Proximal row carpectomy on manual workers: 17 patients followed for an average of 6 years

Résection de la rangée proximale du carpe chez les travailleurs manuels : 17 patients revus au recul moyen de six ans

S. Delclaux, D. Israel, C. Aprédoaei, M. Rongières, P. Mansat *

Département d'orthopédie et traumatologie, urgences mains, hôpital Pierre-Paul-Riquet, hôpital universitaire de Toulouse, place du Dr-Baylac, 31059 Toulouse cedex, France

Abstract

Proximal row carpectomy (PRC) is indicated for the treatment of SNAC or SLAC wrist with preservation of the midcarpal joint. Our hypothesis was that PRC is not appropriate for treating advanced wrist osteoarthritis in patients who carry out heavy manual work. Twenty-three PRCs were performed on 21 patients, 5 women and 16 men with an average age of 54 years (33–77). All patients performed manual work; 11 of them performed heavy manual work. Etiologies were: SLAC wrist in 14 cases (2 stage III, 11 stage II, and 1 stage I) and SNAC wrist in 9 cases (6 stage IIIB and 3 stage IIB). At an average 75 months' follow-up (24–153), five patients were lost to follow-up. Radiocarpal arthrodesis was performed in one patient 10 years after the PRC. In the 17 remaining patients (18 wrists), pain (VAS) averaged 2.2, with residual pain of 5. Flexion–extension range was similar to preoperative levels (67% of contralateral wrist). Wrist strength was decreased by 34% compared to preoperative. The QuickDASH score averaged 26 points and the PRWE 20 points. Radiocapitate distance decreased by 0.3 mm on average with joint line narrowing in 6 patients. The carpal translation index was 0.33 mm, which was unchanged relative to preoperative values. Three patients had work-related limitations that required retraining and one patient had to be reassigned. PRC preserved the preoperative range of motion and reduced pain levels. However, significant loss of strength was observed, resulting in 23% of manual workers needing retraining or reassignment.
Type of study/level of evidence. – Therapeutic IV.

Keywords: Degenerative; Carpus; SLAC; SNAC; Resection

Résumé

La résection de la rangée proximale du carpe (RRP) est indiquée dans le traitement des poignets dégénératifs de type SNAC ou SLAC pour préserver l'articulation médiocarpienne. Notre hypothèse était que la RRP n'était pas adaptée au traitement des poignets arthrosiques du travailleur manuel. Vingt-trois RRP ont été réalisées chez 21 patients, 5 femmes et 16 hommes de 54 ans d'âge moyen (33–77). Tous les patients étaient travailleurs manuels dont 11 travailleurs lourds. L'étiologie initiale était un SLAC dans 14 cas (2 stades III, 11 stades II, 1 stade I) et un SNAC dans 9 cas (6 stades IIIB et 3 stades IIB). Au recul moyen de 75 mois (24–153), 5 patients avaient été perdus de vue. Une arthrodèse radio-carpienne avait été effectuée chez un autre patient à 10 ans de la RRP. Parmi les 17 autres patients (18 poignets), l'EVA moyenne était de 2,2 ; cinq présentaient des douleurs résiduelles. L'arc de flexion/extension était similaire aux amplitudes préopératoires, soit à 67 % du poignet controlatéral. La force de poigne était réduite de 34 % par rapport aux données préopératoires. Le score QuickDASH moyen était de 26 points avec un score PRWE à 20 points. La distance radio-capitale avait diminué de 0,3 mm en moyenne avec un pincement de l'interligne chez 6 patients. L'index de translation du carpe était de 0,33 mm sans modification par rapport aux valeurs préopératoires. Il y avait eu 3 invalidités professionnelles avec reconversion et un reclassement professionnel. La RRP permet la conservation des mobilités préopératoires du poignet et une diminution des douleurs. Cependant,

* Corresponding author.
E-mail addresses: stephanie.delclaux@laposte.net (S. Delclaux), danmsn@hotmail.fr (D. Israel), apredoaei.c@chu-toulouse.fr (C. Aprédoaei), rongieres.m@chu-toulouse.fr (M. Rongières), mansat.p@chu-toulouse.fr, pierre.mansat@univ-tlse3.fr (P. Mansat).

cette technique s'accompagne d'une diminution notable de la force de poigne qui a été responsable de 23 % de reclassement et reconversion professionnelle dans notre série.
Type d'étude/niveau d'évidence. – Thérapeutique IV.

Mots clés : Dégénératif ; Carpe ; SLAC ; SNAC ; Résection

1. Introduction

Proximal row carpectomy (PRC) is indicated for the treatment of scapholunate or scaphoid nonunion advanced collapse (SLAC and SNAC, respectively). Involvement of the radioscaphoid joint with preservation of the radiolunate and midcarpal joints is the best indication. Although some authors consider PRC a salvage procedure, pain control with preservation of the functional range of motion can be obtained, theoretically with decreased wrist strength [1–10]. Some studies have reported stable results even after 20 years follow-up [11]. This surgical procedure is usually discussed relative to other treatment alternatives, such carpal denervation [12,13] and midcarpal arthrodesis [14–16]. A patient's occupation can be a criterion for performing PRC. Our hypothesis was that PRC is not appropriate for treating advanced wrist osteoarthritis in patients who are heavy manual laborers because of the significant loss of wrist strength.

A retrospective study was conducted to evaluate the functional and radiological outcomes of a cohort of continuous PRC procedures in manual laborers, and to validate whether this technique is suitable in this patient population.

2. Patients and methods

2.1. Study design

A retrospective study was conducted in our Orthopedics and Traumatology department. Institutional review board approval was not required for this study. Patients were included who were heavy manual laborers and agreed to be part of this study, had SLAC wrist or SNAC wrist, were treated with PRC, and reviewed with 2 years' minimum follow-up. Exclusion criteria were: PRC for SLAC or SNAC wrist in non-manual laborers, PRC on patients for an etiology other than SNAC or SNAC, or less than 2 years' follow-up.

2.2. Patient demographics

Between 1995 and 2009, PRC was performed on 35 patients. Twelve were excluded because they did not meet the inclusion criteria. Twenty-one patients (23 PRC cases) were included in this study. There were 5 women and 16 men with an average age of 54 years (33–77). All performed manual labor; 11 of them performed heavy manual work (Table 1). The dominant side was involved in 11 (48%) cases. The main complaints were pain at rest or with effort. A history of wrist injury was reported for 8 patients. Wrist damage was identified on radiographs as 14 cases of SLAC (1 stage I, 11 stage II, 2 stage III) and 9 cases of SNAC (3 stage IIB, 6 stage IIIB). According to Yazaki et al. [17], all capitate bones had a round shape except one with a "V" shape. Preoperative functional values are reported in Table 2. Preoperative range of motion was 86 degrees of flexion–extension, 23 degrees of ulnar deviation and 6 degrees of radial deviation. Grip strength evaluated with a JAMAR® dynamometer was 30 kg (5 to 40), or 59% of the contralateral normal wrist. The carpal translation index, measured on A/P views, was 0.38 (0.24 to 0.47) [18].

2.3. Surgical technique

All patients were operated using regional anesthesia. A dorsal approach between the third and fourth extensor compartments was performed. After the extensor retinaculum had been open longitudinally, the terminal branch of the posterior interosseous nerve was systematically resected. The dorsal capsule was then opened in a "T" fashion, preserving two capsular flaps, one radial and one ulnar. PRC began with excision of the lunate, then the triquetrum, and finally the scaphoid. No additional incision was needed to complete the scaphoid excision. No interposition or fixation was used in this cohort. In four cases of hypertrophic radial styloid process, a radial styloidectomy was also performed. The dorsal capsule was then closed by suturing the radial flap to the ulnar flap. After repositioning the extensor tendons, the extensor retinaculum was closed. Time for surgery was 45 minutes on average (40–60). Patients were immobilized in a volar splint in

Table 1
Types of manual labor activities for each patient in the study cohort.

Patient	Sex	Age	Type of manual work	Occupation
1	M	40	Heavy	Carpenter
2	M	77	Light	Handyman
3	M	33	Light	Waiter
4	F	58	Light	Sales rep
5	M	68	Heavy	Tradesman
6	M	63	Heavy	Butcher
7	M	65	Heavy	Tradesman
8	M	74	Heavy	Tradesman
9	M	56	Heavy	Mason
10	M	67	Light	Tradesman
11	F	66	Light	Nurse
12	M	65	Heavy	Farmer
13	F	74	Light	Tradesman
14	M	54	Heavy	Telecommunications
15	M	64	Heavy	Baker
16	M	64	Heavy	Tradesman
17	M	55	Heavy	Car mechanic

Table 2
Preoperative and postoperative clinical data.

