Hand Surgery and Rehabilitation 38 (2019) 34–43

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Original article

Adaptive Proximal Scaphoid Implant (APSI): 10-year outcomes in patients with SNAC wrists

Adaptative proximal scaphoid implant (APSI). Résultats à un recul moyen de 10 ans des poignets de type SNAC

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ARTICLE INFO

Article history:
Received 12 June 2017
Received in revised form 8 October 2018
Accepted 10 October 2018
Available online 2 January 2019

Keywords:
APSI
Wrist
SNAC
Implant
Arthroplasty
Pyrocarbon

ABSTRACT

Radioscaphoid arthroplasty with the Adaptive Proximal Scaphoid Implant (APSI®) is an attractive treatment alternative in the short and medium term for patients with early scaphoid non-union advanced collapse (SNAC) wrist. The purpose of our study was to determine the long-term outcomes of this implant in SNAC wrists. All patients who received the implant from October 2002 to October 2010 were included. A clinical and radiographic study was performed. Our case series included 39 patients, of which 33 were contacted, with a mean follow-up of 10 years (5.8–13.4). Most of the patients had stage-1 SNAC wrist (95%). There were nine complications (27%), seven of which required reoperation: implant dislocation (44%) or progression of the carpal degeneration (33%). Ninety-six percent of patients contacted were satisfied or very satisfied with their surgery (although 21% needed a second surgery) with a Mayo Wrist Score of 80/100 and a Patient-Rated Wrist Evaluation of 17.5/100. Wrist strength was 86% of the contralateral side. Flexion–extension range was 101° and pain assessed using a visual analog scale was at 1.2 (0–6). We report satisfactory and lasting results with the APSI®, similar to those of scaphoid excision with four-corner fusion and proximal row carpectomy. Hence, the APSI® is a reliable alternative for treating osteoarthritis in SNAC wrists.

Mots clés:
APSI
Poignet
SNAC
Implant
Arthroplastie
Pyrocarbone

RÉSUMÉ

L'arthroplastie radio-scaphoïdienne par l'implant APSI® s'est révélée être à court et moyen terme une alternative thérapeutique très séduisante dans les indications de *scaphoid non-union advanced collapse* (SNAC) wrists débutants. Notre but était d'évaluer l'efficacité de cet implant à long-terme dans les SNAC wrists. Nous avons inclus tous les patients porteurs d'un SNAC wrist chez lesquels fut mis en place un implant APSI® entre octobre 2002 et octobre 2010. Une étude clinique et radiographique a été réalisée. Notre série comportait 39 patients dont 33 ont été contactés avec un recul moyen de 10 ans [5,8–13,4]. Il s'agissait majoritairement de patients atteints de SNAC wrist de stade 1 (95 %). Nous avons relevé 9 complications (27 %) dont 7 ont nécessité une reprise chirurgicale. Il s'agissait principalement d'une luxation de l'implant (44 %) ou d'une évolution dégénérative du carpe (33 %). Quatre-vingt-seize pour cent des patients contactés étaient satisfaits ou très satisfaits de leur intervention (bien que 21 % aient eu

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https://doi.org/10.1016/j.hansur.2018.10.245
2468-1229/

besoin d'une deuxième opération) avec un *Mayo wrist score* à 80/100 et un *patient-rated wrist evaluation* à 17,5/100. La force des poignets opérés était de 86 % par rapport au côté opposé. L'arc de mobilité en flexion-extension était de 101° et la douleur évaluée sur une échelle visuelle analogique (EVA) était de 1,2 (0–6). Nous rapportons des résultats satisfaisants, durables dans le temps et comparables à ceux de l'arthrodèse des 4 os et de la résection de la rangée proximale du carpe. L'APSI a désormais une réelle place dans l'arsenal thérapeutique des poignets arthrosiques de type SNAC.

1. Introduction

Osteoarthritis of the wrist causes pain, loss of strength and stiffness. Cases of post-traumatic osteoarthritis related to scaphoid non-union, termed SNAC (Scaphoid Non-union Advanced Collapse) wrist, can occur at a young age and be very debilitating. Only surgical treatment can prevent osteoarthritic progression and bring long-term relief to these patients. There are several surgical options, all imperfect, with the most common being partial wrist fusion and proximal row carpectomy. Both of these solutions result in persistent pain and/or stiffness.

The APSI® (Adaptive Proximal Scaphoid Implant) pyrocarbon implant has proven to be a very useful solution for treating wrists affected by proximal scaphoid non-union and SNAC. This ovoid-shaped implant is intended to replace the scaphoid's proximal pole to maintain carpal height. The implant helps to restore even force distribution at the proximal carpal row and aims to stop osteoarthritic progression. Several studies have demonstrated its effectiveness in the short- and medium term, allowing pain-free use without loss of wrist mobility or strength [1–8]. The main complication of this implant is dislocation. The lack of any meaningful follow-up using this technique makes long-term results uncertain. Only one study on 20 patients evaluated the outcomes of this implant at more than 10 years [9]. Although its biocompatibility is well established [10], the local effects and regional repercussions of this implant, notably progression of osteoarthritis, remain to be determined.

Our goal was to study the long-term outcomes of APSI for treating SNAC wrists. We present the long-term clinical, functional and radiological findings of the APSI implant in a retrospective single-center study. Our hypothesis was that this implant prevents the progression of osteoarthritis to adjacent zones.

2. Patients and methods

2.1. Implant

The APSI is a spacer, implanted by simple interposition, without any fixation. The implant is therefore adaptive insofar that it changes its position and axis based on the movements and constraints applied to the carpus. Because of its pyrocarbon structure, its mechanical properties are similar to those of cortical bone (density and modulus of elasticity). It is also very durable due to a very low friction coefficient. This implant is produced in three sizes: large, medium and small.

2.2. Patients

This retrospective study included all patients who received an APSI as treatment for SNAC wrist at our hand clinic between October 2002 and October 2010. At final follow-up, the postoperative data as well as clinical, functional and radiographic outcomes were reviewed by an independent observer using standardized procedures.

Our case series included 39 patients, 31 (80%) of whom were men. The average age at the time of the surgical procedure was 42 ± 10.5 years (26.5 to 58.3). The dominant hand was affected in 25 (64%) cases. Eighteen (46%) patients performed heavy/very heavy manual activities, 9 (23%) average and 8 (21%) mild activities; 4 (10%) were retired or unemployed. Of the 39 patients, 35 were treated for a SNAC wrist, 33 at stage 1 and 2 at stage 2. The other four patients received an APSI implant for SNAC-like pathologies: two had avascular necrosis of the proximal scaphoid pole (Preiser's disease), one had scaphotrapezio-trapezoid osteoarthritis (STT) with radioscaphoid osteoarthritis and one had scaphoid malunion with radioscaphoid osteoarthritis. In all, 95% of the patients had stage 1 osteoarthritis, 5% had stage 2 osteoarthritis. Moreover, 44% had necrosis of the scaphoid's proximal pole.

The interpositional arthroplasty procedures were performed by eight hand surgeons.

2.3. Surgical technique

All operations were performed using a direct approach with a tourniquet under local anesthesia. Depending on the surgeon, the approach was either transverse or curvilinear dorsal, centered on the radioscaphoid joint line between the 3rd and 4th or 2nd and 3rd extensor tendon compartments. In some cases, resection of the posterior interosseous nerve (PIN) as well as tenosynovectomy of the extensor tendons was performed during the same operation. The capsulotomy was then performed longitudinally. Radial styloidectomy was performed with a bone chisel when styloscaphoid impingement was present, or to prevent impingement with the implant. Depending on the indications (SNAC or SNAC-like wrist), the scaphoid's proximal pole was resected using either a bone chisel, scissors or an oscillating saw. Where needed, the distal part of the scaphoid was reamed to make place for the implant. The size of the trial implant was then determined. It had to be positioned without excessive constraints, granting mobility and adaptability to wrist movements. Its stability and positioning were then verified using fluoroscopy (aiming to achieve complete passive mobility without dislocation or subluxation of the implant). The final implant was inserted and the capsule was closed with PDS 4/0. Depending on the case, dorsal capsuloplasty or capsular retensioning was performed using Dacron or non-absorbable suture, followed by a new static and dynamic fluoroscopic verification. The extensor retinaculum and skin were closed on a suction drain in some cases.

A thermoplastic splint was prescribed for 2 weeks, after which it was removed and patients performed self-directed rehabilitation with the splint used as needed. After 6 weeks, the patients were no longer restricted; in case of stiffness, a short course of rehabilitation (10–20 sessions) was prescribed.

2.4. Outcomes

2.4.1. Review of data and medical records

The demographic data obtained from medical records included age, gender, dominant hand, occupation and principal activity, indication and date of surgery, previous medical and surgical

conditions. The patient's professional activity was divided into three classes according to the workload: light, moderate, heavy/very heavy. Information was sought regarding the precise dates and circumstances of the initial injury and/or the discovery of lesions. Pre-operative symptoms, especially pain, as well as their duration and possible treatments (medical or surgical) and their effectiveness were reported. Pre-operative pain taken from the charts was classified into four levels: none, intermittent, persistent and disabling. The time and conditions for the return to work or usual activities were also reported. Lastly, the intra- and post-operative data allowed us to gather information on implant size, whether or not the PIN was resected, styloidectomy and possible associated capsular repair. The nature, date of onset and management of any complications were reported intraoperatively and throughout the follow-up period.

2.4.2. Subjective evaluation

Pain was assessed using a visual analog scale (VAS, 0 = no pain, 10 = extreme pain) and classified into four levels: none, intermittent, persistent, and disabling. The Quick Disability of Arm Shoulder and Hand questionnaire (QuickDASH, 0 = no complaint, 100 = worst result) and the Patient-Rated Wrist Evaluation questionnaire (PRWE, 0 = best, 100 = worst) were completed. Patients assessed their satisfaction with the outcome of their surgery on four levels: very satisfied, satisfied, dissatisfied and very dissatisfied (in the last 2 cases, the reason for dissatisfaction was determined). Finally, patients were asked if they would undergo the same procedure again in the same context.

2.4.3. Objective evaluation

The flexion, extension, radial deviation, ulnar deviation and pronation–supination mobility of both wrists were measured using a medical goniometer by calculating joint angles in degrees [11]. The grip, lateral (key) and terminal (fine distal pinch) finger strengths were measured using a manual hydraulic hand-held dynamometer (Baseline®, White Plains, NY, 10602, USA) and a hydraulic pinch gauge placed between thumb and forefinger (JAMAR, 60 Page Road, New Jersey 07012, USA), respectively [11]. The results were recorded in kilograms by averaging three successive 1 to 2 second pinches at 2-second intervals. Combining the subjective and objective data, we established the Mayo Wrist Score (MWS) consisting of 7 items (0 = worst result, 100 = best result) for each patient.

2.4.4. Pre-operative and post-operative radiological evaluation

The radiological evaluation was performed by two hand surgeons using standard PA and lateral radiographs. The non-unions were classified according to Schernberg's classification [12]. Osteoarthritis was classified as secondary to scaphoid non-union according to Vender's original classification [13], to which a 4th stage was added: SNAC-1: radioscaphoid osteoarthritis, SNAC-2: SNAC-1 + scapho-capitate osteoarthritis, SNAC-3: SNAC-2 + lunocapitate osteoarthritis, SNAC-4: SNAC-3 + radioulnar osteoarthritis.

