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ORIGINAL PAPER

The kinematic relationship between sitting and standing posture and pelvic inclination and its significance to cup positioning in total hip arthroplasty

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Abstract
Purpose The aim of this study is to describe the influence of sitting and standing posture on sagittal pelvic inclination in total hip replacement patients to assist with correct acetabular component positioning.
Methods Lateral radiographs of the pelvis and lumbar spine in sitting and standing positions were extracted. Pelvic tilt was measured using the vertical inclination of a line from the anterior superior iliac spine (ASIS) to pubic tubercle. Sacral inclination, Cobb angle of the lumbar spine and hip flexion were recorded.
Results Sixty patients were identified with a mean age of 63. Men were more likely to flex the lumbar spine in sitting (p=0.004); 80° of hip flexion is required for seated posture. Stiff hips required compensatory pelvic flexion and lumbar flexion in sitting. There is a linear relationship between hip flexion and pelvic tilt, hip flexion and lumbar lordosis.
Conclusions Pelvic orientation is determined by lumbar and hip stiffness. This impacts on acetabular version.

Keywords Pelvic tilt · Acetabular anteversion · Hip flexion · Lumbar flexion

Introduction

The success of hip arthroplasty is measured by a 90 % satisfaction rate, surpassing all other major surgical procedures [1]. The Australian National Joint Registry (ANJR) indicates that the number of procedures being performed annually is increasing at a rate of 11 % [2].

Malpositioning of the acetabulum has been associated with issues such as edge loading, stripe wear and squeaking [3–5], but it is dislocation of the total hip replacement that remains the major complication of cup malposition across bearing surfaces. The landmark paper by Lewinnek et al. [6] proposed a 'safe zone' for acetabular component position. The majority of dislocations in this series occurred outside the safe zone prompting the authors to recommend acetabular component positioning to be at 40±10° of abduction and 20±10° of anteversion in reference to the anatomical and postural factors relative to a chosen reference plane [7]. There are individual differences to pelvic positioning in different postures [8]. This means that the safe zones need to be individualised.

Anteversion of the native acetabulum is a variable that is determined by pelvic orientation. Flexion of the pelvis increases anteversion, while pelvic extension decreases anteversion of the acetabulum. The degree of pelvic movement is determined by both lumbar spine and hip range of motion (ROM) contributing to the final pelvic position in standing or sitting positions. This is especially important for a stiff lumbar spine which requires a greater compensatory range of hip motion [9]. Specific anatomical landmarks were proposed in an attempt to recreate the native acetabular anatomy of the hip during hip arthroplasty. Archbold et al. [10] proposed aligning the cup to the transverse acetabular ligament. The technique is limited to patients with normal pelvic and acetabular morphology and does not account for pelvic tilt. To achieve a stable functional ROM and to improve dislocation rates, accurate orientation of the cup to anatomical landmarks is advocated by some authors [11–13]. A wide safe zone is suggested to account for the variability in acetabular orientation with changes in pelvic position. Biedermann et al. [14] found that 60 % of dislocations were occurring *within* the proposed safe zone of Lewinnek et al. and recommend a cup

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position of 45° abduction and 15° of anteversion as the most stable position.

Radiographic changes in pelvic tilt between sitting and standing have been previously described [8, 15, 16]. Pelvic orientation is a variable and should reflect individual posture and anatomy. As such, the assumption of the pelvis being orientated to the orthogonal axes introduces error into positioning of the acetabular component. The degree of anteversion needs to be individualised as evidenced by DiGioia et al. [8]. Improved accuracy of acetabular component positioning may be achieved by measuring changes to pelvic tilt between sitting and standing pre-operatively. The aim of this study is to describe the influence of sitting and standing posture on sagittal pelvic inclination in pre-operative patients with known hip pathology. It seeks to establish a relationship between lumbar and hip joint stiffness and their effect on pelvic tilt.

Method

This study was conducted at the Mater Hospital, Crow's Nest, Sydney, NSW, Australia. Approval was obtained from the Mater Hospital Ethics Committee (File number 09/123). All cases were admitted by one surgeon (WLW) and received pre-operative lateral pelvic radiographs in sitting and standing positions. Eligible patients were those with primary hip osteo- or inflammatory arthroses. Privacy of all patients was maintained by blocking the identity of the radiographs taken. All patients consented to their de-identified images being used for research purposes.