	Flexion/extension (degree)	Radial/ulnar deviation (degree)	Strength (kg) (% of contralateral wrist)
Preoperative	42°/44° (86°)	8°/23° (31°)	30 kg (59%)
Postoperative	36°/48° (84°)	7°/33° (40°)	20 kg
Gain or loss	−2°	+9°	−10 kg

neutral position for 1 month. The hospital stay was 3.7 days on average (3–5). Rehabilitation was prescribed 1 month after surgery to help patient regain their functional range of motion and improve strength.

2.4. Evaluation methods

An independent observer (SD) contacted all the patients. The clinical evaluation consisted of a pain assessment using a visual analogic scale (VAS) and range motion analysis on both wrists in flexion, extension, radial and ulnar deviation using a goniometer. Strength was measured in both wrists using a JAMAR® dynamometer. Functional outcome scores were also used: QuickDASH [19] and PWRE [20,21]. Radiographic analysis consisted of A/P and lateral views of the wrist in neutral position. Narrowing of the joint line was noted by measuring the radiocapitate distance. The carpal translation index [18] and carpal height [22] were also analyzed. Osteoarthritis was classified according to Culp et al. [2]:

- absent;
- minimal (reduction of radiocapitate distance);
- moderate (reduction of radiocapitate distance with sclerosis of subchondral bone);
- severe (collapse of joint line with erosion and cyst formation).

3. Results

3.1. Complications and revisions

At an average follow-up of 75 months (24–153), five patients did not return for evaluation and were considered lost to follow-up. During the first year after surgery, three patients developed complex regional pain syndrome (CRPS). One heavy manual labor patient with a SNAC stage IIIB wrist underwent radiocarpal arthrodesis 10 years after the initial procedure because of severe osteoarthritis. One patient underwent total wrist denervation 84 months after the PRC because of persistent pain; he had satisfactory results at the 3-year follow-up with pain improving from 7 to 3 (VAS) and a QuickDASH score of 16 points.

3.2. Clinical results

3.2.1. Subjective outcomes

Seventeen patients (18 wrists) were reviewed. Pain level in the VAS averaged 2.2 ± 2.3; five patients still had pain. The QuickDASH score averaged 26 ± 18 points and the PWRE score averaged 20 ± 17 points, with pain levels of 2.8 out of 10 points (0–5) and function of 1.6 out of 10 (0–7). According to the PWRE score, there was slight difference between SLAC (20.5 points) and SNAC wrists (21 points). Slightly better results were obtained for stage I or II SNAC and SLAC wrists (17 points) compared to stage III (22 points). Sixteen patients were satisfied with their surgery; 11 of them were very satisfied.

3.2.2. Objective outcomes

Postoperative results are summarized in Table 2. Postoperative flexion–extension range of motion was similar to preoperative values and 67% of the contralateral normal wrist. Postoperatively, the radial deviation decreased and the ulnar deviation increased. At the last follow-up, strength of the operated wrist was only 34% of the preoperative values.

3.3. Radiographic results

Radiocapitate joint narrowing was observed in 6 patients (6 wrists). According to the Culp et al. classification [2], signs of osteoarthritis were absent in 12, minimal in 4, and moderate in one. There was no difference in the incidence of osteoarthritis related to SLAC or SNAC type of degenerative wrist. Also, advanced stage III SLAC or SNAC wrists did not have a higher stage of osteoarthritis than stage I or II wrists. The radiocapitate distance decreased by 0.3 mm on average (0.31–0.36). The carpal translation index was 0.33 mm (0.21–0.40) and was unchanged relative to preoperative values. At follow-up, there were no changes in the shape of the capitate.

3.4. Return to work

Thirteen patients were able to return to their previous work activities within 6 months postoperatively. Seven of them were involved in heavy manual labor. Three patients had work-related disabilities that required retraining and one needed to be reassigned. These four patients were all heavy manual laborers and loss of strength was their main complaint. All of them had stage II or IIB SLAC/SNAC lesions. Nevertheless, three of them were satisfied with the procedure.

4. Discussion

In our study, PRC preserved the preoperative range of motion and reduced pain levels. However, significant loss of strength was observed and 23% of patients requiring retraining or reassignment. The limitations of this study were its retrospective nature, low number of evaluated patients, and the five patients lost to follow-up. However, it reported the results of a continuous cohort with more than 6 years' follow-up.

PRC is indicated for post-traumatic sequelae of the wrist with SLAC or SNAC type damage, or in some cases of Kienböck's disease. The pain levels gradually decrease and the patients recover usually their preoperative range of motion. But strength recovery is slow and unpredictable (Table 3).

Table 3
Results of proximal row carpectomy procedures from published studies.

Authors	*n*	Indications	F/U (years)	No pain or slight pain	ROM in F/E (degrees) (% opposite)	ROM in RD/UD (degrees) (% opposite)	Strength (% opposite) (kg)	Non satisf. results (%)/Revision (%)
Imbriglia et al. (1990) [5]	27	Mixed	4	96%	60%	–	80%	1 arthrodesis
Foucher and Chmiel (1992) [32]	21	Mixed	–	–	71°	–	60%	7/–
Legré and Sassoon (1992) [8]	128	Mixed	2.5	50%	+10°	–	–	16 non satisf
Culp et al. (1993) [2]	17	Mixed	3.5	–	63°	–	67%	2/–
Tomaino et al. (1994) [10]	23	Post-trauma	6	87%	74° (61%)	8°/19°	79% (15 kg)	13/1
Alnot et al. (1997) [1]	45	Mixed	2.5	82%	61°	10°/20°	80%	6/6
Rettig and Raskin (1999) [36]	12	Post-trauma	40 m	75%	80°	20°	80% (34 kg)	0
Nagelvoort et al. (2002) [31]	11	Mixed	3	–	70°	(39%)/(81%)	70%	0%
Welby and Alnot (2003) [39]	27	Mixed	4–6	80%	60–67°	–	63%–74%	–
Jebson et al. (2003) [6]	20	Mixed	13	85%	77° (63%)	12°/22°	83% (30 kg)	15/10
DiDonna et al. (2004) [4]	22	Mixed	14	60%	72° (61%)	9°/31° (47%)/(73%)	91%	18/18
Lecomte et al. (2005) [7]	25	Mixed	2.5	60%	85°	10.3°/–	65%	24/2
De Smet et al. (2006) [3]	51	Mixed	5	–	(66%)/(73%)	(74%)/(76%)	70%	–/9
Croog and Stern (2008) [44]	21	Kienböck	10	76%	105° (78%)	9°/33°	87% (35 kg)	14/14
Lumsden et al. (2008) [45]	13	Kienböck	15	69%	88° (73%)	20°/35°	92% (32 kg)	0%/–
Liu et al. (2009) [34]	10	Mixed	16.5	–	–	–	75–99%	1/0%
Richou et al. (2009) [9]	45	Post-trauma	7.5	31%	74°	40.5°	77%	3/3
Ali et al. (2012) [33]	61	Mixed	20	26%	69°	9.8°/21°	48% (14 kg)	74/20
Wall et al. (2013) [35]	17	Mixed	24	65%	68°	(22%)/(65%)	72%	6 arthrodesis
Our study	18	Post-trauma	6	72%	84° (67%)	7°/33°	73% (20 kg)	1 arthrodesis 1 denervation

F/U: follow-up; ROM in F/E: range of motion in flexion/extension expressed; ROM in RD/UD: range of motion in radial deviation/ulnar deviation; Non satisf. results/Revision: non satisfactory results expressed in % and revision surgery expressed in %; Mixed indications: post-traumatic arthritis and Kienböck disease.

