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Medium- and long-term outcomes for hand and wrist pyrocarbon implants

Philippe Bellemère

Abstract

The article reviews the techniques and surgical outcomes of arthroplasties of the metacarpophalangeal, carpometacarpal and the wrist joints. In my patients, interposition pyrocarbon implants quickly achieve functional recovery and do not deteriorate time. Bony and articular tolerances are remarkable. These implants are a valid alternative to conventional arthroplasties, such as trapeziectomies, silicone implants and total joint replacements. Because of the implant's small size, the surgery can be done through minimally invasive approaches especially for young and active patients. A technical key is to properly manage the bone surfaces of the joint and the peri-articular soft tissues to avoid early implant instability.

Keywords

Pyrocarbon, implant, thumb, wrist, finger, arthroplasty, outcomes

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Introduction

The elastic modulus of pyrocarbon is close to that of cortical bone. Pyrocarbon is smooth, resistant to wear and has well-known bio-tolerance stemming from its use in cardiac valves in the 1950s. These facts make it attractive to hand surgeons for arthroplasties in hand and wrist. Furthermore, the properties of pyrocarbon make it suitable for a direct sliding interface between implant and cartilage or subchondral bone. However, technical manufacturing constraints limit the number of possible designs of implants, which are produced so far by two manufacturers. Since the first use of a pyrocarbon metacarpophalangeal (MCP) joint implant in 1979 (Beckenbaugh, 1983), around 15 pyrocarbon implants are now available for various arthroplasties in the hand and wrist (Bellemère, 2018).

These implants can be divided into two categories. The first is total and hemiarthroplasty implants that replicate the concept of non-constrained arthroplasty with an intramedullary stem for fixation. As pyrocarbon cannot be attached directly to the bone, fixation of total or hemi-prostheses with intramedullary stems is difficult and unpredictable. Furthermore, a hemiarthroplasty implant that can be used in the trapeziometacarpal (TMC) joint tends to lengthen the lever arm of the thumb, possibly leading instability. The second category of interposition implants is free spacers. They are less bulky and offer a large joint contact surface. Due to the lack of bone fixation the implant moves during the joint motion, and its stability may be a concern.

The Editor in Chief (Jin Bo Tang) invited me to write this review article. My experience and that of the senior colleagues of my team are summarized for the techniques and outcomes with hand and wrist pyrocarbon implants we began using in 2002. All the joint implant surgeries in this review were performed in our unit by one of eight senior surgeons, who are of expertise level 3 or above for the procedures (Tang, 2009; Tang and Giddins, 2016). The majority of the patients who have mid- or long-term follow-up reported in this review were treated by me.

The implants that we use

Interposition implants are our preferred choice because they allow minimally invasive surgery and spare as much as possible the bone stock and the

Institut de la Main Nantes-Atlantique, Saint-Herblain, France

Corresponding Author:
Philippe Bellemère, Institut de la Main Nantes-Atlantique, Santé Atlantique, Avenue Claude Bernard, 44800 Saint-Herblain, France.
Email: philippe.bellemere@me.com

periarticular soft tissues. They offer new options for minimally invasive arthroplasty procedures at the thumb basal joint, the wrist and the MCP joint of the long finger. Furthermore, their large joint contact surface and, for many of the interposition implants, their ability to move during the joint motion, could be a positive point to avoid permanent localization of peak constraints during rest, joint loading and movement.

Proximal interphalangeal (PIP) and MCP joint implants

With the pyrocarbon PIP total joint (two-stemmed bicondylar anatomical implants) I have faced a high incidence of reoperation (five cases out of 22 treated for osteoarthritic joint destruction). This incidence was higher than those for my silicone implant and modular resurfacing metallic–polyethylene implants for the same indication. Furthermore, despite very good functional results in some cases, radiologically they showed progressive implant migration with weakening of the cortical bone, which was a concern for the long term. Therefore, we stopped use of PIP pyrocarbon total joints. Better results are achieved so far with new modular anatomic stemmed implants that we have used for almost 9 years (Athlani et al., 2016).

For pyrocarbon MCP total joints (two-stemmed anatomical implants), we share the positive results found from the majority of published series. Since October 2009, however, we have opted to use a spherical implant (the HAPY® implant) (Figure 1). This simplified interposition is less bulky and less invasive than a total MCP joint replacement. Implantation is performed after a transverse resection of the metacarpal head distal to the collateral ligaments and transection of the metacarpal palmar edge. The resected bone is then fragmented and packed into the epiphysis and metaphysis to strengthen the bony base of the implant. Manual reamers prepare progressively the metacarpal epiphysis to match the shape and size of the final implant. No preparation of the proximal phalanx base is required, except if a uniform, slightly concave surface is needed.

Two of my colleagues and I have implanted more than 80 HAPY implants in cases of primary or post-traumatic osteoarthritis (OA) and inflammatory arthritis, silicone implant failure or pyrocarbon MCP total joint failure. Fifty-three of these implants have been retrospectively evaluated with a minimum follow-up of 3 years (unpublished data). The clinical results can be superimposed on those of the pyrocarbon MCP studies. No implants have been removed so far.

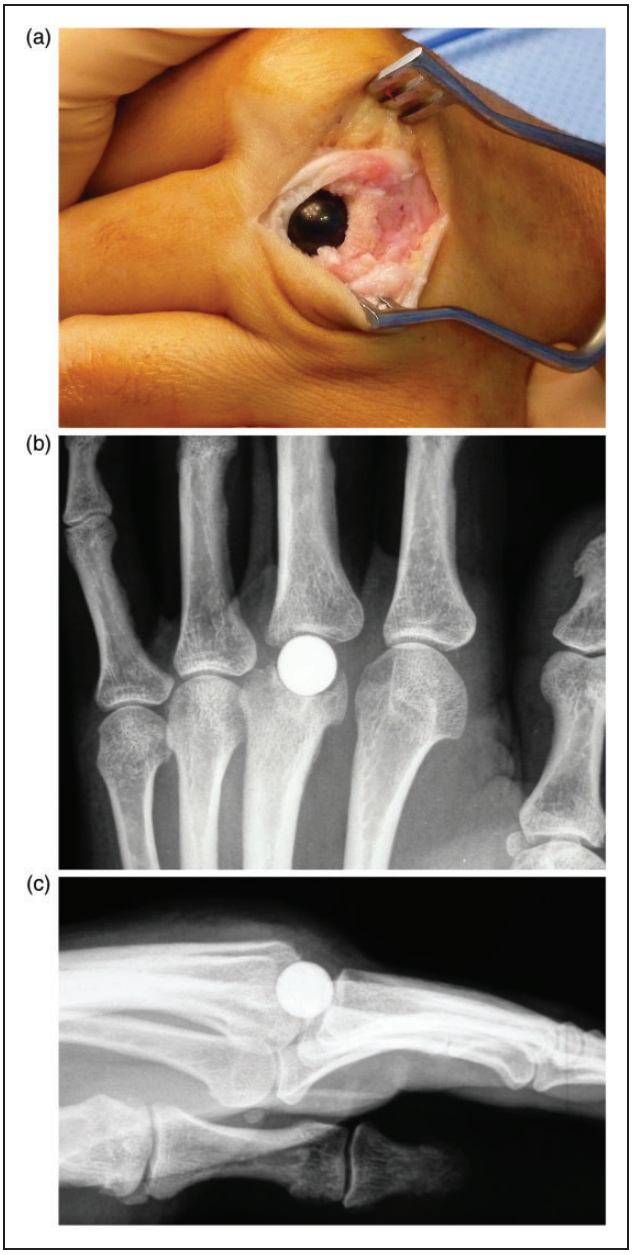

Figure 1. HAPY implant for treatment of OA of the third MCP joint of a 36-year-old manual worker. (a) Insertion of a HAPY implant. (b) and (c) Plain radiographs 9.5 years after surgery.

Radiolucent lines surrounding the implant can appear as early as the fourth month postoperatively. For inflammatory arthritis, minimal non-progressive subsidence at the metacarpal metaphysis may occur, as well as metacarpal or phalangeal remodelling without any clinical impact. The HAPY implant is our first choice for arthroplasty of the MCP joint for OA and selected cases of rheumatoid arthritis.

TMC and scaphotrapeziotrapezoidal (STT) implants

One of the main goals of the TMC joint pyrocarbon implants is to avoid shortening of the thumb column in order to limit weakness and MCP joint hyperextension. Hemiarthroplasties for the TMC joint with metacarpal pyrocarbon implants exist with several models. They all lengthen the lever arm of the metacarpal and possibly lead to joint and implant instability. For this reason and those explained previously, we prefer to use interposition pyrocarbon arthroplasties for the treatment of TMC joint OA.

Trapezium pyrocarbon spacer (Pi2® or Pyrodisk®)

The Pi2 implant is a 9-mm thick ellipsoidal implant that comes in two sizes. The Pyrodisk implant is a slightly biconvex disc with a large opening in its centre for a ligamentoplasty. It exists in various diameters and thicknesses.

These two spacers are used when the trapezium is not salvageable due to its collapse or severe arthritis. A total trapeziectomy is performed through an anterior approach. A partial trapezoidectomy (1/3) permits medialization of the implant and addresses scaphotrapezoidal OA. A dorsal capsuloraphy by plication reduces redundancy of the capsuloperiosteal pocket.