SNAC-like wrists were classified as osteoarthritic, unrelated to scaphoid non-union, but whose pathophysiology (adaptive carpus) was similar to SNAC wrists. These included osteoarthritic wrists associated with avascular necrosis of the proximal scaphoid (Preiser's disease), STT arthrodesis and scaphoid malunion [16]. Three measurements were performed using Mesurim (Open Access Software: http://acces.ens-lyon.fr/acces/logiciels/applications/mesurim/telechargement), namely the carpal height ratio (CHR), the ulnar carpal distance ratio or ulnar carpal translation (UCT) and the radioulnar angle (RUA). A dorsal intercalated segment instability (DISI) was retained for an anterior tilt of the lunate associated with a RUA greater than 25° [17]. The measurements were performed twice for each patient, with their result being the average of the two. We identified the position of the implant: palmar or dorsal dislocation, or at the scaphoid's proximal pole (specifying the sagittal or frontal plane of the implant's major axis). We noted any bone modifications: presence of osteophytes and bone notches in contact with the implant. The implant's stability was determined on dynamic images (in flexion and extension on lateral views and in radial and ulnar inclination on PA views).

2.5. Statistics

Continuous variables were compared using Student's *t*-test while categorical variables were compared using X^2 tests. Statistical analyses were performed using STATISTICA (TIBCO Software Inc., Palo Alto, CA, USA). A value of $P < 0.05$ (P = P-value) was considered significant.

3. Results

At the final review, among the initial 39 patients, 2 patients had died, 4 were lost to follow-up and 33 patients were re-contacted at an average follow-up of 10 ± 2.6 years (5.8 to 13.4 years). Twenty-nine of these 33 patients were evaluated at the clinic, while 4 were contacted by phone and mailed their radiographs and questionnaires to us. Three of these four patients still had their implant at the final review (Table 1)

3.1. Pre-operative data

The initial 39 patients were operated after 1.6 ± 1.8 years (1 month to 7 years) of wrist symptoms. In all patients, pain was the main reason for consultation. The mean range of motion (ROM) in flexion–extension was 99° ± 35° (73%/contralateral) with 52° ± 20° of flexion (73%/contralateral) and 47° ± 19° of extension (74%/contralateral). The mean ROM in radial–ulnar deviation was 39° ± 20° (59%/contralateral) with 15° ± 6° of radial deviation (66%/contralateral) and 24° ± 9° of ulnar deviation (55%/contralateral). The grip strength was 27 kg ± 15 kg (64%/contralateral). The implant size used was distributed as follows: 24 (62%) medium, 12 (31%) small and 3 (7%) large. The PIN was resected in 24 (62%) cases and a styloidectomy was performed in 31 (79%) cases. Dorsal capsular surgery was performed in eight patients (20%) of which one was a posterior ligamentoplasty using Dacron and eight were capsulodesis procedures including one Blatt capsulodesis. All patients did their own rehabilitation after the immobilization period. Of the 33 patients that were re-contacted, 15 (45%) needed formal rehabilitation, including 10 to 20 sessions with a physical therapist.

3.2. Complications and surgical revisions

Of the 33 patients re-contacted, 9 (27%) had suffered complications: 6 early (occurring in the first 3 months postoperatively) and 3 late (occurring after 2 years). Seven (78 %) required surgical revision. There was one case of early joint sepsis with moderate chondrolysis of the proximal pole of the capitate, which was treated by implant removal, 13 days after surgery. There were also four cases of complete implant dislocation (Fig. 1), which occurred at 1.6 months post-surgery on average (1 day to 3 months): three were dorsal (one creating stiffness in extension which required implant removal, the other two were painless and did not require surgical revision) and the other one was palmar and asymptomatic for 8 years in a patient who had previous undergone dorsal capsuloplasty; the implant was eventually removed because it became symptomatic with paresthesia in the median nerve area. One patient had significant persistent pain caused by radioscaphoid impingement; he was re-operated at 4 months for scaphoid excision with four-corner fusion. Three patients had degenerative carpal progression (Fig. 2) treated by scaphoid excision and four-corner fusion at 2.9, 7.2 and 9.4 years post-operatively; these three patients had all

Table 1
Summary of preoperative data and postoperative outcomes at the last follow-up.

Time point	Pain VAS	Mobility		Grip strength (%/Clt)	MWS	QDASH	PRWE	Satisfaction
		Arc F – E (%/Clt)	Arc RD – UD(%/Clt)					
Preop	–	99° (73%)	39° (59%)	27 kg (64%)	–	–	–	–
Postop (10 years)	1.2	101° (77%)	47° (73%)	38 kg (85%)	80	19.5	17.5	90% S and VS
Preop/postop gain (% gain)	–	+ 2° (4%) $P = 0.8$	+ 8° (14%) $P = 0.45$	+ 11 kg (21%) $P = 0.08$	–	–	–	–

Preop: pre-operative; postop: post-operative; VAS: visual analog scale; Clt: contralateral; F: flexion; E: extension; RD: radial deviation; UD: ulnar deviation; Grip: hand grip strength; kg: kilogram; VS: very satisfied; S: satisfied; MWS: Mayo wrist score; QDASH: quick disabilities of the arm, shoulder and hand; PRWE: patient-rated wrist evaluation;–: no data.

benefited from the implant, two of whom were totally asymptomatic before the onset of degenerative symptoms.

Of the nine patients who had complications, five were heavy/very heavy manual workers and three were light manual workers. All had returned to work after an average of 8 ± 15 months (1 month to 4 years) post-surgery. Three of these patients (re-operated by scaphoid excision with four-corner fusion) were heavy/very heavy manual workers and had to change jobs because of their wrist pain.

At the last follow-up, seven patients (78%) were satisfied or very satisfied with their APSI® implant surgery and two (22%) considered the result insufficient or were dissatisfied due to pain. Two patients said they would not undergo the same procedure again in the same context.

3.3. Patients who did not suffer complications

3.3.1. Pain

The average VAS grade was 1.2 ± 1.6 (0 to 6); 75% of patients had no pain, 37% had intermittent pain (VAS between 3 and 6) mostly during forced movements associated with ulnar deviation of the wrist; of these, two wore a night-time brace for about 5 years and declined scaphoid excision with four-corner fusion revision surgery; none of the patients had pain at rest > 2 on the VAS, nor persistent or disabling pain.

3.3.2. Mobility and strength

Postoperatively, the ROM in flexion–extension was 101° ± 18° (with 50° ± 11° of flexion and 51° ± 9° of extension), a 2° (4%) gain compared with pre-operative measurements (95% confidence interval CI = −20° to 17°, $P > 0.05$). The ROM in radial–ulnar deviation was 47° ± 19° (with 11° ± 8° of radial deviation and 36° ± 12° of ulnar deviation), an 8° (14%) increase compared to the preoperative measurement (95% CI = −24° to 11°, $P > 0.05$). Pronation–supination on the operated side was the same as on the contralateral side for all patients at final follow-up.

The post-operative grip strength averaged 38 ± 12 kg, an increase of 11 kg (21%) over the preoperative level (95% CI = 5 to 26 kg, $P < 0.05$), which was 86% of the contralateral side. The lateral (key) and terminal (tip) pinch forces at the last follow-up were 12% less than the contralateral side.

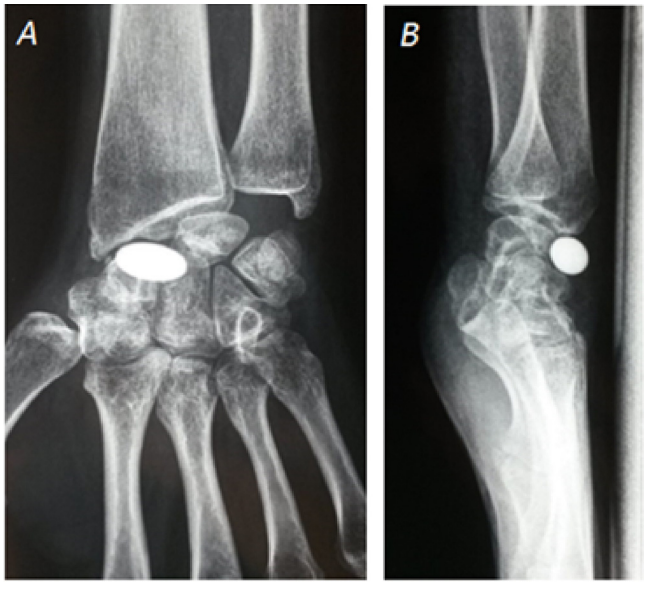

Fig. 1. Dislocation of the implant and degenerative progression of the carpus. PA (A) and lateral (B) views.

3.3.3. Functional scores

The PRWE at the last follow-up was 17.5/100 ± 19 (0 to 59), the QuickDASH Score was 19.5/100 ± 22 (0 to 70.5) and the MWS was 80/100 ± 11.5 (55 to 100). Based on the MWS Score, there were five excellent, nine good, eight moderate and two poor results.

3.3.4. Satisfaction

Twenty-three (96%) of the patients were satisfied or very satisfied with their surgery and one patient (4%) rated the outcome as insufficient because of pain (VAS = 3.3). All patients without complications said they would undergo the same procedure again if necessary.

3.3.5. Return to work

Twenty-three of the 24 patients who still had their implants in place had resumed their pre-operative occupation after a delay of 2.1 ± 1.8 months (2 days to 10 months). Two of them had taken-up lighter work. One patient was unable to return to work (a sailor) and was laid-off because of his wrist pain upon exertion. At the last follow-up, 19 patients were still working, 47% of them being heavy/very heavy manual laborers (31% moderate manual workers and 22% light manual workers). Three had retired, one had still not found work after being laid-off because of his wrist and the last was disabled due to a medical problem unrelated to his wrist.

3.4. Radiological outcomes

3.4.1. Implant

Thirty-six of the 39 (92%) patients had the implant positioned with its largest axis in the sagittal plane. Three patients (8%) had an implant positioned with an inverted axis, with the longest axis being in the frontal plane; these three patients were reviewed in person; one of them was asymptomatic while the other two experienced intermittent pain (average VAS 3.8) and wore a night splint to relieve their pain.

In 23 of the 24 cases (96%) contacted by phone, the implant had adaptive mobility and was stable (Fig. 3). In one asymptomatic patient, volar subluxation of the implant manifested only during wrist extension. In 30% of cases, we found that the implant

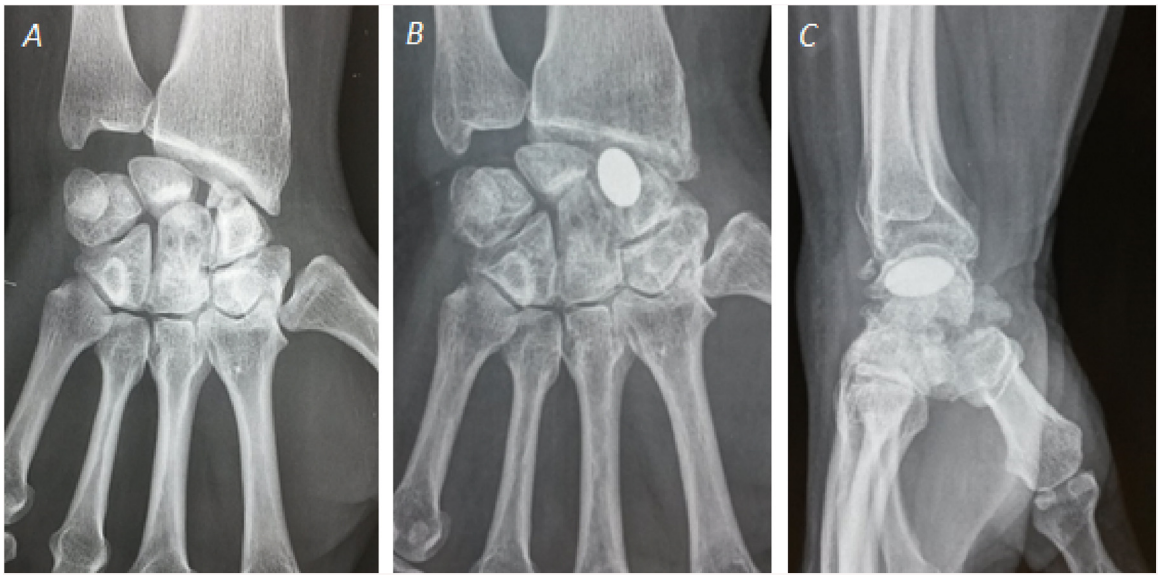

Fig. 2. Progression of the osteoarthritis of a SNAC wrist when comparing preoperative PA view SNAC 1 (A) and PA (B) and lateral (C) views at 12.6 years' follow-up SNAC 3.

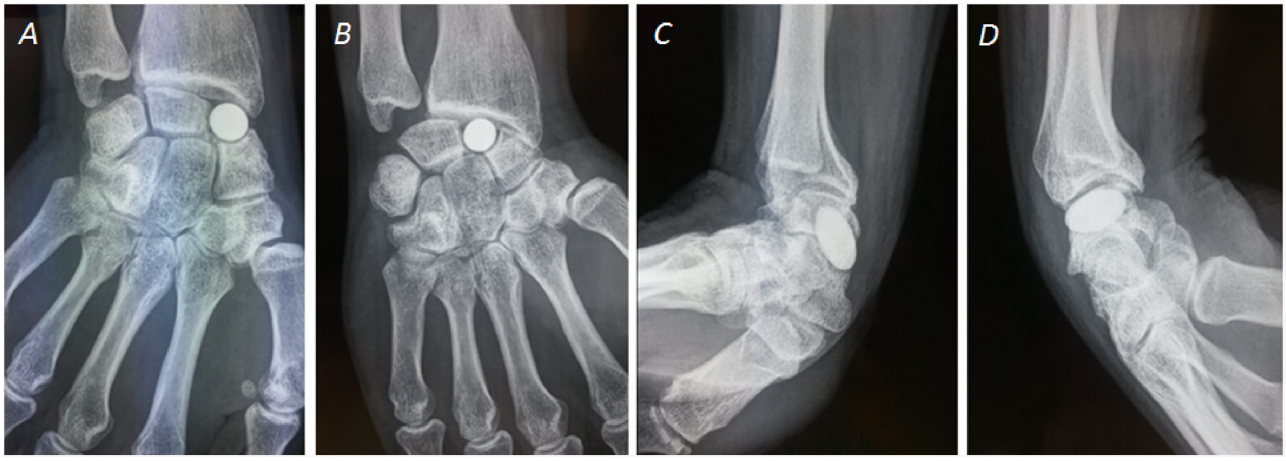

Fig. 3. Dynamic radiographic views demonstrating wrist motion at 12.5 years' follow-up. PA views in ulnar (A) and radial (B) deviation. Lateral views in extension (C) and flexion (D).

became oblique during ulnar deviation. A notch made by the implant at the radial slope of the proximal pole of the capitate was found in 40% of cases at the last follow-up (Fig. 4). We did not find any relationship between the presence of notching and pain.

3.4.2. Carpal misalignment and osteoarthritis

For the 26 patients contacted who still had their implant in place, the mean RUA was 23.5° ± 10° (2 to 40°) with a normal value ≤ 25°. A lunate DISI was present in 41.6% with a mean RUA of 33° ± 5° (27 to 40°). Mean CHR was 0.52 ± 0.05 (0.44 to 0.63) with a normal value of 0.54 ± 0.03. Mean carpal ulnar translation was 0.33 ± 0.05 (0.23 to 0.44) with a normal value of 0.3 ± 0.03.

In six cases (23%), we found stage 2 or 3 osteoarthritis progression (P = 0.009, with a mean radiolunate angle (RLA) of 27° ± 7°), three of whom had a reversed axis implant. In 77% of cases, the osteoarthritis stage was unchanged (RLA = 22° ± 11°).

Seventy percent of the patients had osteophytes, mostly on the dorsal aspect (opposite to the scaphoid and the distal radius) and the radial styloid process.

4. Discussion

Our findings are consistent with our initial hypothesis. The APSI® implant is effective at preventing long-term osteoarthritis progression of scaphoid non-union in SNAC wrists.

4.1. Comparison with the literature and study limitations

shows the main APSI studies found in the literature. Our results are comparable to the other studies in terms of pain, ROM, strength, satisfaction and functional scores [1–9], especially the two studies with the longest follow-up [8,9]. Since we did not have preoperative radiographic data, we could not draw clear conclusions about carpal misalignment (< 25% of collected data). (Table 2)

4.1.1. Functional outcome scores

It is difficult to compare the functional outcomes of these studies because different scores were used. However, pain and

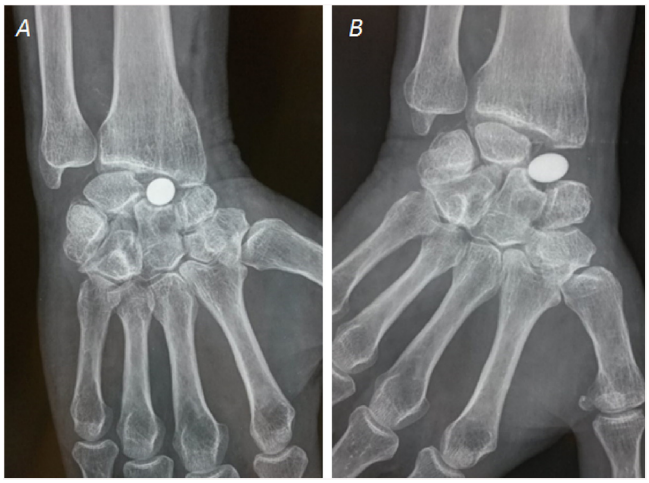

Fig. 4. Notching on the capitate's head and oblique implant in ulnar deviation. PA views in radial (A) and ulnar (B) deviation.

function were included in each score. According to Adams et al., we can assume the DASH and QuickDASH Scores have the same potential to distinguish the overall functional ability of patients. PRWE is the most discriminating score compared to the DASH and QuickDASH [18]. We consider that the PRWE Score and the MWS, being specific to the wrist, are more appropriate for evaluating functional outcomes, unlike the DASH and QuickDASH Scores, which evaluate the entire upper limb.

4.1.2. Pain

Pain is the major symptom in wrist osteoarthritis. It is always present preoperatively and remains the main source of dissatisfaction post-operatively. We therefore evaluated this symptom specifically using several measurement methods. Unfortunately, the lack of standardized preoperative pain measurements forced us to refer to pre-operative charts. Pain could be differentiated and classified into four categories (none, intermittent, persistent, and disabling). It was disabling in 70% of cases. This measurement method is not validated, but by using it at the final follow-up visit, we were able to highlight that all patients experienced less pain than they did preoperatively.

4.1.3. Classification and interpretation of SNAC wrist

There is large individual variability in the classification of osteoarthritis based on radiographs [19], which also limits the reproducibility of interlinear interpretations and the overall diagnosis [20]. In our study, there was a 20% discrepancy the two surgeons' interpretations of the pre-operative and post-operative radiographs. The scaphocapitate and lunocapitate joint spaces were the most problematic. In 63% of the cases in our study, the initial classification was established solely by the surgeon, so the pre-operative radiographs could not be studied at the last follow-up. Due to the absence of comparative images, this lack of precision can be a source of error in the initial diagnosis of the osteoarthritis stage, but above all, in the interpretation of the results at the last follow-up. This can also be a source of error in the surgical indication. Indeed, underestimation of the osteoarthritis preoperatively can be the cause of late complications caused by osteoarthritis progression. It therefore seems advisable to add computed tomography arthrography (CTA) or arthroscopic evaluation to the pre-operative assessment of arthritic wrists intended for an APSI®, especially in cases suspected of having impingements that may not be clearly visible on radiographs (notably in stages 2 and 3). These CTA or arthroscopic examinations would help refine surgical indications by determining the exact stage of osteoarthritis.

4.1.4. Associated capsuloplasty

In our study, eight patients had dorsal capsulodesis as an adjuvant procedure. Three of these patients (37%) had a subsequent complication requiring surgical revision by scaphoid excision with four-corner fusion (two for osteoarthritis progression and DISI). Pequignot and Allieu reported having performed capsulodesis in 7 cases for a DISI greater than 10° but did not provide detailed outcomes [8]. This surgery provided no benefit in our study. We consider that dorsal capsular surgery to correct a DISI is henceforth useless, even harmful, because it would lengthen the surgical procedure and be ineffective in the long-term [21]. Volar or dorsal capsular retensioning may be justified if the implant becomes unstable during surgery.

4.1.5. Complications

We classified complications according to their onset. In studying the literature [1–9], we were able to distinguish two categories: so-called early complications, occurring less than 3 months after the procedure (infection, complex regional pain syndrome, dislocation, painful impingement, etc.), and late-onset complications that occur on average after 5 years and appear to be similar to degenerative carpal progression.

The main drawback of using this mobile and adaptive implant is that it cannot support excessive stress, which causes it to become unstable and dislocate. No cases of dislocation beyond 3 months were found in our study and in the literature.

The persistence of radioscaphoid pain is the second most common early complication found in the literature. Drilling or a styloidectomy was used to treat these complications secondarily in 77% of cases, unrelated to a possible change in implant size. According to the literature, a styloidectomy is performed in 60% of cases. It has never been a cause of implant instability and helps to eliminate painful radiocarpal impingement [1–3,8,9].

In our study we defined "osteoarthritis progression" as applicable to patients who had temporary relief following APSI® implantation and whose osteoarthritis stage worsened after the preoperative diagnosis. Indeed, the three patients who had a late complication were re-operated (scaphoid excision with four-corner fusion) following the discovery of symptomatic lunocapitate osteoarthritis that had not been identified on the preoperative radiographs.

There is very likely a learning curve in the technique that we have not been able to show. This is probably related to the large number of surgeons who participated in our study (8 surgeons, i.e. an average of 4 patients each) but is also related to the lack of standardized surgical technique.

4.1.6. Comparison between open versus arthroscopic approach

Arthroscopy is advocated by some authors [9]. This technique helps to preserve the extrinsic ligaments and joint capsule but does not allow capsular retensioning when necessary. Nor is it possible to correctly assess implant size from the resected scaphoid, because it is often necrotic and/or too fragmented to be extracted. Moreover, the traction and fluid distort the positioning and the space intended for the implant. Lastly, multiple manipulations of the wrist, forearm and implant are required to position the trial implant, select the most suitable size, verify its clinical and radiological stability by fluoroscopy, and then remove it to install the final implant. Due to the equipment installation time and the untimely relaxation and wrist tensioning maneuvers, to us, arthroscopy seems to be a considerable waste of time and a source of error in determining of the implant size and position.

Table 2
Main APSI studies found in the literature.

Study	No. cases	Follow-up (years)	Etiology	No. of complication (%)	Type of complication	Reoperation	Pain (pre/postop)	Mobility postop (ROM F–E)	Strength postop (%/Clt)	Patient satisfaction (Test used)
Pequignot et al. 2000 [1]	25	6	SNAC 60% SLAC 40%	0	–	–	60% totally painless 88% improvement	> 95°	77%	88% VS
Grandis et al. 2004 [2]	41	3	Non-union 68% (SNAC 15%) (SLAC 5%)	0	–	–	63% totally painless 90% improvement	> 100°	–	(KWS)
Grandis and Berzero 2007 [3]	83	5	Non-union (±SNAC)	–	–	–	–	–	–	79% S (KWS = 75)
Pequignot and Allieu 2010 [9]	20	12	SNAC	–	–	–	75% totally painless 100% improvement	100°	77%	100% VS
Gaisne and Bouju 2010 [4]	20	3.3	SNAC 63% non-union 37%	4 (20%)	3 dislocations 1 impingement	2 implants removed 2 not re-operated	20% totally painless 85% improvement	88°	75%	83% S and VS (PRWE = 29.8) (QDASH = 31.8)
Gras et al. 2012 [27]	14	8.7	SNAC	6 (43%)	3 subluxations 3 impingements	2 four-corner fusion 4 styloidectomy	68% improvement (VAS: 7.5 to 0.7)	95°	78%	(MWS = 79.6) (DASH = 7.6)
Daruwalla et al. 2013 [5]	12	1.5	SNAC	0	–	–	62% improvement (VAS: 8 to 2)	90°	65%	100% S and VS (DASH = 20)
Lima Santos et al. 2015 [6]	12	6.5	Non-union	0	–	–	–	–	–	(MWS = 67.5) (QDASH = 25)
Dréant et al. 2015 [8]	38	5	SNAC 55% SLAC 23% Non-union 21%	3 (8%)	3 dislocations	3 reaming and implant repositioning	–	–	78%	(MWS = 80)
Our study	33	10	SNAC	9 (27%)	4 dislocations 3 osteoarthritis progressions 1 impingement 1 infection	4 four-corner fusion 3 implants removed 2 not re-operated	75% totally painless 100% improvement (VAS = 1.2)	101°	85%	90% S and VS (PRWE = 17.5) (MWS = 80) (QDASH = 19.5)

