Prosthetic hemi-arthroplasty for post-traumatic articular cartilage loss in the proximal interphalangeal joint

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Abstract This article discusses the indications, contraindications, and technique for proximal interphalangeal joint prosthetic hemi-arthroplasty in the setting of sub-acute or chronic post-traumatic articular cartilage loss. Two case examples are provided: one for replacement of the head of the proximal phalanx, the other for replacement of the base of the middle phalanx. This procedure serves as a recently available alternative to fusion, silicone total joint replacement, total joint arthroplasty with unlinked surface replacements, volar plate arthroplasty, hemi-condylar osteochondral autograft reconstruction, or free vascularized joint transfer.

Keywords Phalanx · Arthroplasty

Introduction

In the setting of acute proximal interphalangeal (PIP) joint trauma, repair of the articular surface is usually possible by conventional means. Unfortunately, many patients present to the hand clinic in the sub-acute or chronic phase of the injury. At this point in time, the hyaline cartilage on one or both sides of the joint may have become so damaged as to preclude functional articulation. Faced with the absence of hyaline cartilage, the surgical strategy becomes one of reconstruction as opposed to repair. At one end of the spectrum of reconstructive options is fusion. Although the operation is highly reliable, the patient must be willing to

sacrifice all motion. The options that retain motion when hyaline cartilage is missing on only one side of the joint include non-vascularized (or vascularized) osteochondral replacement. An excellent example is the hemi-hamate osteochondral autograft reconstruction of the volar base of the middle phalanx (P2) following PIP joint dorsal fracture dislocation [3, 4, 9, 10, 17]. Small series have demonstrated PIP arcs of motion between 70° and 85° with a low rate of complications [3, 17]. This operation depends on retaining some hyaline cartilage intact at the dorsal base of P2 in continuity with the shaft and, most importantly, intact hyaline cartilage on the opposing surface of the head of the proximal phalanx (P1). In chronic cases, especially if the patient has been moving the joint, the roughened surface on the base of P2 may have worn away the cartilage on the head of P1, precluding this technique. Alternative osteochondral reconstructions use one side (non-vascularized or vascularized) or both sides (must be vascularized) of the toe PIP as a partial or whole joint transfer [5, 8, 13, 14]. Non-vascularized whole joint transfers are subject to bony resorption and chondrolysis. Vascularized transfers, although providing for a viable whole joint, suffer from limited range of motion (24–25°), extensor lag (41°), and fixed flexion contractures [5, 8, 14]. Most patients are unwilling to accept the donor site morbidity in the foot for such limited motion in the finger and decline that option when offered. When both sides of the joint have lost articular cartilage, but motion is still desired, the remaining options are silicone or surface total joint replacement [1, 2, 6, 7, 11, 12, 15, 16].

The various concerns over the alternative procedures are partially addressed by having an additional option available: prosthetic hemi-arthroplasty of the PIP joint in which only the head of the proximal phalanx or only the base of the middle phalanx is replaced. The contraindications for prosthetic hemi-arthroplasty are infection and unrecon-

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structable ligament insufficiency. The indication is loss of articular cartilage, with or without the loss of subchondral bone support on the side to be replaced. If the pyrocarbon implant (Ascension Orthopedics, Austin, TX) is used, a pain-free articulation can be achieved as long as there is intact subchondral bone on the side not being replaced, even if that surface is devoid of hyaline cartilage. This is a unique feature of this operation and one not to be overlooked as the situation can easily occur in late presenting dorsal fracture dislocations. The prosthetic hemi-arthroplasty option plays a particularly valuable role as a planned backup strategy when taking a chronic patient to the operating room for an intended hemi-hamate arthroplasty, but the status of the cartilage on the head of the proximal phalanx remains to be determined.

Surgical Technique

The surgical approach is almost identical to that of a hemi-hamate arthroplasty. A volar Bruner incision is used, opening the flexor sheath between the A2 and A4 pulleys, reflecting the flexor digitorum sublimis and flexor digitorum profundus to either side. The volar plate is detached at its distal margin, and the PIP joint is hyper-extended in the “shotgun” approach. To achieve full hyper-extension, partial release of the accessory and proper collateral ligaments is needed. This may be done either at the head of the proximal phalanx or the base of the middle phalanx depending on the side being replaced. One should perform the release on the side to be replaced, leaving the anatomy of the ligament insertion untouched on the side not to be replaced. Preparation of the recipient phalanx is then carried out with small saws, burrs, and hand instruments to implant the largest size possible that can be fully seated without fracturing the phalanx. When using the trial implant, the surgeon should remember that the actual implant is slightly larger than the trial. This means that if the trial barely fits, then the final implant is at risk of fracturing the phalanx when seating it fully. It is critically important to fully seat the implant in hemi-arthroplasty, perhaps even more so than in total joint arthroplasty. One of the subtle advantages of hemi-arthroplasty over total joint arthroplasty is the greater ability to reproduce normal joint mechanics by preserving more of the normal anatomy, one half of the bony anatomy, and the attached ligament complex. In theory, this should reduce the transmission of non-physiologic loads to the single bone–implant interface. This offers the potential for greater longevity of the bone–implant interface at the stem of the implant, provided the articular interface between pyrocarbon and subchondral bone wears equally well.

Rehabilitation

The volar approach allows immediate full range motion without the need to protect an extensor tendon that has been transgressed by the surgical approach. One inch cohesive elastic wrap is used to control swelling in the digit and active rather than passive motion is emphasized. Assisted motion is permitted from the outset, but is applied with a single digit of the therapist to the middle phalanx of the operated digit while the patient continues to make his own active contraction. When the patient is exposed to a more dangerous environment, added protection may be used. The choice of protection is dependent on factors observed at the time of surgery and ranges from simple side to side strapping to the adjacent digit to hard splinting in the sagittal plane, or even both. The need for such added protections should not extend beyond 6 weeks from surgery. Formal strengthening can begin at that time as collateral ligament integrity is sufficient. Ongoing range of motion (ROM) and strengthening therapy then continues as the patient transitions over to a home program that he should continue until at least 3 months postoperatively.

Case Example: Head of Proximal Phalanx

The patient was a 58-year-old right hand dominant pastor who sustained a side grinder injury to the left long PIP joint dorsally resulting in central slip transection and loss of the dorsal 60% of the head of the proximal phalanx. He was operated elsewhere with central slip repair but no articular reconstruction at all and started on joint motion therapy. He presented to our clinic 4 months later with a painful, stiff joint and complaints of overall loss of left hand function. Range of motion at the PIP joint was 40° flexion, 15° extension. Radiographs demonstrated the articular loss from the head of the proximal phalanx and loss of joint space reflecting the incongruent wear against the base of the middle phalanx over the intervening 4 months of attempted motion (Fig. 1). The patient was offered the range of surgical options listed in the preceding discussion. Of the available options, the only ones he was interested in were osteochondral autograft replacement, prosthetic replacement, or fusion. He was taken to surgery with osteochondral autograft as the preferred procedure dependent on adequate hyaline cartilage remaining on the base of the middle phalanx. If the cartilage of the middle phalanx had been worn by the 4 months of motion as expected, the second choice procedure was prosthetic hemi-arthroplasty, provided the middle phalanx had maintained subchondral integrity. This proved to be the case, and hemi-arthroplasty was performed. The extensor tendon was left intact and tenolysed, having healed from the prior procedure, permitting immediate PIP range of motion following the

Fig. 1 Preoperative view case 1: missing the dorsal segment of the head of the proximal phalanx and loss of articular cartilage from base of the middle phalanx

hemi-arthroplasty. The patient has been followed for 4 years now with no evidence of subsidence of the prosthesis into the proximal phalanx or erosion of the prosthesis into the base of the middle phalanx (Fig. 2). Range of motion at the PIP joint is 0–90°. He declares no pain and states he has normal use of the hand including participation in competitive fencing.

Case Example: Base of Middle Phalanx

The patient was a 48-year-old mechanic who sustained a dorsal fracture dislocation of his dominant right ring PIP joint in an accident involving a drill. He had an attempt elsewhere at extension block pinning that failed and resulted in a persistently incongruent joint due to both dorsal subluxation as well as impacted fracture fragments at the volar base of the middle phalanx (Fig. 3). He presented to our clinic for alternative options at 10 months after the original injury stating that he had too much pain and loss of function to leave the digit in its current state. Range of motion at the PIP joint was 30–70°. After presentation of the full set of reconstructive options, he selected as his preferred treatment a hemi-hamate arthroplasty hinging upon the preservation of

Fig. 3 Preoperative view case 2: chronic dorsal fracture dislocation of the PIP joint after failed extension block pinning

hyaline cartilage on the head of P1. After 10 months, expectations were limited that the cartilage would prove adequate and hemi-arthroplasty was set as the primary backup procedure. At the time of surgery, only eburnated subchondral bone remained on P1, and hemi-arthroplasty of the incongruent base of P2 was performed. The patient started immediate motion therapy. At 18-month follow-up, he reports no pain and states that he has normal use of the hand (Fig. 4). Active range of motion at the PIP joint is 0–95° (Fig. 5).

Discussion

The proximal interphalangeal joint is a site of frequent trauma, the majority of which is relatively simple and straightforward to treat. Isolated cases arise where confounding factors such as unique mechanism of injury, delay in presentation, and failed prior surgery conspire to render the standard treatment options no longer viable. It is at such junctures that alternatives are needed. This article presents one alternative that fills a missing niche in the treatment armamentarium. The specific niche falls in between a case that can be successfully reconstructed with an autogenous osteochondral graft such as a hemi-hamate arthroplasty and a case that would otherwise require total joint arthroplasty

Fig. 2 Postoperative view case 1: proximal phalanx prosthetic hemi-arthroplasty demonstrating a congruent PIP joint and no erosion at long-term follow-up

Fig. 4 Postoperative view case 2: middle phalanx prosthetic hemi-arthroplasty demonstrating a congruent PIP joint

Fig. 5 Clinical range of motion case 2 at 18 months postoperative

or fusion. Vascularized toe joint transfers (partial or whole) can fill the same niche but are rarely chosen by American patients when offered [5, 8, 13, 14]. The indication for pyrocarbon hemi-arthroplasty differs from a case that can be solved by autogenous osteochondral grafting because the autograft can only be placed on one side of the joint. Non-vascularized whole joint transfers fail by chondrolysis. Since the autograft can only replace one of the two joint surfaces, the opposing surface must have reasonably well-preserved hyaline cartilage for the joint to function well over time. Pyrocarbon is a smooth material with a modulus of elasticity close to that of bone and can articulate effectively with eburnated subchondral bone that is devoid of hyaline cartilage. This is particularly germane in those delayed or previously operated cases where the incongruent profile of the more damaged joint surface has, over time, eroded the hyaline cartilage from the less damaged opposing joint surface. By the time the case presents for reconstruction, the surgeon is faced with one surface that has no cartilage and the other that lacks both cartilage and subchondral integrity. By replacing only the side that lacks subchondral integrity with pyrocarbon prosthesis, the case is solved, at least for the short term. The long-term durability of this application in the PIP joint is unknown. Our longest follow-up is the patient in the first case example who reports no pain and normal use of the hand with excellent range of motion at 4 years.

If such a result eventually proves both reproducible and durable, that would represent an advantage over total joint arthroplasty. Grip strength and ROM are not substantially improved by PIP joint surface replacement [16]. Mean total arc of motion has been reported from 38° to 53° [1, 2, 6, 13]. A meta-analysis involving 520 articles compared

vascularized toe joint transfer, silicone arthroplasty, and pyrocarbon surface arthroplasty. The arcs of motion were respectively 37°, 44°, and 43° [13]. The major complication rates requiring revision were, respectively, 29%, 18%, and 33% [13]. The desirability of silicone replacement is limited by particulate synovitis and ultimate fracture of the implant in a younger, high-demand patient [1, 13]. The desirability of surface replacement is limited by the modest ROM, dislocation, squeaking joints, and prosthetic loosening/subsidence at the prosthesis–bone interface [2, 6, 7, 13, 15, 16]. When used for post-traumatic cases as opposed to arthritis, the results may be even worse [12].

Most of the published series on total joint replacement concern the typical arthritis patients for whom the prostheses were originally intended, but the patients discussed in the current article are trauma patients. In post-traumatic patients 5/7 pyrocarbon PIP total joint replacements had disappointing results with pain rated 4/10 and poor subjective and objective outcomes [12]. There are a number of theoretical benefits of hemi-arthroplasty over total joint arthroplasty. Prosthetic implants, in general, run the risk of loosening over time. As of 20 months mean follow-up, 8/17 pyrocarbon PIP total joints had demonstrated migration of the implant [7]. That occurs in response to the mechanical forces borne each day through motion and load application at the bone–prosthesis interface. The more physiologic the force application, the less loosening should occur. Thus, prostheses have been designed to try to replicate normal joint motion as closely as possible. Constrained prostheses loosen at a higher rate than non-constrained prostheses. The latest trend at the PIP joint specifically has been towards two component surface replacement away from the original monoblock silicone prostheses [1, 13]. By replacing only

one joint surface and preserving the remaining joint architecture consisting of the natural relationship between the opposing joint surface and the collateral ligament/volar plate complex, one should more closely replicate normal joint mechanics. This, in turn, should lessen the stresses at the bone–prosthesis interface as well as reduce the likelihood of dislocation. Most series of pyrocarbon PIP total joint arthroplasty report dislocation, loosening, and subsidence [1, 2, 6, 7, 12, 13, 15]. The other benefit of more closely replicating joint mechanics should be better motion. The hemi-arthroplasty patients made substantial gains from their preoperative contractures to a final range of 90°, which is much better than that reported for total joint replacement (38–53°) [1, 2, 6, 13]. Finally, this article's approach for hemi-arthroplasty preserves the extensor mechanism. Although, it has been reported that the volar approach can be used for total joint arthroplasty, most surgeons use the dorsal approach which transgresses the extensor mechanism.

The two primary unknowns in PIP joint hemi-arthroplasty were the degree of pain patients would experience at a pyrocarbon to subchondral bone articulation and whether such an articulation would prove durable. At up to 4 years, this report provides limited case evidence for well-functioning and pain-free hemi-arthroplasty. This report is intended to serve as a foundation for future ongoing research on the role that hemi-arthroplasty may play in select trauma patients or possibly certain arthritis patients as well.

Declaration of conflict of interest statement The author declares that he has no conflict of interest.

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