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ORIGINAL ARTICLE

Pelvic tilt measurement before and after total hip arthroplasty

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KEYWORDS
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Summary
Introduction: Most computer-assisted navigation systems used in total hip arthroplasty (THA) reference the anterior pelvic plane, which connects the anterior superior iliac spines and the pubic symphysis. The pelvic tilt is defined as the angle between this anterior pelvic plane (APP) and a vertical line in the standing position. Important interindividual variations of this angle have been reported and may affect final functional anteversion of the acetabular cup. The preoperative value of the pelvic tilt has been included in computer-assisted navigation systems to improve acetabular cup positioning. However, there is no data available which strongly confirms the consistency of this angle for each individual after hip prosthesis implantation.
Hypothesis: The orientation of the APP in the standing position is not significantly modified after THA.
Objectives: To evaluate in a prospective manner, the reproducibility of pelvic tilt measurement and its variability between THA preoperative and 3-year postoperative measurements.
Materials and methods: A lateral teleradiograph of the pelvis and dorsolumbar spine was obtained in the standing position preoperatively and 3 years after THA. Fifty patients undergoing THA performed by a single operator via an anterolateral approach (26 males and 24 females) were included prospectively. The pelvic tilt was measured on radiographs by two independent observers. The angle was defined as positive in case of pelvis retroversion relative to the vertical plane and negative in case of anteversion. Bland-Altman analysis was used to assess levels of agreement between both operator measurements while preoperative and last follow-up measurements were compared using the Student *t*-test for unpaired samples.
Results: The level of agreement between measurements of both operators was satisfactory. Mean preoperative pelvic tilt was 4.68° ± 0.68 S.D. (−6° to 14°), and 4.78° ± 0.64 S.D. (−5° to 14°) at last follow-up. The mean difference between preoperative and last follow-up

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measurements was 3° ± 0.3 S.D. There was no statistically significant variation between preoperative and 3-year follow-up values ($p > 0.05$). Ninety-five percent of the patients had less than a 5° difference between both measurements while 5% had a difference ranging from 5° to 10°; none of the patients reported a variation greater than 10°.
Discussion: Our findings show no significant variation in pelvic tilt between preoperative and 3-year follow-up values after THA. Therefore, the individual preoperative value of this angle should be integrated to achieve proper acetabular cup placement during THA especially when using computed assisted navigation based on the APP.
Level of evidence: Level III prospective diagnostic study.

Introduction

Computer-assisted total hip arthroplasty (THA) results in a lower risk of acetabular component malposition by reducing the standard deviation relative to the targeted reference [1—6]. Two types of computer navigation systems have been described. The first one is functional [7], and provides proper alignment of both cup and femoral components thus resulting in an optimal range of motion. The second type relies on anatomical bony landmarks to determine angles of positioning and patient's position within the 3D space. This essential element requires the use of the anterior pelvic plane (also called Lewinnek plane) as the reference plane connecting the anterior and superior iliac spines and the pubic symphysis (Fig. 1).

Most computer navigation systems assume this plane is globally vertical which creates an artificial alignment of the anterior superior iliac spines and the pubic symphysis. However, it has been demonstrated that the anterior pelvic plane differs from the vertical plane [8,9] and reports important interindividual variations [10]. To make up for this problem, the angle of pelvic tilt (alpha angle), reflecting the degree of pelvic anteversion or retroversion, was defined in the standing position as being the angle formed between the anterior pelvic plane and a vertical line connecting the anterior and superior iliac spines (Fig. 2). This angle should always be considered otherwise it may have important consequences on functional cup position [11]. A 5° error or variation in the sagittal plane may produce a range of error of 5° in cup anteversion. That is why this angle should be integrated in computer navigation software. This angle is obtained on lateral radiographs in the standing position, superimposition of anterior and superior iliac spines being defined as the success criterion. Adding the individual angle of pelvic tilt to the common parameters of computer navigation will help correct the reference plane according to

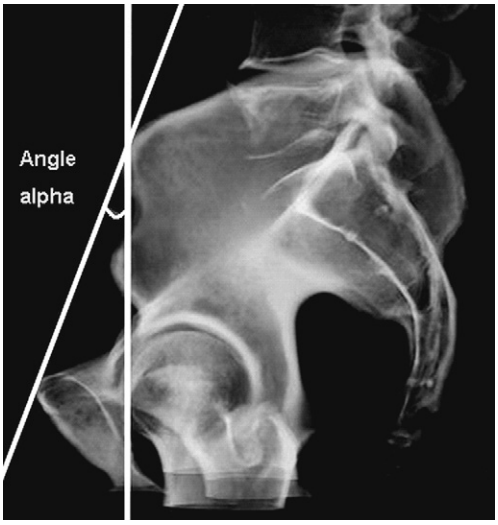

Figure 2 Angle of pelvic tilt (alpha angle) is defined as the angle between the anterior pelvic plane and the vertical plane. This angle is positive in case of pelvic anteversion and negative in case of pelvic retroversion.

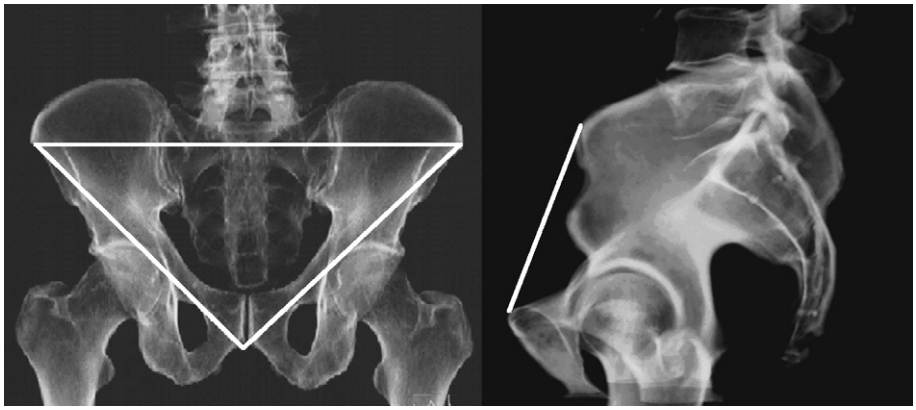

Figure 1 Anterior pelvic plane, connecting the anterior superior iliac spines and the pelvic symphysis.

each patient's specific lumbopelvic statics in the standing position. Patient's specific parameters, measured in the weight-bearing position will allow more accurate acetabular component placement. However, it requires a good repeatability and consistency between pre- and postoperative measurements for each patient. According to our initial hypothesis, the alpha angle of pelvic tilt, which reflects the sagittal orientation of the pelvis within the space in a standing patient, was stable at three years after THA. Therefore, the two objectives of this study were first to assess the inter- and intraobserver agreement between different series of measurements and secondly to confirm there is no variation of this angle after THA [12] in order to integrate this parameter in computer navigation systems.

Material and methods

Features of the study

Fifty patients with primitive osteoarthritis of the hip were included in this prospective nonrandomized study over a period of 3 years, between 2002 and 2005. Pre- and postoperative pelvic tilt measurement was performed in each patient by two independent observers in order to evaluate the reproducibility and repeatability of the different series. Only patients with primitive unilateral osteoarthritis of the hip were included in the study, while those with bilateral osteoarthritis and having previously undergone arthroplasty or suffering from severe spinal arthrosis [13] were excluded. The series included 26 males and 24 females with a mean age of 64 years (47—81 years) and mean BMI of 28 kg/m^2 (24—32 kg/m^2).

Operative technique

All selected patients were operated on by two senior surgeons (JMA and JNA) via a Watson-Jones anterolateral approach and with the same operative protocol, in a strict supine position. A single uncemented acetabular (Inlock™, Symbios, Yverdon) and femoral (Symbios™, Symbios, Yverdon) component was implanted in all patients. Postoperatively, all patients followed the same rehabilitation protocol.

Methods of measurement

A standardized pre- and postoperative radiographic protocol was used in all patients. Lateral radiographs were obtained in the standing position with the hip in extension and the arm resting at 90° on a support, at equal distance from the tube, on large radiographic tapes. Radiographic success criterion was defined as proper superimposition of the anterior superior iliac spines (Fig. 3). Preoperative radiographic assessment was based on a lateral teleradiograph of the lower limbs which included pelvis and lumbar spine to check the absence of any lumbar pathology in the selected patients. The same radiographic view was taken at 3-year follow-up, thus allowing optimal comparability between both series of images.

Figure 3 Angle of pelvic tilt measurement before (a) and after (b) total hip arthroplasty.

The pelvic tilt was measured preoperatively and at 3-year follow-up in all selected patients. This angle was defined as the angle formed by a line drawn from the anterior superior iliac spines to the pubic symphysis (anterior pelvic plane) and the vertical line connecting the anterior superior iliac spines. This angle was positive in case of pelvis retroversion and negative with the pelvis in anteversion.

Each pre- and postoperative measurement was performed twice by two observers, independent from the operators (BB and SP), to assess the reliability of the pelvic tilt measurements and investigate any significant variation of this angle after THA. The absence of statistically significant pelvis incidence variation, in daily practice [14], which is an anatomical parameter therefore non-correlated with pelvic position within the space, was investigated to check the agreement between the series of measurements performed by the two observers.

Postoperatively, proper orientation of the acetabular component was also radiographically assessed according to the Widmer method [15] to exclude any pelvic statics modification due to implant malposition.

Statistical analysis

Statistical analysis was performed by the Hospital computer department using the SPSS 12.0 software (Chicago, Illinois). First, inter- and intraobserver variability of pelvic tilt measurement was quantified using the Bland Altman method [16]. Then unpaired *t*-test and Pearson's intraclass correlation coefficient [17,18] between the different series of pre- and postoperative measurements were performed to evaluate de degree of pelvic tilt variation before and after THA in all patients. Individual pelvic tilt variations were also analyzed between pre- and postoperative examination and expressed as a percentage of patients with a less than 5°, ranging from 5 to 10° or greater than 10° variation.

Table 1 Results of pelvic tilt and pelvic incidence mean values in the whole series.

	Preoperative		At 3-year follow-up		*P*
	Mean value	*Extremes*	Mean value	*Extremes*	
Pelvic tilt	4.68°	−6° to 14	4.78°	−5° to 14°	NS
Pelvic incidence	56.04°	40° to 87	55.96°	40° to 83°	NS

NS: non-significant.

Results

Analysis of intra- and interobserver variations

In the whole series of measurements performed by each observer, intraclass correlation coefficients evaluating the agreement between the series of pelvic incidence and pelvic tilt measurements were greater than 92% ($p < 0.05$). The analysis of interobserver variability, reflecting the repeatability of measurements, demonstrated a good level of agreement between the series of measurements with correlation coefficients greater than 93% ($p < 0.05$). Results were similar for intraobserver variability (reproducibility) with correlation coefficients greater than 93% ($p < 0.05$).

The correlation between the different series of measurements performed by the two observers was also assessed by comparing preoperative and last follow-up pelvic incidence. In the whole series of measurements, the mean preoperative pelvic incidence was 56.04° versus 55.96° (40—83°) postoperatively. No statistically significant differences appeared between measurements at the 5% threshold, which reflects the agreement between measurements performed by each examiner.

Results of pelvic tilt measurements

Mean pelvic tilt value was 4.68° ± 0.68 (−6 ; 14°) preoperatively.

Mean pelvic tilt value was 4.78° ± 0.64 (−5 ; 14°) postoperatively.

When parameters were compared to one another, the Student *t*-test did not demonstrate any significant difference at the 5% threshold between pre- and postoperative pelvic tilt (Table 1). On the whole series, 95% of the patients showed a pelvic tilt variation of less than 5° between pre- and postoperative measurements whereas a 5 to 10° variation was reported in the other cases (5%).

Evaluation of acetabular component position

Postoperative measurements of the acetabular implant position according to Widmer [15] reported a mean anteversion of 17.32° (11—29°) and a mean inclination of 43.94° (38—56°).

