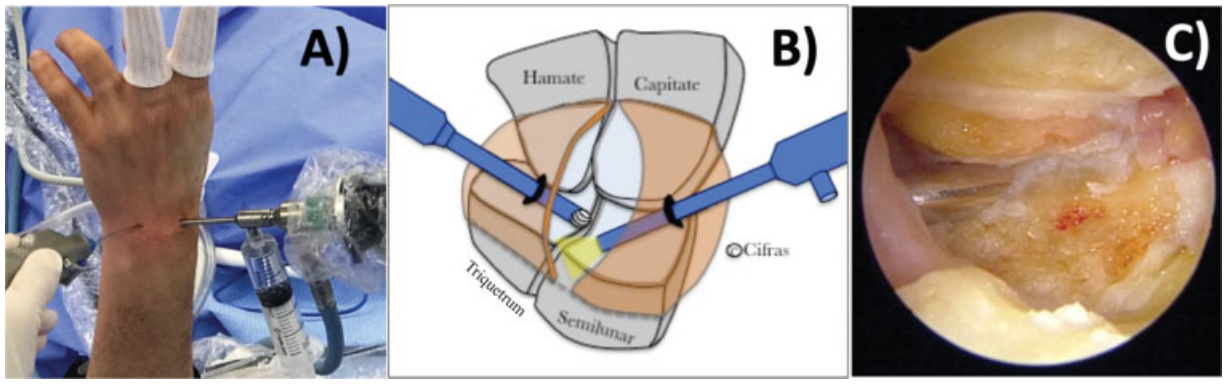

Fig. 4 Diagnostic arthroscopy of the midcarpal joint and resection of the articular cartilage. (**A**) Intraoperative diagnostic arthroscopy image of the midcarpal joint. (**B**) Scheme of the resection of the midcarpal articular cartilage. Optics placed through the midcarpal radial (MCR) portal and working portal at the midcarpal ulnar (MCU) portal with a burr. (**C**) Arthroscopic image of the result of the resection of the articular cartilage.

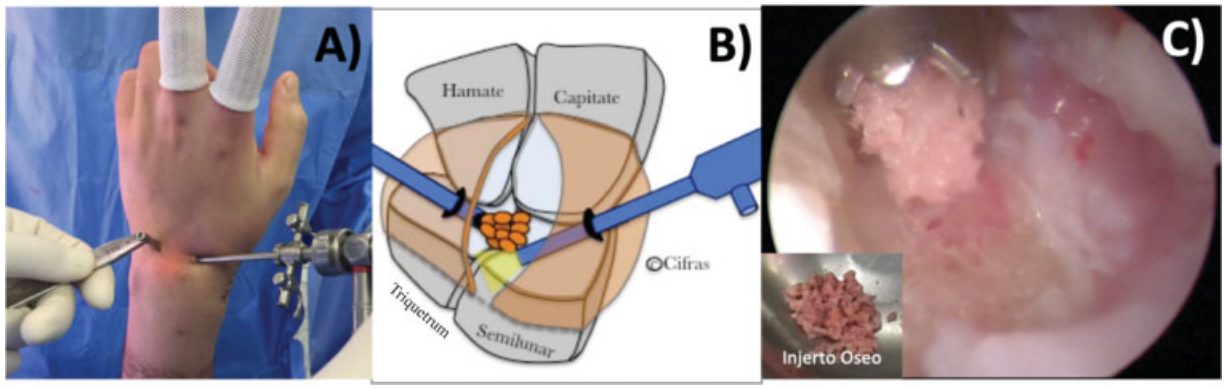

Fig. 5 Delivery of percutaneous bone graft at the midcarpal joint. (**A**) Intraoperative image of the graft delivery through the midcarpal ulnar (MCU) portal using a 2.5-mm drill shield. (**B**) Diagram of the graft delivery through the MCU portal with the optics at the midcarpal radial (MCR) portal. Arthroscopic image of graft insertion at the midcarpal joint. The morselized graft obtained from the resected scaphoid bone is shown.

sleeve is important for joint cleaning and to reduce the heat generated by the burr.

