Arch Orthop Trauma Surg
DOI 10.1007/s00402-011-1379-1

ORTHOPAEDIC SURGERY

Cup positioning in total hip arthoplasty: spatial alignment of the acetabular entry plane

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Received: 18 May 2011

Abstract
Purpose Correct cup positioning is one of the keys for successful total hip replacement. There are mechanical and computer assistant guides for correct cup positioning in the market. To optimize the cup positioning, the use of navigation systems is recommended. The aim of this study was to compare spatial orientation of the acetabulary entry plane in relation to tables plane which is used by mechanical guides as well as anterior pelvic plane used for cup orientation by navigation systems.
Methods CT raw data of 80 Caucasians (160 acetabuli) (done in supine position) with osteoartritic hips were collected. 3-D pelvic reconstruction was generated using Amira® software (Visage Imaging Berlin, Germany). Anterior pelvic plane and acetabulary entry plane were defined by reliable anatomical landmarks. Spatial orientation were calculated by a custom made program code for the Amira® software.
Results There were no differences between anterior pelvic plane and table's plane as well as spatial orientation of acetabulary entry plane of both acetabuli in relation to anterior pelvic plane or table's plane. Furthermore, there was no correlation between age, sex or body mass index and spatial orientation of the acetabulary entry plane as well.
Conclusions The use of mechanical alignment guides for cup orientation during total hip arthroplasty based on table's plane in patient's supine position is a successful method to achieve proper cup orientation.

Keywords Total hip replacement · Cup alignment · Anatomical landmarks · Acetabulary entry plane

Introduction

Optimal acetabular cup position is an important determinant of early and long-term success of total hip arthroplasty (THA). Poor cup position is associated with impingement, dislocation, increasing polyethylene wear, pelvic osteolysis, component loosening and migration [1]. Numerous studies deal with the problem of a correct cup orientation in THA [2–9]. Many companies offer different mechanical or computer assisted guides to optimize the cup positioning.

However, to the author's knowledge there are no studies, which investigate the variation of patient's position relatively to the operating table. Therefore, the influence to the spatial alignment of the acetabulum stays unclear.

The patient lying supine on the operating table is a common position for a total hip replacement procedure. Basically, version and abduction of the cup orientation is referenced to the anterior pelvic plane defined by the anterior superior iliac spine (ASIS) bilaterally and pubic tubercles (PT) [5, 7, 10]. This plane is also used for cup

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orientation used by navigation systems [11]. However, intraoperative identification of the anterior pelvic plane is controversial because of the patient covered with blankets. Cup alignment in relation to the plane of the operating table represents a simple alternative, but does not reflect the appearance of pelvic tilting at the table within supine position of the patient. This circumstance unavoidably leads to a spatial shift of the acetabular entry plane. Unrecognized pelvic tilting consequently results in cup malpositioning, if the surgeon aligns the implant position to the plane of the table. To date it is unknown, how strong the variance of this pelvis tilt is in reality. Similar to the supine position in the operating theatre, an accurate alignment of the patient's body axis, respectively, pelvis to the table in a CT scanner is aspired. Consequently, these procedures are basically comparable. This notion acts as the basis for this study.

The aim of this study was to compare the spatial orientation of the acetabulary entry plane in relation to table's plane, which is used by mechanical guides as well as anterior pelvic plane used for cup orientation by navigation systems.

Materials and methods

In this retrospective study, CT raw datasets of patients with osteoarthritic hip (III° or IV° Kellgren and Lawrence classification) joints were collected to examine the influence of the individual spatial pelvic orientation in supine position in relation to the table. All patients were treated in our hospital from July to December, 2008 and each CT scan was well-founded for individual diagnostics of patient's diseases. No CT scans were done for study reasons only. Declaration of content of every patient for further research applications of individual image data was purchased. Pelvic bones showing traumatic residuals as well as tumorous or inflammatory alterations were excluded. All CT scans were performed on a medical multislice CT scanner Siemens SOMATOM Sensation (Siemens AG, Erlangen, Germany). Scanning parameters included image resolution 512 × 512 pixels, a slice distance of 0.6 mm and kernel B45f. All CT datasets were anonymised at the beginning of the following conversion process. Patient's demographic data (age, sex, body mass index) were collected.

CT data were post processed by a standardized conversion workflow [12, 13]. DICOM (Digital Imaging and Communication in Medicine) CT files were post processed using the Amira 4.2 software (Visage Imaging GmbH, Berlin, Germany) to generate 3-D pelvic reconstructions. In a first step, cross-sectional images were cropped by neglecting all soft tissue as long as no bone structure gets hurt to decrease the data amount. In second, in each slice the bone structures were isolated using semiautomatic labeling program codes, regarded to DICOM threshold values of grey scales to bone. In some cases of thin cortical bone in high osteoporotic pelves, an additional manual segmentation was required to avoid pseudo-holes in 3-D views. As a result of the segmentation process, the software produced triangulated bone surfaces in the STL format (standard triangulated language) [13].

To create a reproducible geometrical model, exact definitions are needed to analyze the spatial relationship of the individual left and right acetabular orientation relating to the pelvis itself as well as to the CT table. Basically, the table plane is given by the coordinate system of the CT scanner (T), i.e. 0° in the *x*/*y*-, *x*/*z*- and *y*/*z*-plane. The z_T-axis points into cranial direction, the x_T-axis to the left and the y_T-axis into anterior-posterior direction. Thus, the table plane corresponds to the *x*/*z*-plane of the CT scan (Fig. 1). The plane of the acetabular entry area and the frontal pelvic plane are defined, marking reliable anatomical landmarks in the 3-D CT dataset using the Amira® software application.

The anterior pelvic plane is determined by four anatomical landmarks placed on the virtual pelvis model, namely the ASIS and the pubic tubercles bilaterally. This anatomical definition is widely accepted in the literature [5, 7, 10]. This plane defines the pelvic coordinate system (P). The z_P-axis points into cranial direction, the x_P-axis to the left and the y_P-axis into anterior-posterior direction (Fig. 2).

At least three anatomical bone landmarks are needed to define the spatial orientation of the acetabular entry plane. However, the acetabular rim does not reflect a simple circle in one plane. In fact, the rim conforms to a complex 3-D construct. Additionally, the shape is strongly influenced by the extent of osteophytes in arthritis. Hence, the rim cannot be used to determine the anatomical entry plane of the acetabulum. The problem consists in a reliable definition of the acetabular spatial orientation. In the ontogenic growth the acetabulum is build by the fusion of the iliac, the pubic and the ischial bone. Therefore, these three parts define the lateral spatial orientation of the acetabular entry plane. Regarding to this fact, three osseous pelvic landmarks were determined forming the acetabular entry plane. At first on the pubic bone: the prominence of the lateral aspect of the superior pelvic ramus (Eminentia iliopectinea) (A), at second for the ilium bone: the lowest point of the trough between the anterior inferior iliac spine and the acetabular rim (B), at third: the lowest point of the acetabular sulcus of the ischium (C) (Fig. 3).

The fully automatic analysis of the CT datasets was performed by a custom made program code based on analytical geometry. Therefore, the normal vector which is perpendicular to the acetabular entry plane was calculated to determine the plane orientation in the coordinate system of the pelvis, respectively, of the CT-scanner. The tilt of the pelvis itself related to the table was measured by angle

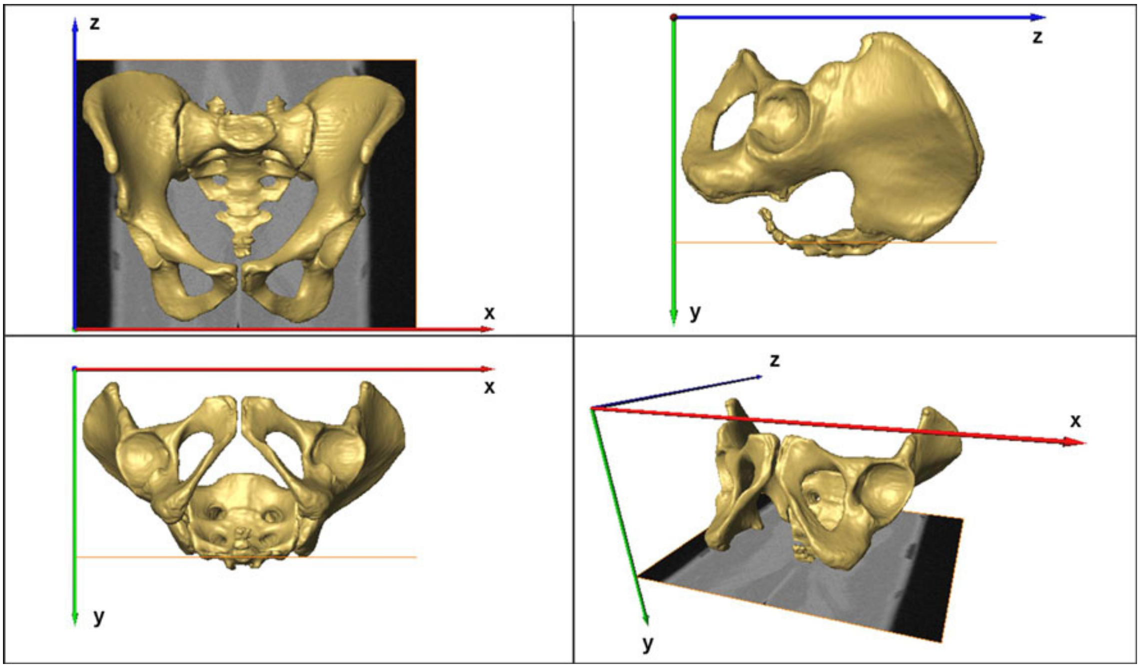

Fig. 1 The table plane given by the *zx* plane of the CT-scan

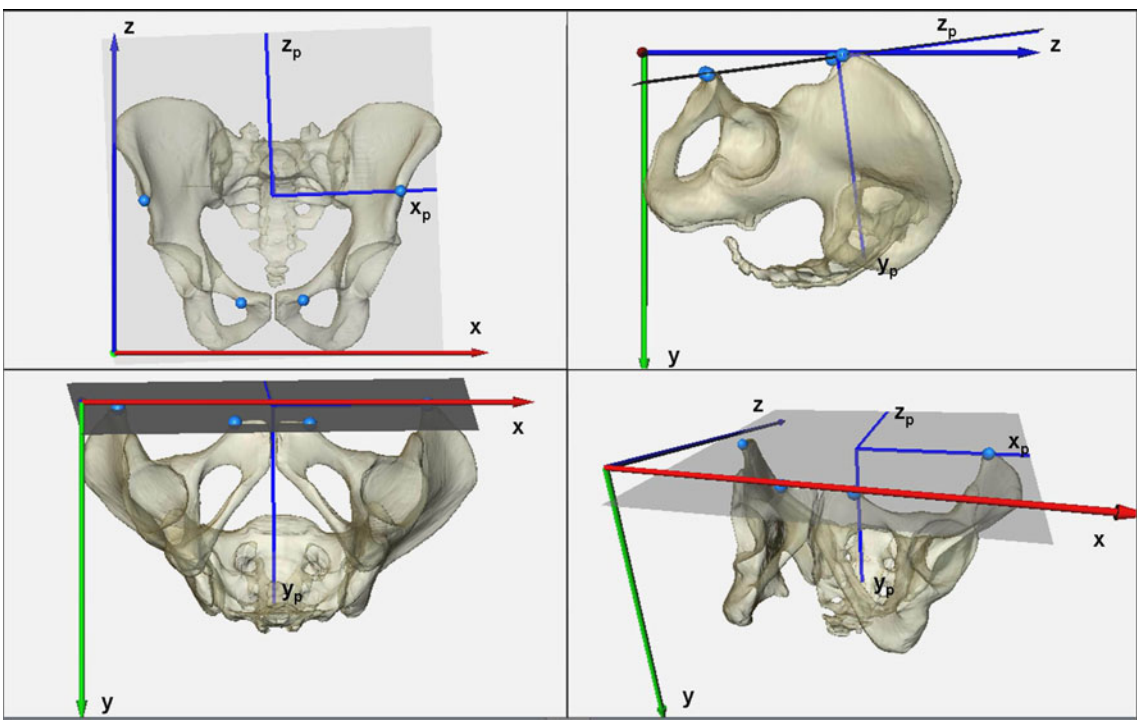

Fig. 2 Spatial orientation of the anterior pelvic plane given by bony landmarks (*blue dots*)

deviation of the *x*, *y* and *z*-axes between the pelvic (P) and the table (T) coordinate system. The scripts compute all angles with respect to the table coordinate system, alternatively with respect to the pelvis coordinate system defined by the placed landmarks.