Patients were assessed prior to imaging for hip ROM by the consultant in charge. Hip flexion was measured in supine with the lumbar spine flat against the bed. The Thomas test was performed for identifying fixed flexion deformity of the hip. Lateral standing and sitting radiographs of the relevant patients were chosen for review. Measurements were made digitally using the IntelePACS system InteleViewer Ver 4-2-1-P242© (Intelerad Medical Systems, Montreal, QC, Canada). A total of 60 complete sets of radiographs fit the inclusion criteria.

Pelvic tilt was measured using the vertical inclination of a line drawn from the anterior superior iliac spine (ASIS) to the pubic tubercle. This is the anterior pelvic plane (APP). To account for pelvic rotation, a line was drawn to connect contralateral anterior iliac spines and the midpoint of this line taken as the proximal measurement point. Distally, the pubic tubercle was taken as the most prominent and reliable landmark. A vertical line was then drawn as the vertical reference. The angle between the APP and the vertical is the pelvic tilt angle (Fig. 1). Pelvic extension (forward tilt) was measured as a positive angular displacement.

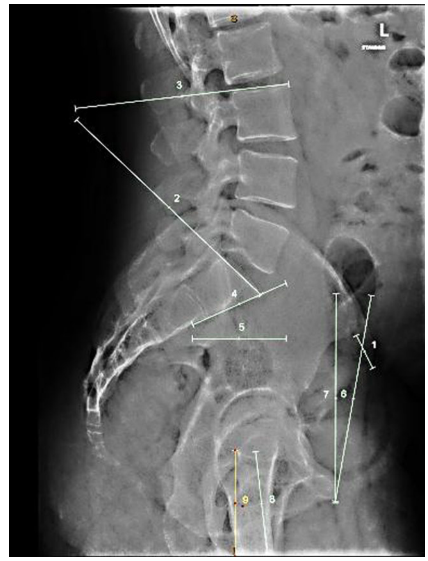

Fig. 1 Angles measured from radiographs. **a** Cobb angle between L3 and S1 between lines 2 and 3. **b** Sacral inclination between inferior surface of sacrum and horizontal line (lines 4 and 5). **c** Pelvic tilt angle (lines 6 and 7) posterior tilt negative anterior tilt positive. **d** Femur flexion relative to the vertical axis (between lines 8 and 9)

Sacral inclination was measured as the angle between a line drawn along the anterior surface of the sacrum and a horizontal reference (Fig. 1). The Cobb angle of the lumbar spine was recorded between L3 and S1. The hip flexion was the angle formed between the mid-axis of the femur and the vertical (Fig. 1). All measurements were collected on an Excel spreadsheet (2010, Microsoft, Redmond, WA, USA). Statistical analysis of data was performed on SPSS statistical package (SPSS IBM Statistics). Images were obtained from the InteleViewer system Ver 4-2-1-P242© (Intelerad Medical Systems)

Analysis of data

Raw data were collated on a Microsoft© Excel spreadsheet which provided simple F tests, means, standard deviations and range. Further analysis was performed on SPSS version 22 (IBM SPSS Statistics).

Results

Sixty patients attending the orthopaedic consultants' (WLW) rooms were identified preoperatively for either unilateral or bilateral total hip replacement. Patients with ankylosing spondylitis, long spinal fusions or previous pelvic fractures were excluded from the cohort. The mean age of the cohort was 63.2 ranging from 37 to 93 years.

There were 30 female and 30 male patients. Clinically, fixed flexion deformities were identified in 27 patients (mean

9.4°). The mean hip flexion range was not significantly different between genders (p>0.05). Men had a mean hip flexion range of 78.7 [95 % confidence interval (CI) 75.1–82.2], while women had a mean hip flexion range of 74.2 (95 % CI 66.6–81.9) (p=0.27). Both genders had equal range of total hip flexion measured radiographically (p=0.27). Sacral inclination relative to the horizontal ranged from 1 to 55° in standing with a mean of 25.7° across all patients. There was a significant difference in sacral inclination adopted between women and men in standing with women having a more flexed pelvis (mean 22.6 vs 29.3°, p=0.014) (Table 1). In sitting, sacral inclination ranged from 0.3 (horizontal) to 84.5° (more vertical) with a mean of 24.1° (SD 18.2). While women had a more vertical sacral orientation, this was not statistically significant (p=0.14) The change in sacral inclination between sitting and standing was highly variable between individuals, but the mean sacral inclination for this cohort does not appear to change significantly between the two positions (p=0.94). Pelvic tilt in standing ranged from 30°posteriorly to 21.5° anteriorly (extension) in standing. Pelvic tilt in sitting ranged from 48 posterior (flexion) to 42° anterior tilt. The total change in pelvic tilt from standing to sitting ranged from 37.6 posteriorly to 32.8° anterior and this was significant. The change in pelvic tilt between sitting and standing was similar between men and women (p=0.098). Lumbar Cobb angle ranged from 11.6 to 91.7° in standing. Lumbar sagittal Cobb angles in sitting ranged from 29.5 (kyphosis) to 42° (lordosis). The net change in lumbar lordosis from standing to sitting varied from extending by 20.2° to flexing by 71°. Men were more lordotic than women (p=0.004) in standing.

