Evaluation of a reconstruction reverse shoulder for tumour surgery and tribological comparison with an anatomical shoulder arthroplasty

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Abstract

Purpose The functional results after reconstruction of the proximal humerus in tumour surgery are poor. Therefore, a reversed proximal humerus replacement was developed in our institution (MUTARS humerus inverse). A low degree of wear on the polyethylene is required because of the patients' youth and demands on shoulder function. A special type of polyethylene with shock-absorbing properties has been developed to minimise polyethylene wear in the MUTARS inverse proximal humerus replacement. We compared the tribological properties of an anatomical shoulder prosthesis (CAPICA) with the new reversed proximal humerus replacement (MUTARS humerus inverse).

Methods Both prostheses were tested up to 5×10^6 cycles. Every millionth cycle the surface was inspected and a gravimetric measurement was performed. A measurement of surface roughness was done before testing and after 5×10^6 cycles.

Results In both prostheses after 5×10^6 cycles there were no major defects, such as delamination, observed. In the reversed proximal humerus replacement abrasion of 28 mg/ 10^6 cycles was detected. The mean abrasion of the anatomical prosthesis was 9.28 mg/ 10^6 cycles.

Conclusion The glenoid component of the first reversed humerus replacement (MUTARS humerus inverse) has wear properties comparable to those of normal reversed shoulder

prostheses. This is important, as this type of prosthesis is used in young patients after resection of bone tumours, with a good functional outcome. It can, therefore, be expected that the revision rate due to wear will be as high as in patients with normal reversed shoulder prostheses.

Introduction

Limb reconstruction using modular tumour megaendoprostheses is a standard procedure nowadays in patients with malignant tumours [1–3]. Particularly with modern imaging and surgical techniques, limb salvage is possible in most cases. Rates of major complications such as periprosthetic infections, aseptic loosening, and luxations have been significantly reduced over the last few decades, and good functional results can be achieved in the lower limb [1, 4–6]. In the upper limb, the rate of implant-associated complications is low, but the functional results are poor [1]. This is due firstly to the resection of the axillary nerve that is often required for oncological reasons; secondly, even if the nerve can be preserved, relevant parts of the rotator cuff have to be sacrificed, resulting in loss of congruity of the humeral head and loss of function of the deltoid muscle.

Reconstruction with an anatomical proximal humerus replacement has been the standard procedure to date. In our department, the prosthesis was embedded in an attachment tube and the remaining muscles were attached to it. This procedure provided a stable situation in the joint, but the patient was unable to actively abduct and elevate the arm [1]. Even techniques such as the Bateman procedure in cases of axillary nerve resection were unsuccessful with a

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conventional prosthesis, due to the residual loss of congruity of the humeral head [7].

Reversed shoulder arthroplasty is an established procedure in patients with loss of rotator cuff function [8]. The medialised and semi-constrained artificial joint restores stability and mobility [9]. In the past, this procedure was only used in older patients, due to its high complication rates [10] and declining function after eight to ten years [11]. Complications observed during the long-term follow-up included periprosthetic infection, instability and dislocation, infraglenoid notching, and also abrasive wear [10, 12, 13]. Wear in particular represents an underestimated risk for loosening of the prosthesis. In addition to permanent deformation of the component, small particles of polyethylene can cause an inflammatory response in the surrounding bone [14–16]. Particles of debris generated by wear are also responsible for changes in osteogenesis, producing an imbalance between osteoclastic and osteoblastic activity that may result in resorption of bone at the implant–bone interface, leading to failure of the bond between the implant and the bone [14–16].

The Modular Universal Tumour and Replacement System (MUTARS) inverse proximal humerus replacement is indicated in young patients in whom the axillary nerve can be preserved and little muscle resection is necessary. A low degree of wear on the polyethylene is required because of the patients' youth and the expected high demands on shoulder function. A special type of polyethylene with shock-absorbing properties has been developed to minimise polyethylene wear in the MUTARS inverse proximal humerus replacement (Implantcast Ltd., Buxtehude, Germany). This study compared tribological data for the new MUTARS inverse proximal humerus replacement with those for a standard anatomical prosthesis (Capica, Implantcast Ltd., Buxtehude).

Materials and methods

The tribological properties of the two prostheses were tested using the IMA-PV C/33.1 shoulder standard system developed by the Institute of Materials Research and Applications Technology (*IMA Materialforschung und Anwendungstechnik*) in Dresden (Table 1).