Statistical analysis was performed by SPSS® 13 software (SPSS Inc., Chicago, USA). For comparisons between normally distributed paired groups we used Student's *t* test. In order to measure the degree of linear relationship between two variables the Pearson product moment correlation

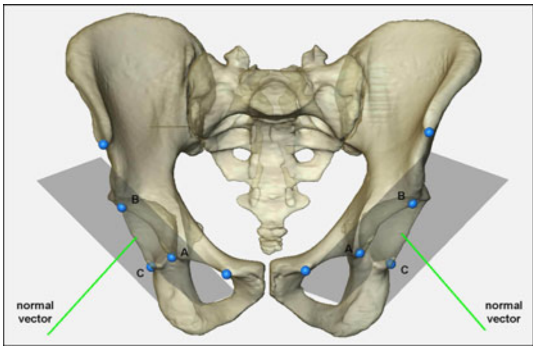

Fig. 3 Left and right acetabulum plane and normal vectors (*green*) defined by 3 anatomical landmarks (*A*, *B*, *C*)

(PPMC) was performed. Multilinear regression analysis was used for the modeling and analysis of numerical data consisting of values of a dependent variable (response variable) and of one or more independent variables (explanatory variables). A p value of less than 0.05 was considered significant.

Results

CT raw datasets of 80 patients (33 females, 47 males) of a representative Caucasian population were collected to examine the influence of the individual spatial pelvic orientation in supine position in relation to the table. Patient's mean age was 56 ± years (range 18–89) with a mean body height of 173 ± 11 cm (range 147–193 cm) and a mean body weight of 76 ± 13 kg (54–125 kg). The body mass index was calculated with 25 ± 4 kg/m^2 (range 20–39 kg/m^2).

Comparing the relation between the CT table plane and patient's pelvic plane there were only marginal differences in version (1.1 ± 6.6°), abduction (0.3 ± 2.5°) and rotation (0.3 ± 1.7°) (Fig. 4). However, variance of the acetabular version was remarkable higher than for abduction. For this consideration overall 160 acetabula (left and right side of 80 pelves) were subsumed.

In the next step, the angles between the acetabular entry plane and table's plane as well as pelvis entry plane were calculated for the right and left hip, separately.

Abduction angles between acetabular entry plane and table's plane are for the left hip 44.6 ± 4.3° (ranged from 32.9 to 56.6°) and for the right hip 44.4 ± 4.1° (ranged from 34.3 to 55.9°). Acetabular anteversion in relation to the table's plane was measured for the left hip with 24.7 ± 6.8° (ranged from 7.9 to 45.3°) and for the right hip with 26.1 ± 6.6° (ranged from 8.9 to 44.6°). Comparing the abduction angles between acetabular entry plane and pelvis plane are for the left hip 44.1 ± 4.0° (ranged from 34.9 to 54.5°) and for the right hip 44.6 ± 4.1° (ranged from 35.8 to 58.5°). Acetabular anteversion in relation to the pelvis plane was measured for the left hip with 23.8 ± 7.1° (ranged from 8.5 to 38.4°) and for the right hip with 24.8 ± 6.7° (ranged from 11.0 to 40.9°) (Table 1). There were no significant differences in acetabular abduction and anteversion between the both sides.

Comparing the acetabular abduction in relation to pelvis entry plane and table's plane, there were no differences on the left side ($p = 0.44$) and right side ($p = 0.77$) as well (Fig. 5).

Comparing the acetabular version in relation to pelvis entry plane and table's plane, there were no differences on the left side ($p = 0.43$) and right side ($p = 0.24$) as well (Fig. 6).

In conclusion, differences between pelvis entry plane and table plane are marginal and without any statistical

Fig. 4 Orientation of patient's pelvic plane and the CT table plane (angles measured in degree)

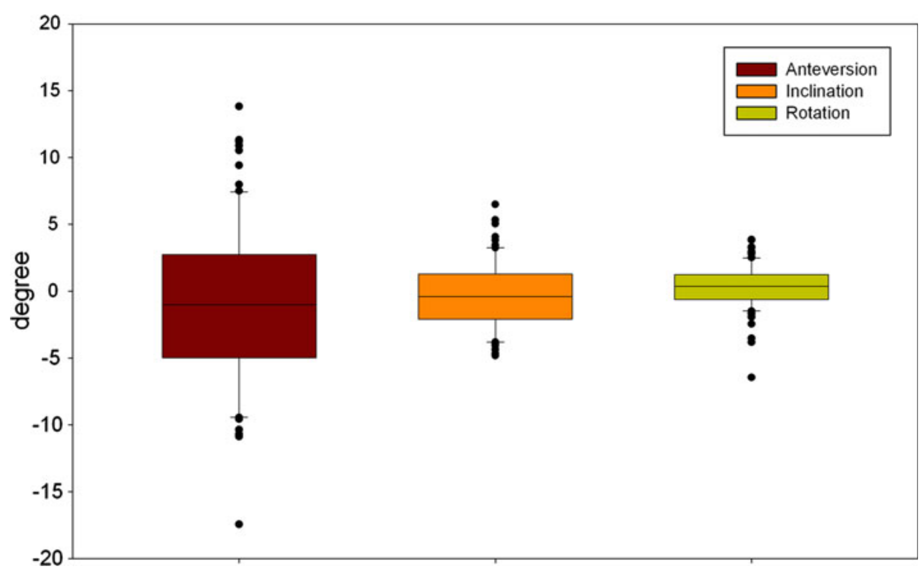

Table 1 Spatial orientation of the acetabuli in relation to anterior pelvic plane and CT table plane

	Acetabulum versus table plane		Acetabulum versus pelvis plane	
	Left (°)	Right (°)	Left (°)	Right (°)
Abduction				
Mean ± SD	44.6 ± 4.3	44.4 ± 4.1	44.1 ± 4.0	44.6 ± 4.1
Min	32.9	34.3	34.9	35.8
Max	56.6	55.9	54.5	58.5
Anteversion				
Mean ± SD	24.7 ± 6.8	26.1 ± 6.6	23.8 ± 7.1	24.8 ± 6.7
Min	7.9	8.9	8.5	11.0
Max	45.3	44.6	38.4	40.9

SD standard deviation, *Min* minimum, *Max* maximum

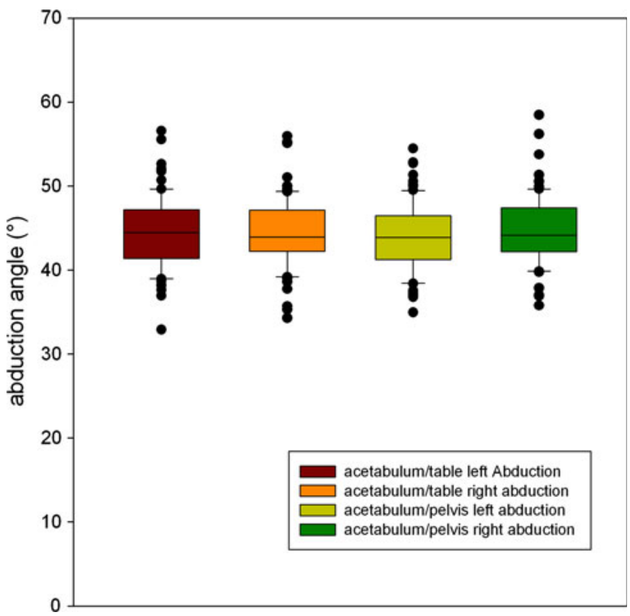

Fig. 5 Acetabular abduction in relation to patient's pelvic plane and the CT table plane (angles measured in degree)

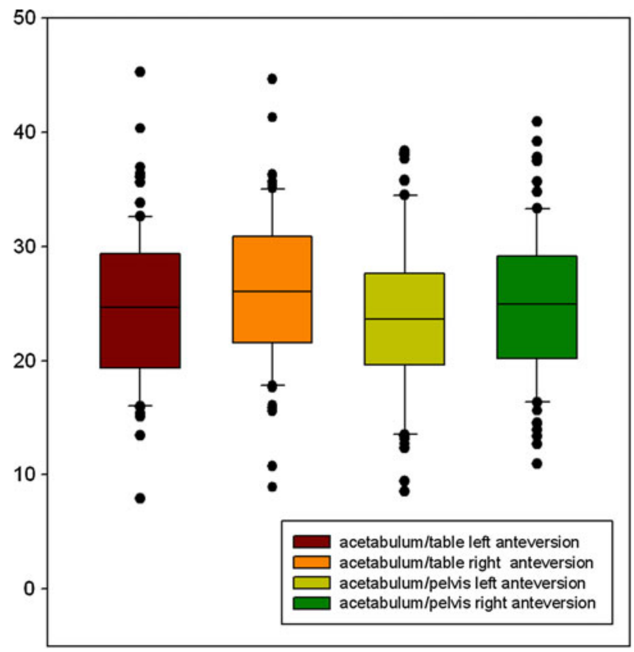

Fig. 6 Acetabular version in relation to patient's anterior pelvic plane and the CT table plane (angles measured in degree)

significance. There were no relevant differences in spatial orientation of acetabular entry plane of both acetabuli in relation to pelvis entry plane or table's plane.

Furthermore, there was no correlation between age, sex or body mass index and spatial orientation of the acetabular entry plane as well (data not shown).

