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Intraoperative Imaging Improves Posterolateral THA Accuracy with Increased Time Cost

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Abstract

Intraoperative imaging may improve total hip arthroplasty (THA) component placement, but the time and cost associated with this approach have not been well described. We assessed component placement accuracy, operative time, and operating room (OR) charges for 270 patients undergoing posterolateral THA (PL-THA) with or without intraoperative imaging. This study retrospectively compared 135 PL-THA performed with intraoperative digital radiography (group PLxr) and a contemporary cohort of 135 PL-THA performed without imaging (group PL). Postoperative radiographs were evaluated to determine outlier rates for acetabular inclination of 55 degrees or higher, anteversion less than 15 or more than 40 degrees, and leg length or offset differences more than 10 mm. Surgical procedure time was extracted from hospital OR records, and procedural costs were estimated from facility charges associated with 30-minute OR time blocks and intraoperative imaging. Group PLxr had significantly fewer outliers for acetabular inclination more than 50 degrees (5.2 vs. 21.5%, $p < 0.001$), acetabular inclination of 55 degrees or higher (0.7 vs. 8.1%, $p = 0.01$), acetabular anteversion less than 15 or more than 40 degrees (14.8 vs. 28.9%, $p < 0.01$), leg length difference more than 10 mm (2.2 vs. 10.4%, $p = 0.01$), and femoral offset difference more than 10 mm (1.5 vs. 9.6%, $p < 0.01$). The difference in component inclination less than 30 degrees was not significant (0.0 vs. 2.2%, $p = 0.24$). Intraoperative component adjustment occurred in 26 cases (21.5%), was associated with a 19-minute mean increase in operative time ($p < 0.001$) and $1,504 mean increase in facility charges compared with nonimaged cases. Imaged cases without component adjustment increased mean operative time by 9.4 minutes ($p < 0.001$) and mean operative charges by $766. Intraoperative imaging improves component placement accuracy during PL-THA and significantly reduces component placement outliers, particularly with respect to acetabular component inclination, femoral length, and femoral offset.

Level of Evidence Level III, case-control study.

Keywords
- total hip arthroplasty
- posterolateral
- alignment
- component placement outliers
- digital radiography
- operative charges

Total hip arthroplasty (THA) is a highly effective surgical procedure that results in excellent pain relief and functional improvement for most patients.[1] Optimizing acetabular and femoral component placement during THA is important to enhance hip biomechanics and bearing surface longevity, decrease prosthetic impingement and instability risk, and limit patient dissatisfaction associated with unintended limb length inequality.[2–7]

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Experienced surgeons have traditionally used freehand positioning and cross-referencing with internal and external anatomic landmarks. While some surgeons have associated this approach with a high degree of success, others have demonstrated a relatively high rate of acetabular component placement inaccuracy during THA performed using conventional approaches without imaging.[8–11] Internal landmark assessment may be compromised by preoperative structural deformity (e.g., dysplasia), osteoarthritic disease altering normal anatomy (e.g., bone loss, osteophyte formation), patient obesity, or smaller surgical incisions.[8] External landmark assessment may be adversely affected by variable pelvic alignment during lateral decubitus positioning.[12] While intraoperative fluoroscopy and digital imaging have demonstrated improved component placement accuracy during lateral decubitus THA in single cohort studies, observations have been confined to procedural accuracy without consideration of potential time or cost increase.[13–15] Hambright et al noted improved component placement accuracy with limited operative time increase for 50 posterolateral THA (PL-THA) performed with intraoperative imaging compared with a historical 50 PL-THA cohort performed by the same surgeon without imaging.[16]

We performed this study to assess acetabular and femoral component placement accuracy and operative time for PL-THA procedures performed with intraoperative digital radiography compared with a contemporary nonimaged PL-THA cohort. We hypothesized that the use of imaging would improve component placement accuracy without a substantial increase in operative time or operating room cost.

Methods

After obtaining institutional review board approval, we performed a retrospective radiographic analysis of 270 primary total hip replacements performed with a PL surgical approach by two experienced arthroplasty surgeons at a single, tertiary care, teaching institution between December 1, 2016, and July 31, 2018. One surgeon has performed all PL-THA cases without intraoperative imaging (group PL), while the other surgeon has performed all PL-THA with intraoperative digital radiography (group PLxr) since 2014. Both surgeons had completed the same total joint arthroplasty fellowship more than 10 years prior to the surgical procedures and have exclusively used posterior hip approaches during their THA procedures since fellowship training. Surgical procedures were performed in a nonsimultaneous, overlapping dual room workflow with a similar team construct consisting of a senior level resident or adult reconstruction fellow and the surgeon's nurse clinician. An a priori power analysis determined that a minimum of 132 patients would be required to confirm a 2-degree difference in acetabular placement accuracy with a standard deviation of 5 degrees and power of 0.9. Study inclusion criterion was primary THA performed for a diagnosis of osteoarthritis or osteonecrosis, with high-quality anteroposterior (AP) and cross-table lateral radiographs available from both before surgery and at the patients' 6-week postoperative follow-up appointment. Exclusion criteria included primary THA performed for another diagnosis (i.e., fracture, posttraumatic arthritis, inflammatory arthritis, infection), THA performed with concurrent additional procedures (e.g., hardware removal, femoral deformity correction), or if acceptable quality preoperative or postoperative radiographs were not available. A total of 135 patients were consecutively enrolled into each treatment group from an institutional operating room database containing surgical case data (procedure, approach, surgical time, total operating room time) after the exclusion of 18 patients in group PL (12 with inadequate radiographs and 6 with additional procedures) and 15 patients in group PLxr (12 with inadequate radiographs and 3 with additional procedures). For the 270 included patients, a detailed electronic medical record review was performed to identify patient demographic features including age, gender, and body mass index (BMI). Mean patient age was younger in group PL reflecting that surgeon's hip preservation practice (56.4 vs. 62.2 years, $p < 0.001$), but other demographic characteristics were similar (►**Table 1**). Surgical time and total operating room time were obtained from hospital operating room records. Operating room costs were estimated from surgical suite charges generated from 30-minute time block increments. An additional radiology service charge of $280 was added for intraoperative digital radiography.

Surgical Technique

Preoperative surgical templating was performed for all patients using a digital software system (TraumaCAD, BrainLab, Munich, Germany). PL-THA procedures were performed with patients positioned in a lateral position with the pelvis secured into a peg board positioning system. Acetabular components were placed using manual instrumentation with visual cross-referencing against anatomic landmarks. Femoral reconstructions were based on a manually

Table 1 Comparison of patient demographics by surgical approach

Demographic variable	Group PL ($n = 135$)	Group PLxr ($n = 135$)	p-Value
Age (y)	56.4 (± 13.8)	62.2 (± 11.7)	< 0.01
Male gender (%)	54 (40.0%)	48 (35.6%)	0.53
Body mass index (kg/m^2)	32.2 (± 6.6)	32.5 (± 6.4)	0.43
Morbid obesity (%)	25 (18.5%)	21 (15.6%)	0.63

Abbreviations: BMI, body mass index; PL, posterolateral; PLxr, posterolateral with intraoperative X-ray.

measured femoral neck resection based on preoperative templating. In group PL (nonimaged THA), the decision to accept a reconstruction was based in the attending surgeon's clinical judgment on whether the reconstruction had reasonably recreated the templated operative plan for hip length and offset, appropriate combined acetabular-femoral anteversion, and acceptable intraoperative stability assessment. In group PLxr, intraoperative digital radiography was performed after acetabular component impaction, trial femoral component placement, and the attending surgeon's clinical assessment of hip length and offset, combined acetabular-femoral anteversion, and intraoperative stability assessment. Acetabular and femoral component adjustments were made if intraoperative radiographs indicated that acetabular component position and/or femoral length and offset relationships were not adequately established.

Radiographic Assessment

Preoperative radiographs were assessed to confirm appropriate preoperative diagnosis, and to evaluate relationships between the surgical and contralateral hip to determine appropriate leg length and offset restoration relationships. The 6-week postoperative radiographs were assessed using the digital ruler and goniometer available on a web-based digital imaging platform (McKesson Corp, San Francisco, CA). Acetabular inclination, leg length symmetry, and femoral offset symmetry were measured from AP pelvis radiographs (►**Fig. 1**). Acetabular anteversion was measured from cross-lateral radiographs using the angle measured by the opening of the cup in relation to the axis of a vertical plane to the radiographic image (►**Fig. 2**). Outlier cases were identified for cases with acetabular inclination less than 30, more than 50, or 55 degrees or greater, acetabular anteversion less than 15 or more than 40 degrees, leg length asymmetry more than 10 mm, or femoral offset asymmetry more than 10 mm. These parameters were selected based on the participating

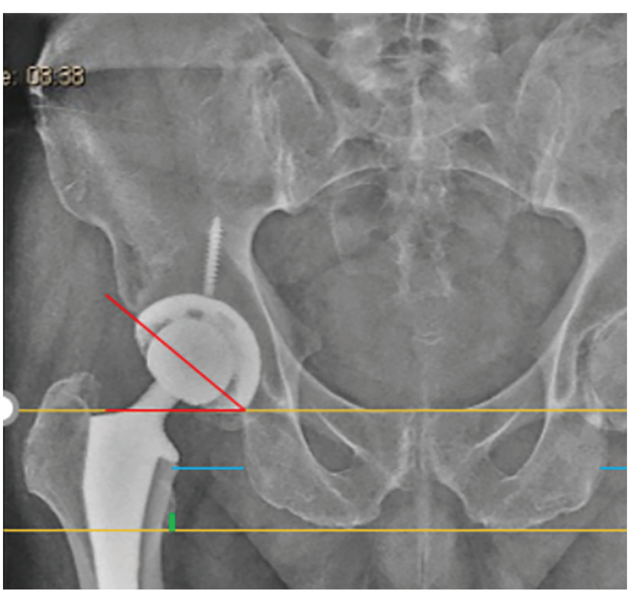

Fig. 1 Angle measured B, acetabular inclination on anteroposterior radiograph.

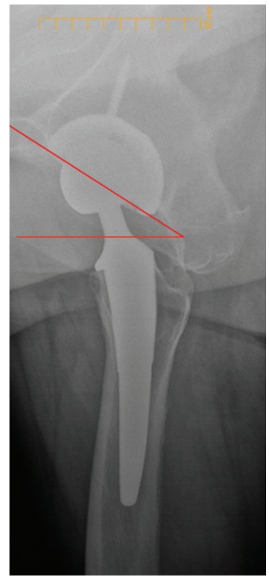

Fig. 2 Angle measured A, acetabular anteversion on cross-table lateral radiograph.

surgeons' component placement targets as supported by previously published reports.[17–19]

Comparisons were performed using a two-sided Student's *t*-test for continuous variables (i.e., age, BMI, inclination angle, anteversion angle, leg length, femoral offset, operating room time, surgical procedure time). Proportional outlier rates and categorical demographic variables (gender, age, morbidly obese percentages) were compared using a two-sided Fisher's exact test. We accepted a *p*-value less than 0.05 to designate statistical significance.

Results

Acetabular component placement accuracy was improved with the use of intraoperative imaging (►**Fig. 3**). The outlier rate with intraoperative imaging (group PLxr) was significantly lower than nonimaged THAs (►**Table 2**). This included fewer hips with acetabular inclination more than 50 degrees (5.2 vs. 21.5%, $p < 0.001$), acetabular inclination of 55 degrees or greater (0.7 vs. 8.1%, $p = 0.01$), acetabular anteversion less than 15 or more than 40 degrees (14.8 vs. 28.9%, $p < 0.01$), leg

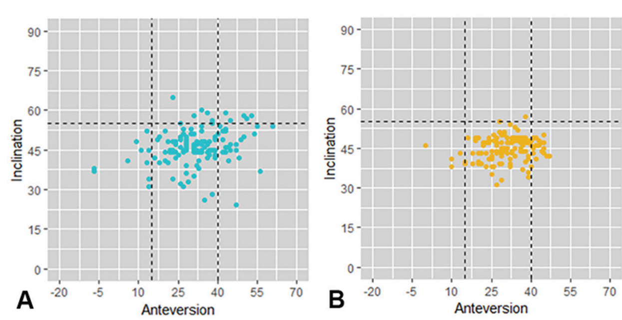

Fig. 3 (**A**) Scatterplot of acetabular anteversion and inclination data for group posterolateral. (**B**) Scatterplot of acetabular anteversion and inclination data for group posterolateral with radiology.

Table 2 Comparison of component outliers by surgical approach

Outlier Variable	Group PL ($n = 135$)	Group PLxr ($n = 135$)	p-Value
Inclination < 30 degrees	3 (2.2%)	0 (0.0%)	0.24
Inclination > 50 degrees	30 (22.2%)	7 (5.2%)	< 0.001
Inclination ≥ 55 degrees	10 (7.4%)	1 (0.7%)	0.01
Acetabular anteversion < 15 or > 40 degrees	41 (30.4%)	20 (14.8%)	< 0.01
Leg length > 10 mm	14 (10.4%)	3 (2.2%)	0.01
Patients with inclination ≥ 55 or other outlier	56 (41.5%)	23 (17.0%)	< 0.001

Abbreviations: PL, posterolateral total hip arthroplasty (THA); PLxr, posterolateral THA performed with intraoperative radiography.

length difference more than 10 mm (2.2 vs. 10.4%, $p = 0.01$), and femoral offset difference more than 10 mm (1.5 vs. 9.6%, $p < 0.01$). The difference in component inclination less than 30 degrees was not significant (0.0 vs. 2.2%, $p = 0.24$).

Intraoperative imaging was associated with a significantly longer mean surgical procedure time (99.8 ± 19.5 minutes vs. 88.4 ± 16.3 minutes, $p < 0.001$) and longer mean operating room time (149.6 ± 22.9 minutes vs. 138.6 ± 19.8 minutes, $p < 0.001$). However, there was no difference in the in-room time for anesthesia, patient positioning, dressing placement, and recovery room transfer (49.6 ± 10.4 minutes vs. 50.5 ± 11.1 minutes, $p = 0.49$). Intraoperative imaging resulted in acetabular component repositioning in 29 imaged cases (21.5%) with 6 residual outliers. This included one patient with an increased inclination angle (54 degrees), one patient with an increased femoral offset (13 mm), and four patients with an anteversion angle between 40 and 45 degrees. The mean surgical time in these cases (107.4 ± 20.2 minutes) was 19.0 minutes longer than for 135 THAs performed without imaging ($p < 0.001$) and 9.6 minutes longer than for 106 THA performed with imaging when the acetabular component position was not changed (97.8 ± 18.9 minutes, $p = 0.02$). Operating room charges were related to the increased time associated with surgical procedures that used digital imaging. Mean operating room charges were $1,200 greater for group PLxr patients compared with group PL patients overall. The difference in mean operating room charges was more substantial for the 29 cases with a component position change ($1,504) than for the 106 cases without a component adjustment ($766).

Discussion

This study is unique in that it considers improved accuracy gained by intraoperative imaging as well as time-based procedural cost associated with this approach.

THA performed with intraoperative digital radiography results in an improved component placement accuracy when compared with a nonimaged traditional PL-THA, including a sixfold reduction in major acetabular inclination and femoral offset outliers, a nearly fivefold reduction in leg length outliers, and a 50% reduction in acetabular component anteversion outliers. Ideal component positioning is considered important in improving function, long-term survivorship, and decreasing complications.