Stabilization of the implant is crucial. For the Pi2, a ligamentoplasty is performed using hemi-bands taken from the abductor pollicis longus and flexor carpi radialis (Bellemère and Ardouin, 2011) (Figures 2 and 3). For the Pyrodisk, a Goretex CV/0 thread runs through the hole of the implant and around the flexor carpi radialis tendon and then around the implant (Figure 4).

The Pi2 implant is my preference for the treatment of basal thumb arthritis. In comparison with trapeziectomy, the patients achieve earlier functional recovery and have better overall satisfaction (Alligand-Perrin et al., 2010). At mid- and long-term follow-up (Agout et al., 2016), pain was 1.6/10 and the QuickDASH score was 20/100, while grip strength was 24 kg and key pinch was 5.9 kg. No worsening of the preoperative MCP joint hyperextension was found. No implants have required revision. Radiologically, 4% of the implants were dislocated, and 48% (29% at 5-years follow-up) showed bone remodelling, mainly of the scaphoid base, and without functional repercussions.

Figure 3. A plain radiograph of a patient with a Pi2 implant at 13 years of follow-up.

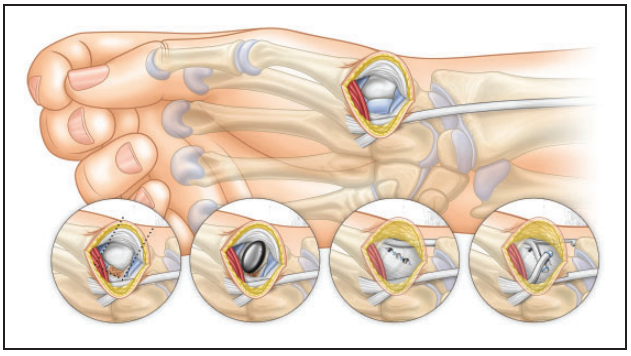

Figure 2. A drawing of a Pi2 implant after total trapeziectomy.

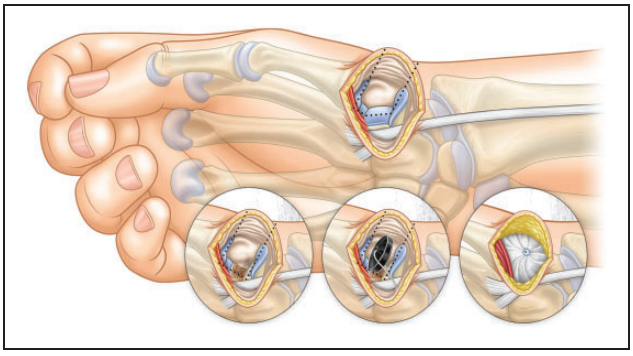

Figure 4. A drawing of a Pyrodisk implant after total trapeziectomy.

Stabilization of this implant is a concern. When surgery is not well performed, there is a high incidence of early dislocation leading to a revision rate of to 33% (Cheval et al., 2013; Van Aaken et al., 2016). For about 4 years I have replaced the Pi2 with the Pyrodisk because the required stabilization is less invasive, easier and quicker to perform (Chaise, 2011). However, in my experience with more than 80 implants, the failure rate (revised by implant removal) for chronic pain lasting beyond 1 year was about 6%, and I found that the overall outcomes, especially regarding pain, seemed inferior to the Pi2 implant. Since the Pyrodisk implant is more constrained than the Pi2, pain may be associated with excessive stress peaks.

In case of severe Z deformity of the thumb column, pyrocarbon trapezium spacers are not able to restore thumb length and realign the metacarpal base. Other techniques are preferable.

Interfacing the TMC joint with the Pyrocardan® implant

In the early stages of TMC OA, Eaton's stages 1 and 2, or even in some early stage 3, a minimally invasive interfacing arthroplasty with the Pyrocardan implant is indicated. This implant is rectangular with two perpendicularly opposing tubular concave faces. This geometry is intended to replicate the TMC joint movements. The implant has a 1-mm central thickness regardless of size. There are seven variants between 12 and 18 mm wide. Its placement requires minimal intra-articular bone resection, which respects the capsule and ligamentous insertions (Maes-Clavier et al., 2014). Therefore, a stabilization ligamentoplasty is not necessary.

With a dorsal approach to the TMC joint, a longitudinal medial joint opening delimiting two capsuloperiosteal flaps is performed (Figure 5) (supplementary video 1). Bone preparation entails obliquely resecting the dorsal and palmar metacarpal beaks and then the lateral and medial trapezium horns by an orthogonal section to the thumb column axis. This allows metacarpal realignment in case of dislocation (less or equal to one-third). The joint surfaces are then milled so that the metacarpal surface has a slight spherical convexity and the trapezium surface is convex along a dorsopalmar axis. The definitive implant must completely cover the trapezium surface. Capsuloperiosteal closure should be firm but without excessive tension. It may be necessary to assist the closure with an intraosseous anchorage at the metacarpal base.

