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## ORIGINAL ARTICLE

# Pelvic balance in sagittal and Lewinnek reference planes in the standing, supine and sitting positions<sup>☆</sup>

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Accepted: 9 January 2008

## KEYWORDS

Total hip arthroplasty;  
 Computed-assisted surgery;  
 Pelvic balance;  
 Total hip arthroplasty dislocation;  
 Navigation

## Summary

**Introduction.** – Sagittal pelvic balance is a recognized factor influencing targeted acetabular-component anteversion during total hip arthroplasty implantation. However, no studies in the literature have systematically reported pelvic parameters data in the standing, sitting and supine positions.

**Hypothesis.** – Variations in acetabular cup orientation can be traced to eventual pelvic balance changes in one of these three usual positions.

**Materials and methods.** – In these three positions (supine, standing and sitting), pelvic anatomical parameters and reference planes were radiologically defined from a group of 67 patients (average age:  $70.2 \pm 3.2$  years). The complete X-rays individual sets were digitized and measurements were obtained by a single operator using a Spineview software (previously, strictly validated for these kind of measurements). Positioning according to the Lewinnek pelvic coordinate system, which is considered as a possible source of errors when vertically standing or horizontally lying, was also investigated.

**Results.** – The average pelvic incidence of  $59.6^\circ$  did not vary in the sitting, supine or standing positions, with no statistically significant difference between sexes. The Legaye equation – pelvic incidence is equals to pelvic version plus sacral slope – was verified. Pelvic version increased by an average  $22^\circ$  from the sitting to the supine or standing positions. Sacral slope varied in a reverse order. Pelvic-femoral angle (PFA) decreased by  $20^\circ$  from the standing to the supine position. The Lewinnek plane was located  $4^\circ$  posterior to the vertical plane. Whatever the position adopted, pelvi-Lewinnek angle appeared constant, averaging  $12^\circ$ .

**Discussion.** – The average pelvic incidence in this series was high, most probably associated with advancing patient age and/or pathology. The concept of functional anteversion

<sup>☆</sup> Level of evidence: level III; diagnostic study.

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appeared critical when taking into account pelvic version variations (according to the position, sitting, supine or standing) positions. The Lewinnek plane, commonly accepted as the reference plane for hip navigation, was individualised to each patient and should not be mistaken with the vertical plane; positioning of the femur in relation to the Lewinnek plane was also specific to each patient. Cumulative approximation on these two parameters at surgery resulted in a combined imprecision of  $26^\circ$  when standing and  $36^\circ$  when lying down. We have thus defined crucial parameters to be integrated in computer-assisted hip surgery softwares: positional variations of the pelvic version (functional anteversion), positioning of the Lewinnek plane, and PFA value (both specifically patient's dependant). If integration of these parameters into new softwares versions appears possible, this would represent a reliable compromise between maximum prosthetic stability, maximum joint amplitudes and elimination of possible prosthetic conflict.

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## Introduction

The adoption of a standing position implies complex modifications at the level of the spine and pelvic statics, particularly in the sagittal plane. For example, osteoligamentary and muscular elements find states of balance, but vary in each individual, depending on movement and posture; they also vary according to individual morphotype, age, and eventual pathology [1,2].

We have defined the main pelvic sagittal parameters. In the first place, anatomical parameters are constant in a given patient, and are not modified by posture or movement. The main anatomical parameter is "pelvic incidence" [3]. Then, there are pelvic positional parameters: "pelvic version" [4–8], "sacral slope and pelvic-femoral angle" (PFA) defined by Mangione and S en egas [6].

Legaye et al. [3] were the first to prove the existence of a fundamental geometric construction in the sagittal analysis of pelvic statics, demonstrating that incidence, the only constant parameter, was equal to sacral slope plus pelvic version. However, no study up to now has reported the analysis of variations in these positional pelvic parameters in the standing, seated and lying positions.

The Lewinnek plane [9] or anterior-pelvic plane constitutes the reference plane in computer-assisted prosthetic hip surgery [10,11]. In fact, the positioning of this plane, which up to now was considered to be vertical in the standing position and horizontal in the lying position, undergoes numerous intra- and interindividual variations, which limit its use in computer-assisted surgery [12,13].

The primary objective of our study, from a descriptive viewpoint, was to determine the different pelvic sagittal parameters with precision in a large cohort of elderly patients, along with their variations, depending on whether they were sitting, standing or lying. The second objective, from an analytical viewpoint, was to precisely determine the sagittal position of the Lewinnek plane and of the femoral axis (FA), in space as well as their positional variations, to estimate their value in computer-assisted surgery.