Lewinnek et al initially described a relatively broad "safe zone" (LSZ) for acetabular placement between 30 to 50 degrees of inclination and between 5 and 25 degrees of anteversion, citing a dislocation rate of approximately 1.5% when placed within this target compared with a 3.0% dislocation among outlier cases.[17] McCollum and Gray suggested that a higher anteversion angle—between 20 and 40 degrees—provided more predictable hip stability during PL-THA.[19] Several contemporary studies have challenged the Lewinnek safe zone concept.[20–25] Abdel et al reported that as many as 50% of PL-THA dislocations occur with acceptably positioned acetabular components.[20] Elkins et al suggested that the acetabular component safe zone is narrower than the traditional Lewinnek safe zone based on computer modeling.[23] Other studies have advocated for a more individualized approach accommodating patient-specific variation in spinopelvic position and mobility.[21,22,24,25] While Sotereanos et al reported reproducible acetabular component placement using anatomic landmarks among 617 primary THA procedures, other authors have suggested increased variability in component positioning with influences of patient physical size, surgical incision size, and surgeon experience.[8,10,11] Callanan et al reported on a large series of 1,823 THAs performed by adult reconstruction specialists, noting that only 48% of freehand placed acetabular components were within the LSZ for both inclination and anteversion.[10] Barrack et al noted that only 38% of THA and hip resurfacing procedures simultaneous met narrowed targets for inclination (30–45 degrees) and anteversion (5–25 degrees), but 88% of cases simultaneously met broader targets for inclination (30–55 degrees) and anteversion (5–35 degrees).[8] Restoration of limb length and femoral offset are also important considerations following THA. Limb length discrepancies and poor femoral offset restoration have been associated with hip pain, low back pain, weakness, gait abnormality, THA instability, and polyethylene wear.[26–31]

The use of intraoperative imaging increased mean operative time by 11.4 minutes with a $1,200 increase in operating room charges per procedure. Acetabular component repositioning occurred in 21.5% of cases assessed with digital radiography and was associated with a 10-minute increase in operative time and $738 increase in operating room charges relative to nonadjusted cases. While hospital charges may not accurately represent the true costs associated with intraoperative radiography, the process requires an individual radiology technician to be available in the operative room—either as a shared resource with other procedures in an active surgical facility or with other clinical operations. While this may not contribute to direct costs to patients or insurers, it may have impact on other aspects of practice efficiency, surgeon, and patient experience.

Prior to the availability of digital radiography, routine intraoperative imaging was not a cost-efficient approach for most primary THA procedures. Substantial time was required for image acquisition, image development, and image return to the operating room. The development of digital imaging technologies has resulted in real-time image availability at or near the time of image acquisition using portable imaging machines. Penenberg et al have reported on a series of 369 consecutive THA patients, noting greater than 97% acetabular component placement accuracy for both inclination and anteversion using intraoperative digital imaging.[15] Their study reported that acetabular component position adjustments were made in 28% of cases, which is comparable to the 21.5% rate reported in this study. Debbi et al reported on a cohort of 102 hips, noting intraoperative radiography successfully reproduced limb length within 5 mm (100% of cases) and restored femoral offset within 5 mm in greater than 97% of cases.[14] In these studies, operative time was not reported, and comparative cohorts were not included. Hambright et al reported a retrospective case–control study of 100 primary THA patients performed by a single surgeon—50 with digital imaging and 50 treated without imaging—noting that adjustments in femoral length or offset were performed during 86% of cases performed with intraoperative imaging. These changes occurred with a limited, 5-minute average increased in operative time (range: 2–14 minutes).[16] There is otherwise limited recent published data evaluating component placement accuracy, operative time, and reported hospital charges/costs associated with intraoperative digital radiography during PL-THA.

There are several noteworthy study limitations. Foremost, this is a retrospective observational study involving the practices of two distinct surgeons. It is not possible to exclusively ascribe differences in technique or operative time to the addition of intraoperative digital radiography. However, as the procedures are being performed in an educational construct with the same residents or fellows participating in procedures and a nearly identical nonsurgical room time between the two study groups, it is not unreasonable to consider that the addition of intraoperative imaging contributed more substantively to differences in operative time than other considerations. Second, the study does not provide a comprehensive assessment of clinical or functional outcomes for patients. The focus of the study on radiographic alignment parameters cannot provide an assessment of clinical or functional performance. Third, while intraoperative changes in acetabular component placement were well documented in the operative reports, intraoperative adjustments of either femoral component length or offset were not routinely included. Fourthly, cross-table lateral radiographs may not accurately relate true acetabular component anteversion relative to measurements obtained with computed tomography, and likely overestimate true acetabular component anteversion.[6,7,12,15,26,32,33] It is also not possible to assert whether components may have been intentionally placed outside of the study alignment parameters to address acetabular bone deficiency, extra-articular leg length discrepancy, unresolved hip impingement, or residual soft tissue imbalance. Finally, estimates of operating room charges are not necessarily representative of the costs associated with surgical procedures, and the additional time required to perform intraoperative imaging has not substantively affected our ability to complete surgical cases during a typical operative day.

Conclusion

Intraoperative imaging improves component placement accuracy during PL-THA and significantly reduces component placement outliers, particularly with respect to acetabular component inclination, femoral length, and femoral offset. There was a moderate decrease in acetabular anteversion outliers, with PL-approach surgeons generally accepting a higher acetabular anteversion position based on the surgical approach. A moderate increase in both operative time and surgical charges was associated with the use of intraoperative imaging, particularly among cases where component modification and imaging reassessment were performed. However, these differences did not substantively affect clinical workflow or patient access to arthroplasty care.

Ethical Approval
This study was approved and executed under approval from the University of Missouri's Institutional Review Board (#2017063). No external funding was used in the execution of this study.

Conflict of Interest
Each author certifies that he or she has no commercial associations (e.g., consultancies, stock ownership, equity interest, and patent/licensing arrangements) that might pose a conflict of interest in connection with the submitted article.

References

1 Berry DJ, Harmsen WS, Cabanela ME, Morrey BF. Twenty-five-year survivorship of two thousand consecutive primary Charnley total hip replacements: factors affecting survivorship of acetabular and femoral components. J Bone Joint Surg Am 2002;84(02):171–177
2 Kelley SS, Lachiewicz PF, Hickman JM, Paterno SM. Relationship of femoral head and acetabular size to the prevalence of dislocation. Clin Orthop Relat Res 1998;(355):163–170
3 Kennedy JG, Rogers WB, Soffe KE, Sullivan RJ, Griffen DG, Sheehan LJ. Effect of acetabular component orientation on recurrent dislocation, pelvic osteolysis, polyethylene wear, and component migration. J Arthroplasty 1998;13(05):530–534
4 Kluess D, Martin H, Mittelmeier W, Schmitz KP, Bader R. Influence of femoral head size on impingement, dislocation and stress

distribution in total hip replacement. Med Eng Phys 2007;29(04): 465–471

5 Mallory TH, Lombardi AV, Fada RA, Herrington SM, Eberle RW. Dislocation after total hip arthroplasty using the anterolateral abductor split approach. Clin Orthop Relat Res 1999;(358): 166–172

6 Parvizi J, Sharkey PF, Bissett GA, Rothman RH, Hozack WJ. Surgical treatment of limb-length discrepancy following total hip arthroplasty. J Bone Joint Surg Am 2003;85(12):2310–2317

7 Patil S, Bergula A, Chen PC, Colwell CW, D'Lima DD. Polyethylene wear and acetabular component orientation. J Bone Joint Surg Am 2003;85-A(Suppl 4):56–63

8 Barrack RL, Krempec JA, Clohisy JC, et al. Accuracy of acetabular component position in hip arthroplasty. J Bone Joint Surg Am 2013;95(19):1760–1768

9 Bosker BH, Verheyen CCPM, Horstmann WG, Tulp NJA. Poor accuracy of freehand cup positioning during total hip arthroplasty. Arch Orthop Trauma Surg 2007;127(05):375–379

10 Callanan MC, Jarrett B, Bragdon CR, et al. The John Charnley Award: risk factors for cup malpositioning: quality improvement through a joint registry at a tertiary hospital. Clin Orthop Relat Res 2011;469(02):319–329

11 Sotereanos NG, Miller MC, Smith B, Hube R, Sewecke JJ, Wohlrab D. Using intraoperative pelvic landmarks for acetabular component placement in total hip arthroplasty. J Arthroplasty 2006;21 (06):832–840

12 Otero JE, Fehring KA, Martin JR, Odum SM, Fehring TK. Variability of pelvic orientation in the lateral decubitus position: are external alignment guides trustworthy? J Arthroplasty 2018;33(11): 3496–3501

13 Beamer BS, Morgan JH, Barr C, Weaver MJ, Vrahas MS. Does fluoroscopy improve acetabular component placement in total hip arthroplasty? Clin Orthop Relat Res 2014;472(12):3953–3962

14 Debbi EM, Rajaee SS, Mayeda BF, Penenberg BL. Determining and achieving target limb length and offset in total hip arthroplasty using intraoperative digital radiography. J Arthroplasty 2020;35 (03):779–785

15 Penenberg BL, Samagh SP, Rajaee SS, Woehnl A, Brien WW. Digital radiography in total hip arthroplasty: technique and radiographic results. J Bone Joint Surg Am 2018;100(03):226–235

16 Hambright D, Hellman M, Barrack R. Intra-operative digital imaging: assuring the alignment of components when undertaking total hip arthroplasty. Bone Joint J 2018;100-B(1, Supple A):36–43

17 Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60(02):217–220

18 Dorr LD, Wan Z. Causes of and treatment protocol for instability of total hip replacement. Clin Orthop Relat Res 1998;(355):144–151

19 McCollum DE, Gray WJ. Dislocation after total hip arthroplasty. Causes and prevention. Clin Orthop Relat Res 1990;(261):159–170

20 Abdel MP, von Roth P, Jennings MT, Hanssen AD, Pagnano MW. What safe zone? The vast majority of dislocated THAs are within the Lewinnek safe zone for acetabular component position. Clin Orthop Relat Res 2016;474(02):386–391

21 Buckland AJ, Vigdorchik J, Schwab FJ, et al. Acetabular anteversion changes due to spinal deformity correction: bridging the gap between hip and spine surgeons. J Bone Joint Surg Am 2015;97 (23):1913–1920

22 DelSole EM, Vigdorchik JM, Schwarzkopf R, Errico TJ, Buckland AJ. Total hip arthroplasty in the spinal deformity population: does degree of sagittal deformity affect rates of safe zone placement, instability, or revision? J Arthroplasty 2017;32(06): 1910–1917

23 Elkins JM, Callaghan JJ, Brown TD. The 2014 Frank Stinchfield Award: The "landing zone" for wear and stability in total hip arthroplasty is smaller than we thought: a computational analysis. Clin Orthop Relat Res 2015;473(02):441–452

24 Kanawade V, Dorr LD, Wan Z. Predictability of acetabular component angular change with postural shift from standing to sitting position. J Bone Joint Surg Am 2014;96(12):978–986

25 Lum ZC, Coury JG, Cohen JL, Dorr LD. The current knowledge on spinopelvic mobility. J Arthroplasty 2018;33(01):291–296

26 Shapira J, Chen SL, Rosinsky PJ, et al. The effect of postoperative femoral offset on outcomes after hip arthroplasty: a systematic review. J Orthop 2020;22:5–11

27 Giles LG, Taylor JR. Low-back pain associated with leg length inequality. Spine 1981;6(05):510–521

28 Gurney B, Mermier C, Robergs R, Gibson A, Rivero D. Effects of limb-length discrepancy on gait economy and lower-extremity muscle activity in older adults. J Bone Joint Surg Am 2001;83(06): 907–915

29 Ituarte F, Aggarwal A, Leary EV, Hansen BJ, Keeney JA. Relative contribution of acetabular and femoral reconstruction to prosthetic joint instability risk after primary total hip arthroplasty. J Hip Surg 2019;03(03):130–135

30 McGrory BJ, Morrey BF, Cahalan TD, An KN, Cabanela ME. Effect of femoral offset on range of motion and abductor muscle strength after total hip arthroplasty. J Bone Joint Surg Br 1995;77(06): 865–869

31 Nogueira MP, Paley D, Bhave A, Herbert A, Nocente C, Herzenberg JE. Nerve lesions associated with limb-lengthening. J Bone Joint Surg Am 2003;85(08):1502–1510

32 Nunley RM, Keeney JA, Zhu J, Clohisy JC, Barrack RL. The reliability and variation of acetabular component anteversion measurements from cross-table lateral radiographs. J Arthroplasty 2011;26(6, Suppl):84–87

33 Snijders TE, Schlösser TPC, van Gaalen SM, Castelein RM, Weinans H, de Gast A. Non-equivalent results from different anteversion measurements methods for the evaluation of the acetabular cup orientation in total hip arthroplasty. Orthop Surg 2019;11(02): 241–247