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In vivo gleno-humeral joint loads during forward flexion and abduction

G. Bergmann [a,*], F. Graichen [a], A. Bender [a,b], A. Rohlmann [a], A. Halder [c], A. Beier [c], P. Westerhoff [a]

[a] *Julius Wolff Institut, Charité—Universitätsmedizin Berlin, Augustenburger Platz 1, 13353 Berlin, Germany*
[b] *Berlin—Brandenburg Center for Regenerative Therapies, Berlin, Germany*
[c] *Klinik für Endoprothetik Sommerfeld, Beetz-Sommerfeld, Germany*

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ABSTRACT

To improve design and preclinical test scenarios of shoulder joint implants as well as computer-based musculoskeletal models, a precise knowledge of realistic loads acting *in vivo* is necessary. Such data are also helpful to optimize physiotherapy after joint replacement and fractures. This is the first study that presents forces and moments measured *in vivo* in the gleno-humeral joint of 6 patients during forward flexion and abduction of the straight arm. The peak forces and, even more, the maximum moments varied inter-individually to a considerable extent. Forces of up to 238%BW (percent of body weight) and moments up to 1.74%BWm were determined. For elevation angles of less than 90° the forces agreed with many previous model-based calculations. At higher elevation angles, however, the measured loads still rose in contrast to the analytical results. When the exercises were performed at a higher speed, the peak forces decreased. The force directions relative to the humerus remained quite constant throughout the whole motion. Large moments in the joint indicate that friction in shoulder implants is high if the glenoid is not replaced. A friction coefficient of 0.1–0.2 seems to be realistic in these cases.

1. Introduction

Previously muscle forces and contact loads in the gleno-humeral joint were calculated using musculoskeletal models, resulting in widely differing results (Anglin et al., 2000; Buechel et al., 1978; Dul, 1988; Inman et al., 1996; Karlsson and Peterson, 1992; Kessel and Bayley, 1986; Poppen and Walker, 1978; Post et al., 1979; Runciman, 1993; Van der Helm, 1994; Van der Helm and Veeger, 1996). Uncertainties can, among others, be caused by the complex shoulder geometry and by large muscles numbers.

Reliable knowledge about shoulder joint loads is essential to improve model predictions (Favre et al., 2009), for pre-clinical test of function, strength, fatigue and fixation of joint and fracture implants, for physiotherapy, and to advise patients. First data from a shoulder implant, measuring the spatial contact forces and moments (Westerhoff et al., 2009b), showed forces higher than 100% body weight (%BW) and high moments during some activities of daily living (Bergmann et al., 2007; Westerhoff et al., 2009a). Very high moments could indicate either high friction coefficients, an eccentric contact force, or additional forces from the surrounding structures. The moments are expected to counteract the momentary rotation in the joint. If this were not the case, additional loads at the head must again be assumed.

The functional outcome of shoulder arthroplasty varies more than for hip and knee joint replacements (Boileau et al., 2002). Furthermore the subjects, investigated now, differed considerably with regard to age and physical abilities. We therefore hypothesized that the loads individually vary much.

The goal of this study was to measure *in vivo* the gleno-humeral contact forces and moments in several subjects during abduction and forward flexion. Due to the standardized movements, we expected more uniform loads than during activities of daily living.

2. Methods

2.1. Instrumented implant

The shoulder endoprosthesis measures the contact load between glenoid and humeral head. It is based on the BIOMODULAR implant (Biomet, Germany). Implant neck and stem are equipped with a 9-channel telemetry, 6 strain-gages and an inductive power supply (Westerhoff et al., 2009b). The inner electronics are connected to the antenna by a heart-pacemaker feedthrough. Extensive mechanical and electrical tests were performed to guarantee the patient's safety. Customized hard- and software is used for measurements, pre-processing the signals, controlling the power supply and transferring the signals (Graichen et al., 2007). The loads are monitored in real time and stored with the subject's video images for detailed analyses.

* Corresponding author. Tel.: +49 30 450 659081.
E-mail address: georg.bergmann@charite.de (G. Bergmann).

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