No.: number; Non-union: scaphoid non-union; SNAC: scaphoid non-union advanced collapse; SLAC: scapho lunate advanced collapse; postop: postoperative; Clt: contralateral; VAS: visual analog scale; ROM: range of motion; F–E: flexion and extension; VS: very satisfied; S: satisfied; KWS: Krimmer wrist score; MWS: Mayo wrist score; QDASH: quick disabilities of the arm, shoulder and hand; PRWE: patient-rated wrist evaluation.

4.2. Effect of the APSI® implant on osteoarthritis progression

In our study, patients were reviewed on average 25 ± 11 years (9 to 37 years) after their initial trauma. According to the literature, osteoarthritis and DISI increase over time in patients with scaphoid non-union, becoming 100% arthritic at 10 years [20–22]. More specifically, Bonnevialle et al. found 83% of DISI at 24.8 years' follow-up versus 41.6% in our study [17]. For carpal height, he found a 58% rate of carpal collapse (CHR < 0.51), whereas Mack et al. found 50% [22], compared to 26% in our study. Mack et al. found an increase in carpal ulnar translocation (UCT ≥ 0.34) in 50% of cases compared to 35% in our study. Thus, the APSI® implant contributed to slowing the progression of osteoarthritis by maintaining the carpal height and preventing the proximoradial elevation of the capitate. The notch made by the implant in the capitate follows this direction. This notch, found in 40% of our patients and in 50% in the Gras et al. study [9], depends on the extent of the scaphoid resection. Because the implant's density and modulus of elasticity are close to that of bone, it transmits forces applied to it without collapsing or impacting the bone. We did not detect any radio-clinical parallelism. We found that the three patients with an inverted axis implant all had major osteoarthritis progression with a significant DISI (33° on average).

4.3. Comparison of the APSI® implant with other techniques

The placement of the APSI® is less aggressive and definitive than conventional treatment methods (fusion, proximal row carpectomy). According to Darwalla et al. the average tourniquet time is 27 minutes [4].

4.3.1. Resection of the proximal pole of the scaphoid and interposition materials

In the long-term, excision of the proximal pole of the scaphoid alone – or its equivalent by interposition with a "soft" material (silicone, fascia, tendon, etc.) – does not prevent osteoarthritis progression and long-term carpal collapse [22–24]. During axial loading, the scaphoid and triquetrum act as lateral and medial stabilizers of the central carpal column (lunate and capitate), respectively. Shortening of the scaphoid or damage to the scapholunate ligament creates an imbalance in the load distribution at the expense of the scaphoid. The triquetrum then imposes an extension movement on the lunate (DISI) and gradual proximoradial migration of the capitate develops. This natural progression of carpal imbalance, at the origin of osteoarthritis, depends on other factors (size of the resected scaphoid fragment, condition of the stabilizing carpal ligaments, degree of patient activity, etc.). This could explain why some patients do not have carpal misalignment in the long-term despite the obvious presence of major lesions. (Table 3)

4.3.2. Scaphoid excision with four-corner fusion

APSI® is a less disruptive technique than scaphoid excision with four-corner fusion. It allows better wrist mobility and satisfies greater functional demands. At the same follow-up, the results in terms of pain, satisfaction and strength are similar. However, APSI® allows a quicker return to function: 2 to 4 weeks in a splint versus 2 months for scaphoid excision with four-corner fusion [25–28]. However, APSI® has a higher complication rate than scaphoid excision with four-corner fusion and is not indicated for treating capitolunate osteoarthritis.

4.3.3. Proximal row carpectomy (PRC)

For the same follow-up time, APSI® has better results than PRC in terms of wrist mobility and patient satisfaction. Strength and pain seem better with the APSI® [1–9]. This is a less disruptive technique, but the APSI® complication rate is higher. PRC is less satisfactory in heavy manual workers and less durable in young patients [27,28].

4.3.4. Total carpal denervation (TCD)

The APSI® provides better mobility than TCD, giving patients better wrist function. APSI® has better results in terms of pain reduction. Strength and satisfaction seem identical for both these equally disruptive procedures [29–31]. The APSI® complication rate is slightly higher.

4.3.5. Rib cartilage autograft at the scaphoid proximal pole

This palliative technique, like APSI®, is an attractive treatment options for arthritic SNAC wrists. There is no risk of malunion because the graft is no longer attached to the bone. This technique

Table 3
Comparison between similar studies: 4-corner arthrodesis, proximal row carpectomy, total wrist denervation and APSI®.

