Ulnar Head Replacement and Related Biomechanics

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Abstract

Keywords

- ▶ distal radioulnar joint (DRUJ)
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- ▶ arthroplasty
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- ▶ ulnar head prosthesis

A stable distal radioulnar joint (DRUJ) is mandatory for the function and load transmission in the wrist and forearm. Resectional salvage procedures such as the Darrach procedure, Bowers arthroplasty, and Sauvé-Kapandji procedure include the potential risk of radioulnar instability and impingement, which can lead to pain and weakness. Soft tissue stabilizing techniques have only limited success rates in solving these problems. In an attempt to stabilize the distal forearm mechanically following ulnar head resection, various endoprotheses have been developed to replace the ulnar head. The prostheses can be used for secondary treatment of failed ulnar head resection, but they can also achieve good results in the primary treatment of osteoarthritis of the DRUJ. Our experience consists of twenty-five patients (follow-up 30 months) with DRUJ osteoarthritis who were treated with an ulnar head prosthesis, with improvement in pain, range of motion, and grip strength. An ulnar head prosthesis should be considered as a treatment option for a painful DRUJ.

Up to 30% of patients after distal radius fractures suffer from ulnar-sided wrist pain.¹ This is manifested in the form of wrist pain, restricted movement, weakness, and instability, even after correct reduction of the fracture and bony union. The integrity of the distal radioulnar joint (DRUJ) is necessary for stability and load transfer from the forearm to the wrist.^{2–4}

Osteoarthritis of the DRUJ may occur after trauma due to a bony deformity, a ligamentous injury, or combination of both.^{1,5,16} In the surgical treatment of osteoarthritis, “salvage operations” are often necessary, in which the ulnar head is resected partially or completely.^{7–10} Numerous clinical studies have demonstrated a reduction of painful clinical symptoms for all these techniques.^{11–14} Biomechanically, even a partial resection of the distal ulna destabilizes the wrist, and clinically, it may lead to instability of the distal ulnar stump

and the radius.^{15,16} Distal radioulnar impingement occurs because the distal support of the radius for rotation and the “cam effect” of the distal ulna have been ablated. As a result, instability of the DRUJ may again lead to restriction of motion and strength as well as to increased pain.^{17–19}

To reduce DRUJ instability, various “soft tissue stabilization operations” have been developed. The most common techniques are the pronator quadratus-interposition flap (Johnson procedure)²⁰ and the extensor carpi ulnaris (ECU)–flexor carpi ulnaris (FCU) tenodesis (Breen-Jupiter tenodesis).^{21–23} Biomechanical studies, however, show that these procedures do not provide adequate stabilization of the distal ulna.²⁴

Ulnar head prostheses have also been developed to restore the integrity of the DRUJ, which has been shown experimentally⁶ and clinically.^{25–28}

Anatomy and Biomechanics of the DRUJ

In addition to the interosseous membrane, the forearm muscles and the proximal radioulnar joint (PRUJ), the DRUJ is important for a stable forearm rotation,²⁹ in which the radius rotates around the ulnar head. The axis of forearm rotation thereby extends proximally through the radial head and distally through the ulnar head. The articular surfaces of the DRUJ are the sigmoid notch of the radius and the articular circumference of the ulnar head. Since the curvature of the sigmoid notch is greater than that of the ulnar head, it comes to an additional translation during forearm rotation.³⁰ In supination, the distal ulnar head shifts proximally and palmarly, and in pronation, in contrast, the ulnar head shifts distally and dorsally. In neutral position there is maximum contact of the articular surfaces, which is ~60% of the entire joint surface. The contact is reduced to less than 10% in maximum supination and pronation.^{2,30} For this reason, the osseous anatomy provides only little stability (20%). The main stabilizer of the DRUJ (80%) is the three-dimensionally structured triangular fibrocartilage complex (TFCC), which is located between the ulnar head and the corresponding carpal bones. The TFCC consists of different components (palmar and dorsal radioulnar ligaments, articular disk, carpal ligaments, meniscus homologue, and the sheath floor of the ECU), which together form one anatomical structure but perform different functions. Besides its main function as a stabilizer of the DRUJ and the ulnocarpal joint, the TFCC also supports the axial load transmission and acts as a buffer.^{2,31}

Essential structures for DRUJ stability are the palmar and dorsal radioulnar ligaments. These bands arise from the dorsal and palmar edge of the sigmoid notch of the radius. In ulnar direction the bands divide into a deep (proximal) and superficial (distal) portions. The proximal portion, also known as the *ligamentum subcruentum*, attaches on the ulnar fovea and the distal fibers at the base and middle of the ulnar styloid process.³² The dorsal superficial portion of the radioulnar ligaments ensures stability in forearm pronation, as do the palmar deep portion of the ligaments. Conversely, in supination, the palmar superficial portion of the radioulnar ligaments tightens, as do the dorsal deep portions of the ligament.³³ Crucial for the stability of the DRUJ are the deep portions of the radioulnar ligaments.

To evaluate the dynamic effects on the DRUJ biomechanically after various salvage operations, Sauerbier et al performed studies with a dynamic, personal computer (PC)-controlled forearm simulator.²⁴ With this dynamic computer-controlled testing device, cadaveric forearm rotation was performed with simultaneous loading of relevant muscles. Torque along the forearm axis was generated by simulated muscle action through pneumoactuators attached to relevant tendons, while the wrist was constrained to prescribed ranges of motion. The instability of the radius relative to the ulna was evaluated using displacement data of digitized landmarks in an ulnar coordinate system. They could demonstrate that the resection of the entire ulnar head (Darrach procedure) creates an extensive instability at the distal forearm, with displacement of the radius toward the ulna

in the radial-ulnar direction. The amount of displacement for a distal ulnar hemiresection interposition arthroplasty (Bowers operation) was significantly lower in all directions compared with the Darrach procedure. When the pronator quadratus interposition flap (Johnson procedure) and the ECU-FCU tenodesis (Breen-Jupiter tenodesis) were tested, the results showed that the radioulnar convergences created with the Johnson and the Breen-Jupiter procedure remained extensive, and these procedures are not able to prevent radioulnar convergence in a laboratory setting.²⁴

After the implantation of an ulnar head endoprosthesis (uHead, Small Bone Innovations Inc., Morrisville, PA, USA), the authors were able to demonstrate a significant decrease of displacement compared with resection of the ulnar head in unloaded conditions and in most of the loading conditions. The stability of the DRUJ was nearly restored.^{15,16} Masaoka et al reported data from a biomechanical study in which they compared two different ulnar head prostheses (the Herbert Ulnar Head Prosthesis and the uHead).³⁴ The results of this study also demonstrated that both prostheses maintained nearly normal biomechanics of the distal radioulnar joint, compared with the irregular behavior occurring after distal ulna resection.

DRUJ Prostheses

The uHead prosthesis (→Fig. 1) is a modular endoprosthesis that consists of a metal stem with a shaft that can be implanted (press-fitted or cemented) into the intramedullary canal of the distal ulna.³⁵ The head has a polished Cobalt Chrome surface and is available in four sizes, interchangeable with four stem diameters. Additionally, the head component has holes that accommodate reattachment of the TFCC and the ECU subsheath. In addition to the standard stems, 20-mm extended collar stems are also available in four diameters for revision operations of Darrach resections.

The Herbert ulnar head prosthesis, or UHP (KLS Martin, Tuttlingen, Germany) (→Fig. 2) is an alternative prosthetic device.²⁷ It is a modular system consisting of a prosthesis stem made of titanium and a prosthetic head of ceramic. All head sizes can be combined with all the stems. The prosthesis stem has a porous titanium coating that permits osteointegration, and therefore, implantation can be done without cement. The prosthesis stem is available in three sizes with different shaft diameters. To restore an optimal length ratio between the ulna and radius, each stem size can be obtained with a collar length of 2 mm (standard), 4 mm (standard +) or 17 mm (revision stem). There are three head sizes (small, medium, large) with a height of 10, 12, and 14 mm and a diameter of 15, 18, and 21 mm.

Surgical Technique

We prefer to use the UHP or the uHead prosthesis. A dorsal incision is made in line with the fourth metacarpal. After identifying the extensor retinaculum, the fifth extensor compartment is divided. A dorsoulnar-based capsuloretinacular flap is raised at the level of the fourth extensor compartment and dissected carefully in an ulnar direction to the base of the sixth compartment. The ECU subsheath and ECU tendon are

Fig. 1 Implantation of a uHead prosthesis.

left in place and elevated subperiosteally in a radial-to-ulnar direction as a capsular flap. The TFCC is left in continuity with the ECU subsheath. With guidance from an intraoperative resection guide that is used to determine the correct length of the implant, an osteotomy is made through the distal third of the ulna. After removal of the ulnar head, the sigmoid notch is inspected for incongruity or bone spurs and is contoured appropriately with a burr if needed. In case of a peripheral TFCC tear, suture repair with a 3-0 nonabsorbable suture is performed. A trial prosthesis is used to check the head and stem sizes that restore optimum length and stability. Biplanar imaging is used to match ulna length and fit with the sigmoid fossa of the distal radius. Ulnar neutral or slight ulnar minus variance is recommended with respect to the length of the

distal radius and ulna head replacement. After implanting the definite stem and ulnar head the capsuloretinacular flap is reattached to the dorsal rim of the sigmoid notch through drilling holes and under advanced tension with 2-0 or 3-0 nonabsorbable sutures.

Failed Sauvé-Kapandji operations with painful forearm instability can be corrected by the implantation of the ulnar head prosthesis. This is done either by distal resection and implantation of a regular revision prosthesis or by the method according to Fernandez, who leaves the distal fusion in place underneath a custom-made spherical ulnar head prosthesis (KLS Martin, Tuttlingen, Germany)³⁶ (→ Fig. 3a–e).

Alternatively, the surgical approach for implantation can be performed through an ulnar incision between the FCU and ECU tendons, preserving the TFCC, ECU sheath, and ulnar capsule in this incision.

An essential requirement for a good result is a stable soft tissue support. In case of rheumatoid arthritis or complex injuries involving the interosseous membrane (e.g., Essex-Lopresti injury), an unconstrained ulnar head prosthesis is contraindicated.

Postoperative Rehabilitation

Our postoperative treatment includes immobilization in a long arm cast for 3 weeks in 70–90° flexion and 20° supination of the elbow, followed by an elbow brace that allows free extension/flexion in the elbow and the wrist but avoids forearm rotation. Therapy is started at 6 weeks. The patient is examined clinically and X-ray images are taken at 6 weeks, 6 months, and then annually.

Material and Methods

Twenty-five patients were treated at the former institution of the senior author (M.S.; BG Trauma Center Ludwigshafen, Germany) with the ulnar head prosthesis after total or partial resection of the distal ulna between 1998 and 2007. In the majority of cases (20 patients) a uHead prosthesis was used. In the other five patients, the Herbert UHP was implanted. Six patients were female, 19 male. The average age at operation date was 48 years (from 28 to 75), and at the last follow-up examination 50.4 years (from 29 to 77). All patients presented with complaints of pain and functional deficiencies. Indications for ulnar head replacement included distal ulnar instability with radioulnar impingement after resection of the ulnar head or primary DRUJ osteoarthritis without any previous salvage operations. The original injury to the DRUJ was trauma-related in 23 cases. A fracture of the distal radius resulted in DRUJ osteoarthritis in 11 patients. Sixteen patients (64%) underwent primary implantation, and nine patients (36%) were treated with a secondary implantation after previous salvage operations. We reevaluated 22 patients out of the 25 patients after ulnar head replacement. The mean follow-up time averaged 30 months (range 2–109 months). On clinical examination, 17 wrists had tenderness localized over the DRUJ before surgery, but mild tenderness was present in only five wrists after surgery. A positive ulna grind test was detected in eight wrists.

Fig. 2 Implantation of a Herbert UHP.

Fig. 3 Patient with painful radioulnar impingement in the stress-loaded X-ray after a Sauvé-Kapandji operation alio loco. Postoperative result after implantation of a custom-made spherical ulnar head prosthesis.

Results

The postoperative total arc of pronation/supination of the affected wrist averaged 124° , which demonstrated an improvement of 8° compared with the preoperative measurements. In primary implanted prostheses we found a significant improvement of 57° for postoperative pronation/supination compared with secondary implanted prostheses. The postoperative total arc of extension and flexion averaged 76.5° with an improvement of 0.5° compared with preoperative measurements. The grip strength after ulnar head replacement averaged 17 kg and showed a significant decrease of 6.2 kg. However, we noticed an improvement of 3.8 kg in case of primary implanted prostheses (16 cases). Pain scores decreased significant from a preoperative mean level of 5.4 at rest to a postoperative mean level of 2.4. Pain scores during stress decreased significant from a preoperative mean level of 8.7 to a postoperative mean level of 5.4. The Disabilities of the

Arm, Shoulder, and Hand (DASH) score improved from 44 preoperatively to 33 postoperatively. Interestingly, in those patients who underwent primarily implantation of an ulnar head prosthesis, the DASH-score was 25. The mean Krimmer score³⁷ after ulnar head replacement was 57 points, and the Cooney wrist score³⁸ was 61 points postoperatively. Results of the primary implantation compared with the secondary implantation were significantly better.

All wrists were stable on the latest postoperative X-ray images. In most of the cases a small amount of bone resorption was seen at the collar of the prosthesis (► Fig. 4a–c), but there were no radiographic signs of loosening. We saw a remodeling of the sigmoid fossa around the metallic head in most of the cases.

The senior author (M.S.) has implanted another 10 prostheses since 2009 (six uHeads and four UHPs) with good outcomes in six of 10 patients available for follow-up at a mean of 20 months (► Fig. 5a–c).

Fig. 4a–c (a) Patient with painful DRUJ osteoarthritis and positive ulnar variance. (b) Early postoperative result after implantation of a uHead prosthesis. (c) One-year follow-up shows a bony resorption of the distal ulnar stump ("stress shielding"), but no signs of loosening.

Fig. 5a–c (a) Patient with painful radioulnar impingement after Darrach resection *alio loco*. (b) Early postoperative result after implantation of a uHead prosthesis with extended collar. (c) Six months after ulnar head replacement, there is a bony resorption of the distal ulnar stump and signs of remodeling of the sigmoid fossa, but again no signs of loosening.

Discussion

Biomechanical loading studies have shown a statistically significant improvement in radioulnar impingement and almost normal kinematics after ulnar head replacement.^{24,34} In 1998, van Schoonhoven et al described their first results using the Herbert UHP³⁹ in a multicenter study. Two years later they published a further study.²⁷ Twenty-three patients were treated using the new ulnar head prosthesis, with a mean follow-up period of 27 months. All patients had significantly improved in terms of pain relief, range of motion, and grip strength, and all patients were satisfied with the clinical situation.

Willis et al²⁸ presented their results after implantation of the uHead modular metal endoprosthesis. In 17 patients in 19 wrists, 6 cemented and 13 press-fitted prostheses were implanted. Follow-up was 32 months (range 26–60 months). The patients showed a significant reduction in pain, increased strength, and improved global function as measured by the Mayo Wrist Score. There was no substantial improvement of the forearm rotation in this study. Two stem loosening (in uncemented prostheses) and one case of persistent instability in a patient with rheumatoid arthritis were found as complications. Only one patient was not satisfied.

Shipley et al⁴⁰ reported in 2009 on 20 patients after 22 prosthetic implants (14 UHPs and 7 uHeads) at an average of 54.3 months postoperatively. Ten wrists with implantation of an ulnar head prosthesis as primary therapy in osteoarthritis showed excellent and good results. In the 12 cases they obtained 75% excellent and good results. Only in three patients was the result unsatisfactory. There was one case of a traumatic prosthesis shaft fracture, and two patients had a persistent posterior subluxation and underwent a stabilizing soft tissue reconstruction. All patients who underwent surgery due to complications presented good and excellent results in the follow-up.

Van Schoonhoven et al recently published long-term results of their initial prospective multicenter study.⁴¹ Twenty-

three patients were treated with the Herbert UHP in three international hand centers. Sixteen of the 22 patients could be assessed at 2 follow-up times: 28 months (range 10–43 months) and 11 years and 2 months (134 months; range, 97–158 months) after surgery. DRUJ stability, forearm rotation, grip strength, pain level (0–4), and satisfaction (0–10) were analyzed, and standardized radiographs of the wrist were taken. All patients demonstrated a clinically stable DRUJ at the latest examination, and no patient required further surgery at the DRUJ since the short-term evaluation. Average pain was measured by a verbal analog scale (1–4; 1 = no pain, 4 = severe pain), measuring 3.7 before surgery, 1.7 at the short-term follow-up, and 1.7 at the long-term follow-up. The patients' satisfaction was measured using a visual analog scale, ranging from 1 (unsatisfactory) to 10 (completely satisfied), measuring 2.2, 8.2, and 8.9. Pronation improved from 73° to 86° (short term) and 83° (long-term); supination improved from 52° to 77° and 81° compared to the unaffected side. Grip strength increased from 42% to 72% and 81% of the unaffected side. All clinical parameters improved significantly from before surgery to the short-term follow-up, with no further statistically significant change between the short-term and long-term follow-ups. Radiographs showed no signs of stem loosening or incongruity of the DRUJ. All patients showed a bony resorption of the distal ulnar stump ("stress shielding") and a remodeling of the sigmoid notch in the first 6–12 months, as already described by Herzberg.⁴² There was no further progress of bone loss afterwards. The changes that were seen on the X-ray images had no clinical significance.

Other research groups^{40,43} as well as our published data⁴⁴ show similar short-term and mid-term results using an ulnar head prosthesis in different disorders.

After reviewing the biomechanical and clinical data for implantation of an ulnar head prosthesis for salvage of the destroyed DRUJ, it can be concluded that this concept stands the test of time. The implantation of such a prosthesis is a very worthwhile addition to the hand surgical armamentarium for those who are specialized in wrist surgery.

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