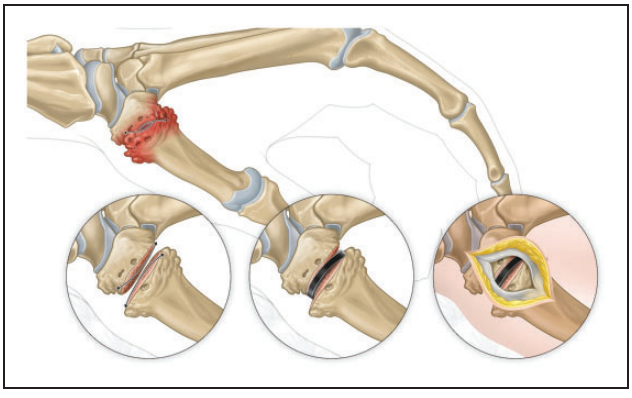

Figure 5. Surgical procedures of the Pyrocardan implant.

My preliminary series of 27 patients (Bellemère et al., 2011), with an average follow-up of 17 months, showed that all of the patients were satisfied or very satisfied. The visual analogue scale score was 1.6, the QuickDASH was 10, mobility was equal to the opposite side, and grip strength of 23 kg and pinch strength 6.4 kg were 94% and 98% of the opposite side, respectively. No revision was needed and no signs of radiological dislocation nor loosening were found.

At a minimum of 5-year follow-up (unpublished study), our prospective series of 62 patients, including 27% manual workers and 31% fixed dislocation of the first metacarpal (Figure 6), found marked improvement in pain (0.6/10) and QuickDASH score (7/100) with no differences in grip strength, pinch strength or mobility compared with the opposite side. Two patients had to have their implant removed and converted to a trapeziectomy after about 1 year for chronic pain. The 5-year implant survival rate was 97%. Favourable results with the Pyrocardan have been also achieved by others (Erne et al., 2017; Russo et al., 2016). Good outcomes require a learning curve (Lauwers et al., 2016; Odella et al., 2015).

Most of the patients we have treated for TMC OA were eligible for a Pyrocardan arthroplasty. However, this implant is not indicated in case of severe collapse or core modification (cyst) of the trapezium or in the case of a subluxation of more than one-third of the metacarpal base.

Pyrocarbon implants for surgical failures of treatments for TMC OA

Failed TMC total prosthesis: The Pi2 implant can be interposed after a total or partial trapeziectomy and even in cases of metacarpal medullary shaft bone grafting. Our experience of 25 cases reviewed at 5.5 years (Péquignot et al., 2011) showed that these procedures were minimally invasive, pain relieving and preservative of thumb function and length.

Figure 6. Pyrocardan implant in TMC joint for OA in a 47-year-old manual worker. (a) Preoperative plain radiograph showing OA with subluxation. (b) and (c) Radiographic views at 7 years of follow-up.

The potential implant instability problems seem to have been solved by the encapsulation created by previous arthroplasty.

Failed trapeziectomies: These are mostly related to metacarpal collapse causing a painful conflict with the scaphoid and/or the trapezoid. If the metacarpal collapse is reducible, a Pi2 interposition implant may be performed. Otherwise an interposed Pyrocardan implant, which is thinner, has been a simple and effective solution for eight patients operated by two surgeons in our unit (Figure 7).

Figure 7. Pyrocardan implant for scaphometacarpal interposition of failed trapeziectomy.

Scaphotrapeziotrapezoidal (STT) joint

STT arthroplasty is a reasonable option to maintain scaphoid mobility and limit intercarpal instabilities exacerbated by excessive scaphoid flexion and height loss or by ankylosis of the trapezotrapezoidal joint in extension. The first pyrocarbon implant for the STT joint, called STPI® (ScaphoTrapezial Pyrocarbon Implant), was proposed in 2000 (Péquignot et al., 2005). Its implantation requires the resection of the distal 3–4 mms of the scaphoid according the size of the implant. This circular disc has two surfaces, one convex for the trapezotrapezoidal joint and the other concave for the scaphoid. This shape may lead to instability of the implant as we have seen and reported in a few cases. Since March 2010 we use the Pyrocardan

implant in the STT joint because its two concave surfaces make it more stable, its rectangular shape is closer to that of the STT joint, its 1-mm thickness reduces bone resection, and it saves the scaphoid surface and its distal ligament attachments, thereby preserving its height and kinematics (Figure 8). Using an anterior approach for its implantation allows for treatment of the frequently associated tendinopathy of the flexor carpi radialis tendon (tenosynovitis, partial or complete rupture) at the level of the STT joint (supplementary video 2).

Relief of pain and function recovery were achieved in our 22 patients reviewed at an average follow-up of 36 months. Average time for functional recovery was 7.2 weeks and the patient satisfaction score was 9.5/10 (Gauthier et al., 2017). No implant instability was found, and preoperative intracarpal instability was partially or completely corrected.

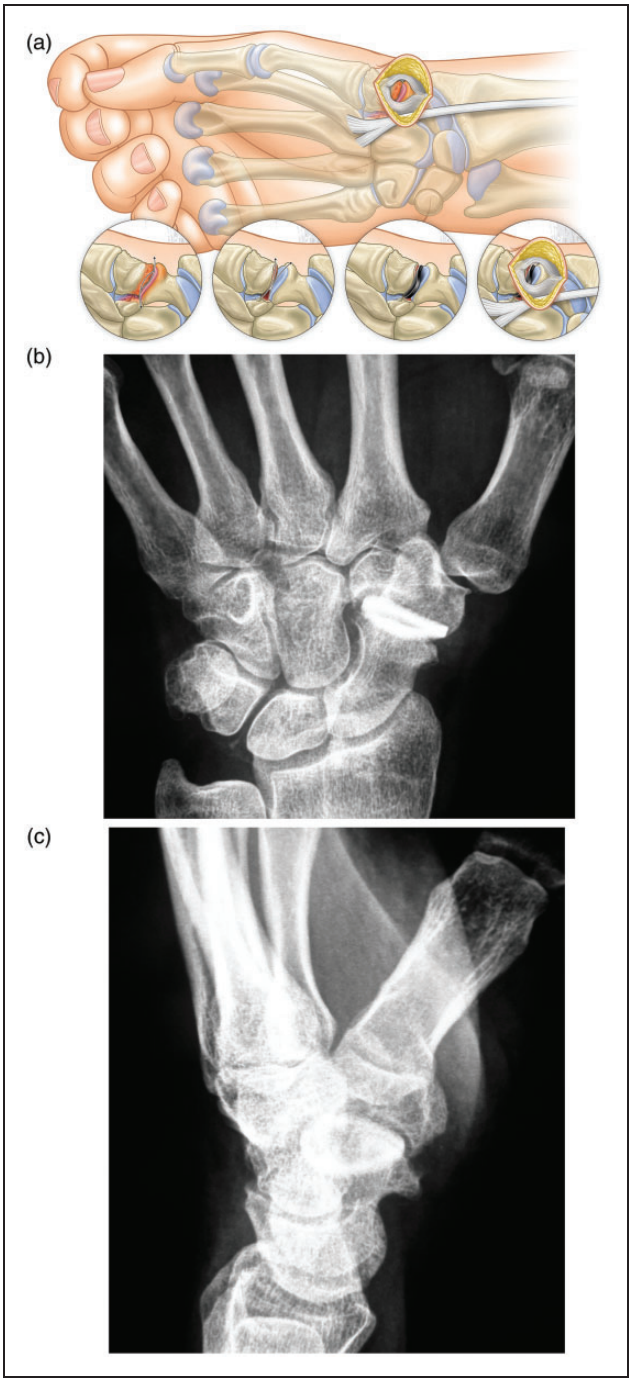

Figure 8. STT joint interposition with a Pyrocardan implant. (a) A drawing of the principle procedures. (b) and (c) Radiographic views after 6 years.

Pantrapezial joints

In case of symptomatic pantrapezium OA, in the early stages, the height and the trabecular structure of the trapezium may be normal. In that case, preserving the trapezium is possible with a 'burger arthroplasty', consisting of a double arthroplasty using Pyrocardan implants in the TMC and STT joints (Figure 9). For each joint we recommend the approach as described above. In order to preserve the bone vascularization as much as possible, caution must be paid to avoid extensive soft tissue dissection.

Figure 9. A radiograph showing the burger arthroplasty.

The clinical and radiological presentation of pantrapezium OA for a 'burger arthroplasty' is not common, and we have operated on 23 patients in 10 years. It may be a satisfactory alternative to other more invasive options. Our results at the midterm (unpublished data) have shown an improvement of QuickDASH and Patient Rated Wrist Evaluation (PRWE) scores, respectively, of 41 and 42 points, a better grip and pinch strengths of 26 kg and 6 kg, and no MCP joint hyperextension. One patient required revision trapeziectomy following trapezium collapse. A preoperative CT-scan can check on the trapezium structure in case of doubt.

Wrist implants

Partial scaphoid Implant

The APSI® (Adaptive Proximal Scaphoid Implant) replaces the proximal scaphoid and creates a radioscaphoid arthroplasty. Designed in the 1990s, it was the first pyrocarbon wrist implant (Péquignot et al., 2000). It is indicated for avascular necrosis or radioscaphoid OA in early stage of scaphoid nonunion avanced collapse (SNAC) or scapholunate advance collapse (SLAC). Because of its ovoid shape, this mobile spacer, existing in three sizes, adapts its position according to the wrist's degree of inclination and flexion/extension (Figure 10). It is designed to treat radioscaphoid arthritis, counter carpal collapse and delay osteoarthritic progression.

For its implantation we prefer to use a radial approach, which is less injurious to the palmar and dorsal wrist ligaments than an anterior or dorsal approach. A styloidectomy is required if styloscaphoid OA is present. After resection of the scaphoid proximal pole, the implant area is milled to obtain congruence and to avoid cam effects. In case of doubt between two sizes, the smaller one is preferred to avoid excessive loads on the implant, which are potential sources of pain and implant instability. No ligamentoplasty is required, and postoperative immobilization or activity restrictions do not exceed 6 weeks.

We do not recommend this implant where there is a marked dorsal intercalated segmental instability, especially in SLAC wrists in which intracarpal instability may induce a postoperative implant instability and an uncontrolled progression of OA. Otherwise in indications of stage 1 and 2 SNAC or proximal pole scaphoid avascular necrosis, the APSI implant is a valid alternative to proximal row carpectomy and four-corner arthrodesis in the medium and long-term (Gras et al., 2012; Péquignot and Allieu, 2011; Santos et al., 2018). In our series of 33 patients with stage 1 SNAC (95%), with a mean follow-up of 10 years (5.8–13.4), flexion–extension range was 101°, pain was at 1.2/10 (0–6) on VAS and wrist strength was 86% of the contralateral side (Aribert et al., 2019). Ninety-six per cent of patients were satisfied or very satisfied, with a Mayo Wrist Score of 80/100 and a PRWE score of 18/100. Four patients had early implant dislocation. Two of them required reoperation. Carpal height was conserved in the majority of cases and spontaneous OA progression could be delayed by interposition of the APSI implant. It was observed radiologically in 25% of cases, 50% of which required surgical revision by scaphoid excision

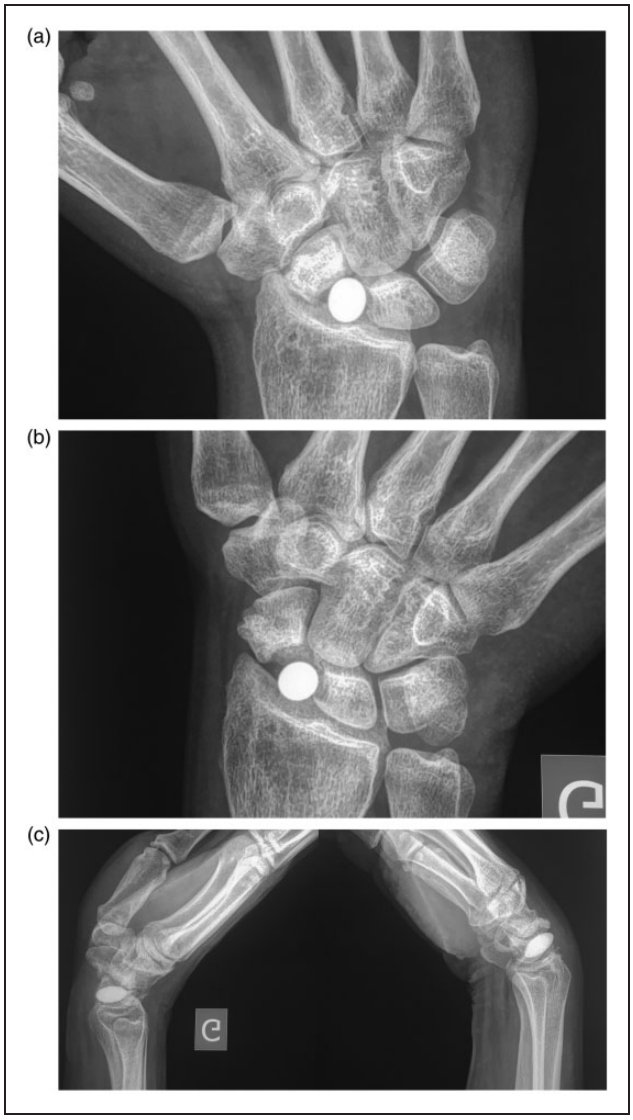

Figure 10. APSI implant after failed treatment for non-union of the proximal scaphoid. Dynamic radiographic views 5 years after surgery. (a) The wrist in radial deviation. (b) The wrist in ulnar deviation. (c) Lateral views in wrist flexion and extension.

with four-corner arthrodesis. Radiologically, notch-shaped bone remodelling of the capitate head opposite the implant occurred in 40% of cases without any clinical repercussions.

Radiocarpal arthroplasty with Amandys® implant

The Amandys implant is a free spacer that creates a new type of radiocarpal interposition arthroplasty (Bellemère et al., 2012a). The implant is ellipsoidal with a quadri-elliptic surface creating two asymmetric convex joint surfaces. The radial surface convexities are more pronounced than those of the mediocarpal surface. The implant comes in eight sizes. It replaces the lunate, 2/3 of the proximal scaphoid, and the proximal portion of the capitate. By preserving the triquetrum, the wrist's main extrinsic ligaments are preserved (Figure 11). The implant has no bone or ligament fixation, and its stability is ensured by its congruence with the radial and midcarpal bone surfaces, by the wrist's posterior and anterior capsuloligamentous structures, and by the bone contours laterally. Preoperative anatomical radiocarpal alignment and preserved and functional periarticular structures are essential in order for this type of arthroplasty to succeed. Amandys was proposed as an alternative to a total wrist prosthesis arthroplasty or total wrist arthrodesis in many indications of extensive radiocarpal and midcarpal damage of osteoarthritic, rheumatoid and inflammatory or post-traumatic origin. It can also be used to salvage failed wrist surgery (partial wrist fusion, silicone implant, proximal row carpectomy or total wrist replacement) (Bellemère et al., 2012b).

The implantation technique requires a learning curve (supplementary video 3). A dorsal approach with an L-shaped capsulotomy preserves the dorsal radiocarpal and intercarpal ligaments. Special attention must be paid to manage properly the periarticular soft tissue release, especially the palmar capsule, during the bone resection. In cases of severe distention or tear, plication or suture reinforcement may be necessary. The bone cavity for the spacer must be prepared to prevent ovoid cam effects on the implant that could create instability. Peroperative fluoroscopy is useful to check the position of the implant during the passive mobilization of the wrist. The ulnocarpal height should not be increased, which would result in an over-constrained implant that is too thick. In case of doubt, selection of a smaller implant size is preferable. Postoperative immobilization does not exceed 6 weeks.

Our 10-year experience with the Amandys implant, operated by all eight senior surgeons on the team, includes more than 200 arthroplasties. Two cases were converted in total wrist arthrodeses due to

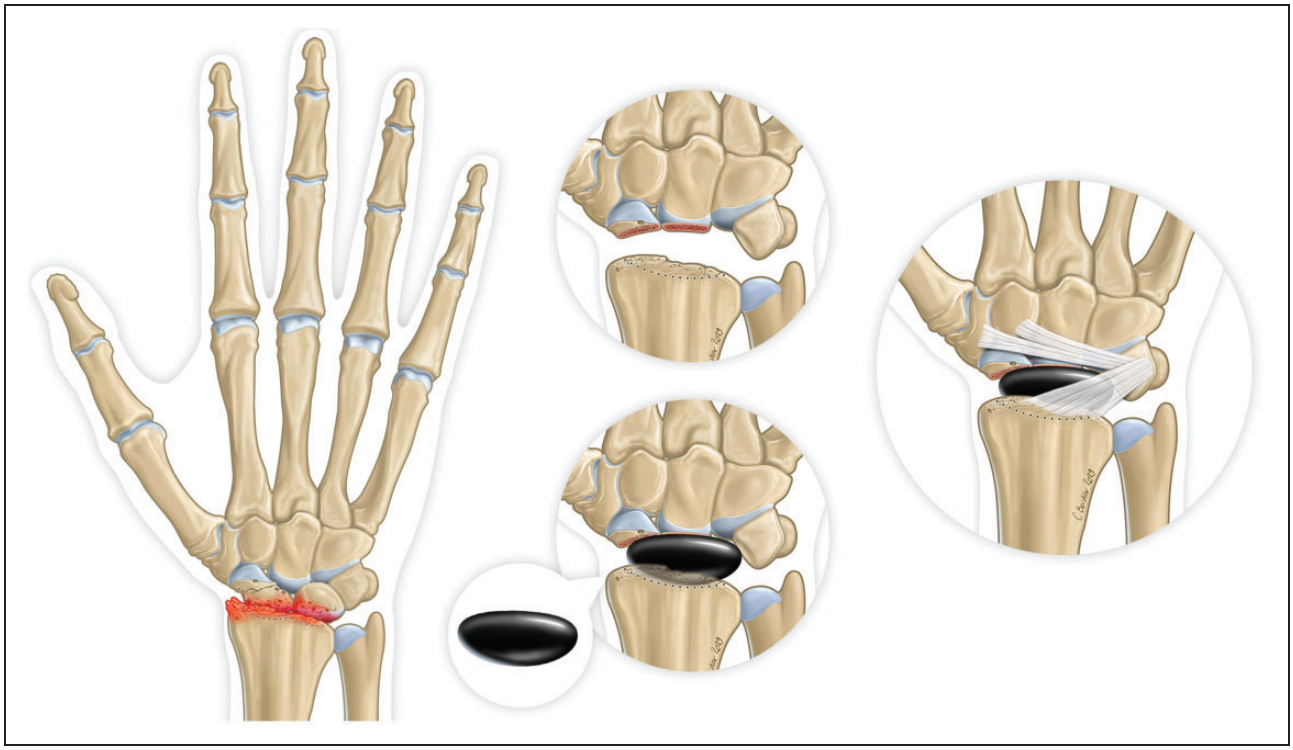

Figure 11. A drawing showing surgical procedures of the Amandys implant.