Series	Type	No. Cases	Follow-up (years)	No. of complications	Pain	Mobility (in °)		Grip strength (%/Clt)	Satisfaction
						ROM F – E (%/Clt)	ROM RD – UD (%/Clt)		
Neubrech et al. [55]	4FC	56	14.7	17.7%	50% pain-free (VAS = 2.35)	(62.5%)	(68.4%)	85%	100% S DASH = 20.4
Bain and Watts [54]	4FC	31	10	6%	(VAS = 1)	57° (48%)	30° (46%)	78%	80% S
Richou et al. [56]	PRC	24	9.6	12.5%	52% pain-free (VAS = 1.2)	76°	–	78%	83% S DASH = 31
Wagner et al.[63]	PRC	144	13.6	12%	64% null to moderate	64.8°	–	64%	68% S DASH = 25.2 MWS = 64.9 PRWE = 23.1
Simon et al. [58]	TWD	27	6.4	22%	44% pain-free (VAS = 2.3)	99°	–	85%	89% S and VS DASH = 30.4
Hohendorff et al. [64]	TWD	36	10	19%	(VAS = 3)	81%	–	82%	90% S DASH = 25 MWS = 73
Lepage et al. [60]	Rib	10	4.6	20%	≈ 44% pain-free	≈ 98°	–	≈ 82%	90% S and VS
Obert et al. [62]	Rib	18	8	16%	(VAS = 2.5)	79°	–	76%	76% S QDASH = 26.3
Pequignot and Allieu [9]	APSI®	20	12	–	75% pain-free	100°	–	77%	100% VS
Our study	APSI®	33		27%	75% pain-free (VAS = 1.2)	101° (77%)	47° (73%)	85%	90% S and S QDASH = 19.5 MWS = 80 PRWE = 17.5

No.: number; 4CF: 4-corner fusion; PRC: proximal row carpectomy; TWD: total wrist denervation; Rib: costal cartilage autograft; Clt: contralateral; ROM: range of motion; F: flexion; E: extension; RD: radial deviation; UD: ulnar deviation; VS: very satisfied; S: satisfied; MWS: Mayo wrist score; QDASH: quick disabilities of the arm, shoulder and hand; PRWE: patient-rated wrist evaluation; –: no data.

is associated with longer duration donor site morbidity (general anesthesia, pneumothorax risk) and its long-term results seem worse overall than those of the APSI® [32,33]. Dislocation of the rib graft and osteoarthritis progression are also common complications of rib cartilage autograft. Indeed, at 8 years' follow-up, Obert et al. found DISI in 76% of cases with an average scapholunate angle of 87.1° (normal value between 30° and 70°) [33].

4.3.6. Vascularized bone graft from the medial femoral condyle

This last, rarely used alternative is a recent technique, first prescribed for scaphoid non-union in 2000 [34]. It may be the preferred technique in indications of proximal scaphoid non-union when conservative treatments have failed or are obsolete. Several studies of vascularized medial femoral condyle grafting reported very good results in scaphoid non-union with proximal pole necrosis and carpal collapse [35]. Kalicke et al. have gone further by proposing an osteochondral graft to treat early stage-1 osteoarthritis (1 case) [36].

4.4. Our indications and technique for implanting the APSI

4.4.1. Indication

The implant is not intended to correct DISI but rather to slow its development. The best indications are proximal scaphoid non-union (zone 1 and 2 of Schernberg's classification) [12] or when conservative treatments have failed or are obsolete (scaphoid proximal pole that cannot be conserved since it is too small and/or fragmented) and SNAC and SNAC-like wrists (stages 1 and 2) without major carpal misalignment (RLA $< 25°$).

We have reservations regarding the indication of SNAC wrists, which should be limited to cases where the carpus is still aligned (RLA $< 20–25°$, without dorsal subluxation of the capitate). Small and medium bone cysts are not contraindications for APSI, as they can be filled during the same operation with bone from the scaphoid proximal pole, the radial styloid process or a bone substitute.

4.4.2. Approach

We now recommend a radial approach between the 1st and 2nd extensor compartments (40). This provides better visibility and avoids damaging the dorsal and palmar capsular ligaments, while allowing their retensioning if necessary. The wrist is placed on a tourniquet in ulnar deviation. This approach allows styloidectomy to be performed as an element of the surgical approach.

4.4.3. Osteotomy of the scaphoid's proximal pole

Bone resection should be as minimal as possible. The cross section should be at the edge of the healthy cartilage, slightly oblique in the medial plane. The anteroposterior section of the scaphoid must be parallel to the radial surface (slightly backward oblique).

4.4.4. Implant positioning

After scaphoid resection, it is essential to use the trial implant to look for and remove any cam effects, especially with the capitate's head. If the latter protrudes, it can be reamed during surgery. In some cases, if there is no scaphocapitate osteoarthritis, this joint line can be preserved by making a cut tangential to it. The implant must be positioned with its major axis in the sagittal plane.

4.4.5. Implant sizing

The correct implant size is determined verifying the alignment of the carpal bones based on the three arcs of Gilula. They must be harmonious without breaking or shifting. If in doubt, it is advisable to use a smaller implant, especially since it always seems smaller on X-rays than in reality (the outer pyrocarbon layer is radiolucent).

4.4.6. Closure

In case of capsular damage compromising its closure (distension, deficiency), the radial capsular compartment can be strengthened by making a dorsal retinaculum graft with a radial hinge. This is then passed under the 1st extensor compartment and secured to the rest of the dorsal capsule.

5. Conclusion

Radioscaphoid arthroplasty using the APSI® implant preserves the harmony of the wrist bones, enabling long-term pain relief by maintaining strength and mobility in SNAC-1 and SNAC-2 wrists. It is an effective technique for preventing osteoarthritis. Though seemingly simple, it is a demanding (21% revision rate), non-iatrogenic procedure, allowing for a quick return of function. It does not preclude further surgery in case of failure. Close adherence to the surgical indications and techniques should grant satisfactory, durable results, comparable to scaphoid excision with four-corner fusion and PRC. APSI® now has a place in the therapeutic arsenal of early stage arthritic wrists. Studies on larger cohorts, in younger patients, and over the longer term are needed to broaden its indication and make it a reliable option in the future.

Uncitedreferences

[14,15].

Disclosure of interest

P.B. has a conflict of interest to disclose with Tornier/Wright Medical Company. The other authors declare that they have no competing interest.

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