Total hip flexion range was up to 107.4° when moving from standing to sitting. The mean hip flexion for men and women to go from standing to sitting was similar (78.7 vs 74.2°, p=0.27).

Lumbar lordosis correlates inversely with hip flexion (r=0.78, r^2=0.62) (Fig. 2). The amount of lumbar and hip motion required to achieve the sitting position varies according to the available range at the hip. In our cohort, once 78.4° of hip flexion was reached, lumbar flexion then occurred to achieve a pelvic position which allowed the patient to sit. The equation describing this relationship is *hip range=78.4+lower lumbar range*. Pelvic tilt forms the link between lumbar movement and hip flexion. Pelvic anterior tilt varies (r=0.78, r^2=0.61) to maintain sitting posture according to the equation *hip range=pelvic tilt+81.8* (Fig. 3). When hip range is limited to less than 80°, the pelvis tilts posteriorly to allow sufficient total flexion for sitting posture.

Further analysis was performed to assess the effect of hip stiffness on pelvic tilt and lumbar lordosis by dividing the sample into groups with clinical fixed flexion deformity (FFD), clinically stiff hip, hip with limited range and hips with good ROM. A clinical FFD resulted in an extended pelvis

Table 1 Gender differences: negative pelvic tilt equals pelvic flexion

Variable means	Men (n=30)	Women (n=30)	p (by t test)
Lumbar Cobb angle	°	°	
Sitting	11.5 (6.9, 16.1)	17.1 (12.0, 22.2)	0.098
Standing	42.8 (37.7, 47.9)	37.0 (32.3, 41.7)	0.093
Difference	31.3 (26.7, 36.0)	19.9 (13.5, 26.4)	0.004[a]
Sacral inclination			
Sitting	20.9 (14.7, 27.1)	27.9 (20.5, 35.2)	0.14
Standing	22.6 (19.3, 26.0)	29.3 (25.1, 33.6)	0.014
Difference	1.8 (−3.6, 7.1)	1.4 (−6.7, 9.5)	0.94
Pelvic tilt			
Sitting	−0.3 (−6.0, 5.4)	−1.8 (−8.8, 5.1)	0.73
Standing	4.5 (2.0, 6.9)	1.4 (−2.1, 5.0)	0.15
Difference	4.8 (−1.5, 11.0)	3.2 (−4.0.7, 11.2)	0.75
Radiographic hip range			
Sitting	83.8 (80.7, 86.9)	79.5 (72.7, 86.2)	0.22
Standing	5.1 (3.9, 6.4)	5.2 (2.8, 7.6)	0.95
Difference	78.7 (75.1, 82.2)	74.2 (66.6, 81.9)	0.27

[a] Significant

with less lumbar lordosis in standing (Table 2). There was no change in pelvic tilt in patients without an FFD when moving from standing to sitting. Stiff hips with less than 80° of flexion achieved sitting posture by pelvic flexion. Hips with greater than 80° of hip flexion did not alter their pelvic tilt to achieve sitting posture.