The test objects used were the articulating parts of the reversed proximal humerus replacement (MUTARS, Implantcast Ltd., Buxtehude), consisting of a proximal humerus component with a length of 50 mm, a humeral head (TiAlVa coated with TiN), two glenospheres (UHMW-PE), and the glenoid (TiAlVa) (Fig. 1). The anatomical prosthesis (Capica, Implantcast) consists of a 54-mm humerus head (TiAlVa coated with TiN) and two glenoid components (UHMW-PE) (Fig. 2). The two glenoids and the glenospheres were identical, with one serving as a reference for liquid absorption.

The test control unit (Fig. 3) was able to simulate four directions: flexion (specified mechanically, with rotation on the longitudinal axis), abduction (specified mechanically, with rotation on the cross-axis), translation (limited with a spring, in the direction of the longitudinal axis) and axial loading (controlled). The movements are specified in Table 1. The flexion and abduction movements were mechanically linked. The glenoid was placed on a table with a sliding surface and was moveable in the longitudinal direction, limited with a spring (3.5 N/mm). Synchronization of the envelopes was adjusted so that in zero crossings of flexion and abduction, the axial load was the highest. The test medium was a bovine solution (protein concentration $30 \text{ g/L} \pm 2 \text{ g/L}$) consisting of a mixture of bovine serum and bidistilled aqua. The test medium was changed every three to four days. After 5×10^5 , 1×10^6 , 2×10^6 , 3×10^6 , 4×10^6 , and 5×10^6 cycles, the tests were stopped and the components were analysed.

Table 1 Test parameters for shoulder prostheses in accordance with IMA-PV C/33.1

Parameter		Value		Comment
		Maximum	Minimum	
Normal force	F_z [N]	500	100	z-direction
Movement around y-axis	α_y [deg]	+10	−10	x-direction
Movement around x-axis	α_x [deg]	+35	−35	y-direction
Movement y direction		about ± 0.7		Free movement possible
Test frequency	f [Hz]	1		
Test medium	-	bovine serum solution		
Protein content	[g/l]	30		
Test temperature	T [°C]	37 ± 2		
Total amount of cycles	N_{total}	5×10^6		
Time point of inspections		0; 5×10^5 , 1×10^6 and then every millionth cycle		7 inspections

Fig. 1 Components of the Modular Universal Tumour and Replacement System (MUTARS) inverse system: 1, embedded MUTARS proximal humerus component; 2, proximal humeral head, 50 mm (TiAlVa coated with TiN); 3, glenosphere (UHMW-PE); 4, glenoid (TiAlVa)

For evaluation of the tribological properties, a surface inspection was carried out, gravimetric measurements were made, and surface roughness was assessed. For the surface inspection, the components were photographed. The gravimetric measurement was carried out to analyse wear on the polyethylene on the glenoid at 0.5×10^6 and every millionth cycle up to 5×10^6 . Measurements were conducted with a weighing machine (KN BA 100, Sartorius Inc., Göttingen, Germany). The gravimetric measurements were based on the specification given in ISO 14 243–2 and AC 3/191. To

Fig. 2 The Capica anatomical component. **a** Glenoid component. **b** Humerus head

Fig. 3 The simulator, with its various components. 1, Servohydraulic cylinder; 2, load cell; 3, table with sliding surface and upper wing; 4, lower wing; 5, drive motor; 6, displacement sensor; 7, spring system; 8, thermostat

eliminate errors due to liquid absorption, an identical glenoid was placed in environmental conditions. At the time of analysis, each specimen was weighed three times and the arithmetic mean was calculated. Measurement of surface roughness was carried out using a Perthometer at 0 and 5×10^6 cycles. The surface roughness was based on DIN 4768. The cut-off length was 0.08 mm, based on ISO 7207–2. The radius of the tracer pin was 2 μm . Surface roughness was measured in four different areas of the reversed glenosphere and five different areas of the anatomical glenoid. The mean arithmetic roughness (Ra) was used for evaluation of the surface.

Results

Surface inspection

At the first inspection of the MUTARS inverse after 500,000 cycles, fine scratches in the TiN coating of the head were observed. At the second inspection after 1×10^6 cycles, a polished, slightly yellow discoloration of the glenosphere was noted. The reason for this was considered to be the batch of bovine serum used. After 4×10^6 cycles, the discoloration disappeared. The areas examined were slightly polished, and a dark tribological reaction layer had developed in the central area of the head. After 5×10^6 cycles, there were no observable major defects such as delamination in particular, for example, on the surface of the glenosphere or humerus head. Small, fine scratches were observed on the stressed parts. The dark discoloration, the tribological reaction layer, and the foggy covering on the humerus head are shown in Fig. 4.

Fig. 4 The components of the Modular Universal Tumour and Replacement System (MUTARS) inverse system after 5×10^6 cycles. **a** Proximal humeral head, 50 mm. **b** Glenosphere

At the first inspection of the anatomical glenoid component, the contact area was only faintly visible. During the course of testing, the contact area increased and acquired a more glossy appearance. At the end of testing, the glenoid showed a definite transition between the loaded and unloaded areas (Fig. 5).

Gravimetric measurement

Gravimetric measurement of the glenoid element of the MUTARS inverse system showed that there was 173 mg of polyethylene after 5×10^6 cycles of abrasion. A mean of 28 mg/ 10^6 cycles in accordance with ISO 14243 was calculated.

Gravimetric measurement of the anatomical glenoid in the Capica prosthesis showed that there was 43.81 mg of polyethylene abrasion after 5×10^6 cycles. The mean abrasion after 10^6 cycles was 9.28 mg.

Measurement of surface roughness

The mean arithmetic surface roughness (Ra) of the humerus head in the MUTARS inverse system was $0.05 \mu\text{m}$, while on

Fig. 5 The components of the Capica prosthesis after 5×10^6 cycles. **a** Glenoid component. **b** Humerus

the glenosphere the figure was $0.4 \mu\text{m}$. The minimum standard for metallic components of shoulder prostheses is required to be at least $0.1 \mu\text{m}$ in accordance with ISO 7207–2. After 5×10^6 cycles, the Ra of the humerus head was $0.035 \mu\text{m}$ and that of the glenosphere was $0.031 \mu\text{m}$. In the Capica prosthesis, the mean arithmetic surface roughness (Ra) of the humerus head was $0.025 \mu\text{m}$, while that of the glenoid component was $0.250 \mu\text{m}$. After 5×10^6 cycles, the mean arithmetic surface roughness (Ra) of the humerus head was $0.022 \mu\text{m}$, and that of the glenoid component was $0.030 \mu\text{m}$.

Discussion

This study tested the wear performance of the first reversed proximal humerus replacement. The characteristics of the polyethylene used in the tumour prosthesis were compared with those of an anatomical shoulder prosthesis. A normal anatomical prosthesis was chosen because patients with an anatomical humerus replacement do not have good shoulder function [1, 7, 17], and wear is, therefore, not a reason for loosening of an anatomical proximal humerus replacement.

Particularly with the good functional results possible with the MUTARS inverse humerus replacement, wear is as important as in an anatomical or reversed humerus prosthesis.

Polyethylene wear particles have been observed in anatomical shoulder prostheses that have been removed after aseptic loosening associated with osteolysis [18, 19]. Retrieved anatomical glenoid components have shown different types of wear [20–23]. Gunther et al. analysed ten retrieved anatomical glenoids and noted a combination of abrasive and fatigue wear [21]. They related this combination of surface and fatigue wear to that seen in hip and knee implants, in which these types of wear predominate. In our series, scratching and burnished areas were present in the anatomical and reversed glenoid. Wear on the rim or delamination were not observed. One limitation of the study is that it was conducted in vitro, with no impingement of the adjacent bone. In addition, the glenoid had a defined optimal position relative to the articulating head and was not dependent on the implantation carried out by a surgeon.

Three times more volumetric wear was observed in study in the reversed prosthesis in comparison with the anatomical model. This is less than the wear reported by Terrier et al. [13], who compared an anatomical shoulder with a reversed prosthesis in an anatomical model. However, this greater volumetric wear does not imply that the clinical loosening rates of the prosthesis will be three times higher. In anatomical prostheses, there are many reasons for loosening of the glenoid component [24]. Glenoid loosening is the main reason for revision of anatomical shoulder prostheses, in up to 12.5 % of cases. An inflammatory reaction to wear debris may not be the most important reason, in comparison with malalignment of the anatomical glenoid [24, 25]. The revision rate for inverse prostheses with aseptic glenoid loosening is thus about 3.5 % [10]. Wear on the reversed shoulder prosthesis is probably associated with loosening of the stem [26], but to date there have been no large studies or studies examining retrieved glenoid components from reversed shoulder prostheses.

The glenoid component of the first reversed humerus replacement (MUTARS humerus inverse) has wear properties comparable to those of normal reversed shoulder prostheses [13]. This is important, as this type of prosthesis is used in particularly in young patients after resection of bone tumours, with a good functional outcome. It can therefore be expected that the revision rate due to wear will be as high as in patients with reversed shoulder prostheses.

