Stiffness and Eigenfrequencies of Press-Fit Acetabular Shell Designs

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METHODS:
Eight contemporary press-fit acetabular shell designs with outside diameters of d = 52 mm were tested. The shells differed in material (Ti- and CoCr-Alloys), weight and with respect to the number of screw holes.

Experimental modal analysis was performed to determine the eigenfrequencies of each shell. For this purpose the acetabular shells were suspended supercritically and were excited using a high frequency impact hammer (PCB 086D80). The structural response was detected using a laser vibrometer (Polytec OFV-505 head, OFV-5000 controller; Figure 1). Frequency response functions (FRF) between multiple excitation locations at the rim of the shell and the vibrometer reading point were determined. First eigenmodes were identified and corresponding frequencies were extracted. Shell stiffness c was calculated by dividing the applied force by the respective diametral deformation (c = F/Δd). Linear regression analysis (SPSS) was performed to investigate the relationship between first eigenfrequency, mass and stiffness.

RESULTS:
The frequencies of the shells' first eigenmodes varied between 4 kHz (Stryker) and 9 kHz (Biomet) and hence were all lying in the audible range (Figure 3). Linear regression showed a significant linear correlation between deformation and load for all shells (p<0.04, R²=0.925). The stiffness of the shells lay between 2 kN/mm (Stryker) and 25 kN/mm (Biomet). The stiffness in the symmetry plane differed from the stiffness in the perpendicular direction for all shells with asymmetric shapes (p<0.02). In accordance with structural dynamic theory, linear regression showed a significant dependency of the eigenfrequency on the square root of the stiffness divided by the mass of a shell (p<0.001, R²=0.89) (Figure 3).

Figure 1: Experimental modal analysis of an acetabular shell

Radial stiffness measurements were taken at the equator of each shell (Figure 2). The specimen was loaded radially (F = 0 N, 500 N, 2000 N) using a custom loading frame with a load cell (Burster). Measurements were taken in the symmetry plane of the shell (0°) and perpendicularly to it (90°). The diametral deformation Δd of the shell (defined as the difference of the undeformed and the deformed state) was measured 1.5 mm below the equator for each load step using a coordinate measuring machine (CMM, Mitutoyo BHN-305 with a TP200 probe, accuracy above 4 µm).

Figure 2: The load frame with acetabular shell and CMM probe during deformation measurement.

Figure 3: First eigenfrequency as a function of the square root of the stiffness divided by the mass of a shell.

DISCUSSION:
The radial stiffness and the first eigenvalues of acetabular shells vary considerably among the various designs. The results of the statistical analysis indicate that the eigenfrequency of the shell can be estimated by its mass and stiffness. This finding now allows to predict, which changes in eigenfrequency can be achieved by changes in mass and radial stiffness and therefore to systematically detune the cup system.

Clinically the decisive factor is the characteristics of the assembled system. Consequently further verification of this finding with inserted ceramic inlays is currently underway.

This investigation comprises a first step in the analysis of design factors which might be responsible for the susceptibility of particular acetabular cup designs to squeaking. A better understanding of the influence of design aspects on this phenomenon could allow to develop more resistant designs in the future.

REFERENCES:

INTRODUCTION:
Squeaking of hard-on-hard hip joint bearings has recently become a concern in modern total hip arthroplasty due to its high impact on the quality of life of the patient [1]. Many factors - such as malpositioning of implant - play a role in the arisl of this phenomenon [2]. The probability of the excitation of audible vibrations is also related to prosthesis design [3]. In particular the first eigenfrequencies of the acetabular shell might play a major role for the susceptibility of a design to squeaking. The purpose of this study was to investigate the stiffness and eigenfrequencies of different shell designs and to verify the theoretically assumed relationship between these variables.

RESULTS:
The frequencies of the shells’ first eigenmodes varied between 4kHz (Stryker) and 9kHz (Biomet) and hence were all lying in the audible range (Figure 3). Linear regression showed a significant linear correlation between deformation and load for all shells (p<0.04, R²=0.925). The stiffness of the shells lay between 2kN/mm (Stryker) and 25kN/mm (Biomet). The stiffness in the symmetry plane differed from the stiffness in the perpendicular direction for all shells with asymmetric shapes (p<0.02). In accordance with structural dynamic theory, linear regression showed a significant dependency of the eigenfrequency on the square root of the stiffness divided by the mass of a shell (p<0.001, R²=0.89) (Figure 3).

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