Discussion

Dislocation forms the primary cause of revision for total hip arthroplasty in the USA at 22.5 % [17]. Australian data were similar in 2013 with dislocation accounting for 21.3 % of

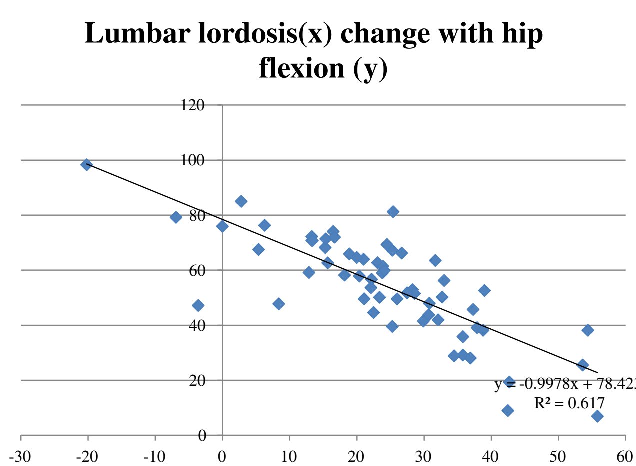

Fig. 2 Lumbar Cobb angle variation with hip flexion from standing to sitting (r=0.78)

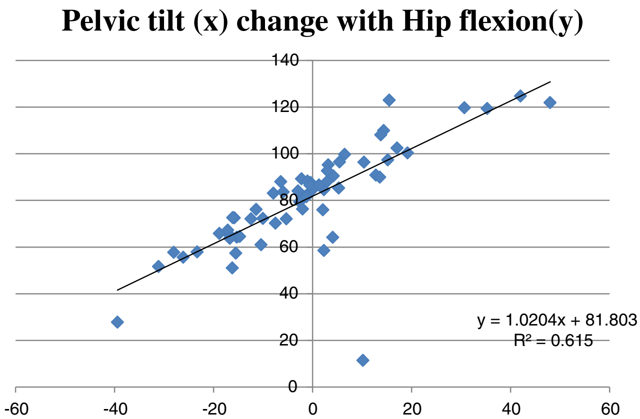

Fig. 3 Variation in pelvic sagittal tilt with hip flexion from standing to sitting (r=0.78)

revised total hips [2]. Preventing hip dislocation will reduce revision rates and reduce morbidity and costs related to it.

Reproducibility of radiographic pelvic parameters has been established in previously published work. An intra-observer error of ±4.3° has been quoted [18]. Straightforward angular parameters were therefore taken for comparison according to a previously documented technique [19].

Coventry et al. [20] attributed acetabular component retroversion as a factor in posterior dislocation with subsequent work by Lewinnek et al. [6] ascribing a safe zone of 20° anteversion with 40° of cup abduction. Neither paper mentions the role of pelvic tilt on estimated anteversion.

Table 2 Mean values for pelvic tilt, hip flexion and lumbar lordosis in sitting and standing

Stiff hip (<80° flexion), n=11	Sitting	Standing
Pelvic tilt	−3.9	15.6 (p=0.03)
Hip flexion	68.6	11.4
Lumbar lordosis	14.8	40.7
Limited range (80–100° flexion), n=39		
Pelvic tilt	3	3
Clinical hip flexion	88.8	10.5
Lumbar lordosis	14.5	37.7
Good range (>100° flexion), n=10		
Pelvic tilt	4.7	−4.2
Clinical hip flexion	117	1.8
Lumbar lordosis	15.7	34.4
FFD (>5°), n=27		
Pelvic tilt	−0.3	3.82
Clinical hip flexion	85.6	15.8
Lumbar lordosis	12.2	39.5
No FFD, n=33		
Pelvic tilt	−0.5	−0.4
Clinical hip flexion	95	1.6
Lumbar lordosis	15.8	34.8

Other authors have attempted to improve the accuracy of cup orientation [7, 11, 12, 16, 21]. Murray [7] proposed a nomogram for determining the anatomical orientation of the acetabulum. Barrack et al. [21] used computer simulation to identify the most appropriate cup position for functional stooping. McCollum and Gray [16] used erect intra-operative lateral radiographs centred over the greater trochanter to determine degree of cup anteversion. Sotereanos et al. [12] used intra-operative pelvic landmarks to orientate the cup. Maruyama et al. [11] developed the concept of the acetabular notch as a reference for cup version and claimed a dislocation rate of 0.34 %. None of these methods account for altered morphology or dysplasia and may not reflect a safe zone for the individual. Computed tomography (CT) studies have shown that accurate acetabular cup placement is difficult to achieve when using currently acceptable anatomical landmarks [22]. Pelvic tilt may be the variable that influences overall acetabular orientation and accuracy of component placement.

To simplify the relationship between pelvic tilt and acetabular version, it is advantageous to know the extremes of sagittal pelvic movement. This study provides a description of changes to pelvic tilt between sitting and standing which may help in estimating the required cup anteversion.