## Materials and methods

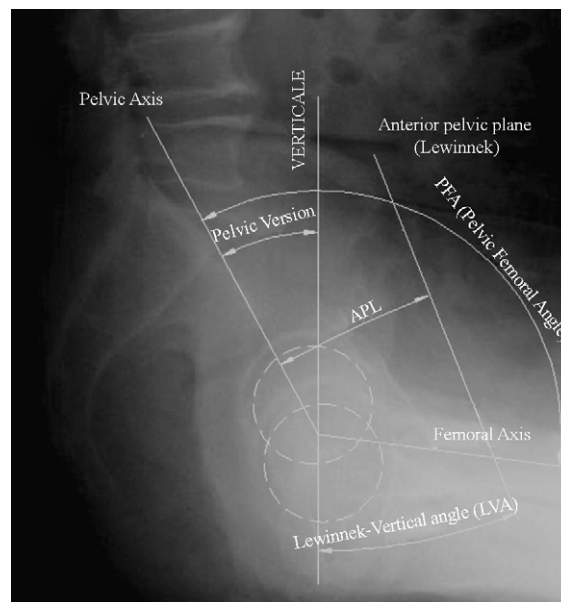
This three-month prospective study was conducted in cooperation with the Radiology Department in our hospital. The analysis dealt with subjects affected by coxarthrosis of different origins and free of any other severe arthrosic

problem, particularly at the level of the spine or knees. Radiological data were collected according to a strict protocol and included a strict pelvic frontview and strict lateral pelvic view in three positions:

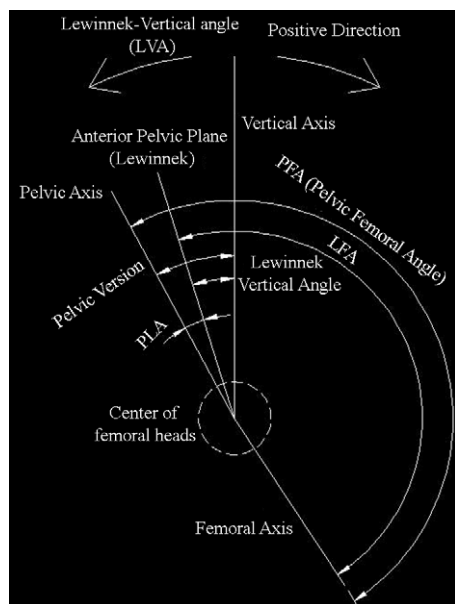
- standing: each subject adopted a comfortable position, with the head resting on a board;
- sitting: in a comfortable position on a stool with adjustable height and backrest, hands on the knees; height was adjusted so that the knees were bent at a  $90^\circ$  angle and both feet rested flat on the floor;
- lying: comfortably, with hands on the stomach.

The entire set of radiological negatives was digitized and printed on paper at the same time to facilitate analysis.

To enable us to compare our results with different series in the literature, we measured the following main parameters (Figs. 1 and 2): pelvic incidence, pelvic version, and sacral slope as well as PFA. "Pelvic incidence" corresponded to the angle formed by a perpendicular line located at the upper edge of the sacral plateau, going through its middle, and a straight line linking the middle of this plateau with



**Figure 1** Angles measured on a profile X-ray taken in the seated position.



**Figure 2** Diagram of the main pelvic sagittal parameters measured. The sign of the Lewinnek-vertical angle (LVA), defined in relation to the vertical plane, is negative when located behind it and positive when located in front of it. LVA: angle between the vertical plane and the sagittal projection of the Lewinnek plane; PV: pelvic version; PFA: angle between the PA and the FA; PLA: angle between the PA and sagittal projection of the Lewinnek plane; LFA: angle between the sagittal projection of the Lewinnek plane and the FA.

the centre of the femoral heads. “Pelvic version” corresponded to the angle formed by a straight line linking the centre of the femoral heads with the middle of the S1 sacral plateau and a vertical line passing through the centre of the femoral heads. Pelvic version was considered to be positive if the centre of the sacral plateau was located behind the femoral heads.

“Sacral slope” corresponded to the angle between the horizontal line passing through the middle of the S1 sacral plateau and the tangent of this sacral plateau. “PFA” was formed by the FA drawn between two diaphysary central points with a 10-cm distance (the highest being at the level of the lesser trochanter) and the pelvic axis (PA, a line passing through the centre of the sacral plateau and the centre of the femoral heads).

In addition, to determine the position of the Lewinnek plane in the sagittal plane, we measured the angle formed between the Lewinnek plane (represented on the sagittal plane by a straight line passing through the anterosuperior iliac spines and the pubic symphyses) and the FA (formed by a straight line passing through two centrodiaphysary reference points at a distance of 10 cm, the highest of which was located at the level of the lesser trochanter). This angle was called the Lewinnek-femoral angle (LFA). We also measured the angle formed by sagittal representation of the Lewinnek plane and the PA (represented on the sagittal plane by a straight line passing through the centre of the sacral plateau and the centre of the femoral heads). This angle was called the pelvic-Lewinnek angle (PLA). We measured the angle formed by sagittal representation of the Lewinnek plane and

a vertical line, this angle being called the Lewinnek-vertical angle (LVA). The sign was given for this LVA angle in relation to the vertical plane: positive when located in front of it and negative when located behind it. These different angle measurements were carried out in all profile X-rays taken in the seated, standing and lying positions. The different measurements and angles are schematized in Figs. 1 and 2.

A baseline-clinical examination, undertaken in each case, included assessment of mobility, limping, length differences in the lower limbs, and the Postel-Merle-d’Aubigné score [14].

The measurements were made on a PC, with Spineview software, which was validated for these types of measurements in a study by Rillardon et al. [15], with slight intra- and interindividual variations. The X-rays were digitized (Vidar-type roller scanner) before being processed. The Spineview software then automatically generated the values of the angle parameters. Since this software did not allow us to analyse all the angle measurements described above, we proceeded to manually measure the values of the PLA, LFA, and LVA.

The entire set of values was then transferred onto a spreadsheet and processed by Statview software. In our statistical analysis, the values of each parameter were compared by Student’s *t* tests, for paired series with  $p < 0.05$ . Polynomial correlation tests were used: a correlation was considered to be excellent if the coefficient was above 0.9, good if it was between 0.8 and 0.9, average between 0.7 and 0.8, and weak if it was below 0.7.

## Results

By the end of the study, 67 patients were included: 26 women and 41 men. Clinically, the preoperative Postel-Merle-d’Aubigné score averaged 7.6. Average patient age was 70.2 years with a typical variation of 3.7 years. We studied 39 left sides and 28 right sides.

The results of the different pelvic measurements are summarized in Table 1.

We compared pelvic incidence values in the three positions by Student’s *t* tests for paired series. These tests showed no significant difference in pelvic incidence between the three positions. Thus, pelvic incidence appeared to be an anatomical parameter that was specific to each individual and invariable, whatever the pelvic position. In our study of 60-year-olds, this incidence thus had an average value of 59.6°.

We compared pelvic version values in the three positions by Student’s *t* tests for paired series. These tests revealed a significant difference between pelvic version in the seated position and the two other positions ( $p \leq 0.001$ ). Moreover, they disclosed no significant difference between pelvic version while lying and standing. Pelvic version therefore constituted a pelvic positional parameter: it increased by an average of 22° when the subject moved from the seated to the standing position or from the seated to the lying position.

We compared sacral slope values in the different positions, using Student’s *t* tests for paired series. These tests showed a significant difference between sacral slope while sitting and in the two other positions ( $p \leq 0.001$ ). Further-

**Table 1** Results of pelvic sagittal parameter values while standing, sitting and lying down.

Values in degrees	Standing (S.D.)	Sitting (S.D.)	Lying (S.D.)
Pelvic incidence	59.6 (6.86)	59.6 (14.4)	59.8 (12.8)
Pelvic version	16.4 (12.5)	37.9 (8.5)*	15.7 (9.8)
Sacral slope	42.4 (12.6)	21.2 (11.6)*	43.9 (11.1)
Pelvic-femoral angle (PFA)	180.5 (15.4)*	132.4 (10.7)*	160 (13.1)*

\*  $p < 0.05$  for one parameter according to the three positions.

**Table 2** Lewinnek-vertical angle (LVA), Lewinnek-femoral angle (LFA) and pelvic-femoral angle (PFA) standing, sitting and lying down.

	LVA (°)ValueStandard deviation	PFA (°)ValueStandard deviation	LFA (°)ValueStandard deviation
Standing	-4.41	12	168.4
	6.68	10.5	12.6*
Sitting	-25.49	12.2	120
	9.6*	11.3	16.3*
Lying	-3.89	11.8	148.2
	8.3	10.1	14.2*

\*  $p < 0.05$  for one parameter according to the three positions.

more, the tests showed no significant difference between sacral slope while lying and standing. Sacral slope, therefore, constituted a pelvic positional parameter: it decreased by an average of  $22^\circ$  when the subject went from the seated to the standing position or from the seated to the lying position.