implant instability with persistent pain. The revision incidence for early implant instability and secondary repositioning was 6%. A series of 51 patients evaluated with a minimum of 5-year follow-up (unpublished data) showed a grip strength of 20 kg, which was 68% of the opposite side (12 kg preoperatively). The flexion–extension arc was 75° (66° preoperatively). The PRWE was 27/100 (63/100 preoperatively), the QuickDASH 34/100 (63/100 preoperative) and the average VAS was 2.3/10 (6.5/10 preoperatively). Comparison of results at 2 years and at 5 years postoperatively found a significant improvement in grip strength, PRWE and QuickDASH scores between these two periods. The radiological results have shown no subsidence or misalignment of the implant over time (Figure 12).

These encouraging results prompted us to extend Amandys indications to less severe wrist damage as an alternative to a four-corner arthrodesis procedure in grade 3 SLAC, scaphoid chondrocalcinosis advanced collapse (SCAC) and SNAC wrists. A comparative series from two of us (not published) of 20 patients with a mean age of 65 years and a mean follow-up of 7 years showed a quicker functional recovery and better improvement of the range of motion with the Amandys implant than those after four-corner fusion.

We do not have experience with the RCPI® (Resurfacing Capitate Pyrocarbon Implant), which is a stemmed hemiarthroplasty for the head of the capitate placed after proximal row carpectomy (Marcuzzi et al., 2014). We always prefer to save as much as possible of the bone stock and the ligaments of the wrist and use a free interposition implant in a less invasive procedure.

Considerations

Pyrocarbon interposition implants have showed in our practice their perfect bony and functional

Figure 12. Amandys implant for septic arthritis sequelae of the left wrist of a 63-year-old woman. (a) and (b) Preoperative radiographs. (c) Radiograph 3 months postoperatively. Inserted is the lateral view. (d) Radiograph at 9 years follow-up. Inserted is the lateral view. The patient had active wrist flexion of 30° and active wrist extension of 50° at 9-years follow-up.

tolerance. Results are acquired relatively quickly compared with some conventional solutions and do not seem to deteriorate over the medium and long-term. In fact, they tend to improve with respect to certain functional criteria. Because of their small size, the implants offer new perspectives for minimally invasive arthroplasties in hand and wrist. Thus, the indications for some of these arthroplasties may be extended to young and active individuals. In case of failure, these implants do not preclude revision surgery by traditional techniques.

For these reasons, in the last 15 years our practice has changed regarding the treatment of destroyed joints in hand and wrist. Motion preserving procedures with pyrocarbon interposition have always been our preference when possible. Total joint arthrodeses are not performed any more for the TMC joint nor in the wrist, except for elective cases not eligible for an interposition (major bone loss and/or instability in rheumatoid arthritis or post-trauma). Partial wrist arthrodeses are less frequently indicated, especially for patients over 60 years old. Results from a pyrocarbon interposition look better with less complications. Total wrist replacement is no longer our option. We could not achieve a satisfactory functional result, and loosening is a concern. Total prosthesis for the TMC joint has very few indications in our practice – only to lengthen and stabilize the thumb column in severe Z deformity if the trapezium is suitable for a cup insertion. We still use PIP joint total prosthesis with new modular metallic and polyethylene implants. Silicone implants for the PIP or MCP joint are reserved for the rarely required salvage procedure.

Stability of pyrocarbon interpositions might be a concern as these implants are not attached directly to bone or soft tissues. Stabilization depends on the targeted indication and especially on the implantation technique, which must be precise and requires a learning curve.

Other types of arthroplasty with pyrocarbon interposition that we use for pisotriquetral, capitolunate or distal radioulnar joint have not been included in this review because the number of cases is small or the follow-up is too short. Meanwhile their short-term results are promising (Bellemère et al., 2018; Ferrand and Bellemère, 2013; Garcia-Elias, 2007).

Long-term comparative studies with other types of arthroplasty or alternative solutions will define the real place of pyrocarbon implants in the therapeutic arsenal. Their benefits, risks and cost must be considered. In addition, detailed experimental studies focused on the tribology and histology of the sliding interface between implant and cartilage, subchondral bone or cancellous bone are essential for a better understanding of the biomechanics and tolerance of these implants.

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Supplemental material Supplemental material for this article is available online.

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