References

- Gosheger G, Gebert C, Ahrens H et al (2006) Endoprosthetic reconstruction in 250 patients with sarcoma. *Clin Orthop Relat Res* 450:164–171
- Mittermayer F, Krepler P, Dominkus M et al (2001) Long-term followup of uncemented tumor endoprostheses for the lower extremity. *Clin Orthop Relat Res* 388:167–177
- Sluga M, Windhager R, Lang S et al (1999) Local and systemic control after ablative and limb sparing surgery in patients with osteosarcoma. *Clin Orthop Relat Res* 358:120–127
- Gosheger G, Goetze C, Harges J et al (2008) The influence of the alloy of megaprotheses on infection rate. *J Arthroplasty* 23(6):916–920
- Harges J, Ahrens H, Gebert C et al (2007) Lack of toxicological side-effects in silver-coated megaprotheses in humans. *Biomaterials* 28(18):2869–2875
- Harges J, von Eiff C, Streitberger A et al (2010) Reduction of periprosthetic infection with silver-coated megaprotheses in patients with bone sarcoma. *J Surg Oncol* 101(5):389–395
- Gosheger G, Harges J, Ahrens H et al (2005) Endoprosthetic replacement of the humerus combined with trapezius and latissimus dorsi transfer: a report of three patients. *Arch Orthop Trauma Surg* 125(1):62–65
- Flury MP, Frey P, Goldhahn J et al (2011) Reverse shoulder arthroplasty as a salvage procedure for failed conventional shoulder replacement due to cuff failure—midterm results. *Int Orthop* 35(1):53–60
- Boileau P, Watkinson D, Hatzidakis AM et al (2006) Neer award 2005: the grammont reverse shoulder prosthesis: results in cuff tear arthritides, fracture sequelae, and revision arthroplasty. *J Shoulder Elbow Surg* 15(5):527–540
- Zumstein MA, Pinedo M, Old J et al (2011) Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: a systematic review. *J Shoulder Elbow Surg / Am Shoulder Elbow Surg* 20(1):146–157
- Favard L, Levigne C, Nerot C et al (2011) Reverse prostheses in arthropathies with cuff tear: are survivorship and function maintained over time? *Clin Orthop Relat Res* 469(9):2469–2475
- Farshad M, Gerber C (2010) Reverse total shoulder arthroplasty—from the most to the least common complication. *Int Orthop* 34(8):1075–1082
- Terrier A, Merlini F, Pioletti DP et al (2009) Comparison of polyethylene wear in anatomical and reversed shoulder prostheses. *J Bone Joint Surg Br* 91(7):977–982
- Margevicius KJ, Bauer TW, McMahon JT et al (1994) Isolation and characterization of debris in membranes around total joint prostheses. *J Bone Joint Surg Am* 76(11):1664–1675
- Purdue PE, Koulouvaris P, Potter HG et al (2007) The cellular and molecular biology of periprosthetic osteolysis. *Clin Orthop Relat Res* 454:251–261
- Schmalzried TP, Jasty M, Harris WH (1992) Periprosthetic bone loss in total hip arthroplasty. Polyethylene wear debris and the concept of the effective joint space. *J Bone Joint Surg Am* 74(6):849–863
- Raiss P, Kinkel S, Sauter U et al (2010) Replacement of the proximal humerus with MUTARS tumor endoprostheses. *Eur J Surg Oncol* 36(4):371–377
- Klimkiewicz JJ, Iannotti JP, Rubash HE et al (1998) Aseptic loosening of the humeral component in total shoulder arthroplasty. *J Shoulder Elbow Surg / Am Shoulder Elbow Surg* 7(4):422–426
- Wirth MA, Agrawal CM, Mabrey JD et al (1999) Isolation and characterization of polyethylene wear debris associated with osteolysis following total shoulder arthroplasty. *J Bone Joint Surg Am Vol* 81(1):29–37
- Braman JP, Falicov A, Boorman R et al (2006) Alterations in surface geometry in retrieved polyethylene glenoid component. *J Orthop Res* 24(6):1249–1260
- Gunther SB, Graham J, Norris TR et al (2002) Retrieved glenoid components: a classification system for surface damage analysis. *J Arthroplast* 17(1):95–100

22. Hertel R, Ballmer FT (2003) Observations on retrieved glenoid components. *J Arthroplast* 18(3):361–366
23. Scarlat MM, Matsen FA 3rd (2001) Observations on retrieved polyethylene glenoid components. *J Arthroplast* 16(6):795–801
24. Matsen FA 3rd, Clinton J, Lynch J et al (2008) Glenoid component failure in total shoulder arthroplasty. *J Bone Joint Surg Am* Vol 90 (4):885–896
25. Farron A, Terrier A, Buchler P (2006) Risks of loosening of a prosthetic glenoid implanted in retroversion. *J Should Elb Surg/ Am Shoulder Elb Surg* 15(4):521–526
26. De Wilde L, Walch G (2006) Humeral prosthetic failure of reversed total shoulder arthroplasty: a report of three cases. *J Should Elb Surg / Am Shoulder Elb Surg* 15(2):260–264