In Vitro Investigation of the Influence of Pelvic Tilt on Acetabular Cup Alignment

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Abstract: This study investigates the influence of pelvic tilt on conventional alignment of acetabular cups. Cementless cups were aligned into a synthetic replica of the pelvis 300 times at different pelvic tilts. At +10° pelvic tilt, average cup inclination was 46.2° (32° to 65°; ±7.0°), and average cup anteversion was 19.8° (4° to 37°; ±9.1°). At neutral pelvic tilt, inclination was 44.5° (28° to 59°; ±7.2°), and anteversion was 15.6° (−5° to 33°; ±8.1°). At −10° pelvic tilt, inclination was 42.6° (25° to 61°; ±7.2°), and anteversion was 10.5° (−10° to 37°; ±12.2°). Overall, 50% of the cups were positioned outside the safe zone: 46% in pelvic inclination, 42% in neutral position, and 63% in pelvic reclination ($P = .007$). This study shows the considerable inaccuracies of conventional cup implantation by experienced and trainee surgeons and shows the influence of pelvic tilt on acetabular cup alignment.
Key words: pelvic tilt, acetabular cup, hip arthroplasty, cup alignment, cup inclination, cup anteversion.

In total hip arthroplasty, a malpositioned acetabular component can increase the risk of impingement, can restrict the range of motion, may lead to increased and premature wear, and is the most common cause of dislocation [1-9]. In clinical and anatomical studies, Lewinnek et al (1978) [10] correlated the complication rate of total hip arthroplasty with cup alignment and what is termed the "safe zone" of cup implantation, defined as an inclination of 40° ± 10° and an anteversion of 15° ± 10°. Since then, numerous studies have shown that even experienced surgeons cannot guarantee to a large extent that the cup will be implanted within this safe zone when using conventional operative techniques [11-13].

One explanation for the considerable inaccuracies of conventional cup implantation is the fact that the surgeon has insufficient information about the actual pelvic position of the patient, which can vary particularly during the individual stages of the operation. Intraoperatively, information concerning the pelvic tilt of patients lying supposedly straight on the operating table may be inaccurate and limited, meaning that the position of the pelvis cannot be ascertained precisely when conventional operating techniques are used [1,11,14-17].

The aim of this in vitro study was to investigate whether the results of conventional cup implantations are influenced by pelvic tilt and whether significant differences in cup alignment occur with increased pelvic inclination or increased pelvic reclination. A further object of investigation was whether or not these inaccuracies occur predominantly among less experienced surgeons.

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Materials and Methods

In Vitro Model

A synthetic pelvis (4060 pelvis complete, Synbone AG, Malans, CH) was fixed in a clamping device with a finely adjustable turning mechanism produced specially for this series of experiments that could be used for the stageless adjustment of pelvic tilt. In accordance with published data on pelvic tilt among patients in the supine position, pelvic tilts of +10° inclination, 0° neutral position, and −10° reclination were selected, where the angle between the anterior pelvic plane and the table level was measured [17,18]. To simulate the intraoperative situation with bony landmarks that can only be palpated to a limited extent under in vivo conditions, the synthetic pelvic model was surrounded by 6-cm-thick expansive foam and integrated into a manikin with head, torso, and lower extremities. To simulate operation conditions, the entire body was covered with drapes. The cup implantation was thus conducted via a lateral approach with the manikin in the supine position.

Ten different surgeons each inserted sequentially 30 cementless cups (Pinnacle, DePuy, Warsaw, IN) with a diameter of 54 mm into the pelvic model. Of the 10 surgeons, 5 had had implanted fewer than 30 hip total hip arthroplasties before participating in the in vitro experiment. They were classified as the group of less-experienced surgeons (group A). The remaining 5 surgeons had each performed more than 300 hip arthroplasty operations and were assigned to the group of experienced surgeons (group B).

In this in vitro model, the acetabular cups were not inserted stable (cementless) into the pelvic model, just aligned, where the surgeon tried to orientate the cup with an inclination of 45° and an anteversion of 15° in each case. A prior cup reaming was not preformed.

Before each cup alignment, the pelvic tilt was randomly set to +10° inclination, neutral position, or −10° reclination without the surgeon's knowledge, until 10 cup alignments at each of the 3 pelvic tilts had been documented for each surgeon.

The result was therefore a total number of 300 documented cup positions: 100 each for the inclination, neutral position, and reclination of the pelvic model.

The cup orientation was measured using computer-assisted navigation (VectorVision, landmark-based hip 3.0, BrainLAB, Heimstetten, Germany). To this end, a dynamic reference basis was fixed to the ipsilateral iliac crest of the synthetic model, and before the beginning of the experiments, the anterior pelvic plane was measured off against points marked with fiducials on the anterior superior iliac spines and the pubic tubercles using a referenced pointer. Cup alignment was performed using a referenced cup inserter, enabling the cup position set in each case to be measured by the navigation system in real time. As soon as the surgeon believed that the correct cup position had been reached, the cup position was documented via a screenshot for subsequent evaluation. The surgeon was neither able to see the cup position values on the monitor, nor were they communicated to him.

To monitor the accuracy of the computer-assisted measuring technique, a cementless cup was fixed to the opposite side of the pelvic model before the start of the experiment. This cup position was measured in a 3-dimensional computer tomography–based reconstruction of the pelvic model and then compared with the results of 10 consecutive computer-assisted measurements using the landmark-based navigation software (VectorVision, landmark-based hip 3.0, BrainLAB), which was used as the measuring method in the following test arrangement. The maximum deviation for inclination and anteversion as compared with the computed tomography–based control measurement was 1°, meaning that a high reproducibility of the measuring procedure could be assumed, as has been described in previous studies [19].

The cup position values recorded using computer-assisted techniques correspond to the definitions for operative inclination and operative anteversion as specified by Murray (1993) [20]. To represent and evaluate the cup positions in relation to the Lewinnek [10] safe zone, the values were converted to the radiological inclination or radiological anteversion using the algorithms described by Murray (2003) [20].

Statistical Analysis

Statistical analysis was done by using SPSS 11.5 (LEAD Technologies Inc, Haddonfield, NJ). The cup positions at different pelvic tilts were examined using one-way analysis of variance and the Student-Neumann-Keuls method as all pairwise multiple comparison procedure. The Student *t* test was used for comparison of cup positions of the experienced and less-experienced surgeons and their deviations from the target values. The statistical analysis of the acetabular cup implanted inside or outside the safe zone depending on pelvic tilt and surgeon's experience was done via the χ^2 test. A P value of less than .05 was considered statistically significant.