Range of Motion after Total Hip Arthroplasty related to Head Design and Neck Geometry

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Introduction:
An insufficient range of motion (ROM) of total hip prostheses leads to contact of the femoral neck on the cup rim (impingement), which may result in subluxation, dislocation, torque on the bone-socket interface, and material failure (wear of polyethylene cups or rim fracture of ceramic cups) (Bader et al., 2000; Murray, 1992). The purpose of this study was to investigate the effects of different femoral head and neck designs on the range of motion in relation to component position.

Methods:
Three-dimensional volume models of hip prosthesis implants were generated using a 3-D CAD program (Euclid 3-D). Singular and combined joint movements were simulated. The centre of rotation of the acetabular and femoral component were in middle of the cup, representing the origin of the three Cartesian coordinates x, y and z. The position of the acetabular cup was varied in y direction (inclination) and in z direction (anteversion). The effect of antetorsion of the femoral stem was evaluated as well.

Results & Discussion:
In comparison to the total hip prosthesis model with a spherical (=standard) head of 28 mm diameter (Fig. 1) and a cylindrical neck of 14 mm diameter, generic models with spherical heads of 32 mm and 36 mm diameter combined with identical cylindrical neck and taper geometry provide increased ROM of flexion by about 6°, respectively 10° (Fig. 2). The increase in ROM is valid for all joint movements, though the extent varies according to position of the cup (inclination and anteversion angle) and of the stem (antetorsion angle). On the other hand, a spherical head of 22 mm diameter combined with a cylindrical neck of 14 mm diameter restricts ROM of flexion by 10° to 15°. Moreover, larger femoral heads show lower rates of dislocation clinically (Kelley et al., 1998).

Figure 1: Femoral stem with a spherical ceramic head (28 mm diameter).

The femoral neck geometry can also effect the artificial joint mobility. So the difference in joint movements between 22 mm diameter heads with taper 9-11 (i.e. prosthesis neck = 11 mm diameter) and 32 mm heads with taper 14-16 is negligible (Fig. 3).
Figure 2: ROM of flexion for various femoral head sizes, each with the mostly used taper 12-14, CCD angle of 135° and a hemispherical cup at an angle of inclination of 45° and anteversion of 15°, stem antetorsion of 0°.

Figure 3: ROM of external rotation for various femoral head and taper combinations (i.e. Ø 22 with taper 9-11; Ø 26 with 11-13; Ø 28 with 12-14; Ø 32 with 14-16), combined with a hemispherical cup at an angle of inclination of 45° and anteversion of 15°, stem antetorsion of 0°.

Cutting back of the cylindrical neck (Fig. 4), e.g. from 14 mm to 12 mm, increases the ROM of all movements by on average 7°.

Figure 4: Spherical metal head with a cylindrical prosthesis neck (left); cutting back of the neck (right).

Skirted metal heads or ceramic mushroom-shaped heads with 28 mm diameter (Fig. 5) reduce maximum possible flexion by about 15° to 25° (Fig. 6).
Figure 5: Skirted metal head (XL-head) (left); mushroom-shaped ceramic head (right).

Figure 6: ROM of flexion for different head designs (XL 18 mm and XL 20 mm: 18 mm, resp. 20 mm neck diameter; m-s: mushroom-shaped design; 12-14: taper 12-14 with 14 mm cylindrical neck), each with 28 mm head diameter, combined with a hemispherical cup at an angle of inclination of 45° and anteverision of 0°, stem antetorsion of 0°.

So the femoral neck contacts with the cup rim at flexion movements of < 90°, as a result impingement can occur with everyday exercises (like sitting on a chair, putting on socks, etc.). Overall ROM were greatly limited, particularly maximum internal rotation combined with flexion and adduction (i.e. hip motions associated with instability of the artificial hip joint).

Conclusion:
Modern total hip prostheses should provide sufficient joint movements avoiding prosthesis failure. To achieve maximum ROM and joint stability, large standard femoral heads with a head-neck ratio more than 2:1 should be preferred. Thereby increasing aseptic loosening rate due to excessive wear debris should not be expected using hard-hard wear bearing couples like ceramic-on-ceramic. Due to restriction of ROM, skirted metal heads or mushroom-shaped ceramic femoral heads should be used only in exceptional cases. Intraoperative positioning of the acetabular cup and the femoral stem have clearly influence on the patients hip mobility. Several design aspects like acetabular cup geometry and stem design, e.g. the CCD-angle, have also to be considered preventing impingement, material failure and dislocation.

References: