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Correction of pelvic adduction during THA reduces variability in radiographic inclination: findings of a randomised controlled trial

Short title: Correcting pelvic adduction reduces variability in radiographic inclination

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Online-only supplementary material:

CONSORT Flow Diagram.

Abstract

Introduction: The study aims were to identify the incidence of pelvic adduction during total hip arthroplasty (THA) in lateral decubitus and to determine, when aiming for 35° of apparent operative inclination (AOI), which of 3 operating table positions most accurately obtained a target radiographic inclination (RI) of 42°: (1) horizontal; (2) 7° head-down; (3) patient-specific position based on correction of pelvic adduction.

Methods: With patients seated on a levelled theatre table, a ruler incorporating a spirit level was used to draw transverse pelvic lines (TPLs) on the skin overlying the pelvis and sacrum. Subsequently, when positioned in lateral decubitus these lines provided a measure of pelvic adduction.

270 participants were recruited, with 90 randomised to each group for operating table position. In all cases target AOI was 35°, aiming to achieve a target RI of 42°. The primary outcome measure was absolute (unsigned) deviation from the target RI of 42°.

Results: 266/270 patients demonstrated pelvic adduction (overall mean 4.4°, range 0– 9.2°). No patients demonstrated pelvic abduction.

There were significant differences in RI between each of the 3 groups. The horizontal table group displayed the highest mean RI. The patient specific table position group achieved the smallest absolute deviation from target RI of 42°.

Discussion: In lateral decubitus, unrecognised pelvic adduction is common and is an important contributor to unexpectedly high RI. The use of

preoperative transverse pelvic lines helps identify pelvic adduction and its subsequent correction reduces variability in RI.

Clinical Trial Protocol number: NCT01831401.

Keywords

Lateral decubitus, pelvic adduction, radiological inclination

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Introduction

Consistent intraoperative placement of the acetabular component remains a major challenge, irrespective of the surgeon's chosen ideal target, patient position or surgical approach.[1] This has been referred to as the "elusive home run" in total hip arthroplasty (THA).[2] Cup placement can be defined in terms of both position and orientation. Position refers to height, depth and anteroposterior location. Orientation refers to operative anteversion (OA) and operative inclination (OI).

Internal landmarks, such as the transverse acetabular ligament (TAL)[3] have been shown to be a reliable guide for version as well as height, depth and anteroposterior location.[4-6] From experience, we do not believe that the TAL is a reliable guide for OI. Like most surgeons, we rely upon an external reference for this, namely the theatre floor (Figure 1).

[**Figure 1.** Operative inclination (OI) is defined as the angle between acetabular axis and the sagittal plane.[10]]

In order to successfully use the floor as an external reference frame for OI, the pelvis must be in neutral orientation with respect to that external frame. More specifically, the pelvic sagittal plane must be parallel with the floor and frequently this is not the case.[7,8] As true OI is defined in relation to the sagittal plane,[9] we therefore believe the angle formed between the acetabular component insertion handle and the theatre floor is more appropriately referred to as Apparent Operative Inclination (AOI).

If the sagittal plane of the pelvis is not parallel with the floor then AOI does not equal true OI. In the example shown in Figure 1 in the preceding article, the upper hemipelvis has adducted resulting in true OI being greater than AOI.

This helps explain the wide variations reported in the literature for Radiographic Inclination (RI) where typically, although the mean value is close to 40°, the range is in excess of 30°.[10] RI is important clinically as high values are associated with dislocation, squeaking, excessive wear and liner dissociation.[11-14]

In a previous study we took intraoperative photographs at the time of cup impaction to measure both AOI and simulated RI.[15] As predicted trigonometrically, for any given value of OI, OA will increase the value of RI.[9,15] Consequently in our study simulated RI was on average 6° greater than AOI because of the influence of OA. To allow for the impact of OA we now aim for 35° of AOI with the aim of achieving 42° of RI. However, postoperative RI was, on average a further 7° greater than the simulated RI. This unexpected difference was likely due to a combination of pelvic adduction and internal rotation.[7] This study focuses on the effect of pelvic adduction only.

The aims were to firstly measure pelvic adduction in a series of 270 THAs and secondly to measure the effect of this pelvic adduction on resultant RI. The outcome measure used for this was absolute (unsigned) deviation from target RI of 42°.

Patients and methods

This was a prospective, randomised controlled trial (Clinical Trial Protocol number: NCT01831401). The design and study size calculations were based on data from Hill et al.[15] A factorial design was used to simultaneously examine the effects of 2 factors: (1) the effect of method of acetabular component insertion on Apparent Operative Inclination; (2) the effect of pelvic positioning on Radiographic Inclination.

The first factor, method of cup insertion, is described in the accompanying operative inclination paper.[16] The second factor, pelvic positioning, is discussed in this paper. The primary end-point for this factor was the absolute deviation from the target RI of 42°. Assuming a standard deviation of 4.6° for this end-point,[15] a study size of 270 patients (90 in each group for pelvic position) provided 85% power to detect a difference in means of 6.5°, 4.5° and 4.5° for this primary end-point between the 3 pelvic positions as statistically significant ($p < 0.05$) in a 1-way analysis of variance.

Medicines and Healthcare Products Regulatory Agency (MHRA) and Regional Ethics Committee (REC) approval was obtained (REC Ref:12/NI/0191). The CONSORT recommendations were followed (see supplementary material). All patients undergoing primary uncemented THA under the care of DB and DM were considered for inclusion. Patients unwilling or unable to provide informed written consent for study participation were excluded.

[AUTHOR: supplementary material must be cited so please check CONSORT sentence above.]

Transverse pelvic lines (TPLs) were drawn using the same method for all patients. Before administration of spinal anaesthetic the patient was seated on the operating table to eliminate pelvic obliquity. A digital inclinometer (Digi-Pas DWL-80E, DigiPas USA, CT, USA) was used to ensure a level table position (Figure 2a) and a ruler with a recessed spirit level was used to draw a single line overlying the sacroiliac joints at the level of the posterior superior iliac spines. In order to increase the number of visual aids, 2 lines were drawn parallel to the first line and finally 2 further lines were then drawn perpendicular to the TPLs on the side of surgery. TPLs were drawn by the same investigator (CO'N) for all 270 patients using a standard protocol.

Following spinal anaesthetic, patients were placed in lateral decubitus and hip supports were applied. All patients were secured with the Universal Lateral Positioner System (Innovative Medical Products, CT, USA) by the same investigator (CO'N) using a standard protocol with focus on achieving a secure pelvis with twin anterior superior iliac spine supports.

Using a digital inclinometer and plumb line, the Patient Specific Adduction Angle (PSAA) was then measured in every case. This was defined as the degree of head-down table position required to obtain vertical TPLs. Figure 2b shows initial adduction of the uppermost hemipelvis in lateral decubitus. Figure 2c shows the use of TPLs and plumb line to correct adduction.

[**Figure 2a:** TPLs drawn in sitting position with horizontal operating table.
Figure 2b: TPLs in lateral decubitus position with horizontal operating table. Upper hemipelvis appears adducted.
Figure 2c: Operating table position adjusted with aid of plumb line in order to obtain vertical TPLs and obtain neutral pelvic position. (6.7° head down in this example).]