A cancellous graft is taken from the previously-resected scaphoid and introduced into the joint space through a 2.5-mm drill protector from the small fragment cage using the same midcarpal portals. The graft is reduced under arthroscopic visualization (►**Fig. 5**) of the entire bony surface of the capitolunate joints and between the triquetrum and hamate bones.

Wrist traction is released, and fixation with cannulated screws is performed percutaneously under fluoroscopic view, beginning with a capitolunate screw, followed by a screw from the triquetrum to the lunate bones, and a screw fixating the triquetrum, hamate and capitate bones (►**Fig. 6** and **7**). This is the screw configuration described by Ho.[6] Next, the radiolunate wire is withdrawn. The maximum ischemia time should be lower than 120 minutes.

Finally, the skin from the portals and radial area is closed, the ischemia is released, and a short arm split cast is placed. Clinical follow-up is performed at 2 weeks for suture removal; the cast is kept until the fourth week. Kinesitherapy begins after cast removal. Follow-up radiographs are taken at 4 and 8 weeks, and then every 2 weeks until consolidation is detected. ►**Figure 8** shows consolidation at 8 weeks.

Surgical Technique for Open Surgery

The patient is placed in supine position on the surgical table and the hand table after regional anesthesia with brachial-plexus block. Ischemia is performed with an ischemia cuff inflated 100 mm Hg higher than the patient's diastolic blood pressure.

A dorsal wrist approach is performed (►**Fig. 9**); the extensor retinaculum is opened through the third extensor compartment, sparing the extensor pollicis longus tendon and approaching the joint capsule as described by Berger et al.[10] (►**Fig. 10**). The posterior interosseous nerve is identified and sectioned proximally. Next, the scaphoid is resected with a Rongeur forceps and a bone graft is extracted from it. The articular cartilage from the lunate, triquetrum, hamate, and capitate bones is resected with a spoon and Rongeur forceps. A 1.25-mm Kirshner wire is inserted into the lunate from a dorsal point to be used as a joystick. The DISI is reduced with the correct alignment of the radius and lunate bones on lateral view (►**Fig. 11**), and radiolunate fixation is performed with a 1.6-mm Kirschner wire. Next, the previously-resected morselized scaphoid bone graft is added, and a 2-column fixation is carried out with two 2.4-mm HFS cannulated screws (DePuy Synthes, Raynham, MA, US) in an antegrade fashion from the lunate to the

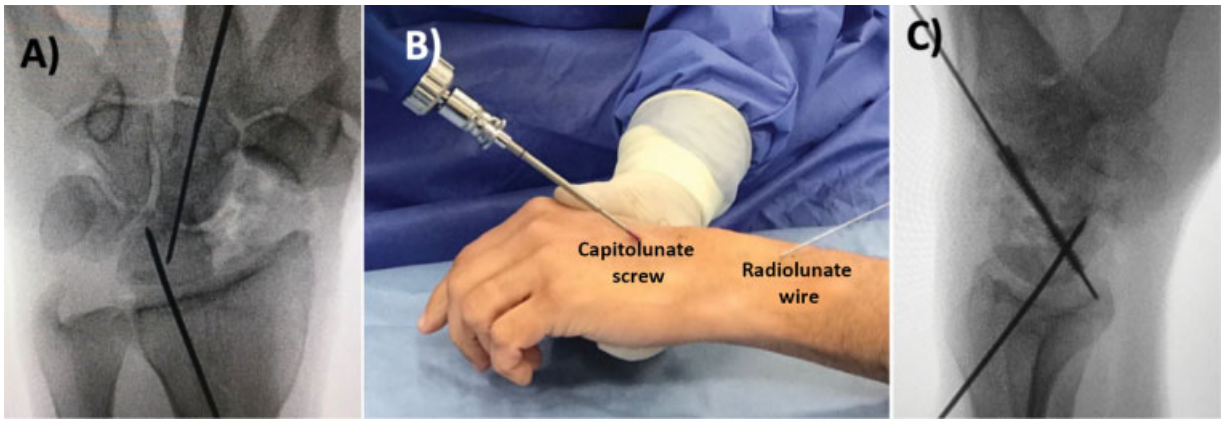

Fig. 6 Fixation of the capitolunate screw. (**A**) Intraoperative anteroposterior radioscopy of the wrist. Note the capitolunate wire and the drill. (**B**) Capitolunate screw insertion. (**C**) Intraoperative lateral radioscopy of the wrist, showing the capitolunate screw.

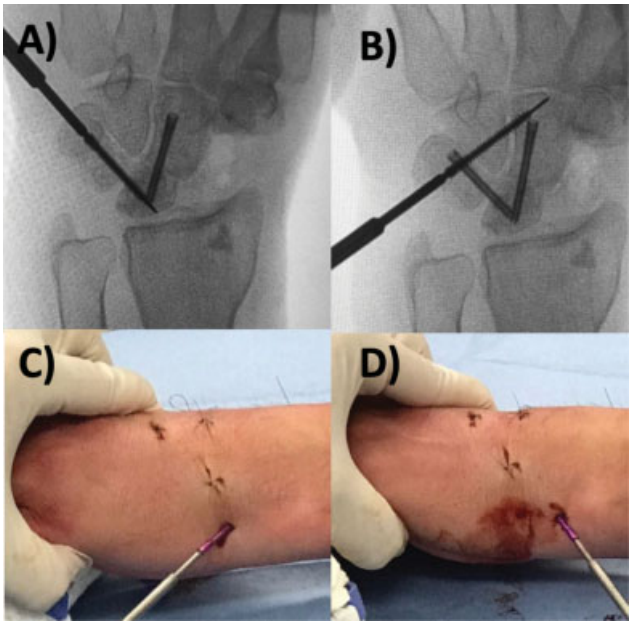

Fig. 7 Fixation with triquetrum-lunate and triquetrum-hamate-capitate screws. (**A**) Intraoperative anteroposterior fluoroscopy showing the triquetrum-lunate screw. (**B**) Intraoperative anteroposterior radioscopy of the wrist showing the triquetrum-hamate-capitate screw. (**C**) Intraoperative clinical image of the fixation of the triquetrum-lunate screw. (**D**) Intraoperative clinical image of the fixation of the triquetrum-hamate-capitate screw.

Fig. 8 Anteroposterior and lateral radiographs of the wrist of a patient submitted to the percutaneous technique with arthroscopic assistance, showing bone consolidation at eight weeks.

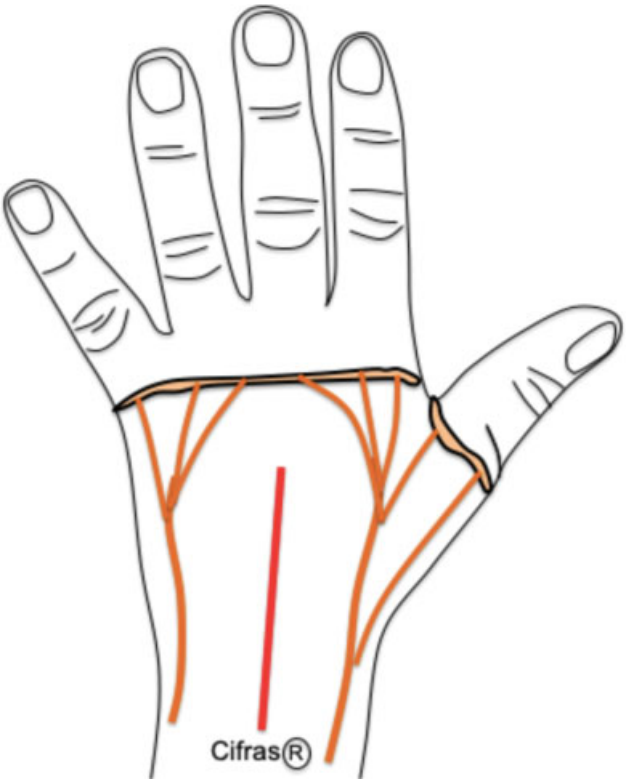

Fig. 9 Diagram of the longitudinal dorsal wrist approach used in the open four-corner arthrodesis technique.