Biomechanical studies have shown that PRC decreases the flexion–extension range of motion compared to a normal wrist, with preservation of ulnar deviation, and decrease of radial deviation due to impingement of the radial styloid process with the trapezium [23]. Musculotendinous relaxation allows postoperatively recovery of the joint range of motion [24]. However, the lack of congruency between the head of the capitate and the radial carpal surface reduces the contact area and increases the pressure at the radial articular surface [5,25–29]. Displacement of the capitate's center of rotation could lead to degradation of the articular surfaces [5,23]. Some authors have shown that the shape of the capitate could have an influence on articular congruence after PRC and on long-term outcomes [17]. However, Tang et al. [29] found that carpal biomechanics or articular pressures were unaltered, whether the head of the capitate was V-shaped or rounded.

Results of published PRC studies confirm the biomechanical studies by reporting that functional range of motion is recovered in the majority of cases (Table 3). Mobility is often close to preoperative range of motion, particularly in flexion–extension. The ulnar deviation is often increased, whereas the radial deviation can be decreased compared to preoperative values. In cases with a hypertrophic radial styloid process, an additional styloidectomy can be performed to improve radial deviation and to avoid impingement with the carpus. The outcomes in terms of pain are variable in these studies and depend on the follow-up. For studies with less than 5 years of follow-up, the wrist was pain-free or had only slight pain in more than 80% of the cases [1,2,5,7,8,30,31]. For studies with follow-up between 5 and 10 years, as in our study, this rate decreases and varies between 50% to 80% [9,10,32]. Finally, for the studies with more than 10 years' follow-up, this rate decreases to between 20% and 70% [5,6,33–35].

The results degrade over time, often due to the appearance of degenerative lesions between the capitate and radius. This was observed in 5 out of 17 cases in our study, without correlation with the type of SLAC or SNAC wrist. However, radiographic modifications are not always correlated with the reappearance of pain. Resection of the terminal branch of the posterior interosseous nerve during the initial procedure as well as some dorsal denervation could explain this pain tolerance – but this is just a hypothesis. However, the revision rate in various published studies generally varies from 0 to 20%. One total arthrodesis was necessary in our study 10 years after the PRC. The arthrodesis rate also varies with the length of the follow-up in literature (Table 3).

Strength recovery is the weak point of this procedure. It has been reported to be between 14 kg and 35 kg in the literature, or 48% to 90% of the strength of the contralateral normal wrist (Table 3). However, some studies reported no strength reduction and a progressive improvement beyond the first postoperative year was reported in certain cases [5,36]. Other studies reported difficulties in returning to work, particularly among patients who perform heavy manual labor [2–4,7,37]. In our study, postoperative grip strength was decreased related to preoperative values (20 kg vs. 30 kg) at 6 years' follow-up.

Other studies have compared the results of PRC and midcarpal arthrodesis in the treatment of degenerative lesions of the carpus (Table 4). While the range of motion in flexion–extension was greater with PRC, strength recovery was better

Table 4
Comparison of the outcomes of proximal row carpectomy and four-corner arthrodesis from published studies.

Authors	Proximal row carpectomy	Four-corner arthrodesis
Tomaino et al. (1994) [38]	F/U: 5.5 years F/E: 77° (51%) Strength: 77% (36 kg)	F/U: 5.5 years F/E: 52° (57%) Strength: 76% (37 kg)
Krakauer et al. (1994) [30]	F/U: 39 months F/E: 71° Strength: 65%	F/U: 41 months F/E: 54° Strength: 78.5%
Wyrick et al. (1995) [46]	F/U: 37 months F/E: 85° (64%) Strength: 94%	F/U: 27 months F/E: 67° (47%) Strength: 74%
Cohen and Kozin (2001) [47]	F/U: 19 months F/E: 81° (62%) Strength: 71% (34 kg)	F/U: 28 months F/E: 80° (58%) Strength: 79% (38 kg)
De Smet et al. (2006) [3]	F/U: 68 months F/E: 81° Strength: 74% (31 kg)	F/U: 31 months F/E: 84° Strength: 66% (24 kg)
Lukas et al. (2006) [43]	F/u: 16.8 months F/E: 69° Strength: 66% (26 kg)	F/U: 13.7 months F/E: 71° Strength: 60% (28 kg)
Dacho et al. (2008) [48]	F/U: 27 months F/E: 75° (57%) Strength: 50% (24 kg)	F/U: 42 months F/E: 61° (56%) Strength: 72% (32 kg)
Vanhove et al. (2008) [49]	F/U: 38 months F/E: 78° Strength: 77%	F/U: 42 months F/E: 75° Strength: 71%
Mulford et al. (2009) [50]	F/E: 78° Strength: 73% (30 kg)	F/E: 70° Strength: 72% (35 kg)
Bisneto et al. (2011) [51]	F/U: 12 months F/E: (55%)/(63%) Strength: 47%	F/U: 12 months F/E: 50%/58% Strength: 73%

F/U: follow-up; F/E: flexion-extension expressed in degrees and in % of the opposite side; Strength: expressed in % of the opposite side and in kg.

with midcarpal arthrodesis, although the difference between the two techniques was not significant in several studies. However, it seems that contrary to PRC, the results of midcarpal arthrodesis are maintained over time [14–16]. According to Tomaino et al. [38] and Welby and Alnot [39], the best outcomes following midcarpal arthrodesis, in terms of strength and range of motion, were observed for stage III of SLAC or SNAC wrist. According to these authors, PRC is indicated only for stage II lesions.

Some authors have proposed using pyrocarbon implant interposition after proximal row carpectomy. However, the follow-up in these studies is still short. The main problem is the loss of wrist strength postoperatively. In the Pierrart et al. study [40], wrist strength decreased from 20.4 kg preoperatively to 8.3 kg postoperatively. The authors underlined that reduced postoperative wrist strength must be discussed with patients before deciding to interpose a pyrocarbon implant.

In our study, rehabilitation was initiated after 1 month of immobilization and could be partly responsible for the lack of strength at follow-up. Some authors have shown that early mobilization could make it possible to more quickly obtain better functional results [39,41,42]. Nevertheless, Richou et al. [9] found the same results as we did, with 22% of cases requiring work retraining despite early rehabilitation.

Many studies have stressed that PRC is the best choice for stage II SLAC or SNAC wrists [4,9,42,43]. The modest results in terms of strength recovery can attributed to the fact that 50% of the cases had stage III lesions in our study, which often have poor functional outcomes [1,39]. As stated previously [4,9], the PRC indication in SLAC or SNAC stage III must be discussed at length with patients who perform heavy manual labor. Other treatment alternatives such as midcarpal arthrodesis or wrist denervation must be brought up.

Disclosure of interest

The authors declare that they have no competing interest.

References

[1] Alnot JY, Apredoaei C, Frot B. Resection of the proximal row of the carpus. A review of 45 cases. Int Orthop 1997;21:145–50.
[2] Culp RW, McGuigan FX, Turner MA, Lichtman DM, Osterman AL, Mc Caroll HR. Proximal row carpectomy: a multicenter study. J Hand Surg Am 1993;18:19–25.
[3] 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 Orthop Belg 2006;72:535–40.
[4] DiDonna ML, Kiefhaber TR, Stern PJ. Proximal row carpectomy: study with a minimum of 10 years of follow-up. J Bone Joint Surg Am 2004;86:2359–65.
[5] Imbriglia JE, Broudy AS, Hagberg WC, Mc Kerman D. Proximal row carpectomy: clinical evaluation. J Hand Surg Am 1990;15:426–30.
[6] Jebson PJL, Hayes EP, Engber WD. Proximal row carpectomy: a minimum 10-year follow-up study. J Hand Surg Am 2003;28:561–9.
[7] Lecomte F, Wavreille G, Limousin M, Strouk G, Fontaine C, Chantelot C. Résection de la rangée proximale des os du carpe. Rev Chir Orthop Reparatrice Appar Mot 2007;93:444–54.
[8] Legré R, Sassoon D. Étude multicentrique de 143 cas de résection de la première rangée des os du carpe. Ann Chir Main Memb Super 1992;11:257–63.
[9] Richou J, Chuinard C, Moineau G, Hanouz N, Hu W, Le Nen D. Proximal row carpectomy: long-term results. Chir Main 2010;29:10–5.
[10] Tomaino MM, Delsignore J, Burton RI. Long-term results following proximal row carpectomy. J Hand Surg Am 1994;19:694–703.
[11] Schernberg F. [Value and limitations of the arthroplastic resection of the first row of the wrist bones in the advanced forms, stages IIIB and IV, of pseudarthroses of the carpal scaphoid]. Rev Chir Orthop Reparatrice Appar Mot 1988;74:735–7.
[12] Braga-Silva J, Román JA, Padoin AV. Wrist denervation for painful conditions of the wrist. J Hand Surg Am 2011;36:961–6.
[13] Schweizer A, von Känel O, Kammer E, Meuli-Simmen C. Long-term follow-up evaluation of denervation of the wrist. J Hand Surg Am 2006;31:559–64.
[14] Bain GI, Watts AC. The outcome of scaphoid excision and four-corner arthrodesis for advanced carpal collapse at a minimum of ten years. J Hand Surg Am 2010;35:719–25.
[15] Delclaux S, Rongières M, Aprédoaei C, Bonnevialle N, Bonnevialle P, Mansat P. [Capitolunate arthrodesis: 12 patients followed-up an average of 10 years]. Chir Main 2013;32:310–6.
[16] Watson HK, Weinzweig J, Guidera PM, Zeppieri J, Ashmead D. One thousand intercarpal arthrodeses. J Hand Surg Br 1999;24:307–15.
[17] Yazaki N, Burns ST, Morris RP, Andersen CR, Patterson RM, Viegas SF. Variations of capitate morphology in the wrist. J Hand Surg Am 2008;33:660–6.
[18] Bouman HW, Messer E, Sennwald G. Measurement of ulnar translation and carpal height. J Hand Surg Br 1994;19:325–9.
[19] Dubert T, Voche P, Dumontier C, Dinh A. [The DASH questionnaire. French translation of a trans-cultural adaptation]. Chir Main 2001;20:294–302.

[20] MacDermid JC. Development of a scale for patient rating of wrist pain and disability. J Hand Ther 1996;9:178–83.
[21] Voche P, Dubert T, Laffargue C, Gosp-Server A. [Patient-rated wrist questionnaire: preliminary report on a proposed French version of a North American questionnaire designed to assess wrist pain and function]. Rev Chir Orthop Reparatrice Appar Mot 2003;89:443–8.
[22] McMurtry RY, Youm Y, Flatt AE, Gillepsie TE. Kinematics of the wrist II. Clinical applications. J Bone Joint Surg Am 1978;60:955–61.
[23] Blankenhorn BD, Pfaeffle HJ, Tang P, Robertson D, Imbriglia J, Goitz RJ. Carpal kinematics after proximal row carpectomy. J Hand Surg Am 2007;32:37–46.
[24] DeBottis DP, Werner FW, Sutton LG, Harley BJ. 4-corner arthrodesis and proximal row carpectomy: a biomechanical comparison of wrist motion and tendon forces. J Hand Surg Am 2013;38:893–8.
[25] Hawkins-Rivers S, Budoff JE, Ismaily SK, Noble PC, Haddad J. MRI study of the capitate, lunate, and lunate fossa with relevance to proximal row carpectomy. J Hand Surg Am 2008;33:841–9.
[26] Hogan CJ, McKay PL, Degnan GG. Changes in radiocarpal loading characteristics after proximal row carpectomy. J Hand Surg Am 2004;29:1109–13.
[27] Tang P, Gauvin J, Muriuki M, Pfaeffle JH, Imbriglia JE, Goitz RJ. Comparison of the ‘‘contact biomechanics’’ of the intact and proximal row carpectomy wrist. J Hand Surg Am 2009;34:660–70.
[28] Tang P, Wei DH, Ueba H, Gardner TR, Rosenwasser MP. Scaphoid excision and 4-bone arthrodesis versus proximal row carpectomy: a comparison of contact biomechanics. J Hand Surg Am 2012;37:1861–7.
[29] Tang P, Swart E, Konopka G, Raskolnikov D, Katcherian C. Effect of capitate morphology on contact biomechanics after proximal row carpectomy. J Hand Surg Am 2013;38:1340–5.
[30] Krakauer JD, Bishop AT, Cooney WP. Surgical treatment of scapholunate advanced collapse. J Hand Surg Am 1994;19:751–9.
[31] Nagelvoort RW, Kon M, Schuurman AH. Proximal row carpectomy: a worthwhile salvage procedure. Scand J Plast Reconstr Surg Hand Surg 2002;36:289–99.
[32] Foucher G, Chmiel Z. La résection de la première rangée du carpe : à propos d’une série de 21 patients. Rev Chir Orthop Reparatrice Appar Mot 1992;78:372–8.
[33] Ali MH, Rizzo M, Shin AY, Moran SL. Long-term outcomes of proximal row carpectomy: a minimum of 15-year follow-up. Hand (NY) 2012;7:72–8.
[34] Liu M, Zhou H, Yang Z, Huang F, Pei F, Xiang Z. Clinical evaluation of proximal row carpectomy revealed by follow-up for 10–29 years. Intern Orthop 2009;33:1315–21.
[35] Wall LB, DiDonna ML, Kiefhaber TR, Stern PJ. Proximal row carpectomy: minimum 20-year follow-up. J Hand Surg Am 2013;38:1498–504.
[36] Rettig ME, Raskin KB. Long-term assessment of proximal row carpectomy for chronic perilunate dislocations. J Hand Surg Am 1999;24:1231–6.
[37] De Smet L, Robijns F, Degreef I. Outcome of proximal row carpectomy. Scand J Plast Reconstr Surg Hand Surg 2006;40:302–6.
[38] Tomaino MM, Miller RJ, Cole I, Burton RI. Scapholunate advanced collapse wrist: proximal row carpectomy or limited wrist arthrodesis with scaphoid excision? J Hand Surg Am 1994;19:134–42.
[39] Welby F, Alnot JY. [Resection of the first row of carpal bones: post-traumatic wrist and Kienböck’s disease] La résection de la première rangée des os du carpe : poignet post-traumatique et maladie de Kienböck. Chir Main 2003;22:148–53.
[40] Pierrart J, Bourgade P, Manane W, Rousselon T, Masmejean EH. Novel approach for posttraumatic panarthritis of the wrist using a pyrocarbon interposition arthroplasty (Amandys®): preliminary series of 11 patients. Chir Main 2012;31:188–94.
[41] Edouard P, Vernay D, Martin S, Hirsch P, Bardoux S, Grange C, et al. Proximal row carpectomy: is early postoperative mobilisation the right rehabilitation protocol? Orthop Traum Surg Res 2010;96:513–20.
[42] Jacobs R, Degreef I, De Smet L. Proximal row carpectomy with or without postoperative immobilisation. J Hand Surg Eur 2008;33:768–70.
[43] Lukas B, Herter F, Englert A, Bäcker K. [The treatment of carpal collapse: proximal row carpectomy or limited midcarpal arthrodesis? A comparative study] Handchir Mikrochir Plast Chir 2003;35:304–9.
[44] Croog AS, Stern PJ. Proximal row carpectomy for advanced Kienböck’s disease: average 10-year follow-up. J Hand Surg Am 2008;33:1122–30.
[45] Lumsden BC, Stone A, Engber WD. Treatment of advanced-stage Kienböck’s disease with proximal row carpectomy: an average 15-year follow-up. J Hand Surg Am 2008;33:493–502.
[46] Wyrick JD, Stern PJ, Kiefhaber TR. Motion-preserving procedures in the treatment of scapholunate advanced collapse wrist: proximal row carpectomy versus four-corner arthrodesis. J Hand Surg Am 1995;20:965–70.
[47] Cohen MS, Kozin SH. Degenerative arthritis of the wrist: proximal row carpectomy versus scaphoid excision and four-corner arthrodesis. J Hand Surg Am 2001;26:94–104.
[48] Dacho AK, Bausmeister 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. J Plastic Reconstr Aesthet Surg 2008;61:1210–8.
[49] Vanhove W, De Vil J, Van Seymortier 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 2008;33:118–25.
[50] Mulford JS, Ceulemans LJ, Nam D, Axelrod TS. Proximal row carpectomy vs. four corner fusion for scapholunate (SLAC) or scaphoid non-union advanced collapse (SNAC) wrists: a systematic review of outcomes. J Hand Surg Eur 2009;34:256–63.
[51] Bisneto ENF, Freitas MC, Leomil de Paula EJ, Mattar Jr R, Zumiotti AV. Comparison between proximal row carpectomy and four-corner fusion for treating osteoarthrosis following carpal trauma: a prospective randomized study. Clinics Sao Paulo 2011;66:51–5.