Article published online: 2021-12-13

Four-Corner Fusion with Locking Dorsal Circular Plate versus Headless Compression Screws: A Clinico-Radiological Comparative Study

Artrodesis de cuatro esquinas con placa circular dorsal bloqueada versus tornillos canulados de compresión sin cabeza: estudio clínico-radiológico comparativo

Francisco R. Melibosky[1] Rene A. Jorquera[1] Felipe Z. Saxton[2] Pablo Orellana[1] Diego Junqueras[2,3] Camila Azócar[1]

[1] Hand Surgery and Microsurgery Unit, Department of Traumatology and Orthopedics, Clínica Indisa – Facultad de Medicina de la Universidad de Valparaíso, Santiago, Chile
[2] Hand Surgery and Microsurgery Unit, Department of Traumatology and Orthopedics, Facultad de Medicina Clínica Alemana de Santiago – Universidad del Desarrollo, Santiago, Chile
[3] Hand Surgery Unit, Department of Traumatology and Orthopedics, Hospital de la Florida, Santiago, Chile

Address for correspondence Francisco Melibosky, MD, Facultad de Medicina de la Universidad de Valparaíso, Avenida Santa María 1.810, Providencia, Santiago, 1111, Chile (e-mail: francisco.melibosky@gmail.com).

Rev Iberam Cir Mano 2021;49(2):e105–e114.

Abstract

Introduction Four-corner fusion is a technique for the treatment of carpal advanced collapse. It consists of scaphoid excision and arthrodesis of the lunate, triquetrum, hamate, and capitate bones. This can be accomplished with different kinds of osteosynthesis. In the first reports of the use of a circular plate, poor outcomes are described, with high rates of non-union, which decreased in later studies, which highlight certain aspects of the surgical technique.

Objective To report our experience with four-corner fusion with the use of a dorsal locking plate (Xpode, Trimed Inc., Santa Clarita, CA, US), and compare it with another traditional fixation method (3.0-mm headless compression screws [HCSs], Synthes, Slothurn, Switzerland), with an emphasis on union, an assessment of the fincitonal outcomes, and the presence of complications.

Material and Methods A comparative study of two prospective series of patients operated on through two fixation techniques for four-corner fusion using autologous bone graft from the iliac crest.

The first group of patients, evaluated between 2010 and 2012, underwent osteosynthesis with 2 HCSs, with a minimum follow up of 18 months. The second group,

Keywords

- SNAC
- SLAC
- partial carpal arthrodesis
- four-corner fusion
- dorsal locking plate
- cannulated compression screws

received October 5, 2020
accepted June 9, 2021

DOI https://doi.org/10.1055/s-0041-1739239.
ISSN 1698-8396.

Thieme Revinter Publicações Ltda., Rua do Matoso 170, Rio de Janeiro, RJ, CEP 20270-135, Brazil

evaluated between 2011 and 2014, underwent osteosynthesis with a dorsal locking plate, with a minimium foloow up of 12 months. The patients were operated on by four different surgeons in four centers.
The patients were evaluated with radiographs to establish the presence of union and the time it took to occur. In case of doubt, union was confirmed through a computed tomography (CT) scan at 8 weeks postoperatrively. We also assessed the range of motion, the presence of complications, and function through the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire and a grip strength score.
Results We achieved a union rate of 100% in both groups at similar times. In the dorsal locking plate group, we obtained better full range of motion, particularly in wrist extension, which was statistically significant ($p = 0.0016$), as well as lower DASH scores, which was also statistically significant ($p = 0.0066$). Complications were only present in two patients in the HCS group.
Conclusion Both techniques are valid and reproducible for the treatment of wrists with scapholunate advanced collapse (SNAC) and scaphoid non-union advanced collapse (SLAC). Based on the outcomes, with the Xpode plate, the patients presented better ranges of motion and DASH scores; therefore it may be an excellent fixation option in the open four-corner fusion surgical technique. The entry point and configuration of the HCS are fundamental variables to analyze.
The union rate of 100% obtained in the present study contrasts with the high rates of non-union reported in the literature published in the early 2000s.

Resumen

Introducción La artrodesis de cuatro esquinas es una técnica para el tratamiento de colapsos avanzados del carpo. Consiste en realizar una escafoidectomía asociada a artrodesis de los huesos semilunar, piramidal, ganchoso y grande. La cirugía se puede realizar con distintos tipos de osteosíntesis. En los primeros reportes de uso de las placas circulares dorsales, se describen malos resultados, con altas tasas de no unión, las cuales disminuyeron en los estudios posteriores, en los cuales se pone especial hincapié en puntos de la técnica quirúrgica.
Objetivo Reportar nuestra experiencia en la artrodesis de cuatro esquinas con el uso de una placa dorsal bloqueada (Xpode, Trimed Inc., Santa Clarita, CA, EEUU), y compararla con otro método de fijación tradicional (tornillos canulados de compresión sin cabeza de 3.0 mm, Synthes, Solothurn, Suiza), con énfasis en la consolidación, evaluación de resultados funcionales, y presencia complicaciones.
Material y Métodos Estudio comparativo de dos series de pacientes operados con dos técnicas distintas de osteosíntesis para una artrodesis de cuatro esquinas utilizando injerto autólogo de cresta iliaca.
En un primer grupo, evaluado entre el 2010 y el 2012, se usó osteosíntesis con 2 tornillos canulados de compresión sin cabeza, con un seguimiento mínimo de 18 meses, y en otro grupo, evaluado entre el 2011 y el 2014, se usó osteosíntesis con placa bloqueada dorsal, con un seguimiento mínimo de 12 meses. Estos fueron operados en cuatro centros por cuatro cirujanos distintos.
Se les evaluó con radiografías, para determinar la presencia de consolidación y el tiempo de la misma. En caso de duda, se certificó la consolidación con tomografía axial computarizada (TAC), a las ocho semanas postquirúrgicas. También se evaluaron los rangos de movimiento, la presencia de complicaciones, y la función con escalas las escalas de discapacidades del brazo, hombro y mano (Disabilities of the Arm, Shoulder and Hand, DASH, en inglés), y de fuerza de puño.

Resultados Logramos tasas de consolidación del 100% en ambos grupos, con tiempos similares. Destaca en el grupo de placas el mejor rango de movimiento total y en especial de la extensión, con una diferencia estadísticamente significativa ($p = 0,0016$), al igual que la obtención de puntajes de DASH más bajos, con una diferencia estadísticamente significativa ($p = 0,0066$). Sólo en el grupo de tornillos hubo dos casos de complicación de la osteosíntesis.

Conclusión Ambas técnicas son válidas y reproducibles para el tratamiento de las muñecas con colapso avanzado del carpo secundario a una lesión escafolunar (*scapholunate advanced collapse*, SLAC, en inglés) y colapso avanzado del carpo secundario a una no unión del escafoides (*scaphoid non-union advanced collapse*, SNAC, en inglés). Con base en los resultados, consideramos que, con la placa Xpode, los pacientes presentan mejores rangos de movimiento y puntajes en el DASH, por lo que puede ser una excelente alternativa para la artrodesis de cuatro esquinas con técnica abierta. La configuración y el sitio de entrada en el caso de usar tornillos son temas fundamentales a analizar.

La tasa de consolidación del 100% obtenida en este estudio contrasta con las altas tasas de no unión de las placas dorsales circulares reportadas en la bibliografía en los años 2000.

Palabras clave

- SNAC
- SLAC
- artrodesis parcial del carpo
- artrodesis de cuatro esquinas
- placa bloqueada dorsal
- tornillos canulados de compresión

Introduction

Degenerative wrist osteoarthritis can be a severely impairing condition due to range of motion (ROM) restriction and pain during daily living activities. As a cause of functional disability, it is estimated to affect more than 10% of the United States population.[1]

In the past, the standard treatment for these degenerative disorders used to be total joint arthrodesis.[2] Although it provides predictable pain relief, the concomitant complete loss of movement is a costly trade-off for patients.[3]

Congenital carpal fusions or coalitions reported as radiographic findings in otherwise normal subjects,[4–6] presenting with no pain or disability, suggested that intercarpal arthrodesis could acceptably restore function in an injured wrist and eliminate the need for total wrist arthrodesis.[7,8]

The first partial carpal arthrodesis was described in the international literature by Thornton in 1924.[9] Next, Sutro (1946) and Helfet (1952) published outcomes from a scaphocapitate arthrodesis.[10,11] In the 1960s, Graner et al.[12] described an intercarpal arthrodesis with lunate or proximal scaphoid fragment resection, while Peterson and Lipscomb,[7] at the Mayo Clinic, reported success in the treatment of degenerative osteoarthritis secondary to scaphoid nonunion, posttraumatic scaphoid subluxations, and Kienböck disease. Then, in 1980, Watson[13,14] popularized the "triscaphoid arthrodesis', that is, scaphoid-trapezium-trapezoid arthrodesis.

"Four-corner fusion" was first described in 1984 by Watson and Ballet[15] to treat advanced carpal collapses secondary to a scapholunate lesion (scapholunate advanced collapse, SLAC). As such, it is part of our arsenal for wrist salvage treatment, consisting of a scaphoidectomy with arthrodesis of the capitate, lunate, triquetrum, and hamate bones along with midcarpal joint fusion.[11,16,17] This technique spares the radiolunate joint movement, resulting in an osteoarthritis-free wrist.

The most common indications for this technique are SLAC, the main degenerative pattern,[2] and scaphoid non-union advanced collapse (SNAC). The SLAC and SNAC degenerative patterns occur in three stages, and stages II and III are indications for four-corner fusion.[18–22] In the first stage, degenerative changes are observed at the radial styloid and the distal scaphoid pole both in scaphoid non-union and scapholunate dissociation. In the second stage of SLAC, the degenerative changes progress from the distal radius to the proximal scaphoid pole; in SNAC, however, this space is spared, and the involvement progresses towards the scaphocapitate joint. The third stage of both SLAC and SNAC is characterized by capitolunate joint involvement while the radiolunate joint is spared.[15,22–27] Preservation of the radiolunate joint is the basis to indicate this surgical technique; however, advanced degenerative changes at this joint are a definitive contraindication for this procedure, along with ulnar translation.[11,16,23] Some surgeons prefer a proximal carpectomy in the absence of capitolunate degeneration as an alternative to four-corner fusion.[18,21,28–30]

Another group of patients who may benefit from four-corner fusion consists of subjects with midcarpal instability,[17,31] scaphoid chondrocalcinosis advanced collapse (SCAC) or other arthritides of rheumatological origin,[32,33] chronic perilunate instabilities,[34] and dynamic chronic or non-dissociative carpal instabilities in which reconstructive treatments have failed.[35,36]

The surgical technique has undergone very few modifications since its first description, and the debate focuses on fixation or osteosynthesis methods. Initially, fixation was performed with multiple Kirschner wires;[37] next, staples[21,38] or compression screws in different positions were used,[11,39] followed by dorsal circular carpal plates,[11] which more recently have been innovated with lock designs.

At first, the dorsal circular plate had poor outcomes, with high non-union rates (48–63%);[40,41] however, authors such as Bedford and Yang[42] and Merrel et al.[43]described union rates of 100%, placing special emphasis on aspects of the surgical technique.[44]

The present study aims to report our experience with four-corner fusion using a radiolucent locking dorsal circular plate (Xpode®, Trimed Inc., Santa Clarita, CA, US), and to compare it with another fixation method (3.0-mm cannulated headless compression screws [HCSs], Synthes, Solothurn, Switzerland) regarding consolidation, functional outcomes, and complication rates. We believe that this technique presents higher rates of union, consistent with traditional osteosynthesis methods.

Material and Methods

The present is a comparative study of two series of patients, totaling 17 subjects, submitted to two different osteosynthesis techniques to perform four-corner fusion.

The patients were divided into two groups according to the surgical technique. The first group underwent four-corner fusion with two cannulated HCSs, according to the Richards et al.[16] technique. The second group was submitted to an osteosynthesis technique with the Xpode plate, according to the technique described by Shin[11] and by Rhee et al.[45]

Both groups were operated on by four orthopedic surgeons in four different medical centers: Hospital de la Fuerza Aérea de Chile, Clínica Indisa, Clínica Alemana de Santiago, and Hospital de la Dirección de Previsión de Carabineros de Chile (DIPRECA). All subjects were radiographically evaluated to determine the presence of consolidation and the time until its completion. In case of doubt, union was assessed with a computed tomography (CT) scan eight weeks after surgery (►**Figure 1**).

The variables for functional analysis of both groups included postoperative ROMs, complications, the need for new surgeries, grip strength determination, and the score on the Disabilities of the Arm, Shoulder, and Hand questionnaire.

Data collection and tabulation were performed using the Microsoft Office Excel (Microsoft Corp., Redmond, WA, US) software. The statistical analysis was performed on the Stata (Statacorp, LLC, College Station, TX, US) software, version 12.0. The continuous variables were analyzed with the Student *t*-test and the Wilcoxon-Mann-Whitney test according to the normal distribution, whereas the categorical variables were analyzed with the Chi-squared test. Statistical significance was set at $p < 0.05$.

Protocol Descriptions

As aforementioned, four-corner fusion underwent few modifications since its original description. It is critical to remember the key points in any partial carpal arthrodesis: 1) achieve adequate carpal reduction and alignment; 2) achieve adequate denudation of the articular surfaces; 3) add and supplement with a bone graft; and 4) provide adequate arthrodesis stabilization using some osteosynthesis material.

Surgical Technique

The procedure is performed under general plus brachial plexus anesthesia and arm ischemia, using the longitudinal dorsal wrist approach. Next, subcutaneous tissue dissection, sparing the sensitive dorsal branches of the radial and ulnar nerves, was performed, followed by a longitudinal incision of the extensor retinaculum between the third and fourth compartments and elevation of the Lister tubercle, releasing the tendon of the extensor pollicis longus muscle and separating it radially. The fourth compartment was opened, releasing the tendons of the extensor digitorum communis and separating them ulnarly. Then, a neurectomy of the posterior interosseous nerve was performed in the most proximal area, leaving the nerve stump as deep as possible, followed by a Berger et al.[46] dorsal capsuloplasty. Scaphoidectomy, exposure of the carpal bones, and denudation of the articular surfaces to be instrumented (lunate-capitate, triquetrum-hamate, capitate-hamate, lunate-triquetrum)

Fig. 1 Clinical case: postoperative radiograph and computed tomography scan to confirm satisfactory consolidation if required.

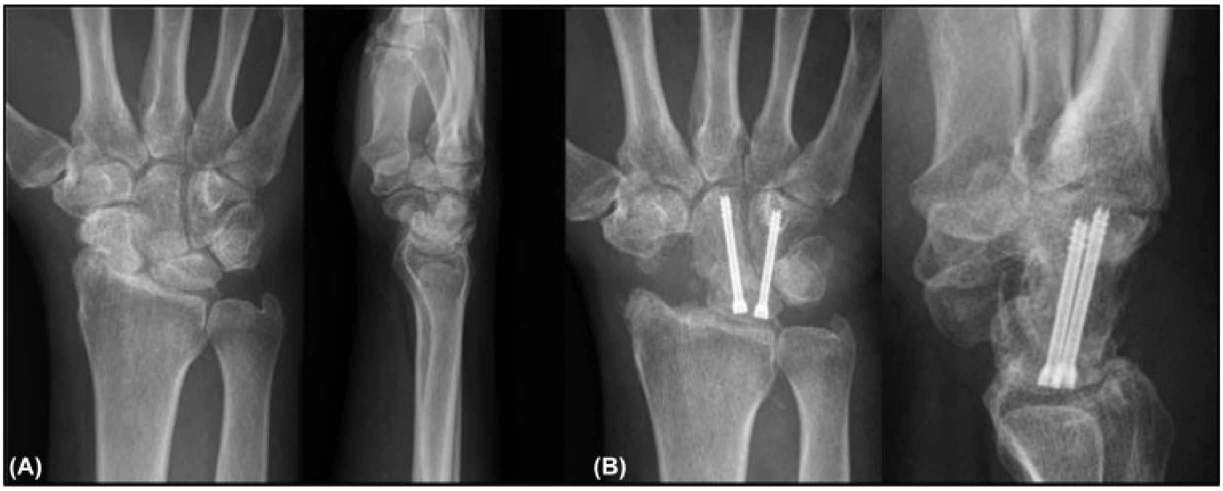

Fig. 2 (A) Preoperative and (B) postoperative radiographs of the surgical technique using cannulated headless compression screws (Richards et al. technique[16]).

were performed using gouges, spoons, and dental burs, followed by removal and cleaning of chondral debris. Up to this point, both techniques were similar, but from here on they differ according to the definitive stabilization with the selected osteosynthesis method.