We compared PFA values in the different positions by Student's  $t$  tests for paired series. These tests revealed significant differences between the three positions ( $p \leq 0.001$ ) insofar as PFA was concerned. Thus, PFA was different for each position and increased when passing from the sitting to the lying position and then to the standing position. It is noteworthy that in the lying position, the femurs were in fact in  $20^\circ$  flexion in relation to the standing position, the difference being far from negligible.

We positioned and measured the Lewinnek plane in relation to the vertical plane, by defining the LVA, the Lewinnek plane in relation to the PA and in relation to sagittal projection of the FA (Table 2).

We performed Student's  $t$  tests to verify if there were statistically significant differences between the respective LVA, PLA, and LFA values in the three positions. In LVA, no significant difference was noted between lying and standing values, but these two values were significantly different

from those obtained in the seated position ( $p \leq 0.001$ ). Concerning the positional relationship between the Lewinnek plane and the PFA, the latter was similar in the standing, lying and seated positions; this angle averaged  $12^\circ$ . As for positioning of the femur in relation to the Lewinnek plane (LFA), for each of the three positions, the LFA value was statistically different ( $p \leq 0.001$ ); this value increased from the seated to the lying and then to the standing position.

## Discussion

We have shown that whatever the position the Legaye equation (pelvic incidence = pelvic version plus sacral slope) has been validated, confirming the quality of our measurements.

Table 3 presents the results of different series appearing in the literature and are thus comparable to the current study. In the literature, the pelvic incidence values vary from  $51.7$  to  $60.5^\circ$ , with a standard deviation of  $11^\circ$  [5,8,16–18]. The series show increased pelvic incidence values during growth [19–21], with a constant value when growth ended, and some studies of aged subjects reveal heightened pelvic incidence because of the probable increase in sacro-iliac joint mobility [17]. In our series, incidence was higher

**Table 3** Comparison of our results in the standing position with those from principal series in the literature.

Authors	Number of subjects	Average age (years)	Pelvic incidence (°)	Pelvic version (°)	Sacral slope (°)
Roussouly et al. [18]	160	43	51.9	12	39.9
Duval-Beaupere et al. [16]	49	24	52	13.2	40.6
Guigui et al. [8]	300	34	54.7	11.4	41.2
Vaz et al. [5]	100	26	51.7	12.3	39.4
Jackson and McManus [34]	75	39		17.7	39.6
Hammerberg and Wood [17]	50	76	60.54	18	42
Hanson et al. [33]	20	60	57	15	42
Our series	67	70	62	16	46



**Table 4** Comparison of our results on the standing, seated and lying positions with two reference series.

Authors	Number of subjects	IN ST	IN L	IN SE	PV ST	PV L	PV SE	SS ST	SS L	SS SE
Sari-Ali et al. [23]	100	53		52.9	13.5		34.3	39.4		18.7
Eddine et al. [22]	24	56.1	53.9		14.4	8.2		41.7	45.7	
Our series	67	62	61.3	60.5	16	15.3	36.3	46	41.4	22.6

IN = pelvic incidence; PV = pelvic version; SS = sacral slope; ST = standing; L = lying; SE = seated.

along with average age of our study subjects. It, therefore, appears that the pelvic incidence value is age-related. However, we must not forget that all of our 67 patients had long-standing hip arthrosis. Does this arthrosis correlate with the high values of pelvic incidence? Here, two hypotheses are conflicting:

- the age-related increase in pelvic incidence could constitute natural evolution with adaptation of the pelvic incidence to spine status, resulting in tipping of the pelvis towards the back and, thus, in tension of the hip-flexing muscles and in hip flexion;
- high pelvic incidence could be a fixed or evolutive anatomical parameter favouring the onset of coxarthrosis.

PFA values have not been widely investigated in different studies, although the femur plays a fundamental role in hip-spine balance [7]. Flexion of the coxofemoral joint and particularly extension of the hips fully participates in the process of rising and, thus, in postural balance, influencing the values of pelvic version and lumbar lordosis. Eddine et al. [22] reported that PFA increases in the standing position in relation to the lying position, and there is a significant correlation between PFA and pelvic incidence. We have confirmed these data. The results relating to the femur are fundamental in the management of postoperative effects. Eddine et al. [22] and Sari-Ali et al. [23] studied 24 and 100 healthy subjects, respectively, the first group standing and lying, and the second group sitting. The variations of pelvic parameters according to position, which they have reported, are fully comparable to ours, but our study has the advantage of being the first to analyse changes in the three positions (Table 4).

