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ORIGINAL ARTICLE

Influence of humeral head material on wear performance in anatomic shoulder joint arthroplasty

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Background: The number of total shoulder arthroplasties has increased in the past years, with encouraging results. However, the survival of anatomic total shoulder arthroplasty (aTSA) is lower compared with that of knee and hip replacements. Wear-associated problems like loosening are well-known causes of long-term failure of aTSA. The main purpose of this study was to investigate the wear behavior of ceramic-polyethylene bearings compared with the standard metal-polyethylene bearings. Because there is a lack of valid experimental wear testing methods, the secondary aim was to develop a validated wear simulation.
Methods: The wear assessment was performed using a force-controlled joint simulator for 3×10^6 cycles, and polyethylene wear was assessed gravimetrically and by particle analysis. Kinetic and kinematic data were adopted from in vivo loading measurements and from several clinical studies on shoulder joint kinematics. The reaction of the rotator cuff was simulated on the basis of a virtual soft tissue model. As activity, an abduction-adduction motion of 0°-90° lifting a load of 2 kg superimposed by an anteversion-retroversion has been chosen.
Results: The studied aTSA resulted in a polyethylene wear rate of 62.75 ± 1.60 mg/10^6 cycles in combination with metallic heads. The ceramic heads significantly reduced the wear rate by 26.7% to 45.99 ± 1.31 mg/10^6. There were no relevant differences in terms of the particle characteristics.
Conclusion: This is the first study that experimentally studied the wear behavior of aTSA based on patient-related and biomechanical data under load-controlled conditions. Regarding polyethylene wear, the analyzed aTSA could benefit from ceramic humeral heads.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Total shoulder arthroplasty; polyethylene wear; glenoid; ceramic; humeral head; wear testing

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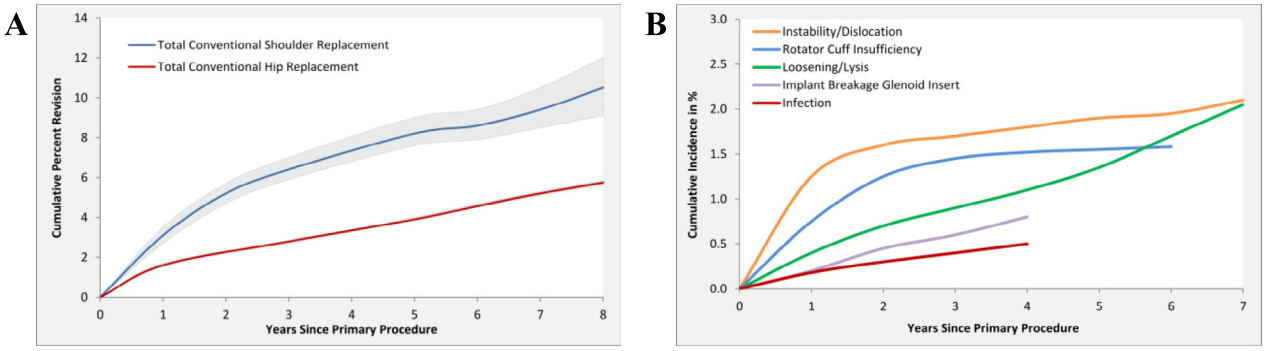

Figure 1 (**A**) Comparison of revision rates between anatomic shoulder and hip joint replacements. (**B**) Reasons for revision surgery in anatomic shoulder joint replacements. (Data from the Australian joint registries.[16,17])

The number of total shoulder joint replacements has increased during the past years, with encouraging clinical results.[51] Patients may benefit from reduced pain, better joint function, and increased range of motion.[28] However, as with all joint replacements, revision surgery may be required over time for various reasons.[2] Based on registry data, the revision rates of shoulder arthroplasties are higher compared with total hip or total knee replacements (Fig. 1, *A*).[16,17] The reasons for revision surgery in shoulder arthroplasties are multifactorial, but they are dominated by dislocation/instability, rotator cuff insufficiency, and loosening/lysis (Fig. 1, *B*).[16] Whereas the progression over time for dislocations or instabilities and rotator cuff insufficiencies seems to become somehow stable, there is a continuing rise in loosening/lysis (Fig. 1, *B*). A further database analysis of 1806 total shoulder revision surgeries revealed that implant-associated mechanical complications like aseptic loosening, surface wear, and implant failure (breakage) were the most prevalent reasons for revision in the analyzed cohort within a period of 17 years.[2] Thus, it seems likely that loosening/lysis is going to be the most relevant complication in shoulder joint replacements in the long term.[2] Osteolysis is often provoked by a biologic response to wear debris.[1,14,43] Wear particles are released by the articulating surfaces. These particles may cause a cytokine-driven inflammatory response that depends on the material, size, dose, and morphology of the wear particles.[18,22] This is also of particular importance in the progression of aseptic loosening for shoulder prostheses.[2,53,56] In this context, several studies on retrieved glenoid components have shown wear-related alterations of the implants.[7,21,24,38,40] For glenoid components, different failure modes are observed compared with hip and knee implants.[9] This is caused by increased eccentric loads, particularly in the case of malalignment, which leads to higher stresses at the polyethylene.[9,42] Thus, polyethylene wear might be high in shoulder joint replacements and has to be considered a relevant cause of complications. A recent clinical study of 165 patients with cementless implants revealed a survival rate of 46% at 12 years, and 80% of the implants undergoing revision surgery had evidence of wear.[6] Consequently, it can be concluded that wear might be a serious issue in shoulder prostheses in the long term.

Total shoulder arthroplasties can be either anatomic or reverse. In reverse shoulder joint replacements, the articulation consists of a ball-in-socket configuration that is limited to rotational movements but stabilizes the joint. On the contrary, if the shoulder joint is still well stabilized by the rotator cuff, anatomic total shoulder arthroplasty (aTSA) can be chosen. The aTSAs are based on a radial mismatch configuration (ball-on-flat), which also allows translational motions of the humeral head on the glenoid component. In shoulder total arthroplasties, the articulation mostly occurs between a metallic part that is typically made of a cobalt-chromium-molybdenum alloy and a counterpart that is made from ultrahigh-molecular-weight polyethylene.

To overcome the problem of polyethylene wear, alternative materials may be considered. For example, in total hip replacements, ceramic materials have been introduced to reduce polyethylene wear, and several experimental and clinical studies confirmed that ceramic heads produce lower wear rates compared with metal heads.[10,55,58] The favorable wear performance and wide use of ceramics can be attributed to its inertness, low coefficient of friction, wettability, scratch resistance, and hardness.[33,54]

Therefore, the first aim of this study was to evaluate whether ceramic humeral heads reduce polyethylene wear in comparison to metallic humeral heads in aTSA. In contrast to total hip[23] and total knee[32] arthroplasty, there is lack of appropriate wear measurement methods for aTSA in terms of biomechanically valid test parameters and boundary conditions. Therefore, the second purpose of this study was to develop a wear testing method and to define the essential experimental parameters, like loading conditions and joint kinematics, for aTSA.

Materials and methods

Biomechanical rationale

Articulation in the anatomic shoulder joint occurs between the humeral head and the glenoid cavity. Compared with the round