J Plast Surg Hand Surg, 2011; 45: 148–156

informa
healthcare

ORIGINAL ARTICLE

New concept for total wrist replacement

ASTOR REIGSTAD, OLE REIGSTAD, CHRISTIAN GRIMSGAARD & MAGNE RØKKUM

Hand and Microsurgery Section, Orthopedic Department, Rikshospitalet, Oslo University Hospital, Oslo, Norway

Abstract

Wrist prostheses have never achieved the sort of clinical outcomes found with those of hips and knees. We have developed a novel uncemented modular wrist prosthesis with screw fixation, metal-on-metal coupling, and ball-and-socket articulation. Eight patients admitted for wrist arthrodesis to treat primary or secondary osteoarthritis (not rheumatoid) were operated on. The prosthesis reduced the amount of bone removed and spared the distal radioulnar joint. After 7 to 9 years we found that the fixed centre of the ball-and-socket articulation provided good stability and mobility, and relief of pain and grip strength were satisfactory. We saw no luxations, metacarpal fractures or cut-outs, or mechanical failures of the implants. Two distal screws loosened (revised with new distal screws), and one early inflammation and one late infection occurred (revised to arthrodesis). We propose modifications to the implant with reduction in the diameter of the screws and the height of the threads, and rounding of the distal tip. The technique should include release of the third carpometacarpal joint, alignment of the capitate and the third metacarpal, and arthrodesis of the joint with bone chips.

Key Words: *Wrist arthroplasty, total wrist replacement, implant, non-rheumatoid*

Introduction

The complexity of the articulation of the wrist makes prosthetic replacement difficult. The joint space is limited, and the small carpal bones make fixation of the distal component problematic. In patients with degenerative wrist disorders, prostheses have never achieved similar clinical success as those in the hip and the knee. Wrist prostheses have been restricted to patients with rheumatoid, with low functional demands, because of the high rates of painful loosening and revision. For all other patients most hand surgeons prefer arthrodesis of the wrist, which relieves pain in most cases. Some patients with a fused wrist have appreciable difficulties with activities of daily living [1], and most would prefer some movement of the wrist if possible [2]. Most of the reported wrist prostheses are articulated by convex-concave ellipsoidal components in an attempt to mimic some of the natural mobility of the wrist [3–5]. Only one reported prosthesis has used a ball-and-socket articulation [6]. The fixation of the components was earlier achieved with bone cement, but in the newer implants that are made of titanium, with or without a coat, cementless fixation by press fit or screw fixation is most common [7,8]. Some designs of wrist prostheses have a metal-on-polyethylene articulation with a convex ellipsoidal polyethylene distal component [9], whereas concave polyethylene is placed in the radial component of others [10]. In a review of the design of wrist prostheses Shepherd and Johnstone [11] suggested that attempts to recreate the natural joint should be avoided, and different materials and methods for fixation should be considered for new implants.

Aim of the study

We have developed and introduced a new total wrist prosthesis based on the principle of simple solutions for the components, instruments, and surgical technique.

Correspondence: Ole Reigstad, MD, Hand and Microsurgery Section, Orthopedic Department, Rikshospitalet, Oslo University Hospital, Songsvannsveien 20, NO-0027 Oslo, Norway. Tel: +47 23076043. Fax: +4723076010. E-mail: ole.reigstad@gmail.com

(Accepted 9 February 2011)

ISSN 2000-656X print/ISSN 2000-6764 online © 2011 Informa Healthcare
DOI: 10.3109/2000656X.2011.579720

Material and methods

Design of the prosthesis

We developed the new wrist prosthesis from 1997 to 2001 together with the company Elos Medical AB, Timmersdala, Sweden. Screw fixation to bone secures primary stability, and modularity on both sides of the joint simplifies the replacement. The distal radioulnar joint is unaffected, and if the prosthesis fails, a wrist arthrodesis should be easy because so little bone needs to be removed. The conical screws are made of grit-blasted Ti6Al4V and coated with Bonit® (DOT Medical, Rostock, Germany), a 15 (5) μm resorbable electrochemically-deposited calcium-phosphate coat with osseointegrative properties [12]. Several experiments with this prosthetic concept were carried out on cadaver wrists, and the components were modified accordingly. First model: in two patients we used the cone-shaped, short and thick screws with rounded ends and high and wide non-cutting threads all along the implants. Second model: six patients were given the revised longer and thinner screws with lower cutting threads and no threads distally (Figure 1). Distal cross-cutting of the metacarpal screw tended to improve stability. The design included a metal-on-metal coupling with ball-and-socket articulation to reduce wear and the need to remove bone, and to improve stability of the joint. The ball-and-socket were made of highly polished cobalt-chrome-molybdenum, fixed with a Morse cone to the screws in the capitate/third metacarpal and the radius. An articulation diameter of 18 mm provided optimal stability of the joint and almost 80° range of movement in all directions (Figure 1).

The capitate/metacapal and the radial screws were produced in three lengths, each to cover the anatomical variations. Balls with two neck-lengths were manufactured for adjustment of tension in the joint.

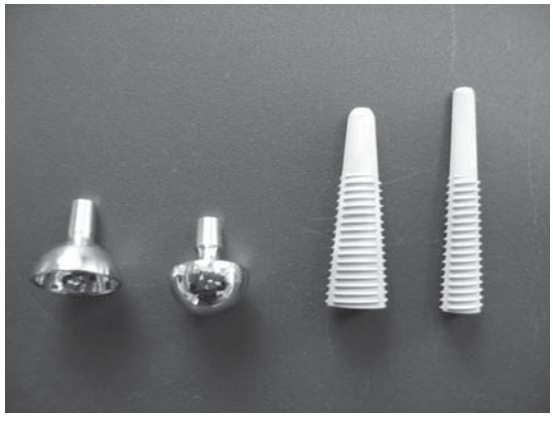

Figure 1. The second model prosthesis, cobalt-chrome-molybdenum ball–and–socket articulation, Bonit® coated Ti6Al4V screws for the radius (left) and capitates and third metacarpal (right).

Focus was aimed at simplifying the instruments to make the procedure easy, thereby reducing the risk of technical errors. The tools were limited to guidewires, two cannulated reamers for the two types of screws with marks for every length of screw, a reamer for the socket, a screwdriver, and trial prostheses (Figure 2).

The Regional Committee for Medical and Health Research Ethics in Norway (letter dated 31 May 1999) allowed insertion of the prostheses in patients who had given informed consent.

Patients

The implants were offered to patients who did not have rheumatoid disease who were admitted for arthrodesis of the wrist and were ineligible for more limited procedures. The characteristics of the eight patients (seven men) operated on from February 2001 to June 2003 are shown in Table I. Their median age was 52 (range 23–76) years. Two patients were pensioners; the remaining six did manual work.

Surgical technique

A straight dorsal midline incision 8 cm long was used. The lunate, the proximal two-thirds of the scaphoid, and the radial styloid were removed. The entry point for the distal guidewire was central on the head of the capitate, transversing the third carpometacarpal joint and entering the diaphyseal canal of the third metacarpal. The proximal guidewire entered the ridge between the lunate and the scaphoid fossa at approximately the midpoint.

With the first model the conical canal was reamed longer than the screw to engage the surrounding bone maximally during insertion without being stopped by

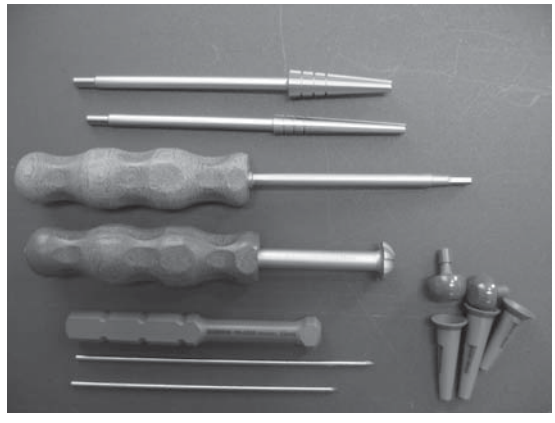

Figure 2. The second model instruments from top to bottom: the proximal and distal reamers, the screwdriver, the reamer for the radial cup, the puncher, the guidewires, and the trials for the ball–and–socket.

Table I. Patient characteristics.

Case No.	Sex	Age (years)	Occupation	Diagnosis	Follow-up (years)	Distal radioulnar joint osteoarthritis preoperativly	Previous operation	Opposite wrist
1	♂	47	Motor mechanic	SNAC wrist	8.9	None	Four-corner fusion	Normal
2	♂	38	Timbermill worker	SNAC wrist	9	Slight	Bone graft and osteosynthesis × 2	Normal
3	♂	23	Carpenter	Lunatum malacia	7.5	None	None	Normal
4	♂	51	Teacher/farmer	Sequele distal radius fracture	7.6	Slight	Osteosynthesis	Normal
5	♀	76	Retired	SLAC wrist	7.2	Slight	None	Triscaphe osteoarthritis
6	♂	68	Retired	SLAC wrist	7.7	None	None	Normal
7	♂	53	Engine driver	SNAC wrist	7	None	Bone graft and osteosynthesis	Normal
8	♂	64	Caretaker	SNAC wrist	7.3	None	None	Normal
Median (range)		52 (23–76)			7.6 (7–9)			

the reaming at the end. In the next model we aimed at exact reaming, for maximal bone-implant contact including distal support.

The use of fluoroscopy was essential to find the correct position for the K-wires, reamers, and screws. No effort was made to fuse the third carpometacarpal joint. Prophylactic antibiotic treatment with cefalotin 2 g (Keflin, EuroCept, Ankeveen, Netherlands) four times a day was used for one day. A forearm cast was applied for a median of 30 (range 24–38) days. Movement of the fingers and rotation of the forearm was encouraged during the period in the cast, and after removal active and passive wrist exercises were taught by our hand therapists.

Follow up

Standard radiographs were taken of the wrist postoperatively and at the clinical follow ups after 3, 6, and 12 months, and yearly thereafter. Hand therapists graded radial-sided and ulnar-sided pain in the wrist at rest and during activity using a visual analogue scale from 0–10, 0 meaning no pain. Active range of movement of the wrist (flexion + extension + radial + ulnar deviation) and forearm rotation were measured using a hand-held goniometer. Grip strength was assessed with a JAMAR® hand-held dynamometer. At follow-up the patients completed the DASH score [13] translated and validated into Norwegian [14], and they were asked whether they would have had the operation if they had known the result.

Results

The critical steps of the procedure were the reaming and insertion of the distal screw. We encountered difficulties with the first model of the distal component, which had a short engagement in the metacarpal. The stability was solely dependent on the fixation to the capitate, and the motion of the third carpometacarpal joint seemed to prevent integration of the bone and implant in the metacarpal. With the longer distal screw of the second edition we experienced two other main problems. The angulation of the third carpometacarpal joint in the frontal and lateral planes (flexion and ulnar deviation) risked the reamer perforating the metacarpal in the proximal cortical region (complete in two cases, incomplete in two others). The cutting threads of the reamers were too sharp, particularly at the tip, making it easy to engage and ream the cortex on one side instead of forcing it distally along the medullary canal. The squared distal end of the screw engaged the bone before the end of the reamed cutout, which prevented the implant from being "screwed home", or necessitating over-reaming, which precluded exact maximal bone-implant contact and support. During reaming for the proximal screw we experienced the same difficulties and near-perforation of the cortex. Centering of the reaming with a longer guidewire introduced to the proximal one-third of the radius solved the problem. The problems with reaming and perforation of the cortex decreased integration of the distal components. Based on radiological evaluation all radial screws integrated well, exhibiting intimate bone implant contact on all follow-up radiographs. A brief summary of each of the eight patients is given below:

Case 1 (first model)

There was a periprosthetic radiolucent line visible in the distal metacarpal at 3 months, and intimate

bone-implant contact was observed in the capitate and the radius. The clinical result was excellent, but deteriorated after two years when the metacarpal lines progressed to the capitate, and the distal screw loosened. The prosthesis was removed and we did an arthrodesis of the wrist. Although pain-free, the patient missed movement of the wrist, particularly at work, and he insisted on rearticulation, which was done after three years. The revision prosthesis integrated well radiologically, and wrist function was good after another three years (Table II, Figure 3).

Case 2 (first model)

There was a line surrounding the metacarpal part of the screw at 1 year, and intimate bone-implant contact in the capitate and radius. The function of the prostheses was excellent.

Case 3 (second model)

A perforation of the ulnar and dorsal cortex of the metacarpal occurred during the reaming. After six months there was intimate bone-implant contact in the radius and the capitate, while a radiolucent line was present in the metacarpal radial and distal along the implant. After two years the distal screw loosened in the capitate as well. A revision screw was inserted, but infectious loosening occurred (*Staphylococcus epidermidis*). The whole prosthesis was removed 18 months after revision, and a bone graft from the iliac crest was inserted together with plate arthrodesis in one stage. Cloxacillin (Diclocil, Bristol-Myers Squibb Company, New York, USA) 1 g was given four times daily for eight weeks, and the arthrodesis healed uneventfully.

Case 4 (second model)

The reaming caused a near complete perforation of the ulnar cortex of the metacarpal, and the same problem occurred on the volar side of the radius. A surrounding radiolucent line was seen from 3 months along the metacarpal part of the implant, but the prosthesis was in intimate bone-implant contact in the capitate and radius. Osteoarthritis of the distal radioulnar joint was treated with Darrach's procedure after four years. The function of the wrist was good at follow-up.

Case 5 (second model)

The distal screw was inserted uneventfully, but the dorsal cortex was perforated in the radius. Radiologically the prosthesis showed intimate bone-implant contact along both components. However, she developed a dorsal tenosynovitis of the wrist, and synovectomy showed that the joint was full of whitish material. The well-fixed prosthesis was removed because infection was suspected. C-reactive protein concentration and erythrocyte sedimentation rates were not taken preoperatively. All cultures taken from the joint grew no pathogens. Histological examination showed inflammation, mainly with lymphocytes. She was given cloxacillin (Diclocil, Bristol-Myers Squibb Company, New York, USA) 1 g four times daily for three months. After two years she was given a new prosthesis. Darrach's procedure was done at the same time. Cultures obtained during the reoperation grew no pathogens. The new prosthesis showed intimate bone-implant contact, and the wrist function was good four years after revision.

Case 6 (second model)

There was a near complete perforation of the radial metacarpal cortex. The radial screw was inserted close to the distal radioulnar joint, but did not penetrate it. After three months there was a surrounding radiolucent metacarpal line around the distal screw, but none in the capitate or radius.

Table II. Radiological results.

		Peroperative complications		Interface at 1 year			Interface at follow-up		
Case No.	Sex	Metacarpal	Radius	Metacarpal	Capitate	Radius	Metacarpal	Capitate	Radius
1	♀	–	–	Lines	Contact	Contact	–	–	–
2	♂	–	–	Lines	Contact	Contact	Loose	Contact	Contact
3	♂	Perforation	–	Lines	Contact	Contact	–	–	–
4	♂	Near perforation	Near perforation	Lines	Contact	Contact	Loose	Contact	Contact
5	♂	–	Perforation	–	–	–	–	–	–
6	♂	Near perforation	–	Lines	Contact	Contact	Loose	Contact	Contact
7	♂	–	Near perforation	Lines	Contact	Contact	Contact	Contact	Contact
8	♂	Perforation	–	Contact	Contact	Contact	–	–	–

