Advances in Proximal Interphalangeal Joint Arthroplasty

Biomechanics and Biomaterials

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KEYWORDS

• Proximal interphalangeal joint • Biomechanics • Arthritis • Silicone arthroplasty
• Surface replacement arthroplasty • Pyrocarbon arthroplasty

KEY POINTS

- Proximal interphalangeal (PIP) joint arthritis is a debilitating condition. The complexity of the joint makes management particularly challenging.
- Treatment of PIP arthritis requires an understanding of the biomechanics of the joint.
- PIP joint arthroplasty is one treatment option that has evolved over time.
- Advances in biomaterials have improved and expanded arthroplasty design. This article reviews biomechanics and arthroplasty design of the PIP joint.

INTRODUCTION

Proximal interphalangeal (PIP) joint arthritis is a painful, debilitating condition causing significant joint deformity and loss of motion. Common causes of arthritis include osteoarthritis, post-traumatic arthritis, and rheumatoid arthritis. Each has its own unique treatment challenges. Surgical management of painful PIP arthritis ranges from arthroplasty to fusion to amputation.[1] Replacement arthroplasty aims to relieve pain, restore motion, and maintain stability of the affected joint. Designing an effective replacement arthroplasty requires a thorough understanding of current biomaterials and an appreciation of the complex PIP joint biomechanics.

BIOMECHANICS

The PIP joint is a ginglymus, hinged joint composed of the proximal phalanx, middle phalanx, and supporting soft tissue structures. Its principal motion is in the sagittal plane but small amounts of motion also occur in the coronal and axial plane. The distal articular surface of the proximal phalanx is composed of two concentric condyles separated by an intercondylar ridge. The condyles are not identical in size and vary in relationship from finger to finger. In the coronal plane, the index and long finger have a more prominent ulnar condyle compared with the ring and small finger, which have a more prominent radial condyle (Fig. 1).[2] The head of the proximal phalanx

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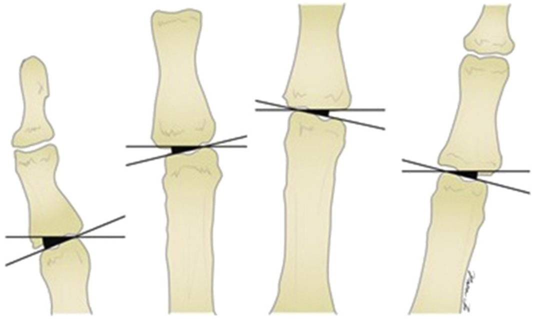

Fig. 1. In the coronal plane, the proximal phalanx of the index and long finger has a more prominent ulnar condyle. The ring and small finger have a more prominent radial condyle. (*Courtesy of* N. Fujihara, MD, Nagoya, Japan.)

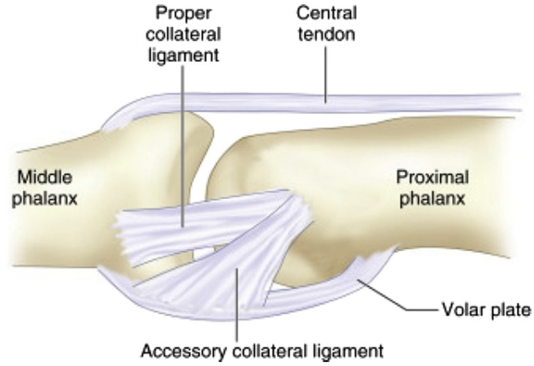

Fig. 2. Origin and attachment of the proper collateral ligament and accessory collateral ligament. (*Adapted from* Chung KC, Brown M. Capsulotomy for proximal interphalangeal contracture. In: Chung KC, editor. Operative techniques: hand and wrist surgery. 3rd edition. Philadelphia: Elsevier; 2018. p. 70; with permission.)

is trapezoidal in shape when viewed in cross-section. The volar aspect is approximately twice the length of the dorsal aspect. These anatomic relationships allow rotation of the joint in addition to flexion and extension.[3]

The base of the middle phalanx consists of a ridge separating the condylar recesses that articulate with the condyles of the proximal phalanx. The PIP joint is not perfectly congruent because the base of the middle phalanx has a larger radius of curvature than the head of the proximal phalanx. This incongruity permits additional motion outside the sagittal plane. On the volar aspect of the joint, the thick volar plate and its associated checkrein ligaments prevent hyperextension. Stability is also provided by the dorsal capsule of the joint that is largely comprised of fibers of the central tendon.[4] The combination of bony anatomy and soft tissue constraints allows for approximately 100° of motion at the PIP joint in the sagittal plane.[3]

Stability of the PIP joint in the coronal plane is derived from congruity of the bony anatomy along with the strong collateral ligaments. The collateral ligaments are divided into two distinct portions: the proper collateral ligament and accessory collateral ligament. The proper collateral ligament is the thicker of the two collateral ligaments and provides the most lateral stability. Both collateral ligaments originate in pits on either side of the proximal phalanx head and insert into the middle phalanx (Fig. 2). The accessory collateral ligament attaches volar to the proper collateral ligament blending with the volar plate and suspending the volar plate to the joint.[3]

The finger is composed of a kinetic chain of joints including the PIP, metacarpophalangeal (MCP), and distal interphalangeal (DIP) joints. These joints work in concert through a complex network of tendons and ligaments to produce coordinated and purposeful movement. In the 1960s, Landsmeer[5–7] provided an in-depth description of PIP joint motion. Rotation of a joint is a product of relative shortening and lengthening of flexor and extensor tendon units. The degree of rotation produced is a function of tendon excursion and distance from the center of rotation of the joint. The excursion of the extensor tendon is a linear function of the radius of curvature of the head of the proximal phalanx and maintains a constant distance from the center of rotation. In contrast, the flexor system runs through a tendon sheath and its distance to the center of rotation increases with progressive flexion of the joint.[7] Understanding and recreating these anatomic relationships in replacement arthroplasty is required to preserve normal joint biomechanics and restore anatomic joint range of motion.

The flexor and extensor system span multiple joints and thus motion at the PIP joint is dictated by the position of the adjacent joints. DIP and PIP joint flexion is determined by laxity of the lateral bands and central slip, respectively. The extensor complex moves as a single unit and is comprised of the central slip and terminal tendon, which is formed by the convergence of the lateral bands. The lateral bands are closer than the central slip to the center of rotation of the PIP joint; therefore, more laxity is produced at the DIP joint per unit excursion than PIP joint. The relative increase in flexion of the DIP with PIP flexion allows for a coordinated flexion movement to grasp objects. This relationship is disrupted in deformities, such as swan-neck and boutonnieres. and replacement arthroplasty alone without soft tissue correction is insufficient treatment.