The data show that individual patients may flex or extend their pelvis between sitting and standing. Our finding is consistent with previous work [8, 9, 23, 24]. If the pelvis extends in sitting, more hip flexion and lumbar flexion are required to accommodate the new posture. Likewise, if hip flexion is insufficient for sitting, more pelvic flexion (posterior tilt) is required. This occurs with the associated flattening in lumbar lordosis. Both pelvic extension and flexion have the effect of taking the hip joint closer to the limit of its arc of motion. To obtain acetabular version within a safe zone requires consideration of the effect of pelvic extension on acetabular anteversion. Acetabular anteversion of 20–30° could be adopted for cup placement based on the total excursion of the pelvis from standing to sitting. Supine on table positioning has been advocated to achieve accurate cup positioning but is subject to surgeon preference [25].

The postural change between standing and sitting is the sum of lumbar and hip flexion. A stiff, lordotic lumbar spine requires greater hip flexion to achieve a sitting posture, and conversely stiff hip joints demand more lumbar flexion to achieve sitting. This is shown by the linear relationship in Fig. 2. At low hip range, a lumbar flexion compensates providing a total flexion of both trunk and hip to achieve sitting posture. The resultant sagittal pelvic tilt is determined by both the lumbar and hip ROM, and a kinematic relationship exists between the lumbar spine and pelvic inclination, influencing hip acetabular version. When hip flexion is limited, the pelvis flexes thus tilting posteriorly (Fig. 3). The implication is altered acetabular version. A large variability exists in how individuals flex or extend the pelvis. These findings are similar to those described by DiGioia et al. [8].

The assessment of pelvic sagittal orientation in standing and comfortable sitting on a level seat provides valuable information to the surgeon when determining acetabular component positioning. Greater acetabular anteversion (25°) closer to the upper limit of Lewinnek's safe zone is required in patients who sit or stand with an extended pelvis. Similarly, anteversion at the lower limit of the safe zone (15°) is required if the patient's natural tendency in standing and sitting is pelvic flexion. Posterior impingement is a risk with excessive anteversion with this population. Preoperative planning with sagittal sitting and standing radiographs may assist in reducing the incidence of prosthetic hip dislocations.

Recommendations

In view of the data presented, it is recommended that all patients undergo lateral sitting and standing radiographs to assess sagittal pelvic tilt. The radiographs should include the lower lumbar spine and proximal femur on the same viewing frame. The range of pelvic flexion and extension should be recorded along with lumbar and hip ROM. Patients with a flexed pelvic orientation in sitting should have 20° of cup anteversion. Lumbar lordosis in sitting and standing should be measured to identify patients with a stiff spine. Patients adopting an extended pelvic orientation may require a greater anteversion of the acetabular component to prevent dislocation.

Limitations

Lumbar and hip stiffness can contribute to pelvic axial rotation in sitting and tilt in standing. The method used aimed to minimise parallax error of the APP and was originally used by Blondel et al. in 2009 [19]. The resolution afforded by IntelePACS was adequate for the majority of angular measurements. To improve accuracy, the radiographer should be made aware of the need to image the ASIS, pubic tubercle and sacrum adequately.

Conclusion

Pelvic orientation in the sagittal plane changes from standing to sitting. There is wide variability in pelvic orientation between individuals in both postures and generalising acetabular implant orientation to the safe zone of Lewinnek may not be ideal in all patients. Orientating acetabular components for total hip arthroplasty should consider changes in native version and the contribution of lumbar and hip range to overall stability. Greater cup anteversion is suggested if the pelvis is extended in sitting.

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Conflict of interest The authors declare that they have no conflict of interest.

