The safety and efficacy of the anterior approach total hip arthroplasty as per body mass index

Title

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Abstract (n=250)

Background: Obesity is associated with component mal-positioning and increased revision risk after total hip arthroplasty (THA). With Anterior Approach (AA) becoming increasingly popular, the goal of this study was to assess whether clinical outcome post-AA-THA is affected by body mass index (BMI).

Methods: This multi-centre, multi-surgeon, consecutive case-series used a prospective database of 1784 AA-THAs (1597 patients) through bikini (n=1172) or standard (n=612) incision (Age 63.2±12.1years; 57.5% Females; Follow-up 2.7±0.5years). Patients were classified into BMI-groups [normal (BMI<25; n=572), overweight (BMI:25-30; n=739), obese (BMI:30-35; n=330), severely-obese (BMI>35; n=143)]. Outcome included hip reconstruction (inclination/anteversion and leg-length), complication-, reoperation- rates, and patient-reported outcome including Oxford Hip Score.

Results: Post-operative leg-length difference was 2.0±9.0mm, with a mean cup inclination/anteversion of 35°/20°. Accuracy of reconstruction was similar between BMI-groups (p=0.1–0.7). Complication- and revision- rates were 2.5% and 1.7% respectively. Most common were fracture (0.7%), periprosthetic joint infection (PJI) (0.5%) and dislocation (0.5%). There was no difference in dislocation- (p=0.885) or fracture- rates (p=0.588) between BMI-groups. Higher rates of wound complications (1.8%; p=0.053) and PJI (2.1%; p=0.029) existed among obese and severely-obese patients. Wound complications were less common with the 'bikini' incision (odds ratio 2.7). Pre-operative OHS was worse among the severely-obese (p<0.001), which showed similar improvement (ΔOHS; p=0.144).

Conclusion: AA-THA is a credible option for obese patients, with low dislocation- or fracture-risk, and excellent ability to reconstruct the hip, leading to comparable functional improvement among BMI-groups. To minimize risk of wound-complications, possibly contributing to PJI, increased in the obese, bikini incision is recommended.

Key words:

Total Hip Arthroplasty, Anterior Approach, Outcome, Complications, Body Mass Index, Obesity

Introduction (n=226)

Obesity is a growing challenge facing the Western healthcare systems, including arthroplasty surgeons. It is estimated that, by the 2030, 20% of the world's adult population will be obese, and this proportion is predicted to continuously increase[1,2]. Obesity is associated with younger age at the time of primary total hip arthroplasty (THA)[2,3]. Although obese patients can expect clinical improvement following THA with a similar survival rate[4], they are at an elevated risk for complications such as infection and dislocation[5,6]. In most studies on the results of THA among patients with obesity, an anterolateral[7-9] or posterior approach[7,10] was used.

The Anterior Approach (AA) is becoming increasingly popular for a primary THA, with presumed advantages such as enhanced recovery and low dislocation rates[11,12]. However, there is literature reporting increased complication-risk[13,14]. AA is associated with technical difficulties, both on the femoral and on the acetabular side[15], as soft tissues might impede access, increasing risk of component malpositioning, contributing to instability, early loosening or periprosthetic fractures[16]. In addition, obesity has been described as a risk factor for wound complications in AA, due to immune dysfunction and the proximity of the adjacent waist crease, exacerbated in obese patients[17-20].

This study aims to assess the impact of BMI on the clinical outcome (component position, complication- and revision rate, and patient-reported outcome) and identify factors associated with outcome for patients with higher BMI.

Methods (n=856)

Study design

This is a retrospective, consecutive case series of prospectively recorded data of patients who underwent a primary THA through AA in one of two high-volume, tertiary referral institutions (Centre 1: [redacted] & Centre 2: [redacted]). All six participating surgeons have a minimum of 3 years' experience with, and predominantly use AA for primary THA[21]. The study was approved by the ethical committee and all participants signed an informed consent.