These results, and especially those concerning pelvic version, put in doubt the recommended values for cup orientation, as defined by different authors [9,24–26] because they are defined for the standing position and do not take into account anteversion values of the acetabulum with positional changes. Therefore, as Lazennec et al. [7] and Eddine et al. [22] also recommend, we must redefine these target values by integrating known variations in the lying and sitting positions. If we apply the rule of Lazennec et al. [7], according to which 1° pelvic retroversion would result in 0.7° hyperanteversion of the cup, then in our series, when passing from the standing to the sitting position, anteversion of the cup would increase by an average of 15.4°. This leads to the notion of target functional anteversion, which in turn would bring about a compromise between maximum stability, maximum articular amplitude and absence of prosthetic conflict: these objectives could be achieved whatever the pelvic version. Unfortunately, at present, no hip navigation software integrates this notion of

functional anteversion, which would allow us to be freed from pelvic version variations. Therefore, before engaging in any hip navigation, we should determine maximal pelvic version variations preoperatively in each patient, which would give us an idea of the patient's functional anteversion.

The Lewinnek plane, the reference plane in hip navigation, is frequently mistaken for standing vertically and lying horizontally [10,11,27]. Our study allowed us to demonstrate that this is an approximation, because it is in fact located 4° behind the vertical plane (in the standing or sitting position) or behind the horizontal (lying) position. We, therefore, confirm the data presented by Pinoit et al. [28] who placed it 1.7° posterior to the vertical plane. Therefore, besides approximation during surgery, when determining the anterior pelvic plane reported by Wolf et al. [29], Blendea et al. [30] and Parratte et al. [31], we must add this average approximation of 4°. Confronted by this technical imprecision and with these intra- and interindividual variations in determining the Lewinnek plane, certain authors have approached hip navigation from another angle. They defined their implant-positioning objective as a function of hip kinematics during surgery [32], the principle being to avoid prosthetic conflicts, to restore optimal joint amplitudes and even to establish ideal prosthetic head size. This is theoretically achievable, but certain limitations also tend to disturb the results: the influence of the spine and pelvic balance is not taken into account, because kinematic evaluation is undertaken during the operation and, thus, in a specific position. Actually, this kinematic aspect of the hip should be determined before the operation, in different positions (sitting, lying, standing) and the data integrated in the navigation software.

The FA itself is also viewed by different hip navigation softwares as being in the standing and lying positions, mistaken for the vertical and horizontal planes and, thus, with the Lewinnek plane. In fact, our study locates it 22° in front of the Lewinnek plane when standing and 32° in front of the Lewinnek plane when lying down. We believe this information is fundamental, because it evaluates global approximation of 26° when standing and 36° when lying, which have major implications when performing hip surgery assisted by navigation and computer studies of prosthetic conflicts. To achieve proper implant positioning, we must consider the true spatial position of the Lewinnek plane as well as the true position of the femur. Therefore, before initiating any hip navigation, we should determine the position of the Lewinnek plane preoperatively, when standing, lying, and even, in principle, in the operation position.

As far as femoral slope is concerned, the main limitation of this analysis is its bidimensional character: it is then freed from rotating components, which are primordial, par-

ticularly for the study of target femoral and acetabular anteversions.

We have defined a new pelvic anatomical parameter, the PLA, which can serve as a reference parameter in hip navigation, because it is constant, whatever the position of the pelvis (particularly, in the operation position), and specific in each individual. Since the Lewinnek plane is clinically accessible during surgery but in an imprecise manner as we know it [29–31], the PA can also be known at all times. We, therefore, think that rather than measuring the position of the Lewinnek plane, it would be better to measure the PLA by means of a single preoperational profile X-ray taken in the standing position. When putting the implants in place, locating the Lewinnek plane would immediately give us the orientation of the PA and, by integrating it, we would obtain ideal implant orientation (cup anteversion and inclination).

## Conclusion

We studied pelvic parameters in 67 patients with coxarthrosis. We demonstrated the specificities of this population, particularly in terms of incidence, which seemed high to us. The variations of pelvic parameters that we measured according to positioning confirm and complete those of already-published series.

The present study has the particular advantage of having positioned the Lewinnek plane and the FA sagittally and, thus, highlighting the considerable imprecision linked with their approximation. The PLA that we defined and measured is, in our opinion, a useful and innovative angle for understanding sagittal positioning of the pelvis during surgery assisted by hip navigation: it is actually characterized by consistency, whatever the position of the pelvis, and allows us to be freed of variations of the Lewinnek plane relative to position.

This study has underlined numerous factors (positional variations of pelvic parameters, positioning of the FA in relation to the pelvis, positioning of the Lewinnek plane), which should be integrated if we want to deploy navigation software in a dependable manner for acetabular and femoral implantation.

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