References

1. Fortina M, Carta S, Gambera D, Crainz E, Ferrata P, Maniscalco P (2005) Recovery of physical function and patient's satisfaction after total hip replacement (THR) surgery supported by a tailored guidebook. Acta Biomed 76(3):152–156
2. AOA (2013) Australian Orthopaedic Association National Joint Replacement Registry. Annual Report. Adelaide
3. Walter WL, Insley GM, Walter WK, Tuke MA (2004) Edge loading in third generation alumina ceramic-on-ceramic bearings: stripe wear. J Arthroplasty 19(4):402–413
4. Walter WL, O'Toole GC, Walter WK, Ellis A, Zicat BA (2007) Squeaking in ceramic hips: the importance of acetabular component orientation. J Arthroplasty 22(4):496–503
5. Sexton SA, Yeung E, Jackson MP, Rajaratnam S, Martell JM, Walter WL, Zicat BA, Walter WK (2011) The role of patient factors and implant position in squeaking of ceramic-on-ceramic total hip replacements. J Bone Joint Surg Br 93(4):439–442
6. Lewinnek G, Lewis J, Tarr R, Compere C, Zimmerman J (1978) Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 60(2):217–220
7. Murray DW (1993) The definition and measurement of acetabular orientation. J Bone Joint Surg Br 75(2):228–232
8. DiGioia AM, Mahmoud AH, Jaramaz B, Levison TJ, Moody JE (2006) Functional pelvic orientation measured from lateral standing and sitting radiographs. Clin Orthop Relat Res 453:272–276
9. Tang WM, Chiu KY (2000) Primary total hip arthroplasty in patients with ankylosing spondylitis. J Arthroplasty 15:52–58
10. Archbold HA, Mockford B, Molloy D, McConway J, Ogonda L, Beverland D (2006) The transverse acetabular ligament: an aid to orientation of the acetabular component during primary total hip replacement: a preliminary study of 1000 cases investigating postoperative stability. J Bone Joint Surg Br 88(7):883–886
11. Maruyama M, Feinberg JR, Capello WN, D'Antonio JA (2001) The Frank Stitchfield Award: morphologic features of the acetabulum and femur: anteversion angle and implant positioning. Clin Orthop Relat Res 393:52–65
12. Sotereanos NG, Miller MC, Smith B, Hube R, Sewecke JJ, Wohlrab D (2006) Using intraoperative pelvic landmarks for acetabular component placement in total hip arthroplasty. J Arthroplasty 21(6):832–840
13. Yoshimine F (2006) The safe-zones for combined cup and neck anteversions that fulfill the essential range of motion and their optimum combination in total hip replacements. J Biomech 39(7):1315–1323
14. Biedermann R, Tonin A, Krismer M, Rachbauer F, Eibl G, Stöckl B (2005) Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. J Bone Joint Surg Br 87:762–769
15. Siebenrock KA, Kalbermatten DF, Ganz R (2003) Effect of pelvic tilt on acetabular retroversion: a study of pelves from cadavers. Clin Orthop Relat Res 407:241–248

16. McCollum DE, Gray WJ (1990) Dislocation after total hip arthroplasty. Causes and prevention. Clin Orthop Relat Res 261(22):159–170
17. Bozic KJ, Kurtz SM, Lau E, Ong K, Vail TP, Berry DJ (2009) The epidemiology of revision total hip arthroplasty in the United States. J Bone Joint Surg Am 91(1):128–133
18. Lazennec JY, Rousseau MA, Rangel A, Gorin M, Belicourt C, Brusson A, Catonné Y (2011) Pelvis and total hip arthroplasty acetabular component orientations in sitting and standing positions: measurements reproducibility with EOS imaging system versus conventional radiographies. Orthop Traumatol Surg Res 97:373–380
19. Blondel B, Parratte S, Tropiano P, Pauly V, Aubaniac JM, Argenson JN (2009) Pelvic tilt measurement before and after total hip arthroplasty. Orthop Traumatol Surg Res 95:568–572
20. Coventry MB, Beckenbaugh RD, Nolan DR, Ilstrup D (1974) 2,012 total hip arthroplasties. A study of postoperative and early complications. J Bone Joint Surg Am 56:273–284
21. Barrack RL, Lavernia C, Ries M, Thornberry R, Tozakoglou E (2001) Virtual reality computer animation of the effect of component position and design on stability after total hip arthroplasty. Orthop Clin North Am 32:569–577
22. Wines AP, McNicol D (2006) Computed tomography measurement of the accuracy of component version in total hip arthroplasty. J Arthroplasty 21(5):696–701
23. Wolf A, Digioia AM 3rd, Mor AB, Jaramaz B (2005) Cup alignment error model for total hip arthroplasty. Clin Orthop Relat Res 437: 132–137
24. Parratte S, Pagnano MW, Coleman-Wood K, Kaufman KR, Berry DJ (2009) The 2008 Frank Stitchfield Award: variation in postoperative pelvic tilt may confound the accuracy of hip navigation systems. Clin Orthop Relat Res 467:43–49
25. Eilander W, Harris SJ, Henkus HE, Cobb JP, Hogervorst T (2013) Functional acetabular component position with supine total hip replacement. Bone Joint J 95-B:1326–1331