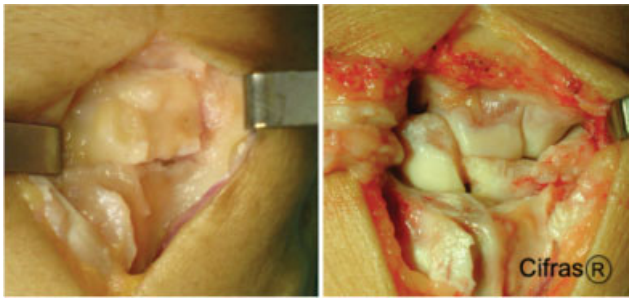

Fig. 10 Capsular approach used in the open technique as described by Berger et al.[10]

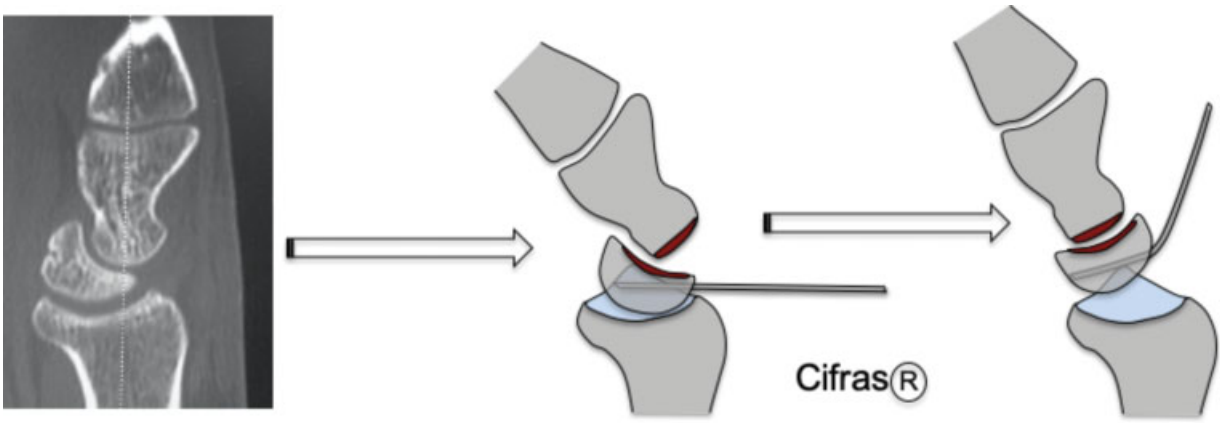

Fig. 11 Technique for the reduction of the dorsal intercalated segment instability (DISI) of the lunate bone with a Kirshner wire used as a joystick during the open surgery.

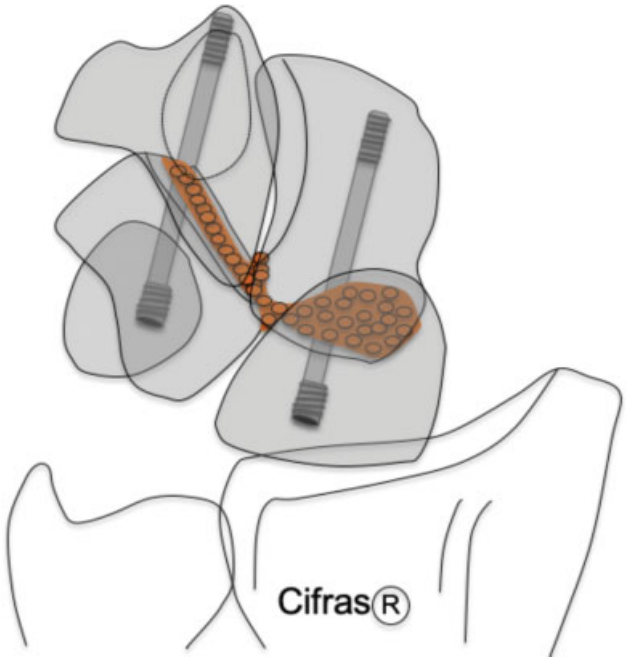

Fig. 12 Two-column fixation (between the lunate-capitate and triquetrum-hamate bones) with antegrade cannulated screws during the open surgery.

capitate bones; another screw is placed from the triquetrum to the hamate bone (►**Fig. 12**). Adequate reduction and fixation are confirmed through fluoroscopy. The joint capsule, the extensor retinaculum, and the skin are closed, and a protective bandage with short arm split cast is placed. Clinical and imaging follow-up, immobilization and rehabilitation are carried out as described for the percutaneous surgery with arthroscopic assistance.

Results

Our sample consisted of 9 male patients in the control group and 13 male patients in the case group. The mean age of both groups was 32.5 years with 32.3 years (standard deviation [SD]: 6.6) for the control group and 32.6 years (SD: 6.2) for the case group, with no statistical difference ($p = 0.82$). The mean follow-up time was of 12 months. Ischemia time was lower than 120 minutes in all patients.

Table 1 Pain score according to the visual analog scale (VAS) at hospital discharge, 30 days after surgery, and reduction

	Control group	Case group	*p*-value
VAS at discharge *Median value (range)*	5 (3–8)	3 (1–5)	0.008*
VAS 30 days after surgery *Median value (range)*	3 (1–5)	0 (0–0)	0.00*
VAS reduction *Median value (range)*	3 (1–5)	3 (1–5)	0.069

Notes: Mann-Whitney U test. *$p < 0.05$.

Table 2 Ranges of motion of the study groups

	Control group	Case group	*p*-value
Final flexion *Mean (standard deviation)*	32.4° (9.2°)	38.7° (6.3°)	0.1119
Final Extension *Mean (standard deviation)*	35.7° (6.4°)	52.6° (11.4°)	0.0016*

Notes: Student *t*-test. *$p < 0.05$.

At the time of hospital discharge, pain at rest was reported as 3 for the case group and 5 for the control group ($p = 0.008$). Thirty days after surgery, pain at rest was assessed again and reported as 0 for case group and 3 for the control group ($p = 0.00$). Results are shown in ►**Table 1**.

Six months after surgery, the ranges of motion in flexion and extension were of 52.6° and 38.7° for the case group, and of 35.7° and 32.4° for the control group ($p = 0.1119$ and 0.0016 respectively), as shown in ►**Table 2**.

Correction of the position of the lunate regarding the capitate bone was assessed using the capitolunate angle, which was of 10° (SD: 3.5°) for the control group, and of 5° (SD: 3.5°) for the case group ($p = 0.0008$).

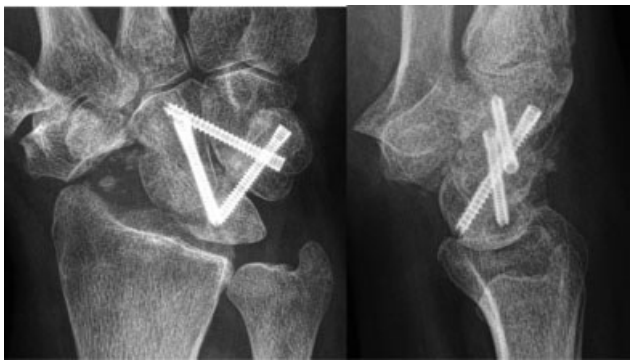

Fig. 13 Anteroposterior and lateral radiographs of the wrist of a patient submitted to percutaneous four-corner arthrodesis with arthroscopic assistance at eight weeks. Note the arrangement of the cannulated screws.

Fig. 14 Anteroposterior and lateral radiographs of the wrist of a patient submitted to open four-corner arthrodesis with cannulated screws.

The mean consolidation time was of 12.5 weeks (SD: 1.58 weeks) for the control group, and of 8.8 weeks (SD: 1.16 weeks) for the case group ($p = 0.039$).

►**Figures 13** and **14** show examples of the imaging outcomes of patients from both groups.