Discussion

The various computer navigation systems aim at improving the acetabular cup positioning during THA. The anterior pelvic plane as an anatomical landmark has been widely used, however, it exhibits some limitations: It is rarely comparable to the vertical plane in clinical practice [12,13] and displays important interindividual variations.

Therefore, the two objectives of that work were: to assess the reliability of the angle of pelvic tilt by two examiners independent from the operator and to confirm, among a wide number of patients, the pelvic tilt evolution after THA [12] in order to integrate the angle of pelvic tilt in the preoperative planning.

The results of this prospective study in the quiet standing position suggest that the angle of pelvic tilt is a reliable and stable parameter at long-term after THA in 95% of the patients. The lumbopelvic statics is not significantly modified by total hip prosthesis implantation. Such data are of great interest for computer-assisted surgery. Once validated, the alpha angle of pelvic tilt may be used during preoperative navigation planning. These data correlate the results of Pinoit et al. [12] who do not find any significant variation in the orientation of the anterior pelvic plane in the standing position before and after THA in 19 patients.

Recent works have emphasized the need to take the sagittal pelvic and spinal balance into account during implantation of the acetabular component. According to the studies of DiGioia et al. [8], Nishihara et al. [9], Pinoit et al. [12] and Philippot et al. [13], the anterior pelvic plane is not vertical and shows major intersubject variations in static conditions. Lembeck et al. [19] have measured the changes in acetabular functional anteversion according to the variations of the sacral tilt. Therefore, a 1° variation of pelvic statics induces a 0.7° variation of the functional anteversion. These variations were also underlined in the work of Chen et al. [20], Müller et al. [21], and Tang et al. [22]. Changes occurring in the sagittal balance of the lumbopelvic complex are not meaningless during THA. These changes are potentially responsible for the occurrence of some secondary complications such as dislocation as shown in De Thomasson et al. study. [23]. 3D pelvic orientation should be registered during THA particularly when using computer-assisted navigation. The anterior pelvic plane taken as a reference may be weighted by the pelvic tilt value which is a parameter established in the weight-bearing position, specific to each patient and demonstrating no significant variation when moving to the supine position [13]. The pelvic position weighting is made possible by operative strict supine position which does not significantly modify the degree of pelvic tilt and thus facilitates location of the anterior pelvic plane. However, these data cannot be validated in the lateral position. Moreover, pelvic tilt variations are observed during position changes, specifically in the sitting position.

This study therefore exhibits some limitations since the pelvic tilt was evaluated in static conditions using a simple daily practice tool which is lateral radiograph. According

to the results, the consistency of pelvic tilt is good in the majority of the patients but requires to be assessed in dynamic conditions [24].

From now on, we integrate the angle of pelvic tilt in our computer-assisted navigation software to improve acetabular cup positioning in all our patients. Complementary studies are being conducted by movement analysis in dynamic situation and appear necessary to evaluate long-term evolution in these patients.

Conflicts of interest

None.

