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PIP Joint Replacement with a Pyrolytic Carbon Implant

Introduction

From the 1960s, finger joint prosthetic reconstruction has been mainly obtained using single-block silicone spacers, whose stems are free, with gliding into the medullary canal (piston effect) according to the biomechanical concepts and models expressed by Swanson over 30 years ago (1). These prostheses represent one of the most frequently used medical devices in rheumatoid patients requiring metacarpophalangeal (MP) joint surgery. Clinical experience in the reconstruction of proximal interphalangeal (PIP) joints has been much less satisfactory. The silicone spacers do not offer lateral stability and therefore suffer from a frequent incidence of angular instability and secondary evolutionary deformity that may cause breakage of the stem at the junction with the central body. This brings about the risk of synovial inflammatory reactions, as a response to silicone debris.

In 2001 the EEC authorized the use of the PIP joint prosthesis, designed by J. Stanley (Wrightington Hospital, Wigam, U.K.) and R. Beckenbaugh (Mayo Clinic, Rochester, MN) made out of Pyrocarbon with a graphite core. This material has been used for some time now for medical implants, being biologically inert and having a low incidence of wear and tear.

It is a bicondylar implant made of graphite with an outer Pyrocarbon layer, which represents the 1mm transparent edge visible around the prosthetic components on X-rays.

The device is a semi-constrained press-fit; the components have been designed anatomically and the device requires a minimal articular resection, which is performed in respect of the anatomic center of rotation of the joint, preserves the collateral ligaments and reduces the axial torque force on the bone-implant interface.

The proximal element has a condylar shape and is implanted after having carried out 90° transverse and 60° volar osteotomies of the distal part of proximal phalanx (P1); the distal component has a matching bicupped condylar conformation.

Discussion

There is quite a small number of mid/long-term reports of PIP joint Pyrocarbon arthroplasty (2,3,4,5,6,7,8,9,10,12,13). The opinions reported by the authors are somewhat controversial. Issues which are debated relate to: the surgical approaches, the rehabilitation regime, the evolutional X-ray findings, the assessment tools and, in brief, the overall appraisal.

Surgical approaches:

Dorsal, lateral and volar approaches are reported. Most frequently a dorsal surgical access is used. Some authors (2, 3, 5,10) prefer a lateral or volar approach and their rationale is because tendon continuity is preserved and a simpler and earlier rehabilitation can be performed.

With a dorsal approach either a longitudinal extensor tendon splitting or a V shaped tenotomy (11) is carried out preserving the central band insertion. The dorsal capsule is elevated whereas the collateral ligaments can be spared. The articular resection is then performed and the medullary canals are broached in order to implant the prosthetic components.

A lateral approach has the advantage of preserving extensor and flexor tendon integrity. The skin incision is longitudinal on the lateral aspect of the proximal phalanx and is then curved dorsally over the middle phalanx. The extensor apparatus is elevated after having severed the oblique and transverse fibers of the retinacular ligament; the tendon is then laterally dislocated preserving the bony insertion of its central band. The volar neurovascular structures are not seen and remain protected by the surrounding soft tissue. The ligament complex is elevated as a single triangular flap and proximally reflected, performing a V shaped incision whose longitudinal branch corresponds to the dorsal margin of the collateral ligament, whereas the anterior-oblique one separates the collateral and accessory collateral from the phalango-glenoidal ligament. The proximal insertion of the volar plate and the dorsal capsule are then partially released in order to laterally dislocate the joint, having the contra-lateral collateral ligament complex as a pivot point. Bone resection and medullary canal reaming are then performed and the Pyrocarbon components are implanted. The joint is reduced and the collateral ligaments are re-sutured to the phalango-glenoidal component. The retinacular ligament is sutured to the lateral band in order to complete the anatomic reconstruction of the extensor apparatus (3).

In a volar approach the palmar skin is incised in a zigzag fashion (Bruner incision). The flexor tendon sheath is exposed. A partial release of the flexor tendon sheath at the PIP joint level is performed to allow lateral retraction of the flexor tendons. The palmar plate is more commonly released from the volar rim of the middle phalanx and retracted. The accessory collateral ligaments are detached. The articular surfaces are removed in reverse order from the dorsal approach. The proximal phalangeal condyles are removed with a 60º-angled cut, and the remaining dorsal aspect of the articular surface with a vertical cut. The base of the middle phalanx is also removed with a vertical cut. This is done carefully so as to preserve the insertion of the central slip.