Study population

Between 2018 and 2020, 901 total hip replacements were performed in 832 patients in centre 1, and 1461 hip replacements in 1267 patients in centre 2. The inclusion process has been outlined in a flowchart (**Figure 1**). Exclusion criteria were age less than 18 years old (n=2), patients deceased during the follow-up from causes unrelated to THA (n=19), THA through lateral (n=3) or posterior approach (n=133), secondary osteoarthritis to childhood diseases (n=22), femoral neck fracture (n=29), avascular necrosis (n=38), post-traumatic arthritis (n=11), conversion of an intramedullary nail (n=10) or hip fusion (n=1) to THA, rheumatoid arthritis (n=2), metastasis (n=1), absent BMI data (n=179) and follow-up less than 2 years (n=128). This left 1784 procedures (1597 patients) for inclusion (726 THA in 674 patients from centre 1; and 1058 THA in 923 patients from centre 2).

Patients were classified into sub-groups based on their BMI at the time of surgery. The groups were BMI<25 (no overweight), BMI 25-30 (overweight), BMI 30-35 (obesity), BMI>35 (severe obesity)[22].

There were 1025 males (43.4%) and 1337 females (56.6%), with a mean BMI of 27.6±5.0 kg/m^2. The mean age of the cohort was 63.2±12.1years. Patients with severe obesity were significantly younger (61.1±10.9y) in comparison to non-overweight (63.5±12.5y; p=0.005) and overweight (62.2±11.5y; p=0.009) patients (**Table 1**).

Surgery and implant characteristics were prospectively collected in the database. All THAs were performed through an AA with the patient in supine position on a standard operating table[23] (n=1388) or using a positioning table[24] (n=396), through a horizontal 'bikini' incision (n=1172) or a longitudinal incision (n=612). Pinnacle® acetabular cup (DePuy-Synthes, Warsaw, Indiana, United States) was used in 934 cases (52.4%), G7 acetabular cup (Zimmer-Biomet, Warsaw, Indiana, United States) in 725 cases (40.6%), and Trilogy® cup (Zimmer-Biomet) in 123 cases (6.9%). 1712 (96.0%) stems were uncemented and 72 stems (4.0%) were cemented. The most commonly used stems were Corail® (DePuy-Synthes) (n=932), Microplasty® (Zimmer-Biomet) (n=656), Avenir® (Zimmer-Biomet) (n=104), and Taperlock® (Zimmer-Biomet) (n=44).

Radiographic analysis

Standing anteroposterior (AP) pelvic radiographs were analysed and a calibration marker was used to correct for magnification error. The longitudinal rotation of the pelvis was verified as correct when the tip of the coccyx was in line with pubic symphysis[25,26]. If the coccyx deviated ≥1cm from the symphyseal line the X-ray was considered unacceptable for measurement purposes.

A power analysis was performed to determine the minimum number of subjects requiring radiographic reconstruction measurements. A sample size was calculated in SPSS v27 (IBM)

with the intention to detect a difference in cup anteversion of 10°, using an anteversion of 15°±10° as a reference[27]. A minimum of 16 patients per group was necessary to achieve sufficient power (1-β=0.80, α=0.05).

Two arthroplasty fellowship-trained orthopaedic surgeons performed the following measurements: (1) *leg length discrepancy (LLD)* – defined as the difference of the leg length between the ipsi- and contra-lateral hip, measured by the distance between the inter-teardrop line and the inferior margin of the lesser trochanter[28], (2) *cup inclination* – defined as the angle between the long axis of the cup and a transverse line connecting the bottom edge of the acetabular teardrops[29] and (3) *acetabular cup anteversion* – defined as the inverse sine of the division between the distance of the short and long axis of the elliptical projection of the rim of the acetabular component[30]. Intraclass correlation coefficient was calculated with a two-way mixed model. A value >0.75 was considered to have excellent reliability (0-1: no – absolute agreement)[31] (**Supplementary Table**).

Outcome measurements

Clinical, surgical, and hospitalization notes were screened for adverse events. The Clavien-Dindo classification was used to grade complications[32].

Patient-reported outcome measures (PROMs) were obtained at 4 weeks pre-operatively, and at a minimum of 12 months post-operatively. Those included Oxford Hip Score (OHS)[33]. EuroQOL Five Dimensions Questionnaire (EQ5D)[34], Patient-Reported Outcome Measurement Information System (PROMIS)[35] in one centre, and Hip disability and Osteoarthritis Outcome Score (HOOS)[36] and 36-item Short Form Survey (SF-36)[37] in the second centre. The difference between the latest follow-up and the pre-operative values was defined as Δ. Length of follow-up was determined from the date of surgery to the last clinical review.

Statistics

Statistical analysis was performed using SPSS v27 (IBM). Normal distribution of data was tested with the Kolmogorov-Smirnov test and Q-Q plots. A Mann Whitney U test or a Kruskal-Wallis was used to compare continuous variables between different groups, for non-normally distributed data, and independent samples t-test or ANOVA test was used for normally distributed data. A paired samples t-test was used to compare pre- and post-operative values and Chi Square test to compare categorical variables. Survival was calculated with failure defined as any re-operation in which any component was changed. Survival data was obtained by Kaplan-Meier analysis[38]. A p-value of <0.05 was considered significant.

Results (n=347)

Radiographic measurements

Mean post-operative leg-length difference was within 2.0±9.0mm. Mean cup inclination and anteversion were 34.8°±7.8° and 20.3°±5.1° respectively. There was no significant difference in any of the radiographic parameters measured (cup anteversion, inclination, and leg length difference) between different obesity groups (**Table 2**), only a slight tendency towards increased cup inclination in patients with higher BMI, however this difference was not significant (**Figure 2**).

Complications & reoperations

The overall rate for Clavien-Dindo grade 3 complications within this cohort was 2.5% (45/1784). Thirty THA were revised (1.7%) at 2.7±0.5 years follow-up. The majority of these were peri-prosthetic fractures (12/1784; 0.7%), followed by peri-prosthetic joint infection (PJI) (9/1784; 0.5%), and instability (8/1784; 0.5%) (**Table 3**). There was no difference in survival rate between the different obesity groups (p=0.095) (**Figure 3**). Patients with obesity had the highest incidence of wound problems (6/324; 1.8%) in comparison to overweight (4/735; 0.5%; p=0.053) and not-overweight (1/571; 0.2%; p=0.012) patients. Similarly, patients with severe obesity (BMI≥35) had a significantly higher risk to develop PJI (3/143; 2.1%) in comparison to overweight (3/739; 0.4%; p=0.024) and not-overweight (3/572; 0.5%; p=0.065) patients. The incidence of wound complications was lower among patients that had a horizontal 'bikini' incision (odds ratio 2.7; 95% C.I. 0.9-8.5; p=0.039).

Patient-reported outcome measures

Patients with higher BMI had lower preoperative PROM scores (OHS, HOOS and SF-36) in comparison to patients with lower BMI (**Table 4 & Figure 4**). Patients with severe obesity (15.4±8.0) had lower pre-operative OHS scores than not-overweight (21.2±8.5; $p<0.001$), overweight (19.9±9.6; $p=0.002$) and obesity patients (18.7±7.8; $p=0.031$). Patients with severe obesity had higher ΔOHS, ΔHOOS and ΔSF-36 scores than the other groups, although only significant for ΔHOOS quality of life ($p=0.006$) (**Table 4 & Figure 4**). PROM scores at latest follow-up were lower in groups of patients with higher BMI for EQ5D and OHS, but not anymore for HOOS and SF-36 (**Table 4 & Figure 4**). Post-hoc analysis revealed that patients with severe obesity (42.0±5.4) had lower post-operative OHS scores than not-overweight (43.9±5.5; $p<0.001$) and overweight (43.9±5.2; $p=0.001$) patients, but similar post-operative OHS scores than obese patients (42.1±6.1; $p=0.603$).

Discussion (n=1249)

This large, multi-centre, multi-surgeon, consecutive case series showed that AA-THA is safe and effective in obese patients, even amongst those with BMI>35. Reconstruction with AA allowed for reliable component orientation and hip reconstruction even in obese patients, in contrast to other approaches[39,40]. At a follow-up of 2.7±0.5 years, overall complication and revision rates were 2.5% and 1.7% respectively. The low dislocation (0.5%) and periprosthetic fracture risk (0.7%) was not higher in obese patients. However, patients with severe obesity had a higher risk to develop PJI (2.1%). Patients with higher BMI had lower preoperative PROM scores but sustained a similar improvement in PROMs, further illustrating the efficacy of AA-THA. The risk of infection in obese patients remains a challenge, regardless of approach, even among experienced surgeons, and special attention should be paid to adjunct measure, including post-operative wound management, to minimize this.

The AA has been shown to lead to superior reconstruction and component orientation accuracy[41,42]. This accuracy does not seem to be adversely affected by BMI. Although BMI did not have effect on cup position, nor orientation with AA-THA, there was a tendency towards an increased inclination and anteversion in patients with obesity. It is plausible that during cup positioning, anterior soft tissues push the handle towards increased anteversion and inclination. We would therefore recommend the use of an offset handle during cup placement to help avoid cup malpositioning. One other study assessed the influence of obesity on acetabular cup positioning in AA-THA and also found no significant difference in cup anteversion/inclination[18], while studies in anterolateral or posterior THA showed that high BMI is a risk factor of cup malpositioning[39,40]. A significantly increased inclination and decreased anteversion among obese patients[43-45] led to the suggestion of using navigation to improve cup orientation when conducting anterolateral or posterior approach THA in obese patients[46-48]. A

large depth of fat can influence the angle of the acetabular component inserter, and pelvic positioning in lateral decubitus is more difficult in obese patients, risking intraoperative pelvic motion[40]. All patients in our study underwent an AA in supine position, which likely contributes to a more reproducible position of the pelvis during surgery. Leg length restoration was not affected by obesity in our study, while BMI was found to affect leg-length restoration in posterior approach THA[49].

Different studies found a higher complication rate after primary THA in patients with obesity, including instability, periprosthetic fracture, and infection[2,8,9,50,51]. The overall dislocation rate was very low in this cohort (0.5%), and was similar among the different BMI-groups. AA appears to be protective against instability, even among obese patients. For other approaches, a dislocation risk up to 3-7% has been described in severely obese patients[8,9,50]. This is likely the consequence of improved cup positioning and preservation of the muscle envelope with AA. Femoral exposure is one of the technical difficulties associated with AA-THA[15]. Soft tissues in patients with obesity might impede the access to the femoral canal, risking femoral stem malpositioning and femoral fractures. Although we found a relatively higher periprosthetic fracture rate among patients with severe obesity (1.4%), this was not significantly different than in other groups (0.5-0.7%). We found no perioperative calcar fractures among patients with obesity, the overall risk was 0.6%. Although no significant differences in periprosthetic fracture risk were found in this study, it should be acknowledged that femoral exposure can be more difficult in obese patients. All surgeons included in this study are very experienced with AA and femoral exposure in AA is an important aspect of the learning curve[52].

Patients with severe obesity have a higher risk of PJI (2.1%) in comparison to an overall risk within this cohort (0.5%), and patients with obesity have a higher risk of wound complications

(1.8%) compared to an overall risk (0.6%). Patients with obesity have been shown to be at higher risk for wound complications and infection, due to the increased fat tissue envelope and deeper surgical exploration, adjacency of waist crease with overlying abdominal pannus, and higher prevalence of co-morbidities such as diabetes mellitus or immunodeficiency[17-20]. Delayed wound healing compromises the natural skin barrier allowing for bacterial migration in the wound leading to PJI[53]. The wound complication and infection rate was similar or lower in comparison to other studies on the outcome of AA-THA in patients with obesity. Purcell et al reported a 2.5% incidence of PJI and 2.0% of superficial wound dehiscence among patients with severe obesity[19]. Antoniadis et al reported a 4.6% incidence of infection requiring reoperation[18]. Jahng et al reported 11.5% wound complications of which 1.9% required a reoperation[54]. Studies on primary THA through anterolateral approach found a rate of 11% superficial wound problems and 4% deep infection among severely obese patients[50]. Similar to our findings, some studies suggested a horizontal 'bikini' incision to be beneficial for wound healing[53,55]. The bikini incision is oriented along Langer's line, allowing for tension free healing during the early-post-operative period[55]. To minimize the risk of wound-complications, possibly contributing to PJI, the bikini incision is recommended. Although incision length was not measured as part of this study, it is plausible that some vertical incisions reached the skin groin crease, which could be associated with an increased risk of slower wound healing[53] due to increased bacterial skin flora[56]. However, the use of the bikini incision is associated with other pitfalls (e.g. not extensile) and should thus be utilized with caution, especially during the learning curve of the AA.

The difference between pre- and postoperative PROM scores was not different between BMI-groups. While patients with obesity had lower pre-operative PROM scores, they can expect similar clinical improvement after THA. Most studies that include PROM scores have found

good functional outcome among obese patients[2,18,57]. Registry data has shown that increased BMI is associated with significantly smaller improvement in post-operative outcome scores, although these studies did not include AA-THA[58,59]. Due to the increased complication risk, the American Association of Hip and Knee Surgeons workgroup released a statement recommending to delay arthroplasty in patients with a BMI>40[60]. Recently, the Cleveland arthroplasty group stated that operative eligibility based on BMI alone could potentially restrict access for patients who would benefit from primary THA and can expect improvement in pain, function and overall quality of life[61], which is supported by our data.

This study has some limitations. First, it is a retrospective study of prospectively recorded data, and there was a lack of complete pre- and post-operative PROM scores, which were available in only 60% and 70% of patients respectively. This might have caused bias interpreting these results. Second, all patients underwent THA through AA, there was no control group to compare risk of complications between different approaches. Third, all authors have a large experience with AA and therefore these results might not be representative to surgeons in an early stage of the learning curve. Fourth, the mean follow-up was only 2.5±0.6 years; longer follow-up would be necessary to evaluate the long-term survival among obese patients treated with AA-THA.

Conclusion

The AA is a safe and effective approach for obese patients undergoing THA. AA allows for excellent and reproducible cup orientation and hip reconstruction, even among severely obese patients, without the need for navigation. The risk of dislocation and periprosthetic fractures was low, even among patients with obesity. Patients with obesity are at higher risk to develop wound complications and PJI following AA-THA. A horizontal ‘bikini’ incision can help to

avoid wound complications. Patients with higher BMI had lower preoperative PROM scores in comparison to patients with lower BMI, but similar improvement can be expected post-operatively.

References

1. Smith K, Smith M. Obesity Statistics. *Prim Care* 2016;43:121-35.

2. Haynes J, Nam D, Barrack R. Obesity in total hip arthroplasty: does it make a difference? *Bone Joint J* 2017;99-B(1):31-36.

3. Changulani M, Kalairajah Y, Peel T, Field R. The relationship between obesity and the age at which hip and knee replacement is undertaken. *J Bone Joint Surg Br* 2008;90(3):360-3.

4. Yeung E, Jackson M, Sexton S, Walter W, Zicat B, Walter W. The effect of obesity on the outcome of hip and knee arthroplasty. *Int Orthop* 2011;35(6):929-34.

5. Ward D, Metz L, Horst P, Kim H, Kuo A. Complications of Morbid Obesity in Total Joint Arthroplasty: Risk Stratification Based on BMI. *J Arthroplasty* 2015;30:42-6.

6. Friedman R, Hess S, Berkowitz S, Homering M. Complication rates after hip or knee arthroplasty in morbidly obese patients. *Clin Orthop Relat Res* 2013;471(10):3358-66.

7. Andrew J, Palan J, Kurup H, Gibson P, Murray D, Beard D. Obesity in total hip replacement. *J Bone Joint Surg Br* 2008;90(4):424-9.

8. Lübbeke A, Stern R, Garavaglia G, Zurcher L, Hoffmeyer P. Differences in outcomes of obese women and men undergoing primary total hip arthroplasty. *Arthritis Rheum* 2007;57(2):327-34.

9. Davis A, Wood A, Keenan A, Brenkel I, Ballantyne J. Does body mass index affect clinical outcome post-operatively and at five years after primary unilateral total hip replacement performed for osteoarthritis? A multivariate analysis of prospective data. *J Bone Joint Surg Br* 2011;93(9):1178-82.

10. Jackson M, Sexton S, Yeung E, Walter W, Walter W, Zicat B. The effect of obesity on the mid-term survival and clinical outcome of cementless total hip replacement. *J Bone Joint Surg Br* 2009;91(10):1296-300.

11. Wang Z, Hou J-Z, Wu C-H, Zhou Y-J, Gu X-M, Wang H-H, Feng W, Cheng Y-X, Sheng X, Bao H-W. A systematic review and meta-analysis of direct anterior approach versus posterior approach in total hip arthroplasty. *J Orthop Surg Res* 2018;13(229) doi: 10.1186/s13018-018-0929-4.

12. Miller L, Gondusky J, Kamath A, Boettner F, Wright J, Bhattacharyya S. Influence of surgical approach on complication risk in primary total hip arthroplasty. *Acta Orthopaedica* 2018;89:289-94.

13. Aggarwal V, Elbuluk A, Dundon J, Herrero C, Hernandez C, Vigdorchik J, Schwarzkopf R, Iorio R, Long W. Surgical approach significantly affects the complication rates associated with total hip arthroplasty. *Bone Joint J* 2019;101-B(6):646-51.

14. Pincus D, Jenkinson R, Paterson M, Leroux T, Ravi B. Association Between Surgical Approach and Major Surgical Complications in Patients Undergoing Total Hip Arthroplasty. *JAMA* 2020;323(11):1070-76.

15. Spaans A, van den Hout J, Bolder S. High complication rate in the early experience of minimally invasive total hip arthroplasty by the direct anterior approach. *Acta Orthopaedica* 2012;83(4):342–46.

16. Hartford J, Knowles S. Risk Factors for Perioperative Femoral Fractures: Cementless Femoral Implants and the Direct Anterior Approach Using a Fracture Table. *J Arthroplasty* 2016;31(9):2013-8.

17. Watts C, Houdek M, Wagner E, Sculco P, Chalmers B, Taunton M. High Risk of Wound Complications Following Direct Anterior Total Hip Arthroplasty in Obese Patients. *J Arthroplasty* 2015;30(12):2296-8.

18. Antoniadis A, Dimitriou D, Flury A, Wiedmer G, Hasler J, Helmy N. Is Direct Anterior Approach a Credible Option for Severely Obese Patients Undergoing Total Hip Arthroplasty? A Matched-Control, Retrospective, Clinical Study. *J Arthroplasty* 2018;33(8):2535-40.

19. Purcell R, Parks N, Gargiulo J, Hamilton W. Severely Obese Patients Have a Higher Risk of Infection After Direct Anterior Approach Total Hip Arthroplasty. *J Arthroplasty* 2016;31:162-5.

20. Russo M, Macdonell J, Paulus M, Keller J, Zawadsky M. Increased Complications in Obese Patients Undergoing Direct Anterior Total Hip Arthroplasty. *J Arthroplasty* 2015;30(8):1384-7.

21. Gofton W, Ibrahim M, Kreviazuk C, Kim P, Feibel R, Beaulé P. Ten-Year Experience With the Anterior Approach to Total Hip Arthroplasty at a Tertiary Care Center. *J Arthroplasty* 2020;35(5):1281-89.

22. Canadian Guidelines for Body Weight Classification in Adults. Health Canada: Minister of Public Works and Government Services Canada. Ottawa. 2003

23. Corten K, Holzapfel B. Direct anterior approach for total hip arthroplasty using the "bikini incision". *Oper Orthop Traumatol* 2021;33(4):318-30. doi: 10.1007/s00064-021-00721-y

24. Matta J, Shahrdar C, Ferguson T. Single-incision anterior approach for total hip arthroplasty on an orthopaedic table. *Clin Orthop Relat R* 2005;441:115-24.

25. Scheerlinck T. Primary hip arthroplasty templating on standard radiographs. A stepwise approach. *Acta Orthop Belg* 2010;76(4):432-42.

26. Tannast M, Zheng G, Anderegg C, Burckhardt K, Langlotz F, Ganz R, Siebenrock K. Tilt and rotation correction of acetabular version on pelvic radiographs. *Clin Orthop Relat Res* 2005;438:182-90.

27. Lewinnek G, Lewis J, Tarr R, Compere C, Zimmerman J. Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg Am* 1978;60(2):217-20.

28. Woolson S, Hartford J, Sawyer A. Results of a Method of Leg-Length Equalization for Patients Undergoing Primary Total Hip Replacement. *J Arthroplasty* 1999;14(2):159-64. doi: doi: 10.1016/s0883-5403(99)90119-5.

29. Engh C, Griffin W, Marx C. Cementless acetabular components. *J Bone Joint Surg Br* 1990;72(1):53-9.

30. Nho J-H, Lee Y-K, Kim HJ, Ha Y-C, Suh Y-S, Koo K-H. Reliability and validity of measuring version of the acetabular component. *Bone Joint Surg Br* 2012;94(1):32-6. doi: doi: 10.1302/0301-620X.94B1.27621.

31. Fleiss J. The design and analysis of clinical experiments. New York: John Wiley and Sons 1986

.

32. Wells J, Schoenecker P, Petrie J, Thomason K, Goss C, Clohisy J. Are Complications After the Bernese Periacetabular Osteotomy Associated With Subsequent Outcomes Scores? *Clin Orthop Relat Res* 2019;477:1157-63.

33. Dawson J, Fitzpatrick R, Carr A, Murray D. Questionnaire on the perceptions of patients about total hip replacement. *J Bone Joint Surg Br* 1996;78(2):185-90.

34. Group E. EuroQol--a new facility for the measurement of health-related quality of life. *Health Policy* 1990;16(3):199-208.

35. Cella D, Riley W, Stone A, Rothrock N, Reeve B, Yount S, Amtmann D, Bode R, Buysse D, Choi S, Cook K, Devellis R, DeWalt D, Fries J, Gershon R, A Hahn E, Lai J-S, Pilkonis P, Revicki D, Rose M, Weinfurt K, Hays R, Group PC. Initial item banks and first wave testing of the Patient-Reported Outcomes Measurement Information System (PROMIS) network: 2005–2008. . *J Clin Epidemiol* 2010;63(11):1179-94.

36. Nilsdotter A, Lohmander L, Klässbo M, Roos E. Hip disability and osteoarthritis outcome score (HOOS)--validity and responsiveness in total hip replacement. *BMC Musculoskelet Disord* 2003;4(10)

37. Ware Jr J, Sherbourne C. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. *Med Care* 1992;30(6):473-83.

38. Kaplan E, Meier P. Nonparametric estimation from incomplete observations. *J Am Stat Assoc* 1958;53:457-81.

39. Callanan M, Jarrett B, Bragdon C, