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The Never-Ending Battle between Proximal Row Carpectomy and Four Corner Arthrodesis: A Systematic Review and Meta-Analysis for the Final Verdict

Ali R. Ahmadi¹, Liron S. Duraku¹, Mark J.W. van der Oest¹, Caroline A. Hundepool¹, Ruud W. Selles¹, J. Michiel Zuidam¹,2 §

¹Department of Plastic and Reconstructive Surgery, Erasmus MC- University Medical Centre Rotterdam, The Netherlands.

²Department of Rehabilitation Medicine, Erasmus MC- University Medical Centre Rotterdam, The Netherlands.

§ Corresponding author: J.M. Zuidam, MD, PhD,
Department of Plastic and Reconstructive Surgery,
Erasmus MC,
Dr. Molewaterplein 40,
3015 GE Rotterdam,
The Netherlands.
E-mail: j.zuidam@erasmusmc.nl

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ABSTRACT

While scaphoid excision combined with Four Corner Arthrodesis (FCA) or Proximal Row Carpectomy (PRC) are commonly-used salvage procedures to treat type two and three Scapholunate Advanced Collapse (SLAC) and Scaphoid Nonunion (SNAC)-induced degenerative arthritis, controversy persists over which treatment provides superior outcomes. We searched for articles comparing range of motion, grip strength, complications requiring reoperation, conversion to wrist arthrodesis, pain, and disability of shoulder and arm scores between FCA and PRC-treated patients. The risk of bias was assessed with the NIH tool. We performed a meta-analysis using Random-Effects Models. Fifteen articles were included, consisting of 10 retrospective, 2 cross-sectional, 1 prospective and 2 randomized trials. There was no significant difference between PRC and FCA in any of the different outcome measures. Risk of bias was consistently high across all studies. Despite the lack of high-quality evidence, based on existing literature, the authors recommend PRC as the preferred choice of treatment because of the simplicity of the surgical procedure, lack of hardware related complications and comparable long-term outcomes.

Keywords: Proximal Row Carpectomy, Four Corner Arthrodesis, Scapholunate Advanced Collapse, Scaphoid Nonunion Advanced Collapse, Systematic Review, Meta-Analysis

Level of evidence: III - Therapeutic
INTRODUCTION

The human wrist is a complex formation with interactions between several small bones and interligamentary connections resulting in a mobile and stable hand function. If left untreated, disruption of this complex anatomical formation can result in degenerative arthritis, pain, and eventually progressive loss of hand function. Degenerative wrist arthritis can arise from rheumatoid arthritis or posttraumatic arthritis affecting the radiocarpal and midcarpal joints of the wrist. The scaphoid bone, in particular, is an important anatomical and junctional link between the proximal and distal carpal bones.

Scapholunate advanced collapse (SLAC) and scaphoid nonunion advanced collapse (SNAC) are the two most common patterns of degenerative wrist arthritis. In 1984, Watson and Ballet were the first to describe SLAC as the most common form of degenerative wrist arthritis. This condition can be attributed to spontaneous osteoarthritis or post-traumatic injury of the wrist. Because of the abnormal distribution of forces across midcarpal and radiocarpal joints, the radioscaphoid joint is affected, which can progress to the capitolunate joint in further stages (Figure 1A). SNAC is a condition of advanced collapse and progressive arthritis of the wrist that results from a chronic scaphoid nonunion, mainly originating from traumatic injury (Figure 1B).

When conservative treatment fails, surgical interventions are indicated. The ideal surgical treatment should result in pain relief and good wrist functionality. Currently, no curative therapies exist; however, many treatment options have been developed for symptomatic relief. Traditionally, end-stage SLAC and SNAC arthritis were treated with total wrist arthrodesis (TWA). Although TWA leads to pain relief in most cases, wrist motion is sacrificed. TWA is currently considered a salvage procedure when other therapies fail. However, newer alternatives to TWA include the use of motion sparing arthroplasty implants.
which are more anatomically aligned and require minimal bone resection and offer improved range of motion and grip strength².

Proximal Row Carpectomy (PRC) and Four Corner Arthrodesis (FCA) are the two most common surgical procedures to treat SLAC and SNAC wrists. These treatment modalities are preferred because they address pain and simultaneously preserve ROM. Briefly, PRC is a resection of the proximal carpal row consisting of the scaphoid, lunate and the triquetrum bones. PRC allows the capitate bone to articulate with the lunate facet of the distal radius, creating a new joint formation (Figure 2A). FCA is a resection of the scaphoid bone and arthrodesis between the lunate, capitate, hamate and triquetrum bones. This procedure aims to fuse the arthritic midcarpal joint and reduce pressure in the scaphoid fossa, by redistributing the cartilage contact areas to the lunate fossa. FCA can be performed traditionally with screw fixation (Figure 2B) or with a circular plate (Figure 2C). The circular plate is used as an alternative fixation method, preferred by some surgeons in comparison to the traditional compression screws. The rationale for both procedures is based on redistributing the force from the scaphoid fossa to the lunate fossa cartilage of the radius since this cartilage is not affected by the degenerative changes. The lunate fossa of the radius is spared from degenerative changes as it is protected from incongruent pressure by its tight ligamentous structures, that control a near spherical joint profile with the capitate base. However, it is not more resilient against arthritic changes than other structures in the wrist and can feature in advanced stage disease. Indications for the use of each operative procedure are listed in Figure 1 & 2. Generally, FCA is essential, if there is midcarpal osteoarthrititis and the capitoluminate joint is affected in the SLAC or SNAC wrist. A possible disadvantage for choosing PRC could be an incongruity between the capitate and the lunate fossa leading to degenerative changes and pain and eventually to TWA. However, controversy persists over which of the two procedures has the superior functional short-term and long-term outcome.
Two systematic reviews have been published on this topic in 2009 and 2015\textsuperscript{3,4}. Only Mulford et al. conducted a meta-analysis but on subjective outcomes, relative risk of postoperative conversion and post-operative osteoarthritic changes\textsuperscript{4}. Our study on the contrary, presents the most up to date systematic review and meta-analysis on the most important postoperative outcome measures to help guide clinicians in patient selection and preferred operative method and patients in their treatment choice.
METHODS

The study was designed according to the Cochrane Handbook for Interventional Systematic Reviews and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P)\textsuperscript{5}.

Literature search strategy

Comprehensive searches were carried out in EMBASE, Medline, Pubmed Publisher, Web-of Science, OvidSP, Cochrane Central Register of Controlled Trials (The Cochrane Library, December 2019, issue 12 of 12) and Google Scholar. The search was conducted for articles published up to December 2019 by using search terms specific to each search engine (Text S1).

Inclusion and exclusion criteria

The main inclusion criteria were studies evaluating one or more of the following postoperative outcomes of PRC and/or FCA for the treatment of SLAC and SNAC wrists: range of motion (ROM), grip strength, complications leading to reoperations, conversion to TWA, Visual Analog Scale (VAS) pain or Disability of the Arm, Shoulder, and Hand Questionnaire (DASH) scores. Studies combining limited 2 or 3 corner with 4 corner arthrodesis versus PRC were excluded. Only full-text, original articles written in English were considered for inclusion in the study. All reviews, conference abstracts, book chapters, letters, case series and editorials were excluded.
**Literature screening**

Articles were screened by two individual researchers (ARA, LSD) for relevance and inclusion. The same independent reviewers screened titles, keywords and abstracts of all considered articles, according to the pre-established criteria. In case of discrepancy, a third author was consulted (JMZ). After inclusion based on the parameters above, full-text articles were retrieved and reviewed for inclusion. All articles were evaluated using the PICO method. All included articles were rated for their level of evidence according to an adapted version from material published by the Centre for Evidence-Based Medicine, Oxford, UK⁶.

**Risk of Bias Assessment**

Risk of bias assessment for observational cohort and cross-sectional studies and intervention studies was carried out by two authors (ARA, LSD) with the National Institutes of Health (NIH) study quality assessment tool⁷.

**Statistical analysis**

We performed a meta-analysis on the following parameters: ROM, grip strength, complications, conversions to total arthrodesis, VAS pain score and DASH score. When standard deviations were not reported, we calculated them based on the method described by Hozo et al.⁸. For continuous outcomes, we performed a meta-analysis using a random-effects models to estimate the pooled mean difference and 95% confidence interval (CI). For dichotomous data, we used a random-effects model to estimate the pooled risk difference. We tested whether the type of surgery influenced the pooled means or proportions by adding the type of surgery as an independent variable. The same methodology was used to test if the patient characteristics were the same for both types of surgery.
The Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines were followed. A p-value lower than 0.05 was deemed statistically significant. All analyses were performed with R version 3.6.0 and the metafor package.
RESULTS

Study demographics

In total, 1619 articles were retrieved and subjected to screening based on the inclusion and exclusion criteria. Only 16 studies fell within the initial scope of our study (Figure S1). Upon reading the full text, one article was excluded because it only reported outcomes of two and four corner fusions combined. Of the remaining 15 studies, ten were retrospective (Level III), two cross-sectional (Level III-IV), one prospective cohort (Level II), and two RCT's (Level I) (Figure 3A). The minimum number of included patients per study was 20, with a maximum number of 123 patients. The two randomized controlled trials had 20 and 26 patients. Despite the differences in the level of evidence due to the study design, we included all studies in the meta-analyses.

In total, 322 FCA and 328 PRC treated patients were included in the analysis with a mean age of 48 in the FCA group and 46 years in the PRC group (Figure 3B). Mean follow-up ranged from 6 months to 18 years between the studies. The mean follow-up time across all studies was 5.1 years in the FCA and 5.3 years in the PRC group. In the FCA group, 77% were male and 23% female and in the PRC group, 68% male and 32% female.

Only nine studies reported the number of treated SLAC and SNAC wrists by either PRC or FCA. The majority of the studies had included patients with a grade II/III SLAC/SNAC diagnosis. Of these eight studies, two studies had also included patients with SLAC/SNAC grade I. The remaining seven studies did not report on the SLAC/SNAC grading. All studies but three reported on whether the dominant hand was operated or not. Merely seven studies reported on the number of surgeons that operated, and 10 out of 15 studies mentioned who registered outcome measurements and performed additional testing or collected clinical data. The majority of the studies cited using independent observers (5/15), occupational therapists
(3/15), and research staff (2/15).

**Risk of Bias**

Risk of bias was evaluated with the NIH tool. The majority of studies were at serious risk due to a poorly defined and specified study population and in some cases from two different countries and different institutions, and the lack of specific inclusion and exclusion criteria (Figure 4). Almost all studies lacked sample size justification, power analysis or proper statistical methods to adjust for confounders. Outcome measurements were not conducted in a blinded setting in any study.

**Active ROM outcomes**

In total, 13/15 studies reported on the ROM. Separate extension, flexion, radial deviation, and ulnar deviation values were reported in eight studies. Of those, three studies were excluded from the pooled analysis because of missing SD or statistical analysis\(^{10-12}\).

In the meta-analysis, we found no significant differences between PRC and FCA in extension -9.35° (-30.72°– 12.02°), \( P = 0.29, \, I^2 = 96\% \); flexion -5.89° (-17.24°– 5.47°), \( P = 0.22, \, I^2 = 91\% \); radial 4.74° (-3.56°– 13.03°), \( P = 0.19, \, I^2 = 94\% \); or ulnar deviation -2.52° (-10.02°– 4.98°), \( P = 0.40, \, I^2 = 76\% \). (Figure 5). High heterogeneity was noted amongst the studies in all motion exercises (\( P < 0.01 \)).

Fivestudies were excluded from the meta-analysis because they reported only either a combined extension/flexion arc\(^{13}\) or a combined radial/ulnar deviation arc\(^{14,15}\) or only the total arc of motion\(^{16}\). Three studies reported on a combined extension/flexion and radial/ulnar deviation arc between PRC and FCA, but no significant differences were observed\(^{13-15}\). One studies reported on the extension/flexion arc, which was significantly improved in PRC 73 ±
5 compared to FCA $54 \pm 6$, $P < 0.01^{17}$. Radial and ulnar deviation were measured separately, but were not significantly different. One study only reported on the postoperative ROM which was not significantly different between PRC and FCA $^{16}$.

**Grip strength**

All studies but two reported on grip strength $^{18,19}$. Ten studies measured grip strength using a Jamar Dynamometer, the other three did not report on the SD and were therefore not included in the meta-analysis $^{11,12,16}$. The three excluded studies did not report a significant difference in grip strength between the two groups. All remaining studies ($N = 10$) reported grip strength as a percentage compared to the contralateral non-operated hand.

In the meta-analysis, we found no difference in grip strength in FCA-treated patients compared to the PRC group: $-0.02 (-0.13 - 0.10)$, $P = 0.74$ (Figure 6). High heterogeneity was noted amongst the studies ($P < 0.01$, $I^2 = 89\%$).

**Complications and reoperations**

Complications resulting in a reoperation were reported in 12 studies and consisted of pin removal because of migration causing discomfort, carpal tunnel syndrome decompression, tenolysis, hematoma evacuation, Quervain’s stenosing tenovaginitis, ulnar impaction and scar revision. Three studies did not report on complications and reoperation $^{15,18,20}$.

The success of FCA partially relies on the successful union between the lunate, capitate, hamate and the triquetrum carpal bones. Adequate union allows for the start of the rehabilitation process, therefore nonunion can delay this process and eventually affect long-term outcomes. Nonunion rates were reported in ten studies, exclusively prevalent in FCA treated patients due to the nature of the operative procedure. In total, 17 (8.8\%) cases of
nonunion were reported amongst all studies. In some cases, non-union was an indication for reoperation or conversion to TWA.

In the meta-analysis, we found no significant difference in the number of complications resulting in reoperation between the two groups 0.03 (-0.03 – 0.10), P = 0.28 (Figure 7). Moderate heterogeneity was noted amongst the studies (P = 0.04, $I^2 = 45\%$).

**Conversions to total wrist arthrodesis**

Since total wrist arthrodesis is a salvage procedure for failed FCA or PRC, conversion rates were reported in 12 studies, but not reported on in the three remaining studies$^{15,18,20}$. In the meta-analysis, we found comparable conversion rates for both groups 0 (-0.03 – 0.04), P = 0.88 (Figure 8). There was no heterogeneity between the studies (P = 0.57, $I^2 = 0\%$). The reason for conversion was persistent or severe pain after FCA or PRC in the majority of the studies.

**Pain**

Postoperative pain measurement was conducted in eight studies during follow-up visits. Two studies did not use the VAS pain score or performed statistical analysis$^{10,11}$. The VAS pain score was used in six studies. However, we were only able to pool four of these studies, because of missing standard deviations in two articles which separately did not show a significant difference in postoperative pain score between the two groups$^{12,13}$. In the meta-analysis, we found pooled postoperative pain scores to be comparable between the two groups -0.24 (-1.19 – 0.71), P = 0.47 (Figure 9). There was low heterogeneity amongst the studies (P = 0.27, $I^2 = 24\%$).
DASH scores

DASH scores were reported in seven studies, of which three studies were excluded from the pooled analysis because of missing SD$^{12,13,21}$.

In the meta-analysis, there was no difference in DASH scores between PRC and FCA treated patients $1.24 (-22.7 – 24.54)$, $P = 0.88$ (Figure 10). High heterogeneity was noted amongst the studies ($P < 0.01, I^2 = 92\%$).
Clinical symptoms in SLAC and SNAC wrists can be variable. Patients can be asymptomatic or have significant wrist pain, reduced grip strength or limited motion of the wrist joint. Conservative treatment strategies include the use of splints, anti-inflammatory medication or corticosteroid injections. Surgical therapies are indicated, if conservative treatment fails. Preventive approaches to the underlying cause such as scaphoid reconstruction of scapholunate interosseous ligament (SLIL) repair can be considered. The scapholunate ligament is important for maintaining carpal stability and a tear of this ligament disrupts the carpal kinematics and can lead to progression of disease. There are different degrees of SLIL injury that may require a tailored approach. Scaphoid non-union happens when the scaphoid does not show signs of healing 6 months after the traumatic injury. Non-union of the scaphoid can result in deformities, incongruence and eventually to osteoarthritic changes. Scaphoid reconstruction can be considered if there are reliable cartilage surfaces in the radiocarpal joint, the scaphoid or both. SLAC and SNAC-induced degenerative osteoarthritis of the wrist, and the availability of several surgical therapies with different outcomes, can be dazzling for clinicians trying to select the best possible procedure. Options include a prosthetic scaphoid replacement, radial styloidectomy, wrist denervation, and total wrist arthrodesis. Nerve denervation is used to relieve patients of pain by severing the terminal branches of the anterior interosseous nerve or the posterior interosseous nerve and other fine articular branches from the other major nerves crossing the wrist joint. A recent study in 33 patients with a 41 month follow up showed 75% reduction in pain levels. Whilst this method provides significant pain relief, it does not stop the ongoing osteoarthritis. Early stage SLAC and SNAC affects the radial styloid and the scaphoid. Radial styloidectomy can be a suitable option for early stage disease. In more advanced stages of disease PRC and FCA are the two most widely used surgical therapies.
In the last few decades, PRC and FCA have gained popularity and are among the most commonly used procedures to treat degenerative osteoarthritis. Both procedures provide pain-relief and preserve ROM; however, because of the lack of RCTs, it remains unclear which procedure provides superior outcomes. We performed a meta-analysis and found no significant difference between ROM, grip strength, reoperation, conversion to TWA, pain, or DASH scores between the two groups. Although nonunion exclusively occurred in the FCA group, this did not affect the reoperation or conversion rate. Only two RCT exist on this topic and our findings are comparable\textsuperscript{12,16}. They did not observe any significant difference in functional or clinical results between the two treatment methods.

Watson and Ballet were the first to introduce FCA in 1984 \textsuperscript{1}. According to Watson, FCA is the preferred treatment option for stage 3 collapse, mainly because the proximal pole of the capitate is involved in the degenerative process, therefore excluding PRC as an option. The main question which remains is whether patients with stage 2 degeneration will have better outcomes with PRC or FCA. In our study, we included all of the available literature comparing outcomes between PRC and FCA and pooled this data to generate a more robust conclusion. It was important to include only comparative studies because of their relatively well-matched study populations and similarity in outcome measurements.

Two systematic reviews have been conducted on this topic. Mulford et al. conducted a systematic review comparing outcomes of 160 PRC and 185 FCA procedures\textsuperscript{4}. Their findings demonstrate that grip strength, pain relief, ROM, and subjective outcomes are comparable for both groups. They found PRC to have a higher range of osteoarthritic change after surgery, although in most cases asymptomatic, but that the FCA group had more complications (10%
more) overall due to nonunion, dorsal impingement and complications related to hardware. No differences in the rate of conversion to TWA were observed. This is in line with our findings. Important to note is the different surgical methods used when performing FCA. This may partially explain the different complications rate reported in FCA treated patients ranging from 2 to 11%.

Mulford et al. noticed more complications and nonunion to be higher in patients receiving a plate as opposed to K-wires and screws. This topic has long been contested and no standard technique exists.

A systematic review by Salzman et al. compared 7 out of the 15 articles we have included in our study. The overall complication rate in the FCA was significantly higher and double that in the PRC group. In our study, we specifically studied complications requiring reoperation, as many of the complications reported, such as nonunion in the included studies by Salzman et al., remained asymptomatic and could be treated conservatively. The included studies are not clear on the distribution of the number of patients with advances SLAC/SNAC grade III receiving PRC of FCA. No statistically significant differences were observed compared to pain severity and satisfaction, DASH score, or conversion rates to TWA, which is in line with our findings.

The outcomes of this study have to be interpreted with the limitations in mind. The majority of the included studies have a retrospective design with all of its inherent drawbacks, are non-randomized, and include only a small number of patients. Statistical analysis is not performed in many instances, and SD or ranges are not mentioned precluding us from pooling the results. Only a minority of the studies measure the pre-operative status of the patient and compares that with the postoperative values. The lack of a baseline pre-operative value makes it particularly difficult to measure the degree of improvement postoperatively and
compare that to other therapies. Several studies have shown the importance of preoperative clinical and functional measurements as a factor in estimating symptom relief after surgical treatment. In addition, the SLAC and SNAC grading distribution within treatment groups are not clear in most studies, making it difficult to make recommendations based on SLAC/SNAC grading. A difference in failure or nonunion rates may be attributable to different SLAC/SNAC grading or related to the surgical experience of the operator. FCA is a much more challenging operation compared to PRC. As demonstrated in Figure 3, many studies do not report the number of surgeons executing this operation. There are only a handful of studies where 1 or 2 surgeons performed both operations. We also evaluated the risk of bias with the NIH tool. All but two studies were observational studies and vulnerable to bias. Risk of bias was high in almost all studies because of a poorly defined patient population and lack of specified inclusion and exclusion criteria. All studies failed to blind examiners during outcome measurements. These limitations and differences could attribute to the high heterogeneity that was noted among the studies for ROM, grip strength, rate of reoperation and DASH scores.

Despite its limitations and the lack of multi-center randomized controlled trials, this study is the most up to date and comprehensive comparative systematic literature review and meta-analysis on comparing FCA and PRC in patients with degenerative SLAC and SNAC wrists. Compared to the most recent systematic review in 2015, this study contains 8 more comparative studies and the largest number of patients treated with PRC or FCA. This study conducted a meta-analysis on the six most important postoperative outcome measures and is a significant update to previously existing literature. A risk of bias assessment was also conducted to establish transparency and provide more insight into the included articles for comparison, which previous studies lacked.
Based on our findings, differences between average treatment effects could not be shown and may be relatively small when evidence accumulates. Since present studies all focus on comparing mean differences between treatments, for future studies, it may be more important to focus on patient-specific factors that determine treatment outcome, preferably, in the future, allowing clinicians to understand and predict which patients will benefit more or less from specific interventions. Based on this study, the authors recommend PRC as the preferred choice over the FCA, if there is no midcarpal osteoarthritis, because of the relative simplicity and the lack of need for a rather long learning curve compared to FCA. In addition, PRC lacks the early postoperative hardware related complications and provides comparable long-term outcomes.
Contributorship

JZM and LSD were responsible for conception and design. ARA and LSD aided in conducting the systematic review search and the process of inclusion and exclusion. ARA collected all the required data and MJWO performed statistical analysis and provided the figures. ARA wrote the first draft of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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References

1. Watson HK, Ballet FL. The SLAC wrist: scapholunate advanced collapse pattern of degenerative arthritis. *The Journal of hand surgery.* May 1984;9(3):358-365.

2. Halim A, Weiss AC. Total Wrist Arthroplasty. *The Journal of hand surgery.* Mar 2017;42(3):198-209.

3. Saltzman BM, Frank JM, Slikker W, Fernandez JJ, Cohen MS, Wysocki RW. Clinical outcomes of proximal row carpectomy versus four-corner arthrodesis for post-traumatic wrist arthropathy: a systematic review. *J Hand Surg Eur Vol.* 2015;40(5):450-457.

4. Mulford JS, Ceulemans LJ, Nam D, Axelrod TS. Proximal row carpectomy vs four corner fusion for scapholunate (SLAC) or scaphoid nonunion advanced collapse (SNAC) wrists: A systematic review of outcomes. *J Hand Surg Eur Vol.* 2009;34(2):256-263.

5. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic reviews.* Jan 1 2015;4:1.

6. OCEBM Working Group. The Oxford 2011 Levels of Evidence. Oxford Centre for Evidence-Based Medicine. 2011; http://www.cebm.net/cebm-levels-of-evidence/.

7. National Institutes of Health (NIH). Study Quality Assessment Tools. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools. Accessed 28-05-2020.

8. Hozo SP, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range, and the size of a sample. *BMC medical research methodology.* Apr 20 2005;5:13.
9. Viechtbauer W. Conducting meta-analyses in R with the metafor package. *Journal of statistical software*. 2010;36(3):1-48.

10. Wyrick JD, Stern PJ, Kiefhaber TR. Motion-preserving procedures in the treatment of scapholunate advanced collapse wrist: proximal row carpectomy versus four-corner arthrodesis. *The Journal of hand surgery*. Nov 1995;20(6):965-970.

11. Krakauer JD, Bishop AT, Cooney WP. Surgical treatment of scapholunate advanced collapse. *The Journal of hand surgery*. Sep 1994;19(5):751-759.

12. Bisneto EN, Freitas MC, Paula EJ, Mattar R, Jr., Zumiotti AV. Comparison between proximal row carpectomy and four-corner fusion for treating osteoarthritis following carpal trauma: a prospective randomized study. *Clinics*. 2011;66(1):51-55.

13. Dacho AK, Baumeister S, Germann G, Sauerbier M. Comparison of proximal row carpectomy and midcarpal arthrodesis for the treatment of scaphoid nonunion advanced collapse (SNAC-wrist) and scapholunate advanced collapse (SLAC-wrist) in stage II. *Journal of plastic, reconstructive & aesthetic surgery : JPRS*. Oct 2008;61(10):1210-1218.

14. Singh HP, Bhattacharjee D, Dias JJ, Trail I. Dynamic assessment of the wrist after total wrist arthroplasty. *J Hand Surg Eur Vol*. Jul 2017;42(6):573-579.

15. Wolff AL, Garg R, Kraszewski AP, et al. Surgical Treatments for Scapholunate Advanced Collapse Wrist: Kinematics and Functional Performance. *The Journal of hand surgery*. Aug 2015;40(8):1547-1553.

16. Aita MA, Nakano EK, Schaffhausen HL, Fukushima WY, Fujiki EN. Randomized clinical trial between proximal row carpectomy and the four-corner fusion for patients with stage II SNAC. *Revista brasileira de ortopedica*. Sep-Oct 2016;51(5):574-582.
17. Wagner ER, Werthel JD, Elhassan BT, Moran SL. Proximal Row Carpectomy and 4-Corner Arthrodesis in Patients Younger Than Age 45 Years. *The Journal of hand surgery*. Jun 2017;42(6):428-435.

18. Brinkhorst ME, Singh HP, Dias JJ, Feitz R, Hovius SER. Comparison of activities of daily living after proximal row carpectomy or wrist four-corner fusion. *J Hand Surg Eur Vol*. 2017;42(1):57-62.

19. Williams JB, Weiner H, Tyser AR. Long-Term Outcome and Secondary Operations after Proximal Row Carpectomy or Four-Corner Arthrodesis. *Journal of wrist surgery*. Feb 2018;7(1):51-56.

20. De Smet L, Degreef I, Robijns F, Truyen J, Deprez P. Salvage procedures for degenerative osteoarthritis of the wrist due to advanced carpal collapse. *Acta orthopaedica Belgica*. Oct 2006;72(5):535-540.

21. Vanhove W, De Vil J, Van Seymurier P, Boone B, Verdonk R. Proximal row carpectomy versus four-corner arthrodesis as a treatment for SLAC (Scapholunate Advanced Collapse) wrist. *J Hand Surg Eur Vol*. 2008;33(2):118-125.

22. Kitay A, Wolfe SW. Scapholunate instability: current concepts in diagnosis and management. *The Journal of hand surgery*. Oct 2012;37(10):2175-2196.

23. Pappou IP, Basel J, Deal DN. Scapholunate ligament injuries: a review of current concepts. *Hand*. Jun 2013;8(2):146-156.

24. Borges CS, Ruschel PH, Pignataro MB. Scaphoid Reconstruction. *The Orthopedic clinics of North America*. Jan 2020;51(1):65-76.

25. Delclaux S, Elia F, Bouvet C, Apredoaei C, Rongieres M, Mansat P. Denervation of the wrist with two surgical incisions. Is it effective? A review of 33 patients with an average of 41months' follow-up. *Hand surgery & rehabilitation*. Sep 2017;36(4):281-285.
26. Neubrech F, Muhldorfer-Fodor M, Pillukat T, Schoonhoven J, Prommersberger KJ. Long-term results after midcarpal arthrodesis. *Journal of wrist surgery*. Nov 2012;1(2):123-128.

27. Traverso P, Wong A, Wollstein R, Carlson L, Ashmead D, Watson HK. Ten-Year Minimum Follow-Up of 4-Corner Fusion for SLAC and SNAC Wrist. *Hand*. Nov 2017;12(6):568-572.

28. Zhou C, Hovius SE, Slijper HP, et al. Predictors of Patient Satisfaction with Hand Function after Fasciectomy for Dupuytren's Contracture. *Plastic and reconstructive surgery*. Sep 2016;138(3):649-655.

29. Jansen MC, Evers S, Slijper HP, et al. Predicting Clinical Outcome After Surgical Treatment in Patients With Carpal Tunnel Syndrome. *The Journal of hand surgery*. Dec 2018;43(12):1098-1106 e1091.
Stage 1: Degenerative changes of the styloid tip of the radius.

Stage 2: Degenerative changes progress to the radioscaphoid joint. Progressive joint space narrowing and sclerosis are indicative of this stage*#

Stage 3: Degenerative changes progress to the capitolunate joint#

Stage 4: Degenerative changes affect the radiocarpal and intercarpal articulations§

*PRC Indication
#FCA Indication
§TWA Indication
Figure 1B. SNAC Wrist

This image displays the different stages of SNAC and the affected joints and carpal bones.

Stage 1: Degenerative changes of the radial side of the scaphoid and radial styloid.

Stage 2: Degenerative changes progress to the scaphocapitate articulation*#.

Stage 3: Degenerative changes progress to the periscaphoid including the capitolunate articulation#.

Stage 4: Degenerative changes affect the radiocarpal and intercarpal articulations§.

*PRC Indication

#FCA Indication

§TWA Indication
Figure 2A. PRC Operative Procedure

The left figure shows the PRC procedure, whereby the proximal row consisting of the scaphoid, lunate and triquetrum (translucent) will be removed. The figure on the right, shows the post-operative situation. The capitate bone will move down and articulate with the lunate facet of the distal radius, creating a new joint formation (pink highlighted area). Therefore, it is paramount that the capito-lunate articulation is intact and free of osteoarthritic changes for a PRC to work.
Figure 2B. FCA Operative Procedure with Screws

Shown here is the dorsal view of the hand. The scaphoid bone (S) is resected and removed whilst the lunate (L), capitate (C), hamate (H) and triquetrum (T) carpal bones are fused together with compression screws.

Figure 2C: FCA Operative Procedure with Circular Plate

Shown here is the dorsal view of the hand. The scaphoid bone (S) is resected and removed whilst the lunate (L), capitate (C), hamate (H) and triquetrum (T) carpal bones are fused together with a circular plate instead of screws.
Figure 3A. Study Demographic I

Four Corner Arthrodesis (FCA), Proximal Row Carpectomy (PRC), Scapholunate CollapS (SLAC), Scaphoid Nonunion (SNAC), Randomized Controlled Trial (RCT), Not Available (NA), Numbers between parenthesis represent (standard deviation/range).
Figure 3B. Study Demographic II

Four Corner Arthrodensis (FCA), Proximal Row Carpectomy (PRC), Scapholunate Collaps (SLAC), Scaphoid Nonunion (SNAC), Dominant/Nondominant Operated Wrist (Dom/Nondom), Follow-up (FU), Not Available (NA), Numbers between parenthesis represent (standard deviation/range).

| Author       | Year | Type            | Level of Evidence | Patients (N) | FCA (N) | PRC (N) | FCA SLAC/SNAC | PRC SLAC/SNAC | SLAC/SNAC Grade |
|--------------|------|-----------------|-------------------|--------------|---------|---------|---------------|---------------|-----------------|
| Krakauer et al | 1994 | Retrospective   | III               | 34           | 22      | 12      | 23/0         | 12/0          | II/III          |
| Wyrick et al  | 1995 | Prospective Cohort | II               | 27           | 17      | 10      | 11/6         | 9/7           | NA             |
| de Smet et al | 2006 | Retrospective   | III               | 44           | 18      | 26      | 11/7         | 17/9          | NA             |
| Vanhove et al | 2008 | Retrospective   | III               | 30           | 15      | 15      | 15/0         | 15/0          | NA             |
| Dacho et al   | 2008 | Retrospective   | III               | 47           | 17      | 30      | 9/8          | 7/23          | II             |
| Bisneto et al | 2011 | RCT            | I                 | 20           | 10      | 10      | NA           | NA            | II/III          |
| Cohen et al   | 2011 | Retrospective   | II                | 19           | 19      | 19      | 19/0         | 19/0          | II/III          |
| Singh et al   | 2014 | Cross-sectional | IV               | 46           | 24      | 22      | NA           | NA            | III/III         |
| Berkouk et al | 2015 | Retrospective   | III               | 20           | 8      | 12      | 5/2          | 4/4           | NA             |
| Wolfl et al   | 2015 | Retrospective   | III               | 44           | 18      | 14      | 14/12        | 14/12         | 5              |
| Laconi et al  | 2016 | Retrospective   | III               | 33           | 11      | 22      | 7/6          | 8/5           | NA             |
| Alta et al    | 2016 | RCT            | I                 | 27           | 14      | 13      | 0/14         | 0/13          | II             |
| Wagner et al  | 2017 | Retrospective   | IV                | 89           | 51     | 38      | NA           | NA            | NA             |
| Brinkhorst et al | 2017 | Cross-sectional | III               | 48           | 24      | 24      | NA           | NA            | III/III         |
| Williams et al | 2018 | Retrospective   | IV                | 123          | 61      | 62      | NA           | NA            | III/III         |

Figure 4. Risk of Bias

Risk of bias assessed by the NIH study quality assessment tool. Yes (Y), No (N), Not Applicable (NA), Could not Determine (CD). The green color is associated with low risk and
red color with a high risk of bias.

| Observational Cohort and Cross-Sectional Studies | Author          | Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|-------------------------------------------------|-----------------|------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|
| Krakauer et al                                  | 1994            | N    | N | Y | Y | N | Y | Y | NA | N | N | N  | N  | N  | Y  | N  |
| Wyrick et al                                    | 1995            | Y    | N | Y | N | N | Y | Y | NA | N | N | N  | Y  | N  | N  | Y  |
| de Smet et al                                   | 2006            | Y    | N | Y | N | N | Y | Y | NA | N | N | N  | N  | N  | Y  | N  |
| Vanhove et al                                   | 2008            | Y    | Y | Y | N | N | Y | Y | NA | N | N | N  | Y  | N  | N  | Y  |
| Dacho et al                                     | 2008            | Y    | Y | Y | N | N | Y | Y | NA | Y | N | N  | Y  | N  | N  | Y  |
| Cohen et al                                     | 2011            | Y    | Y | Y | N | N | Y | Y | NA | N | N | N  | Y  | N  | N  | Y  |
| Singh et al                                     | 2014            | Y    | Y | N | N | N | Y | Y | NA | Y | N | Y  | N  | N  | Y  | N  |
| Berkhout et al                                  | 2015            | Y    | N | N | N | N | Y | Y | NA | N | N | N  | Y  | N  | N  | Y  |
| Wolff et al                                     | 2015            | Y    | N | NR| N | N | Y | Y | NA | Y | N | N  | N  | N  | Y  | N  |
| Laronde et al                                   | 2016            | Y    | Y | CD| N | N | Y | Y | NA | N | N | N  | N  | Y  | N  | N  |
| Wagner et al                                    | 2017            | Y    | N | Y | Y | N | Y | Y | NA | Y | N | N  | Y  | N  | N  | Y  |
| Brinkhorst et al                                | 2017            | Y    | N | N | N | N | Y | Y | NA | Y | N | Y  | N  | N  | Y  | N  |
| Williams et al                                  | 2018            | Y    | N | N | Y | N | Y | Y | NA | Y | N | Y  | N  | Y  | Y  | N  |

| Intervention Studies                            | Author          | Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|-------------------------------------------------|-----------------|------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|
| Bisneto et al                                    | 2011            | Y    | Y | N | N | N | N | Y | N | NA | Y  | Y  | N  | Y  | Y  |
| Aita et al                                      | 2016            | Y    | Y | Y | N | N | NR| Y | Y | NA | Y  | Y  | N  | Y  | Y  |

Figure 5. Range of Motion

This figure shows the mean difference in ROM between FCA and PRC and the estimated 95% CI of this difference using a Random Effects Model. The lowest diamond is the pooled mean difference of all studies. A negative value indicates that the FCA group had a smaller ROM than the PRC group.
Figure 6. Grip Strength
This figure shows the mean difference between FCA and PRC in the percentage of grip strength compared to the non-operated hand in each study and the estimated 95% CI of this percentage using a Random Effects Model. The lowest diamond is the pooled mean difference of all studies. A negative value indicates that the FCA group had less strength than the PRC group.
Figure 7. Complications & Reoperations

This figure shows the difference between FCA and PRC in the rate of reoperations because of complications in each study and the estimated 95% CI of this percentage using a Random Effects Model. The lowest diamond is the pooled percentage of all studies. A negative value indicates that the FCA group had a less ROM than the PRC group.

![Figure 7 - Complications & Reoperations](image)

Figure 8. Conversion to Total Wrist Arthrodesis

This figure shows the difference between FCA and PRC in the rate of conversion to TWA in each study and the estimated 95% CI of this percentage using a Random Effects Model. The lowest diamond is the pooled percentage of all studies. A negative value indicates that the FCA group had a less ROM than the PRC group.

![Figure 8 - Conversion to Total Wrist Arthrodesis](image)
Figure 9. VAS Pain Score

This figure shows the mean difference between FCA and PRC in VAS pain score in each study and the estimated 95% CI of this percentage using a Random Effects Model. The lowest diamond is the pooled percentage of all studies. A negative value indicates that the FCA group had a less ROM than the PRC group.
Figure 10. DASH Score

This figure shows the mean difference between FCA and PRC of the DASH score in each study and the estimated 95% CI of this percentage using a Random Effects Model. The lowest diamond is the pooled percentage of all studies. A negative value indicates that the FCA group had a less ROM than the PRC group.