X-ray findings:

X-ray findings following a Pyrocarbon arthroplasty show some peculiar aspects that are the subject of discussion and can be used for classifying some predictable patterns of

evolution. Pyrocarbon implant settlement happens by means of an appositional bony process that can usually be observed on a sequential series of x-rays and takes place in the first 2 years after surgery (2,3,5,10,12). This is evidenced by the formation of a high-density bony line, which surrounds the implant stem and seals the medullary canal at the level of the tip of the stem (3,10). The adaptive bony process is a progressive phenomenon, initiated as soon as post-operative mobility is permitted, whose evolution has a finite time of development. Any physiological axial settlement – or any evidence of progressive pathological subsidence and/or loosening - is observed within such a time. No late activations of bone remodelling were reported after the dense bony peri-stem line had become evident on the X-rays.

Rehabilitation:

The rehabilitation regime is correlated to the surgical approach, as tendon and peri-articular soft tissue healing are dependent on this. A dorsal approach is the most commonly used and it requires a longitudinal or V-shaped extensor tenotomy. Mobilization is started not earlier than 4 days after surgery; a dynamic PIP joint extension splint is usually worn during the day and it is gradually adjusted to allow for 60° of PIP flexion by 4 weeks post operation. Splinting is maintained for 4 to 6 weeks. A lateral or volar approach permits an earlier and less restricted mobilization. Active joint mobility is allowed wearing a dorsal custom made static splint that limits PIP joint extension to 5° and prevents lateral deviation. Complete joint extension is to be avoided for the first two weeks, so as to favor healing of the articular ligament complex. A palmar resting splint is worn at night, keeping MP and PIP joints flexed in a resting position with the distal interphalangeal (DIP) joint extended. Four weeks after surgery activities of daily living are permitted, wearing a protective buddy-taping to the adjacent finger for 2 months; an oval eight splint can also be used to prevent PIP joint hyperextension. Hand therapist supervision is recommended for three months after the operation.

Assessment and results:

Concerning the results, some recent mid-term surveys are quite significant for the number of revised cases (2,5,9,13,15). However, there is no uniformity in assessing the outcomes and therefore a comprehensive comparison of the single data cannot be done. The following parameters were evaluated: patient's overall satisfaction, pain relief, grip and key-pinch strength, ROM, quick-DASH and Michigan Hand Outcomes Questionnaire score. The data are summarized in Table 1.

Table 1:

	Patient satisfaction	Pain Pre-op.	Pain Post-op	Grip Pre-op.	Grip Post-op	Pinch	ROM Pre-op.	ROM Post-op	DASH Pre-op.	DASH Post-op	MHQ
Bravo et al. (2007)	77% satisfied	6 (VAS)	1 (VAS)	19 kg (3 – 36)	24 kg (4 – 41)	4.4 kg (2 – 10)	40° (0°-60°)	47° (10° – 90°)			
Sweet et al. (2011)	3.4 (Likert scale)		3 (VAS)				57° (15°-95°)	31° (0°-100°)			53
McGuire et al. (2011)	4.2 (Likert scale)		Excellent Pain relief				30°	66°			
Ceruso et al. (2011)	9.2 (1-10 scale)	7.3 (VAS)	0.8 (VAS)		25 kg	6.9 kg	14.5° AROM	50° AROM	43	16	
Watts et al. (2012)	2 (PEMq)		0 (VAS)		96% of other side		25° (0°-85°	30° (0°-90°)		22 (10-48)	
Ono et al. (2012)				11±7 kg	12.4±13.5 kg	4.8 kg	43°±6	51°± 24			62
Heers et al. (2012)	All pat. satisfied		0-5 (VAS)				46°	58°			
Mashhadi et al. (2012)	All pat. satisfied		0.9 (VAS)		15 kg	7.7 kg	36° AROM 37° PROM	46° AROM 58° AROP			
Hutt et al. (2012)		4.2 rest 8.6 act.	0 rest. 0 act.				40°	45° (0°-90°)			
Tagil et al. (2013)	5.9 (COMP)	4 rest 6 act.	0 rest 1 act.	19 kg	25 kg		53°	54°	40	25	
Reissner et al. (2014)		7.6 (VAS)	0.7 (VAS)	21 kg	17 kg		36°	29°		21	

Sex ratio was 2.5:1 female:male. Etiology was predominantly osteoarthritis and post-traumatic arthritis. Some authors include RA and psoriatic patients and they do not separately evaluate degenerative and inflammatory conditions. This should be considered as a drawback in the overall assessment as soft tissue conditions and a systemic disease substantially interact with the healing process; actually, the proportion of patients with complications was significantly greater in those with a diagnosis of articular inflammatory disease (2,5). The 3rd finger is the most often involved, followed by the 4th, 2nd and 5th. The majority of the series include multi-digital arthroplasties.

Patient's satisfaction and pain relief are mostly reported as good. As a final comment, a larger number of authors will continue to use a Pyrocarbon implant (2,3,5,6,7,9,12,13), a lesser number (4, 8,10) does not support its further use.