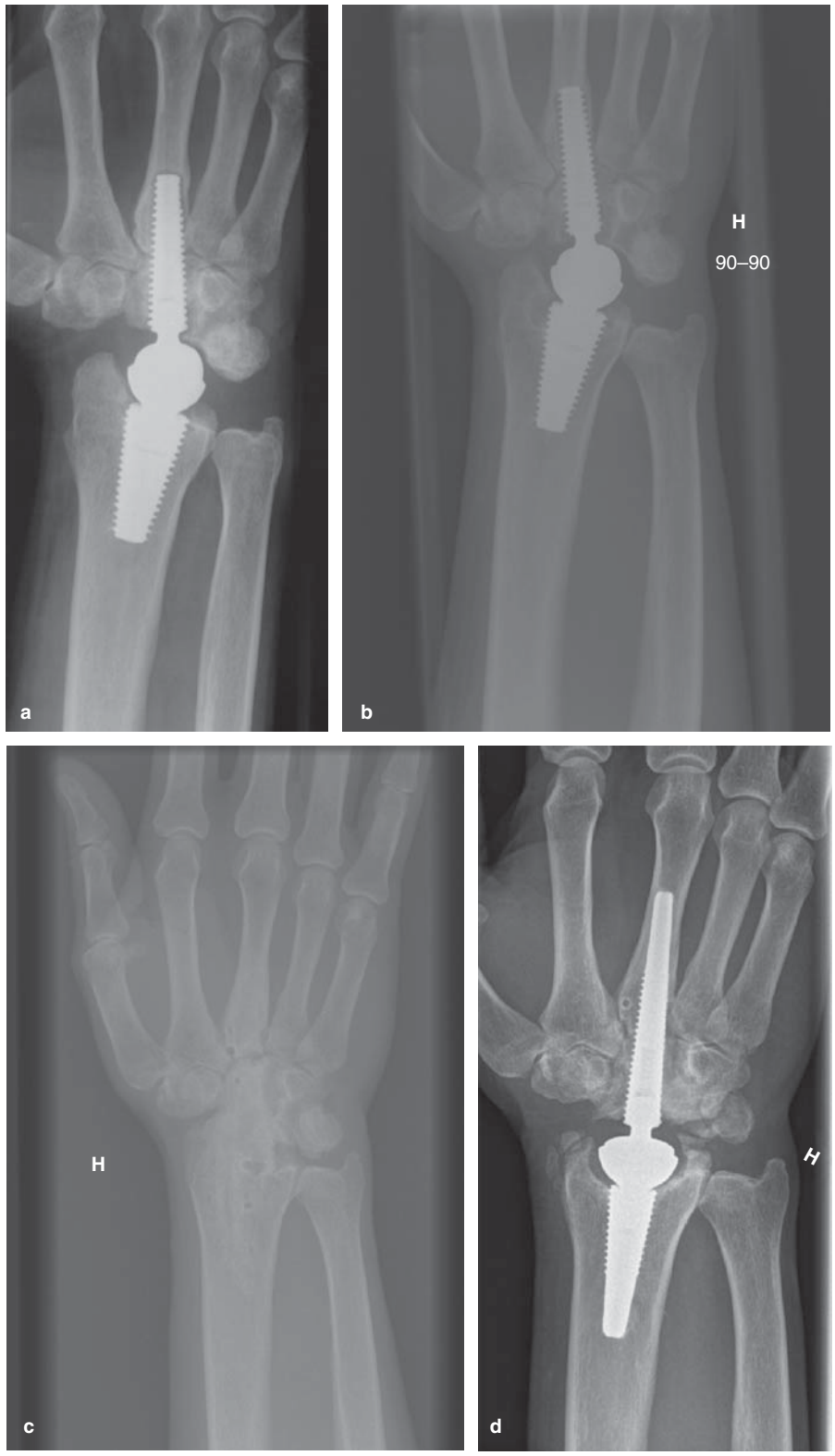

Figure 3. Case 1 with the first model prosthesis (*a*) after 1 year, intimate bone-implant contact in the radius and capitate, radiolucent line surrounding the metacarpal part, (*b*) after 2.5 years, a loose distal component with distal screw migration, (*c*) arthrodesis, symptom-free open third carpometacarpal joint, and (*d*) 3 years after rearticulation, intimate bone-implant contact, and third carpometacarpal arthrodesis after bone transplantation. The distal radioulnar joint is unaffected.

The patient developed distal radioulnar joint osteoarthritis, and had a Darrach's procedure two years later. The wrist functioned well at follow-up.

Case 7 (second model)

The reaming nearly perforated the dorsal radius, but the defect healed well. Both components had intimate bone-implant contact after three months, and the wrist function was excellent (Figure 4).

Case 8 (second model)

The reamer perforated the ulnar diaphysis of the metacarpal. A radiolucent line surrounded the metacarpal part of the implant after three months, but no line was found in the capitate or radius. The wrist functioned well. After five years the distal component loosened, and a fistula developed at the level of the radial styloid while the patient was waiting for revision. At revision a focal osteolysis surrounded the distal 1/5 of the proximal implant adjacent to the

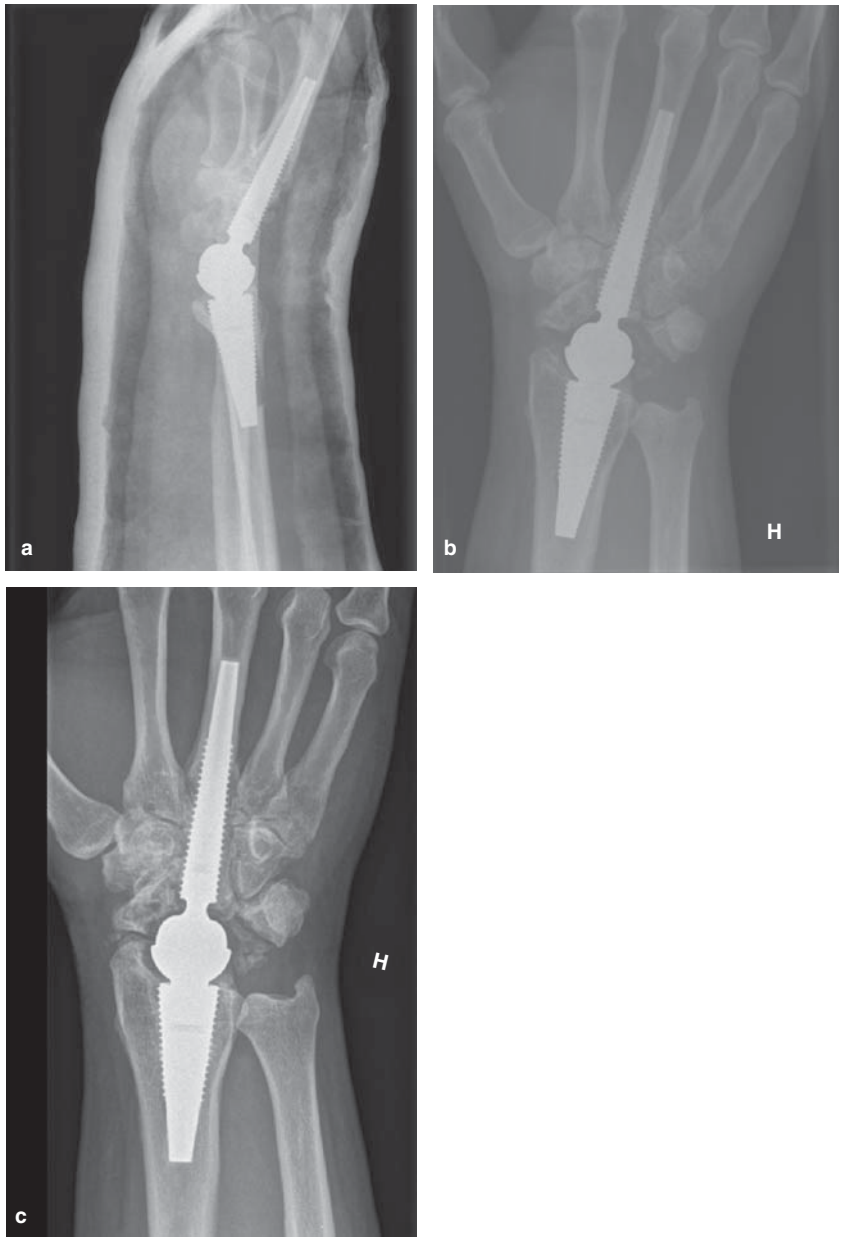

Figure 4. Case 7, second model, (*a*) postoperatively near perforation of the dorsal cortex in radius, (*b*) 1 year postoperatively intimate bone-implant contact along both components, traces of bone radially and ulnarly. (*c*) At 6 years ectopic bone has rebuilt the radial styloid after resection, spots of mature bone are seen in the soft tissue ulnarly. The distal radioulnar joint is unaffected.

joint. C-reactive protein concentration and erythrocyte sedimentation rates were 76 and 25, respectively. *Abiotrophia defectiva* (a nutritionally variant streptococci normally seen in the mouth flora) grew in all cultures, and the infection was considered to be blood-borne. The prosthesis was removed, gentamicin (Septopal®, Biomet Merck Norge AS, Oslo, Norway) was given locally and clindamycin (Dalacin, Orifarm, Oslo, Norway) 300 mg four times a day was given for three months. He then had wrist arthrodesis with an iliac bone graft and a plate, which healed uneventfully.

Radiographic evaluation

Third carpometacarpal fusion was not seen in any patient. All radial screws were integrated into bone with no radiolucent line. The two loosened metacarpal screws started with a radiolucent line at 3–6 months, and gradually surrounded the implant. Except for case 6 where the cup might have interfered with the distal radioulnar joint, the joint was not affected by the prosthesis (Table II).

Functional evaluation

The prosthesis gave excellent pain relief and the patients were satisfied (Table III). No patient used painkillers for the wrist condition. One patient retired during the follow-up period, the remaining five continued to work. All patients would have chosen the arthroplasty again, if they had known the outcome.

The median total active range of movement was 125° and 208°, and the grip strength 31 and 43 kg in the operated and non-operated wrists, respectively. Pronation and supination were unaffected (Table IV).

Discussion

This new implant differs from most of the reported total wrist prostheses by transforming the wrist to a ball-and-socket joint with a metal-on-metal bearing and a fixed centre of articulation. In the normal wrist the centre of rotation for flexion and extension and radial/ulnar deviation is assumed to be located in the head of the capitates [15], which is slightly distal to the centre of our prosthesis. We have not found this transfer of the centre to be of any importance for articulation. The ball-and-socket concept has been stable and resulted in a good range of movement.

According to Youm et al. [15] some rotation of the wrist occurs in the radiocarpal joint. In our opinion an ellipsoidal articulation gives stress risers in rotation as well as in radial and ulnar deviation. A distal convex polyethylene component may increase these problems. A ball-and-socket articulation eliminates the difficulty, transforming the shear forces to compression, which may reduce wear.

Metal-on-metal articulation in the hip was questioned earlier [16]. Wear, metallosis, and the systemic influence of metallic ions were suspected problems, but long-term results from second generation metal-on-metal hip prostheses have not had such difficulties [17]. The low force transmitted through the wrist joint compared with the hip should limit these tribological problems.

With the present implant in patients who did not have rheumatoid we were able to establish stability of the wrist, reduce the amount of bone removed, and spare the distal radioulnar joint during implantation. Unlike other reports on wrist prostheses [9,10,18] we saw no instability or dislocations, and there were no problems with preoperatively normal distal radioulnar joint. The patients achieved satisfactory mobility of the wrist, grip strength, and pain relief. The cementless fixation of the radial component proved effective

Table III. Patients' satisfaction at follow-up.

		Operated side			
Case No.	DASH at follow-up	Pain radially at rest	Pain radially at activity	Pain ulnarly at rest	Pain ulnarly at activity
1	2.3	0	0	0	0
2	16.3	0	3	0	3
3	Arthodesis				
4	46.7	0	0	1	5
5	71.2	5	8	6	6
6	4.2	0	0	0	0
7	1.7	0	0	0	0
8	Arthrodesis				
Median (range)	10.3 (1.7–71.2)	0 (0–5)	0 (0–8)	0 (0–6)	1.5 (0–6)

Table IV. Active range of movement (AROM), flexion, extension, radial and ulnar deviation (°), and grip strength (kg).

Case No.	Follow-up	Preop AROM	AROM operated side follow-up	AROM opposite side	Sup/pronation preop	Sup/pronation postop follow-up	Grip strength operated	Grip strength non-operated
1	8.9	25	100	211	80/80	90/80	24	42
2	9	140	124	205	80/80	85/90	44.6	53.8
3	Arthrodesis	62	Arthrodesis	215	90/90	90/90	Arthrodesis	35.7
4	7.6	80	126	240	90/90	70/75	10.7	44
5	7.2	65	148	152	90/90	90/90	15.8	14.4
6	7.7	40	127	140	90/90	90/90	40.8	45.7
7	7	50	111	190	90/90	85/70	37.7	36
8	Arthrodesis	85	Arthrodesis	210	90/90	90/90	Arthrodesis	48,1
Median (range)	7.7 (7–9)	64 (25–40)	125 (100–48)	208 (140–40)	90 (80–90)/90 (80–90)	90 (70–90)/90 (70–90)	31 (11-45)	43 (14-54)

with no radiolucency, or migration, or loosening of the screw.

As with other wrist prostheses [3,8,18] we encountered problems with the fixation of the distal component. We predicted erroneously that a relatively thick screw secured both in the capitate and the third metacarpal would fuse the third carpometacarpal joint, improving the fixation of the component. In our two cases of loosening of the distal screw, the process started around the tip and progressed proximally. Movement between the metacarpal and the screw may eventually also loosen the screw from the capitate, although this did not happen in all patients with open carpometacarpal joints. The extensive reaming needed for the relatively large threads of the distal screws created another problem with little primary contact between the implant and the bone. To reduce the problems, particularly with fixation of the distal screw, the prosthesis, the instruments, and the surgical technique need some modifications.

The third carpometacarpal joint should be opened and the capitate mobilised to stretch out the angle against the third metacarpal. The guidewire should be placed firmly in the metacarpal head. By doing so, the positioning of the distal screw will be easier and more secure. Bone chips should be transplanted in and around the carpometacarpal joint after insertion of the screw to secure fusion of the joint. The angle of the cutting threads on the reamer should be reduced to force the reamer centrally in the medullary canal, and avoid engagement of the cortex of one of the sides. A reduction in the diameter of the screws and the height of the threads should be optional to avoid over-reaming in small, or thin metacarpal bones, or both. A rounding of the tip of the screw (as in the first model) would avoid engagement on the sides, and promote central positioning of the screw. In the radius, the reamer and the screw should have a rounded tip, and a blunt guidewire should be introduced up to the proximal one third of the radius.

It seems that arthrodesis of the wrist with a graft from the iliac crest can be done as a salvage procedure without specific problems, and with a healing time similar to that of a primary arthrodesis. It could therefore be wise to have the prosthetic replacement as the first option of treatment for a ruined wrist. However, our study has indicated that a fused wrist can be rearticulated and a good functional and clinical result obtained.

Acknowledgement

We thank The Sophies Minde Foundation and The Aase Bye and Trygve J. B. Hoffs Fund for Medical Scientific Research for economic support.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

[1] Sauerbier M, Kluge S, Bickert B, Germann G. Subjective and objective outcomes after total wrist arthrodesis in patients with radiocarpal arthrosis or Kienbock's disease. Chir Main 2000;19:223–31.

[2] Adey L, Ring D, Jupiter JB. Health status after total wrist arthrodesis for posttraumatic arthritis. J Hand Surg 2005; 30A:932–6.

[3] Cobb TK, Beckenbaugh RD. Biaxial total-wrist arthroplasty. J Hand Surg 1996;21A:1011–21.

[4] Divelbiss BJ, Sollerman C, Adams BD. Early results of the Universal total wrist arthroplasty in rheumatoid arthritis. J Hand Surg 2002;27A:195–204.

[5] Menon J. Total wrist replacement using the modified Volz prosthesis. J Bone Joint Surg 1987;69A: 998–1006.

[6] Meuli HC. Total wrist arthroplasty. Experience with a noncemented wrist prosthesis. Clin Orthop Relat Res 1997;342: 77–83.

[7] Lundborg G, Branemark PI. Anchorage of wrist joint prostheses to bone using the osseointegration principle. J Hand Surg 1997;22B:84–9.

[8] Strunk S, Bracker W. [Wrist joint arthroplasty: results after 41 prostheses]. Handchir Mikrochir Plast Chir 2009;41: 141–7.

[9] Menon J. Universal Total Wrist Implant: experience with a carpal component fixed with three screws. J Arthroplasty 1998;13:515–23.

[10] Kretschmer F, Fansa H. [BIAX total wrist arthroplasty: management and results after 42 patients]. Handchir Mikrochir Plast Chir 2007;39:238–48.

[11] Shepherd DE, Johnstone A. A new design concept for wrist arthroplasty. Proc Inst Mech Eng H 2005;219:43–52.

[12] Reigstad O, Franke-Stenport V, Johansson CB, Wennerberg A, Rokkum M, Reigstad A. Improved bone ingrowth and fixation with a thin calcium phosphate coating intended for complete resorption. J Biomed Mater Res B Appl Biomater 2007;83:9–15.

[13] Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: the DASH (disabilities of the arm, shoulder and hand) [corrected]. The Upper Extremity Collaborative Group (UECG). Am J Ind Med 1996;29:602–8.

[14] Finsen V. [Norwegian version of the DASH questionnaire for examination of the arm shoulders and hand]. Tidsskr Nor Laegeforen 2008;128:1070.

[15] Youm Y, McMurthy RY, Flatt AE, Gillespie TE. Kinematics of the wrist. I. An experimental study of radial-ulnar deviation and flexion-extension. J Bone Joint Surg 1978;60A:423–31.

[16] Santavirta S, Bohler M, Harris WH, et al. Alternative materials to improve total hip replacement tribology. Acta Orthop Scand 2003;74:380–8.

[17] Grubl A, Marker M, Brodner W, et al. Long-term follow-up of metal-on-metal total hip replacement. J Orthop Res 2007;25: 841–8.

[18] Bosco JA 3rd, Bynum DK, Bowers WH. Long-term outcome of Volz total wrist arthroplasties. J Arthroplasty 1994;9:25–31.