Discussion

Four-corner arthrodesis has proven to be a salvage treatment for patients with advanced osteoarthritis of the carpus, such as those with SNAC or SLAC wrists, reducing pain and preserving a certain degree of mobility.[6,11] The success of the surgery is based on bone consolidation between the capitolunate and hamate-triquetrum joints for correct DISI reduction.[1,6,7,12]

The gold standard for four-corner arthrodesis is open surgery. The most commonly used screw configuration for carpal bone fixation is the two-column configuration, with a screw between the lunate and capitate bones, and another screw between the triquetrum and the hamate bones.[4,8,9]

In recent years, this surgical technique has been performed percutaneously with arthroscopic assistance. Some publications[6,7] reported good outcomes, and the authors described some advantages of the percutaneous procedure over the open technique. As a minimally-invasive technique, percutaneous surgery is associated with lower tissue damage, greater sparing of the blood supply, preservation of proprioception, and better esthetic outcomes.[6,7]

The present work shows the surgical technique for the open procedure and the minimally-invasive procedure with arthroscopic assistance, both with good outcomes.

Pain at rest at the time of hospital discharge and 30 days after surgery is significantly better in patients submitted to percutaneous surgery; however, both groups presented a decrease in pain. The patients included in the present study had persistent chronic pain, with VAS scores of up to 4 in their daily-life activities, resulting from their underlying SLAC/SNAC wrist pathology. We believe that this difference may be due to the lower soft-tissue damage associated with the percutaneous technique. However, since this is not an isolated factor, it does not enable an adequate recommendation. On the other hand, no mid- and long-term evaluations of active wrist pain were performed, so we cannot make recommendations about it.

The consolidation time was significantly shorter among the patients submitted to the percutaneous technique with arthroscopic assistance. Although we believe that minimally-invasive surgery favors bone consolidation, it is not possible to isolate this factor here because the configuration of the screw differs in both techniques (►**Fig. 8** and **9**). This different configuration can influence the stability provided by the osteosynthesis material and alter consolidation outcomes. Although there is no recommendation regarding screw configuration in the international literature, we believe that the one used in the percutaneous technique is optimal to achieve greater stability, since the lunate-capitate column is fixated on one side (the midcarpal radial column) with a retrograde screw, whereas the triquetrum-hamate column (the midcarpal ulnar column) is fixated with an antegrade oblique screw, which also fixates the ulnar spine to the capitate bone. Lastly, the screw from the triquetrum to the lunate bones also fixates the ulnar spine to the radial spine. Therefore, a two-column fixation is carried out as in the open surgery, but both columns are joined by the transverse screw coming from the triquetrum bone.[6]

The use of cannulated screws has proven to result in better pain and mobility compared to other types of osteosynthesis.[13] As such, we believe that it is the most appropriate method for the four-corner arthrodesis surgery.

In both groups of patients, the ranges of motion were similar to those reported in the literature.[7,8] In the present study, the extension was significantly better among the patients submitted to the percutaneous technique with arthroscopic assistance. This could be due to the intrinsic advantages of the minimally-invasive technique, with reduced soft-tissue damage, lower level of scarring and, therefore, less rigidity, theoretically.

The relationship between the lunate and the capitate bones was evaluated using the capitolunate angle. This angle was within normal limits after both surgeries,[14,15] but with a statistical difference. However, this difference should not have clinical repercussions, since, as previously mentioned, the capitolunate angle was within the normal range in both groups.

We believe that the arthroscopically-assisted percutaneous technique with fixation of cannulated screws is a reproducible and effective procedure to achieve consolidation, pain relief, and sustained wrist mobility. Further prospective, randomized, comparative studies are required to recommend one technique over the other.

Conclusion

Four-corner arthrodesis for patients with advanced carpal osteoarthritis is a reproducible technique with good outcomes regarding pain reduction, ranges of motion, and bone consolidation. Both techniques, namely open surgery and percutaneous surgery with arthroscopic assistance, present favorable outcomes, achieving 100% of consolidation. In the present series, the groups differed regarding reduction in pain at rest during the early postoperative period, range of flexion-extension of the wrist, and time until to consolidation, but these differences cannot be attributed exclusively to the use of arthroscopic assistance.

Conflicts of interests
The authors have no conflicts of interest to declare.

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