X-ray findings were evaluated according to different scoring systems: Herren System (14), Sweet and Stern Grading System (4), Nelson Hospital scoring System (7). The implant settlement was analyzed yearly by comparing the X-rays of post-operative controls with sequential X-rays.

At the radiographic assessment radiolucent lines, subsidence and settling of the implant were evaluated. A certain number of patterns of evolution is described: no variations during time, early X-ray changes followed by unmodified X-ray findings on further controls as implants settle in a stable position (12,13), progression of implant tilting, subsidence and/or loosening (4). It should be noted that ongoing X-ray modifications were all observed during the first 18-24 months post-op (3,5,9,10). In none of the cases, did implant subsidence start later than this time when former controls had shown a stable implant condition. Implant settlement or tilting was not always related to a symptomatic condition (5,13).

As for reoperation rate, additional procedures and implant revisions are summarized in Table 2:

	N.	**ADDITIONAL SURGERY**	**REVISION ARTHROPLASTY (total failures)**
Sweet et al. (2011)	31 implants	1 excision of exostosis	4 arthrodeses 1 Silicone implant
McGuire et al. (2011)	57 implants	6 arthrolyses/tenolyses 7 FDS tenodeses	5 (9%) revision 4 Silicone implants 1 larger proximal component
Ceruso et al. (2011)	40 implants	6 tenolyses	1 arthrodesis 3 Silicone implants 1 larger proximal component
Pritch & Rizzo 2011	203 implants (203/294 from the article were pyrocarbon)	50 (24.6%) 25 arthrolyses/tenolyses 9 ligament/joint stabilization 8 FDS hemitenodeses 4 bone spur removals 1 exposed implant 1 triggering 2 extensor tendon repair	29 Revisions (14.2%) 18 revision 12 larger 4 SRA (+/- cement) 2 silicone 7 arthrodeses 4 amputation
Watts et al.	97 implants	22 (23%)	13 (13%) revision

(2012)		9 arthrolyses/tenolyses 3 percut. accessory collateral release 4 FDS tenodeses 1 central slip advancement 1 collateral ligam. reconstruction 1 retained suture	4 arthrodeses 9 Silicone implants
Ono et al. (2012)	21 implants	NO	NO
Heers et al. (2012)	13 implants	2 tenolyses	NO
Mashhadi et al. (2012)	24 implants	3 arthrolyses/tenolyses	NO
Hutt et al. (2012)	15 implants	2 tenolyses	1 amputation
Tagil et al. (2013)	89 implants	4 arthrolyses/tenolyses 2 Littler tenoplasty	4 arthrodeses (1 after silicone implant) 2 smaller components
Reissner et al. (2014)	15 implants	NO	NO

Total implant failures, requiring either conversion to a Swanson spacer or PIP joint fusion, ranged from 0 to16%. A single component substitution was rarely reported (av. 0.5 %) (3,13).

Conclusions

PIP joint reconstruction by prosthetic replacement has peculiar aspects in relation to replacement of other more proximal articulations. A clear appreciation of these can help in understanding the reasons for the inconveniences encountered in hand joint replacement surgery, whose outcomes are not yet comparable to the common standards currently obtained for other joints. Soft tissue handling and reconstruction is as relevant as the characteristics of the prosthetic device.

Potentially advantageous prosthetic features are the bicondylar semi-constrained anatomic design, which permits a limited bone resection, the press-fit non-cemented fixation, the biological compatibility and low wear proprieties of the material with a similar modulus of elasticity to cortical bone. As for soft tissue handling, the characteristics of the surgical approach should be focused, considering the maintenance

of the extensor apparatus as a key factor. Accordingly, a tendon sparing approach is to be regarded as a first choice option in PIP joint arthroplasty as it permits an anatomical dissection of the peri-prosthetic soft tissues and a stable post-operative ligamentous reconstruction, which allows an earlier and more straightforward rehabilitation of the gliding mechanisms. Finally, a standardised rehabilitation protocol is an essential tool in order to obtain a satisfactory outcome in PIP joint arthroplasty; the patient should undergo surgery only after having been informed that an immediate post-operative mobilization program will be carried out under the supervision of the hand-therapist and with the support of appropriate custom-made orthoses.

As for implant failures, two main risk factors should be considered: the axial alignment of the stems, which is to be precisely obtained intra-operatively, and the adequate sizing of the implant components, whose articular prosthetic plates should be supported by the metaphyseal cortices (3,5).

Malalignment or inadequate cortical support of the components should not be disregarded, as they will be likely amplified by the peculiar reactive remodelling of the peri-prosthetic phalangeal bone

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