*Group 1–Screws (Richards et al.[16]): correction of the carpal alignment with lunate reduction (for dorsal intercalated segment instability, DISI) and capitate migration; temporary stabilization with two Kirschner wires and the selected compression screws: one from the lunate to the capitate bones, and another from the lunate to the hamate bones. Two 3.0-mm HCSs were placed, from proximal to distal, with the lunate bone as an entry point. Finally, after the addition of an iliac crest bone graft, the capsulotomy was closed, followed by closure of the surgical wound in planes (►**Figure 2**).

Group 2–Xpode plate (Shin[11] and Rhee et al.[45]): correction of the carpal alignment with lunate reduction (for DISI) and temporary stabilization with two Kirschner wires: one from the radius to the lunate bones and another from the capitate to the triquetrum bones. After providing abundant iliac crest bone graft, the site for the placement of the Xpode plate was drilled, and the plate was definitively stabilized with two locking screws per corner (►Figure 3**), with care to achieve adequate radiocarpal mobility and avoid dorsal impingement. Finally, the capsulotomy was closed, followed by closure of the surgical wound in planes.

Subjects from both groups used a wrist immobilizer two weeks after surgery, until suture removal. Next, immobilization was performed with a short arm cast for four to six weeks. Subsequently, a kinesic rehabilitation protocol was instituted for ROM recovery.

Results

In total, 17 subjects were included; 8 patients were operated on from 2010 to 2012 with osteosynthesis using 2 HCSs, and 9 patients were operated on between 2011 and 2014 with a radiolucent locking dorsal circular plate made of a synthetic polymer called polyether-ether-ketone (PEEK).

The mean age in the first group was 45 years (range: 32–64 years). This group consisted of six men and two women;

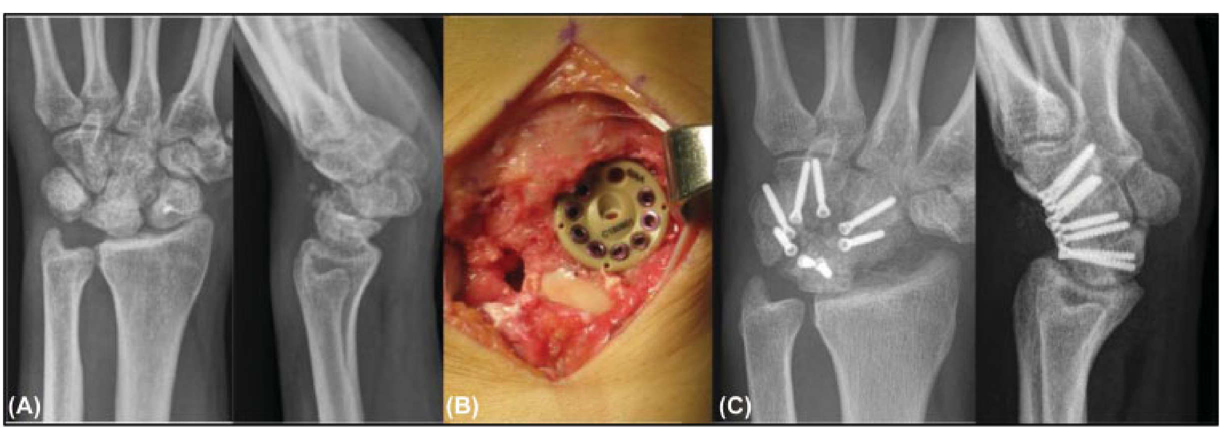

Fig. 3 (A) Preoperative radiograph, (B) intraoperative photograph: Xpode plate in situ with two screws per bone (corner) and autologous bone graft, and (C) postoperative radiograph of the surgical technique using a plate (Rhee et al.[45] technique).

Table 1 Comparison of outcomes in the plate and screw groups

Outcome	Plate (Xpode)	Screws	*P*-value
	($N = 9$)	($N = 8$)	($p < 0.05$)
Flexion-extension range of motion (°)	78	67.8	0.131
Flexion (°)	35.1	38.1	0.214
Extension (°)	50.7	29.7	**0.001**
Radialization (°)	13.1	15.6	0.478
Ulnarization (°)	28.3	26.8	0.795
Strength (kg)	29.6	23.7	0.102
DASH score (points)	5.3	15.2	**0.006**
Complications (%)	0	11.76 (osteolysis)	0.111

Abbreviation: DASH, Disabilities of the Arm, Shoulder, and Hand questionnaire.

Table 2 Comparison of consolidation times

Outcome	Plate (Xpode)	Screws	*P*-value
	($N = 9$)	($N = 8$)	($p < 0.05$)
Consolidation (weeks)	8	8.25	0.408
Non-union (%)	0	0	

the dominant wrist was involved in five cases, and the non-dominant wrist was affected in three cases. This group had three cases of SLAC and five of SNAC as etiological diagnoses. The average follow-up period was of 18 months.

In the second group, the mean age was 40 years (range: 18–62 years). This group consisted of eight men and one woman; the dominant wrist was involved in five cases and the non-dominant wrist was affected in three cases. This group had three cases of SLAC, three of SNAC, and three of instability and midcarpal osteoarthritis secondary to perilunate carpal lesions as etiological diagnoses. The average follow-up period was of 12 months.

Both groups were comparable, with no significant differences regarding age and gender. The ROMs, DASH scores, and grip strength were determined after six months of follow-up, as shown in ►**Table 1**.

The mean flexion-extension ROM among the HCS group was of 68°, with an average flexion of 38.1° (range: 20°–45°) and an average extension of 29.7° (range: 20°–40°). In contrast, the mean flexion-extension ROM among the plate group was of 78°, with an average flexion of 27.2° (range: 10°–40°) and an average extension of 50.7° (range: 30°–75°). This difference in the extension range for both groups was statistically significant ($p = 0.0016$). There were no statistically significant differences regarding flexion, radialization, or ulnarization.

The mean DASH score was of 15.2 points in the HCS group, and of 5.3 points in the plate group, with a statistically significant difference ($p = 0.0066$). Grip strength showed no statistically significant differences between the groups.

The mean consolidation time was of 8.2 weeks in the HCS group, and of 8 weeks in the plate group, with no statistically significant difference ($p = 0.408$). Consolidation was achieved in 100% of the patients, with no cases of non-union in both series, which is consistent with the international literature (►**Tables 2** and **3**).

As for osteosynthesis complications, there were only two cases of osteolysis, which did not result in non-union, in the HCS group. In one case, a clinically-asymptomatic patient presented migration of one of the capitate-lunate screws on the control radiograph taken at sic months; since there was a risk of involvement of the radiocarpal articular surface, a new surgery was required for the removal of the osteosynthesis material nine months after the first procedure. The second patient presented persistent pain that did not subside with rehabilitation, so we decided to perform a total wrist arthrodesis, which is still pending.

Discussion and Conclusion

Four-corner fusion is a reliable and reproducible surgical procedure to treat stage-II and -III SLAC/SNAC wrists, preserving an adequate ROM.[18,20,21,43,49]

Throughout its history, several osteosynthesis methods have been used, since an optimal or perfect technique has clearly not been found. The traditional Kirschner wires described by Watson initially resulted in reports of low non-union rates (3–18%) in the literature,[16,23,28,49–51] but criticism of this technique can be made, because it is known that, biomechanically, Kirschner wires present deficiencies compared to more recent implants[52] In addition, they are associated with considerable migration rates, tendon irritation, insertion-site infection, and patient discomfort. Staples also result in low non-union rates, and in complications such as dorsal impingement;[50] their use was never considered in our institutions.

There were no cases of non-union using cannulated HCSs, since we achieved consolidation in 100% of the patients, which is in line with the reports in the literature.[16,39,40,50] There were no cases of conversion to total wrist arthrodesis in any of our series, even though the conversion rate ranges from 2.4% to 29%.[28,40,41,51,53–55] However, in the HCS group, there is a procedure pending for one patient, due to residual pain, osteolysis caused by the cannulated HCSs, and radiolunate joint wear (►**Figure 4**).

We must bear in mind that the rate of total wrist arthrodesis may be falsely low due to relatively short follow-up periods. Nevertheless, Bain and Watts[50] and Watson and Ryu[22] showed that mobility, pain scores, and the conversion rate to total arthrodesis were not different regarding patients with follow-ups consultations held 1 and 10 years after surgery.

Table 3 Comparison of outcomes with other four-corner fusion series

Series	Follow-up	Sample	Osteosynthesis	F-E ROM	DASH	Non-union
	(years)	(n)		(°)	(points)	(%)
Watson and Ballet[15] (1984)	3.6	252	Kirschner wires	–	–	3%
Vance et al.[40] (2005)	4.9	31	Kirschner wires, staples, and screws	65	8	3%
Vance et al.[40] (2005)	4.9	27	Spider plate	65	27	26%
Richards et al.[16] (2011)	4	21	Screws (HCSs)	30–60	–	5%
Ozyurekoglu and Turker[39] (2012)	2.3	33	Screws	71	13	6%
Merrell et al.[43] (2008)	3.8	28	Spider plate	61	–	0%
Kendall et al.[41] (2005)	1.6	18	Spider plate	50	–	62.50%
Rhee et al.[45] (2013)	1.33	23	Xpode	–	–	4%
Luegmair and Houvet[62] (2012)	5.25	24	Xpode	64	19.1	8%
Tchurukdichian[47] (2006)	1.4	24	Xpode	61	–	8%
Roux[48] (2006)	0.75	11	Xpode	63	–	9%
Present study	2.5	9	Xpode	78	5.3	0%
Present study	3	8	Screws	67.8	15.2	0%

Abbreviations: DASH, Disabilities of the Arm, Shoulder, and Hand questionnaire; F-E ROM, flexion-extension range of motion; HCSs, headless compression screws.

Fig. 4 Clinical case: (**A**,**B**) ccrew osteolysis in postoperative radiograph and computed tomography scan; (**C**) progression of the degenerative process and osteoarthritis.

We performed the surgical technique described by the first authors to use screws in four-corner fusion, Richards et al.:[16] fixation with two proximal-to-distal screws entering the radiolunate joint. Despite the good outcomes, perforation of the lunate articular cartilage causes defects on the articular surface, including iatrogenic lesions, resulting in an inflammatory response that could accelerate the apoptosis of chondrocytes.[56] Research[56,57] in other joints has shown an accelerated progression of joint surface defects in patients with preexisting osteoarthritis. However, these defects can be replaced by fibrocartilage, and many subjects remain asymptomatic. This is why some authors[39,58] recommend avoiding damaging this joint, since the success of a four-corner fusion procedure is based on the preservation of the radiolunate articular surface. As such, when opting for this technique, it is essential to consider the configuration and entry points of the screws. Today, many surgeons prefer a triangular-shaped screw configuration,[59] which would decrease the probability of degenerative damage to the radiocarpal joint due to iatrogenic injuries, since the entry point of the screws is at another site. This technique consists of three cannulated screws with entry points from distal to proximal and in a triangular configuration, as described by Ho in 2008.[59]

The mean postoperative flexion-extension ROM in the HCS group was of 68°, which is consistent with that of other published series.[16,39] However, it is worse than the mean value obtained among the plate group: 78°. This last figure is due to a higher extension in this group, and this difference was statistically significant. This finding can have multiple debatable causes, but lunate and DISI reduction are the most relevant, enabling a higher wrist extension;[11] in fact, a neutral or slightly flexed lunate position is optimal to facilitate wrist extension.[41,49] There was no dorsal carpal impingement in the plate group, a potential cause of postoperative pain and ROM limitation. Theoretically, one of the advantages of screws compared to plates is avoiding dorsal impingement; however, in our series, not only did this complication not occur, but dorsal extension significantly increased.

The comparison of DASH scores also favored the plate group, who presented a score of 5.3 points against 15.2 points for the screw group, with a statistically significant difference. However, the DASH scores from each group are consistent with those described in the literature (►**Table 3**).

The dorsal circular plates are the latest materials incorporated as fixation alternatives for four-corner fusion. Their consolidation rates have varied over the years. One of the elements that could play a role in this variation is the difficulty in accurately assessing bone healing, especially with the first spider metal plates (Spider Limited Wrist Fusion Plate, Kineticos Medical Inc., San Diego, CA, US). Kendall et al.[41] and Vance et al.[40] reported high non-union rates, of up to 63%. However, in 2008, Merrell et al.[43] reversed the plate union rates, reporting 100% of consolidation and few complications; this started a debate about the importance of the technical aspects of the surgery, emphasizing the following points: use of autologous bone graft (distal radius), careful debridement of articular surfaces, adequate debris removal, and placement of at least two screws of adequate size at each corner or bone. When analyzing the reasons for poor outcomes using plates, Weiss[44] agrees with Merrell et al.[43] on the importance of the technical aspects of the surgery, and also discusses the origin of the graft and mechanical (not biological) factors, such as the locking construct of the screws to the plate.

In the present study, we used well-known surgical techniques; the Richards et al.[16] technique for screws, and the Shin[11] and Rhee et al.[45] technique and tips for plates. Regarding the surgical approach, note that a posterior interosseous nerve neurectomy was performed in both techniques; although some authors question this procedure due to issues regarding wrist proprioception, we believe that it is an important source of postoperative analgesia and rehabilitation. Furthermore, since partial arthrodesis alters wrist biomechanics, we believe its role in proprioception may be minor.

Regarding bone grafts, we prefer the iliac crest bone graft used in both series due to its advantages and the recommendations made by Shin[11] and by Rhee et al.[45] Although there were no theoretical differences regarding the graft donor site (compared to the distal radius), the findings were consistent with those published by Kitzinger et al. in 2012.[61] In addition, we believe that it is necessary to consider donor-site comorbidity and patient satisfaction.

For the plate group, we used the Xpode dorsal circular plate, a new generation of radiolucent locking implants made of PEEK, a thermoplastic polymer with many benefits in orthopedic applications.[62,63] The high (100%) union rate in the present series may also be due to the screw-plate construct. In a biomechanical investigation, Kraisarin et al.[52] observed that a fixed Xpode plate is the most stable construct compared with the conventional spider dorsal plate or Kirschner wires; in addition, it was the only construct to tolerate a range of simulated forces in motion with no catastrophic failure. Furthermore, its radiolucency enables a more accurate assessment of the consolidation.

Failure of the osteosynthesis material only occurred in two patients treated with screws; both cases were due to osteolysis, and happened after consolidation. In one subject, this complication required a new surgery for removal of the material; in the other case, the patient is waiting for a total wrist arthrodesis, as aforementioned. No failures or need for new surgeries were observed in the plate group. The international literature reports that conventional dorsal circular plates present failure rates from 0% to 27%.[40–43,53,64] The most frequent failures include broken screws due to persistent movement and non-union at the capitate-hamate joint, which highlights the need for at least two screws in each carpal bone (particularly the capitate and lunate bones). Unlike conventional steel plates, there have been few reports of failure of locking plates, suggesting that the PEEK locking dorsal circular plate can provide sufficient fatigue strength in vivo to resist breakage; in addition, the locking mechanism can prevent the screw from breaking at the screw-plate interface.[45,65] Moreover, the screws of the PEEK locking plate present a variable instead of a fixed angle, which would limit micromovements and facilitate screw fixation loss within the carpal bones.

Although the present work shows relevant data on the different osteosynthesis techniques for four-corner fusion, one of its limitations is the lack of preoperative evaluation, which hinders and assessment of the functional recovery. In addition, it presents the limitations inherent to a non-randomized study with no blinding.

In conclusion, based on our outcomes and an analysis of the existing literature, we consider both osteosynthesis methods for four-corner fusion reproducible and valid, resulting in adequate consolidation and demystifying the high rates of non-union with dorsal circular plates reported in the literature in the 2000s[41]. However, due to the functional outcomes, complications, and secondary surgeries, we believe that the locking dorsal circular plate is the best current alternative for an open four-corner fusion with a dorsal approach, always bearing in mind the details and concerns regarding the surgical technique itself.[66]

Likewise, although cannulated HCSs are an excellent alternative, we currently reserve them for cases in which an arthroscopic surgery is desired,[59,67] using an arrangement and configuration other than those described by Richards et al.[16]

Conflict of interests
The authors have no conflict of interests to declare.

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