References

[1] Parratte S, Argenson JN, Flecher X, Aubaniac JM. Positionnement acétabulaire assisté par ordinateur dans les prothèses totales de hanche : étude prospective comparative randomisée. Rev Chir Orthop 2007;93:238—46.
[2] Parratte S, Argenson JN. Validation and usefulness of a computer-assisted cup-positioning system in total hip arthroplasty. A prospective, randomized, controlled study. J Bone Joint Surg (Am) 2007;89:494—9.
[3] Haaker RG, Tiedjen K, Ottersbach A, Rubenthaler F, Stockheim M, Stiehl JB. Comparison of conventional versus computer-navigated acetabular component insertion. J Arthroplasty 2007;22:151—9.
[4] Jolles BM, Genoud P, Hoffmeyer P. Computer-assisted cup placement techniques in total hip arthroplasty improve accuracy of placement. Clin Orthop 2004;426:174—9.
[5] Leenders T, Vandevelde D, Mahieu G, Nuyts R. Reduction in variability of acetabular cup abduction using computer-assisted surgery: a prospective and randomized study. Comput Aided Surg 2002;7:99—106.
[6] Kalteis T, Handel M, Bathis H, Perlick L, Tingart M, Grifka J. Imageless navigation for insertion of the acetabular component in total hip arthroplasty: is it as accurate as CT-based navigation? J Bone Joint Surg (Br) 2006;88:163—7.
[7] Laffargue P, Pinoit Y, Tabutin J, Giraud F, Puget J, Migaud H. Positionnement de la cupule d'une prothèse totale de hanche par navigation sans image basée sur la cinématique articulaire : premiers résultats avec évaluation tomodensitométrique de l'orientation des implants. Rev Chir Orthop 2006;92:316—25.
[8] DiGioia AM, Hafez MA, Jaramaz B, Levison TJ, Moody JE. Functional pelvic orientation measured from lateral standing and sitting radiographs. Clin Orthop 2006;453:272—6.
[9] Nishihara S, Sugano N, Nishii T, Ohzono K, Yoshikawa H. Measurements of pelvic flexion angle using three-dimensional computed tomography. Clin Orthop 2003;411:140—51.
[10] Eddine TA, Migaud H, Chantelot C, Cotten A, Fontaine C, Duquennoy A. Variations of pelvic anteversion in the lying and standing positions: analysis of 24 control subjects and implications for CT measurement of position of a prosthetic cup. Surg Radiol Anat 2001;23:105—10.
[11] Wolf A, Digioia 3rd AM, Mor AB, Jaramaz B. Cup alignment error model for total hip arthroplasty. Clin Orthop 2005;437:132—7.
[12] Pinoit Y, May O, Girard J, Laffargue P, Ala Eddine T, Migaud H. Low accuracy of the anterior pelvic plane to guide the position of the cup with imageless computer assistance: variation of position in 106 patients. Rev Chir Orthop 2007;93:455—60.
[13] Philippot R, Wegrzyn J, Farizon F, Fessy MH. Pelvic balance in sagittal and Lewinnek reference planes in the standing, supine and sitting positions. Orthop Traumatol Surg Res 2009;95:70—6.
[14] Blondel B, Jouve JL, Panuel M, Adalian P, Solari C, Tropiano P, et al. Étude de la fiabilité des mesures de l'incidence pelvienne dans l'analyse de l'équilibre sagittal du bassin. Rev Chir Orthop 2008;94:321—6.
[15] Widmer KH. A simplified method to determine acetabular cup anteversion from plain radiographs. J Arthroplasty 2004;19:387—90.
[16] Bland JM, Altman DG. A note on the use of the intraclass correlation coefficient in the evaluation of agreement between two methods of measurement. Comput Biol Med 1990;20:337—40.
[17] Fleiss JL. The design and analysis of clinical experiments. New-York: John Wiley & Sons Ed.; 1986.
[18] Lin Li. A concordance correlation coefficient to evaluate reproducibility. Biometrics 1989;45:255—68.
[19] Lembeck B, Mueller O, Reize P, Wuelker N. Pelvic tilt makes acetabular cup navigation inaccurate. Acta Ortho 2005;76:517—23.
[20] Chen E, Goertz W, Lill CA. Implant position calculation for acetabular cup placement considering pelvic lateral tilt and inclination. Comput Aided Surg 2006;11:309—16.
[21] Muller O, Lembeck B, Reize P, Wulker N. Quantification and visualization of the influence of pelvic tilt upon measurement of acetabular inclination and anteversion. Z Orthop Ihre Grenzgeb 2005;143:72—8.
[22] Tang WM, Chiu KY, Kwan MF, Ng TP. Sagittal pelvic mal-rotation and positioning of the acetabular component in total hip arthroplasty: three-dimensional computer model analysis. J Orthop Res 2007;25:766—71.
[23] De Thomasson E, Guingand O, Terracher R, Mazel C. Rôle de la courbure rachidienne sagittale dans la survenue des luxations précoces après reprise de prothèse totale de hanche. Rev Chir Orthop 2004;90:226—31.
[24] Parratte S, Pagnano MW, Coleman-Wood K, Kaufman KR, Berry DJ. The 2008 Frank Stinchfield Award: Variation in postoperative pelvic tilt may confound the accuracy of hip navigation systems. Clin Orthop 2008;467:43—9.