Discussion

Hip dislocation after THA occurs with a reported incidence ranging from 1 to 11% [14–16]. Dislocations can be attributed to patient age, gender, medical conditions, cognitive dysfunction, surgical approach, implant orientation, implant type, revision procedures, and patient postoperative compliance. Of these factors, the surgeon directly controls implant choice, implant orientation and surgical approach. Component orientation, specifically acetabular orientation, is responsible for the majority of dislocations [14, 16], although head sizing, leg length, offset and patient compliance can play important roles.

Proper orientation of an acetabular implant can be obtained by careful consideration of abduction and version angles. Most manufacturers recommend placement of the acetabulum within a so-called safe zone [17]. This safe zone is based upon studies showing that the optimal radiographic orientation of the acetabulum is an abduction angle of 40 ± 10° and an anteversion angle of 15 ± 10° [18]. Lewinnek et al. [19] reported a 6% rate of instability when either the abduction angle or the anteversion angle fell outside of this safe range and a significantly ($p < 0.05$) lower dislocation rate of 1.5% when implants were within the safe range.

An increasing number of surgeons uses computer navigation to optimize cup positioning in THA [1, 20–23]. The use of computer assisted navigation tools is also affiliated with a learning curve in matter of cup positioning and length of operation room time [22]. However, many studies suggest that navigation-based implantation can improve cup positioning in THA. DiGioia et al. [24] used CT scans and computerized component guidance to minimize dislocation in a small group of patients up to. Even though this technique demonstrates promise, the high financial costs and limited availability restricts the usefulness in routine daily application in all centers performing hip arthroplasty.

On the other hand, Beckmann et al. [25] reported in 2009, results of a meta-analysis of 363 citations. Mean cup abduction and anteversion were not statistically significantly different between conventional groups and the navigated groups.

The use of bony landmark during surgery is another option to get the cup fixed in correct position. Sotereanos et al. [2] reported a dislocation of 0.81% (5 of 617 hips) at an average follow-up of 4.5 years after using three pelvic bony landmarks (ilium, superior pubic ramus, and superior acetabulum) for cup orientation in abduction and anteversion. Other investigations have delved into the use of the transverse acetabular ligament (TAL) for acetabular component positioning [26–31]. Archbold et al. [27] noted a postoperative dislocation rate of 0.6% after using the TAL to guide acetabular reaming and positioning in 1,000 THP. However, the identification of the ligament remains controversial. Epstein et al. were able to identify the TAL only in 47% of their hips (30 of 64). This was mainly due to the osteophytes located of the inferior aspect of the acetabulum and covering the ligament. After removing the osteophytes, the ligament could only be identified in 31% (10 of 31) [28]. However, in the hip joint revision endoprosthetics anatomical landmarks are largely missing and the correct positioning of the cup can be critical, especially in large defect situations.

Cup alignment in relation to the plane of the operating table represents a simple alternative method, independently of anatomical landmarks. The presented study displays the results of evaluation of CT raw datasets of 80 patients in a supine position. The change of pelvic position to the table reference can occur in all of the three spatial axes. There were no significant differences between pelvis entry plane and table plane as well as in spatial orientation of acetabular entry plane of both acetabuli in relation to pelvis entry plane or table's plane. This fact implies that the variance of the spatial pelvic shift within the patient's supine position at the table only plays a negligible role. However, our data implicate that the main alignment of the body axis to the table's longitudinal axis (z_P-axis) regularly succeeds in a very accurate manner shown by the small deviation of pelvis rotation as well as acetabular abduction. On the other hand, version of the acetabulum in relation to both, the pelvis as well as the table, represent a remarkable higher variance. The authors interpret this result as a higher inter individual anatomical variance of the acetabular alignment in the sagittal plane (y/z-plane).

One major limitation of our study is the fact that intraoperative manipulations of the patient that may lead to a change of the pelvic anteversion, rotation or inclination in relation to the table plane have not been taken into account. The effect of special positioning, for example, patient in the supine position with elevation of the contralateral leg, was not quantified and needs to be examined in further investigations.

We conclude that the use of table's plane for cup orientation during THA in patients in a supine position using commercial cup positioning instruments is a successful method in assuring proper acetabular component orientation. The precondition is that the surgeon continuously checks patient positioning on the operating table to be able to react to any changes that may effect the relation between pelvic anterior plane and table plane. Care should be taken especially in a correct version of the acetabular cup component.

The findings of the presented study may be useful in standardization of the cup positioning with new approaches in minimally invasive total hip replacement. A supine position of the patient is mandatory.

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