

World Journal of *Orthopedics*

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INDEXING/ABSTRACTING

The WJO is now abstracted and indexed in PubMed, PubMed Central, Emerging Sources Citation Index (Web of Science), Scopus, China National Knowledge Infrastructure (CNKI), China Science and Technology Journal Database (CSTJ), and Superstar Journals Database. The 2021 edition of Journal Citation Reports® cites the 2020 Journal Citation Indicator (JCI) for WJO as 0.66. The WJO's CiteScore for 2020 is 3.2 and Scopus CiteScore rank 2020: Orthopedics and Sports Medicine is 87/262.

RESPONSIBLE EDITORS FOR THIS ISSUE

Production Editor: *Ying-Yi Yuan*, Production Department Director: *Xiang Li*, Editorial Office Director: *Jin-Lei Wang*.

NAME OF JOURNAL

World Journal of Orthopedics

ISSN

ISSN 2218-5836 (online)

LAUNCH DATE

November 18, 2010

FREQUENCY

Monthly

EDITORS-IN-CHIEF

Massimiliano Leigheb

EDITORIAL BOARD MEMBERS

<http://www.wjgnet.com/2218-5836/editorialboard.htm>

PUBLICATION DATE

January 18, 2022

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INSTRUCTIONS TO AUTHORS

<https://www.wjgnet.com/bpg/gerinfo/204>

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<https://www.wjgnet.com/bpg/GerInfo/287>

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<https://www.wjgnet.com/bpg/gerinfo/240>

PUBLICATION ETHICS

<https://www.wjgnet.com/bpg/GerInfo/288>

PUBLICATION MISCONDUCT

<https://www.wjgnet.com/bpg/gerinfo/208>

ARTICLE PROCESSING CHARGE

<https://www.wjgnet.com/bpg/gerinfo/242>

STEPS FOR SUBMITTING MANUSCRIPTS

<https://www.wjgnet.com/bpg/GerInfo/239>

ONLINE SUBMISSION

<https://www.f6publishing.com>



Long-term outcomes of the four-corner fusion of the wrist: A systematic review

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Author contributions: Andronic O designed the research methodology and the research question; Jud L managed the research team and wrote the first draft of the manuscript; Burkhard MD, Casari FA, Kriechling P and Karczewski D performed the systematic research and the risk of bias assessment analysis; Nagy L and Schweizer A critically appraised the scientific approach and the final draft of the manuscript; All authors read, edited and approved the final manuscript.

Conflict-of-interest statement: On behalf of all authors, the corresponding author states that there is no conflict of interest.

PRISMA 2009 Checklist statement: The systematic review followed the PRISMA guidelines and included a flowchart for the systematic search.

Country/Territory of origin:

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Abstract

BACKGROUND

Four-corner fusion (4CF) is a motion sparing salvage procedure that is used to treat osteoarthritis secondary to advanced scapholunate collapse or longstanding scaphoid nonunion advanced collapse. Little is known about the long-term survivorship and outcomes of 4CF.

AIM

To report on clinical and functional long-term outcomes as well as conversion rates to total wrist fusion or arthroplasty.

METHODS

The systematic review protocol was registered in the international prospective register of systematic reviews (PROSPERO) and followed the PRISMA guidelines. Original articles were screened using four different databases. Studies with a minimum Level IV of evidence that reported on long-term outcome after 4CF with a minimum follow-up of 5 years were included. Quality assessment was performed using the Methodological Index for Non-Randomized Studies criteria.

RESULTS

A total of 11 studies including 436 wrists with a mean follow-up of 11 ± 4 years (range: 6-18 years) was included. Quality assessment according to Methodological Index for Non-Randomized Studies criteria tool averaged $69\% \pm 11\%$ (range: 50%-87%). Fusion rate could be extracted from 9/11 studies and averaged 91%. Patient-reported outcomes were extracted at last follow-up from 8 studies with an average visual analog scale of 1 ± 1 (range: 0-2) and across 9 studies with an average Disabilities of the Arm, Shoulder and Hand score of 21 ± 8 (range: 8-37).

Switzerland

Specialty type: Orthopedics**Provenance and peer review:**

Invited article; Externally peer reviewed.

Peer-review model: Single blind**Peer-review report's scientific quality classification**

Grade A (Excellent): 0

Grade B (Very good): 0

Grade C (Good): C

Grade D (Fair): 0

Grade E (Poor): 0

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Received: March 29, 2021**Peer-review started:** March 29, 2021**First decision:** October 17, 2021**Revised:** October 26, 2021**Accepted:** December 21, 2021**Article in press:** December 21, 2021**Published online:** January 18, 2022**P-Reviewer:** Anand P**S-Editor:** Wang LL**L-Editor:** Filipodia**P-Editor:** Wang LL

At last follow-up, the cumulative conversion rate to total wrist fusion averaged 6%. There were no conversions to total wrist arthroplasty.

CONCLUSION

The 4CF of the wrist is a reliable surgical technique, capable of achieving a good long-term patient satisfaction and survivorship with low rates of conversion to total wrist fusion.

Key Words: Four-corner fusion; Partial wrist arthrodesis; Midcarpal arthrodesis; Scapholunate collapse wrist; Scaphoid nonunion advanced collapse; Scaphoid nonunion

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Core Tip: Four-corner fusion is a motion sparing salvage procedure that is used to treat osteoarthritis secondary to scaphoid advanced collapse or longstanding scaphoid nonunion advanced collapse. Our systematic review evaluated long-term clinical and radiographic outcomes of the four-corner fusion and critically appraised the methodology of studies. The results showed that four-corner fusion is capable of achieving a good long-term patient satisfaction and survivorship with low rates of conversion to total wrist fusion. Recommendations for future research are provided.

Citation: Andronic O, Nagy L, Burkhard MD, Casari FA, Karczewski D, Kriechling P, Schweizer A, Jud L. Long-term outcomes of the four-corner fusion of the wrist: A systematic review. *World J Orthop* 2022; 13(1): 112-121

URL: <https://www.wjgnet.com/2218-5836/full/v13/i1/112.htm>

DOI: <https://dx.doi.org/10.5312/wjo.v13.i1.112>

INTRODUCTION

Four-corner fusion (4CF) is a motion sparing salvage procedure that is used to treat osteoarthritis secondary to advanced scapholunate collapse or longstanding scaphoid nonunion advanced collapse. Proximal row carpectomy (PRC) and 4CF are the two mainly used surgical techniques in such cases[1]. The decision to choose one technique over the other is primarily based on the surgeon's preference and experience, as long-term results are not clearly elucidated in the current literature so far[2]. 4CF seems to show longer survivorship, where PRC seems to provide better wrist motion[1,3-5]. Since the introduction of the 4CF by Watson and Ballet in 1984[6], various fixation techniques have been described, including Kirschner wires, headless compression screws, staples and plates[6-9]. However, using these techniques, different potential complications have been observed, in particular: nonunion, progressive osteoarthritis (OA) or hardware impingement/irritation[1,10-12].

The long-term survivorship and ultimate conversion rate of 4CF to wrist arthrodesis remains an unelucidated aspect. Although different studies are emerging that report on long-term outcomes of 4CF, it remains difficult to draw conclusions based on individual studies due to heterogeneity of outcome measures and surgical techniques. Hence, it was the aim of the current study to provide a systematic approach on evaluating evidence reporting on the long-term outcomes of 4CF with appropriate tools for critical appraisal.

MATERIALS AND METHODS

Search strategy

A systematic computer-based database search was conducted using CENTRAL (Cochrane Central Register of Controlled Trials), MEDLINE (Pubmed), EMBASE and Web of Science Core Collection. A total of fifteen combinations for each database using the following key-words were used: "four corner," "4 corner," "midcarpal," "scapholunate advanced collapse" and "scaphoid nonunion advanced collapse" with

the terms “surgery,” “fusion” and “arthrodesis.” All published studies from January 1, 1978 until January 1, 2020 were included in the systematic search. First, a blinded and independent process of selection was carried out by two authors (D.K., P.K.) based on title and abstract. Next, a thorough analysis of eligible studies was performed by evaluating full texts. Any excluded study together with the reason of exclusion was noted and compared between readers. Studies reporting clinical or radiographic outcomes of 4CF for the treatment of degenerative wrist conditions were selected based on predefined eligibility criteria. The protocol of a parallel ongoing systematic review used by the same group regarding the 4CF has been published and registered in the international prospective register of systematic reviews (PROSPERO) under the registration number: CRD42020164301. Inclusion and exclusion criteria are emphasized in [Table 1](#).

Data extraction and quality assessment

Data collection included fusion rates, revision rates and conversion rates to total wrist arthrodesis. Wrist range of motion (ROM), including wrist flexion and extension, total flexion-extension arc as well as radial-ulnar deviation, was extracted. Grip strength was noted as percentage of the opposite hand. Patient-reported outcome measures were included as the Disabilities of the Arm, Shoulder and Hand questionnaire (DASH) and the visual analog scale (VAS) scores. Where available, data regarding incidence of radiolunate arthritis was included. The quality of all the studies was then assessed using the Methodological Index for Non-Randomized Studies criteria[13]. Methodological Index for Non-Randomized Studies criteria assess eight critical aspects of the study design for non-comparative clinical studies and an additional four aspects of study design for comparative clinical studies. Each item is given a score of zero if information is not reported, one if information is reported but inadequate, and two if information is reported and adequate. Therefore, the maximum possible score is 16 for non-comparative studies and 24 for comparative studies. Each score was then converted into a percentage to harmonize the scoring system.

Statistical analysis

The statistical analysis was performed using Review Manager (RevMan Cochrane) and Comprehensive Meta-Analysis Software. For quantification of methodological inconsistency and heterogeneity across studies, an I^2 test was performed, with a P value of $P = 0.10$. A level of more than 75% was considered as considerable. This has assessed whether observed differences in results are compatible with chance alone.

RESULTS

Systematic database search

The initial database search yielded 4726 studies. After removal of duplicates, 2323 studies remained. Next, screening based on title and abstract was performed, and 126 studies remained for further assessment. These were then screened for eligibility against the inclusion and exclusion criteria based on abstract and full-text review. Finally, 11 studies could be included in the final analysis ([Figure 1](#)) with the reasons for exclusion separately emphasized in the flow-chart.

Quality assessment

A quality assessment was performed in all included studies ([Table 2](#)). There were seven retrospective case series[3,5,14-18], three retrospective cohort studies[19-21] and one prospective cohort study[22]. The calculated average from scores according to the Methodological Index for Non-Randomized Studies criteria tool was $69.0\% \pm 11.1\%$ (range: 50%-87%).

Demographics, indications and surgical fixation techniques

A total of 463 wrists was included for further analysis ([Table 2](#)). The mean age at time of surgery over all included studies was 49 ± 7 years (range: 34-63 years). The most frequent indications were degenerative wrist conditions such as scapholunate collapse (10/11 studies)[3,5,14-19,21,22] or scaphoid nonunion advanced collapse (8/11 studies)[3,5,15-19,21]. Other less frequent indications were scaphoid chondrocalcinosis advanced collapse[16], an unclassified OA[5,20] and perilunate OA[21]. The following fixation techniques were used: Kirschner wires[3,5,14,15,18,19,21], locking or non-locking plates[3,16,17,21], staples[3,22] and screws[3,21].

Table 1 Criteria for study selection

Inclusion criteria	Exclusion criteria
Human studies in English or German language	Oral presentations, cadaveric or review articles, animal studies
Minimum Level IV case series studies using Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence	Language not in English or German
Four corner fusion surgery using any technique	Minimum follow-up less than 5 yr
A minimum follow-up of 5 yr	Inflammatory arthropathy as etiology
Clinical and radiographic data including patient-reported outcomes, grip/pinch strength, range of motion, fusion rates, revisions or complications have been reported	Insufficient outcome data reported

Table 2 Demographics, surgical techniques and patient-reported outcomes

Author	Year	Study design	Number of wrists	Indication	Mean age (yr)	Fixation Technique	VAS		DASH		MINORS (%)
							Preop	Postop	Preop	Postop	
Cha SM	2013	Retrospective case series	40	SLAC	47	K-wires	6.3	2.0	44	17	75
Luegmair M	2012	Retrospective case series	24	SLAC, SNAC, SCAC	53	Plates	-	-	-	19	75
Bain GI	2010	Prospective cohort study	31	SLAC	47	Staples	6.0	1.0	-	-	87
Berkhout MJL	2015	Retrospective cohort study	8	SLAC, SNAC	45	K-wires	-	0.3	-	-	62
Kitzinger HB	2003	Retrospective case series	37	SLAC, SNAC	46	K-wires	2.7	1.7	-	24	62
Trail I	2015	Retrospective case series	116	SLAC, SNAC	47	K-wires, Plates, Staples, Screws	-	1.9	-	37	62
Neubrech F	2012	Retrospective case series	60	SLAC, SNAC, unclassified OA	63	K-Wires	-	1.4	-	20	87
Odella S	2018	Retrospective case series	20	SLAC, SNAC	53	Plates	-	2.0	-	17	62
Traverso P	2017	Retrospective case series	15	SLAC, SNAC	49	K-wires	-	-	-	8	62
Wagner ER	2017	Retrospective cohort study	51	Unclassified OA	34	Plates	-	-	-	19	75
Williams J	2018	Retrospective cohort study	61	SLAC, SNAC, perilunate OA	52	K-wires, Plates, Screws	-	1.0	-	27	50
Total/Averages			463		49			1.4		21	69
SD					± 7			± 0.6		± 8	± 11

SD: Standard deviation; VAS: Visual analog scale; DASH: Disabilities of the Arm, Shoulder and Hand questionnaire; SLAC: Scapholunate advanced collapse; SNAC: Scaphoid nonunion advanced collapse; SCAC: Scaphoid chondrocalcinosis advanced collapse; MINORS: Methodological items for non-randomized studies; OA: Osteoarthritis; K-wires: Kirschner wires.

Patient-reported outcomes

Preoperative VAS and DASH scores were only reported in a minority of studies (3 for VAS[14,15,22] and 1 for DASH[14]), which did not allow direct pre- to postoperative comparison (Table 2). Eight studies reported on postoperative VAS score and averaged 1 ± 1 (range: 0-2) at the latest follow-up. Postoperative data on DASH scores were pooled from 9 studies[3,5,14-18,20,21], which averaged 21 ± 8 (range: 8-37).

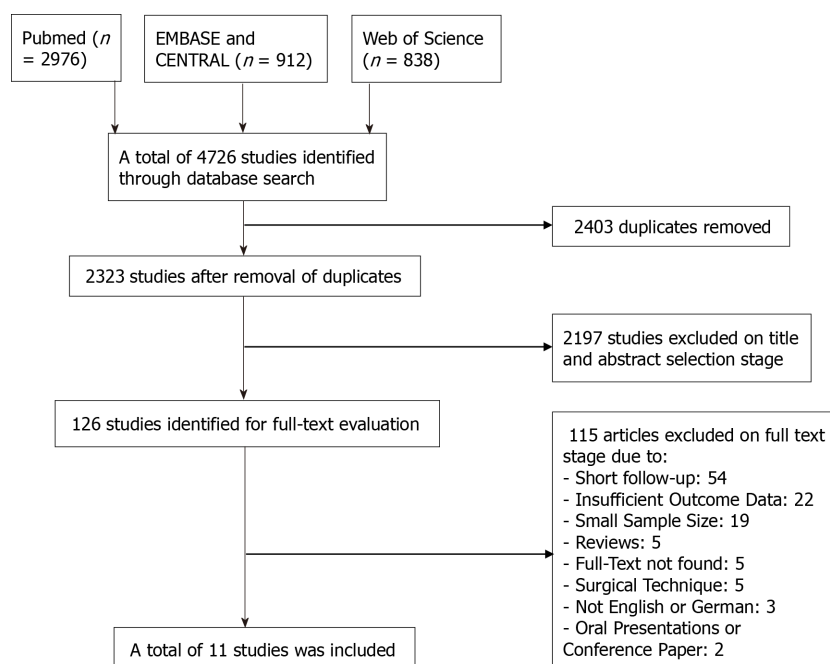


Figure 1 Flowchart of the systematic search.

Fusion rates, revisions and survivorship

The mean follow-up was 11 ± 4 years (range: 6-18 years) (Table 3). Revision rates were reported in 8 studies[3,14,16-18,20-22] and had an overall average of 13% (range: 5%-34%). Nine studies (82%)[3,14,16-22] included data on the total number of nonunions, averaging 9% (range: 0%-24%) at last follow-up, resulting in a fusion rate of 91% (range: 76%-100%). Eight studies[3,14,16-18,20-22] reported on conversion rates to a total wrist fusion (TWF). A conversion to a TWF was needed on average in 6% of cases (range: 0%-20%). There were no cases reported of conversion to total wrist arthroplasty.

Development of radiocarpal osteoarthritis

None of the included studies reported on preoperative signs of radiocarpal OA (Table 3). Five studies[5,14,15,18,20] reported on postoperative signs of radiocarpal OA of grade 2 or higher with an average incidence of $42\% \pm 26\%$ (range: 5%-73%) at an average follow-up of 13 ± 3 years (range: 8-18 years). This was determined radiographically on conventional radiographs.

Grip strength and range of motion

Preoperative grip strength was only available in 5 studies and preoperative data on ROM in only 4 studies (Table 4), which did not allow meaningful comparison to the postoperative results. The postoperative grip strength was noted in 8 studies[3,5,14-17,20,22] and averaged $68\% \pm 18\%$ of the contralateral side (range: 30%-85%). Total postoperative flexion-extension arc, noted in 10 studies[3,5,14-20,22], was on average 66 ± 9 (range: 54-87). Postoperative ROM for radial-ulnar deviation, available in 9 studies[3,5,14-16,18-20,22], averaged 34 ± 6 (range: 26-49).

Statistical analysis

The level of evidence of studies that were included lacked randomized controlled trials and did not allow performance of meta-analysis.

DISCUSSION

This is the first systematic review to investigate outcomes of the 4CF procedure at the long-term follow-up. The most important finding of the study is that 4CF can achieve good long-term patient satisfaction as well as good functional results. This can be observed out of the pooled data with low VAS values and positive DASH scores on

Table 3 Fusion rates, survivorship including rates of conversion to total wrist fusion and complications

Author	Number of wrists	Fixation technique	Nonunion (n)	Fusion (%)	Revisions (%)	Conversion to TWF (%)	Complications
Cha SM	40	K-wires	0	100	2 (5)	1 (3)	1 x impingement
Luegmair M	24	Plates	2	92	2 (8)	0	-
Bain GI	31	Staples	3	90	5 (16)	2 (7)	1 x delayed union
Berkhout MJL	8	K-wires	1	88	-	-	1 x CRPS, 1 x delayed union
Kitzinger HB	37	K-wires	-	-	-	-	-
Trail I	116	K-wires, plates, staples, screws	28	76	14 (12)	6 (5)	3 x impingement
Neubrech F	60	K-wires	-	-	-	-	-
Odella S	20	Plates	0	100	1 (5)	0	1 x implant loosening
Traverso P	15	K-wires	0	100	2 (13)	1 (7)	-
Wagner ER	51	Plates	6	88	15 (29)	6 (12)	1 x infection, 8 x impingement
Williams J	61	K-wires, plates, screws	3	95	21 (34)	12 (20)	4 x impingement, 1 x ulnar impaction, 1 x infection
Totals/Averages	463		43 (9%)	91 ± 7	62 (13%)	28 (6%)	

TWF: Total wrist fusion; CRPS: Complex regional pain syndrome; K-wires: Kirschner wires.

Table 4 Range of motion and grip strength

Author	Grip strength (%)		ROM Flexion-extension		ROM radial-ulnar (%)	
	Preop	Postop	Preop	Postop	Preop	Postop
Cha SM	71	85	84	66	45	39
Luegmair M	38	70	57	64	24	30
Bain GI	27	30	78	57	35	30
Berkhout MJL	-	-	-	87	-	49
Kitzinger HB	69	80	68	62	35	34
Trail I	-	53	-	60	-	26
Neubrech F	-	85	-	63	-	30
Odella S	-	75	-	79	-	-
Traverso P	-	-	-	69	-	33
Wagner ER	60	65	-	54	-	32
Williams J	-	-	-	-	-	-
Averages	53	68	72	66	35	34
SD	± 17	± 18	± 10	± 10	± 8	± 6

ROM: Range of motion; SD: Standard deviation; Preop: Preoperative; Postop: Postoperative.

last follow-up. An average fusion rate over 90% could be achieved, however with large variations across studies. Trail *et al*[3] reported a high nonunion percentage with only 76% fusion, further indicating the future need of 4CF for technique improvements and advancements in implant choice. Surprisingly, in the case of a successful 4CF, only an average of 6% of ultimate conversion to TWF was observed. This was in the context of lacking data on the preoperative state of the radiolunate joint, where a substantial amount could have been present at the time of surgery.

Nevertheless, the quality assessment provided important data on the evidence level of the studies, where relevant issues were elucidated. First, there were no double-blinded randomized controlled trials. Second, the single prospective cohort study, as declared by authors, had a questionable design whereas only the data collection might have been prospective[22]. The lack of preoperative data for almost all functional outcomes (ROM, grip strength) in the majority of studies precludes the quantification of the clinical gain from surgery[5,17-21]. Another important limitation was the fact that the outcomes were mostly reported in a cumulative fashion and not longitudinally over time. As such, a subgroup analysis of outcomes based on etiology (degenerative or post-traumatic) or the creation of a Kaplan-Meier survivorship curve to observe the time points of conversions could not be performed.

Although many treatments are available for scapholunate collapse and scaphoid nonunion advanced collapse wrist[23], the main debatable alternative to 4CF is the PRC[24,25]. A systematic review of long-term outcomes of PRC studies reported a reoperation rate of 14.3%[26]. Of particular value is to mention that these failures were not only represented by conversions to TWF but also contained cases where revision arthroplasty was undertaken[4]. As such, the reoperation rates and conversion rates to TWF were not equal in this systematic review[26]. Generally, it was thought that PRC might yield better ROM[27]. However, this cannot be stated consistently, as recent systematic reviews and meta-analysis question the clinical relevance of differences that were observed between these techniques[2]. These relevant differences were limited to ROM, grip strength and patient-reported outcomes. In contrast, another systematic review reported a benefit in 4CF in terms of grip strength[28].

A further subject that was recently explored is the cost-effectiveness of PRC, where findings yielded either superior[29,30] or similar results[31] when compared to 4CF. Revision rates, especially during early follow-up, are higher in 4CF among some reports[21], highlighting impingement of hardware and nonunion as main reasons of revision[32]. This is attributed by authors to technical challenges and aspects, such as incomplete removal of the cartilage and subchondral bone, which is a key step of the procedure[11], quality and location of bone graft[33] as well as compression and carpal height achieved[34]. Optimal placement has yet to be defined to avoid revisions in 4CF due to impingement[32].

As such, in the context of continuous debate, an analysis of the long-term results, especially of the ultimate conversion rate to TWF or wrist arthroplasty, is crucial in determining the long-term benefit when choosing the surgical treatment option. The current systematic review is a substantial contribution to the understanding and knowledge of 4CF long-term outcomes as well as an analytical exploration of the limitations of studies (sources of heterogeneity and bias) that provide recommendations for future work.

CONCLUSION

The 4CF of the wrist is a reliable surgical technique, capable of achieving a good long-term patient satisfaction and survivorship with low rates of conversion to total wrist fusion.

ARTICLE HIGHLIGHTS

Research background

Four-corner fusion (4CF) is a motion sparing salvage procedure that is used to treat osteoarthritis secondary to advanced collapse or longstanding scaphoid nonunion advanced collapse. Proximal row carpectomy and 4CF are the two mainly used surgical techniques in such cases. The decision to choose one technique over the other is primarily based on the surgeon's preference and experience, as long-term results are not clearly elucidated in the current literature so far.

Research motivation

The long-term survivorship and ultimate conversion rate of 4CF to wrist arthrodesis remains poorly described. As various fixation techniques have been employed (Kirschner wires, headless compression screws, staples, plates), different potential complications have been observed, in particular, nonunion, progressive osteoarthritis or hardware impingement/irritation. There is no consensus on the best surgical

implant and no synthesis on the long-term outcomes.

Research objectives

To provide a systematic approach on evaluating evidence reporting on the long-term outcomes of 4CF with appropriate tools for critical appraisal. We aimed to compare patient-reported outcomes, fusion rates, grip strength, range of motion and rates of development of radiocarpal osteoarthritis and revision to total wrist fusion.

Research methods

A study protocol for the systematic search was registered prospectively in the international prospective register (PROSPERO) and performed according to the PRISMA guidelines. Data collection included fusion rates, revision rates and conversion rates to total wrist arthrodesis. Wrist range of motion, including wrist flexion and extension, total flexion-extension arc, as well as radial-ulnar deviation, was extracted. Grip strength was noted as percentage of the opposite hand. Patient-reported outcome measures were included as the Disabilities of the Arm, Shoulder, and Hand questionnaire and the visual analog scale scores (Table 4). Where available, data regarding incidence of radiolunate arthritis was included. The quality of all the studies were then assessed using the Methodological Index for Non-Randomized Studies criteria.

Research results

A total of 11 studies including 436 wrists with a mean follow-up of 11 ± 4 years (range: 6-18 years) was included. Quality assessment according to Methodological Index for Non-Randomized Studies criteria tool averaged $69\% \pm 11\%$ (range: 50%-87%). Fusion rate could be extracted from 9/11 studies and averaged 91%. Patient-reported outcomes were extracted at last follow-up from 8 studies with an average visual analog score of 1 ± 1 (range: 0-2) and across 9 studies with an average Disabilities of the Arm, Shoulder, and Hand score of 21 ± 8 (range: 8-37). The postoperative grip strength was noted in 8 studies and averaged $68\% \pm 18\%$ of the contralateral side. Total postoperative flexion-extension arc was on average 66 ± 9 . At last follow-up, the cumulative conversion rate to total wrist fusion averaged 6%.

Research conclusions

The 4CF of the wrist is a reliable surgical technique, capable of achieving a good long-term patient satisfaction and survivorship with low rates of conversion to total wrist fusion.

Research perspectives

Future studies should define their study populations and protocols a priori before analysis. More in-depth details regarding patient selection (mostly preoperative data on range of motion, grip strength and radiolunate osteoarthritis) should be provided that would allow objective comparison.

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