Randomisation was performed using Stata release 11 (StataCorp, College Station, Tx, USA) in balanced blocks of 9 patients, with 30 patients allocated to each of the 9 possible groups for combination for operating table position and method of acetabular component insertion. Randomisation was additionally stratified by surgeon. Overall, this resulted in randomisation to one of 3 possible groups for operating table position, with 90 patients in each group: horizontal table position (0°HD group), 7° head-down position (7°HD group) and patient specific head-down position (PS°HD group). The surgeon remained blinded to table position in all cases. 7 degrees head-down was chosen for one group as this was the mean difference between simulated and actual RI found by Hill et al.[15]

A posterior approach with a cementless Pinnacle Acetabular System (DePuy Synthes, Leeds, UK) was used in all cases. A digital inclinometer was used to measure AOI after final cup impaction in all cases. The method used to intraoperatively determine AOI is discussed in the accompanying inclination paper.[16]

The primary outcome measure was deviation from target RI as measured by CO'N who was blinded to patient groups at time of measurement. Measurements were obtained from postoperative digital antero-posterior supine pelvic radiographs using validated EBRA software.[17] Analysis for inter-rater reliability was performed. A second investigator (JH) repeated RI measurements on 50 postoperative radiographs, selected randomly from the study cohort. Inter-rater reliability was assessed on paired values using the intra-class correlation coefficient.

Initial statistical analyses were performed by 2-factor analysis of variance to check for evidence of interaction between method of cup insertion and pelvic adduction. In the absence of such interaction, 1-way analysis of variance was then used to compare the 3 pelvic adduction groups. Where significant differences were observed post-hoc multiple range tests were used taking into account heterogeneity of variance where present. All tests were conducted at the 5% significance level. Statistical analysis was performed using SPSS version 20 (IBM Corp., Armonk, NY, USA).

Results

The 3 groups were well matched for gender distribution, age and body mass index (BMI). Preliminary 2-way analyses of variance confirmed that there was no evidence of interaction between method of cup insertion and operating table position when considering values for RI ($p = 0.76$) or their absolute (unsigned) deviations from 42° ($p = 0.84$). Additionally there was no evidence that the method of cup insertion had any influence on either the RI values ($p = 0.17$) or their absolute (unsigned) deviations from 42° ($p = 0.821$).

Overall, the mean Patient Specific Adduction Angle (PSAA) was 4.4° with a range from 0° to 9.2°. Table 1 shows PSAA values for each of the 3 groups for operating table position. There were no cases of pelvic abduction and only 4 cases that were not adducted (0°). There were no difference in either the mean ($p = 0.31$) or variance ($p = 0.96$) of PSAA values between the 3 groups.

Regarding the AOI, although there were no differences in variances ($p = 0.24$) the means were significantly different ($p = 0.03$) with multiple range tests showing that the 7°HD group was significantly different from the other 2 groups ($p < 0.05$) (Table 1).

The EBRA method of RI measurement was found to be repeatable with an intra-class correlation coefficient of 0.96 (95% CI 0.95 to 0.98). RI distribution for each group is shown in Figure 3. Mean RI in the 0°HD group was 46.6° (range 32.4–62.6°). Mean RI in the 7° HD group was 40.1° (range 24.2–53.0°). Mean RI in the PS°HD group was 42.7° (range 30.3–55.2°). There was a significant difference ($p < 0.001$) between mean RI values for each pair of groups.

Table 1. Comparison of outcomes for each group.

Group	0°HD	7°HD	PS°HD
Mean patient specific adduction angle (PSSA), degrees (range)	4.2 (0–7.7)	4.5 (0–9.2)	4.6 (0–8.6)
Mean AOI, degrees (range)	33.3 (25–39)	34.0 (25–43)	33.2 (27–37)
Mean RI, degrees (range)	46.6 (32.4–62.6)	40.1 (24.2–53.0)	42.7 (30.3–55.2)
Mean absolute deviation from target 42° RI, degrees (range)	5.7 (0.1–20.6)	4.4 (0.1–17.8)	3.8 (0–13.2)
Number of patients within range 42 +/- 5° (%)	42 (47%)	58 (64%)	66 (73%)

0°HD, horizontal table position; 7°HD, 7° head-down position; PS°HD, patient-specific head-down position; AOI, apparent operative inclination; RI, radiographic inclination.

[**Figure 3.** Comparison of radiographic inclination (RI) for each group. Red cross indicates the mean value in each group.]

Absolute deviation from target RI (42°) was largest in the 0°HD group and smallest in the PS°HD group (Figure 4). There was significant heterogeneity of variance (p = 0.003) with the greatest spread in the 0°HD group and the least spread in the PS°HD group. With the 0°HD group taken as the reference, the mean absolute deviation from 42° was 1.9° (95% CI; 0.7° to 3.1°) lower for the PS°HD group and 1.3° (95% CI; -0.1° to 2.6°) lower for the 7°HD group. The PS°HD group was significantly superior in terms of proximity to 42° when compared to the 0°HD group (p < 0.001) but there was no significant superiority between the 7°HD and PS°HD groups (p = 0.41).

[**Figure 4.** Box and whisker plot showing absolute deviation from target RI for each operating table position.]

Discussion

The 3 groups were clinically comparable. Although the greater mean AOI in the 7°HD group attained statistical significance when compared to the other 2 groups, this difference was only 0.8º , which we argue is not *clinically* significant (Table 1). We believe that any difference in mean AOI of less than 1° between groups is not clinically significant and the differences between groups in this study were only 0.1°, 0.7° and 0.8°. In addition, our target AOI in clinical practice is 35° +/- 2.5° and mean AOI for all 3 groups was comfortably within this range.

AOI, although termed 'apparent', is an accurate reading in itself because it was measured with a calibrated digital inclinometer accurate to 1 decimal place.

Only 4 pelves out of 270 (1.5%) were not adducted (0°). None were abducted. The mean pelvic adduction was 4.4° with a range from 0 to 9.2° (Table 1). We propose that pelvic adduction in the lateral decubitus position appears to be the norm, at least in our series, and is under-recognised. We are unaware of any prior publication describing this.

The next question is whether pelvic adduction affects RI? As seen in Table 1 and Figure 3, the mean RI for the 3 groups was significantly different. Since there was no clinically significant difference in AOI between the groups, and the only comparable difference between the groups was in pelvic positioning, we believe it is reasonable to conclude that pelvic adduction does affect RI.

The highest mean value of RI (46.6°) was observed when the operating table position was horizontal (0°HD group). The 0°HD group had a mean patient specific adduction angle of 4.2° and therefore uncorrected pelvic adduction increased RI. Considering that the horizontal theatre table position is common surgical practice, it is likely that many surgeons will have higher than expected RI values for a given AOI if pelvic adduction remains unrecognised or uncorrected.

The PS°HD and 7°HD groups were closer to 42° and were not significantly different in terms of mean absolute deviation of RI from the 42° target (Figure 4). By tilting the operating table head-down and negating the impact of pelvic adduction, there is a significant improvement in the RI, closer to the target. Given that the overall mean resting pelvic adduction was 4.4°, one would expect that the 7°HD group were tilted excessively and thus over-compensated. This is reflected in the mean RI for the 7°HD group being lower than the target at 40.1°.

There are limitations to this study. Firstly, correction of pelvic adduction was based on clinical rather than radiographic measurements. Secondly, the TPL method was not assessed for repeatability and may be less reliable in the grossly obese patient because of an increased potential for skin movement. In addition, only pelvic adduction was considered but we now know that RI is also influenced by pelvic internal rotation.[7] Best efforts were made to eliminate all pelvic movements by secure patient placement, however intraoperative pelvic movement is inevitable especially in obese patients.[18] Ongoing work is being done to both monitor and control this movement intraoperatively.

We conclude that pelvic adduction is under-recognised and that it is an important contributing factor to high outliers for RI. We advocate the use of TPLs as a visual aid to guide preoperative pelvic positioning in order to address this.

We believe that failure to ensure that the pelvic sagittal plane is horizontal during THA is by far the greatest source of error with respect to radiographic inclination.

Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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Supplementary Online-only material

CONSORT Flow Diagram

CONSORT
TRANSPARENT REPORTING of TRIALS

CONSORT Flow Diagram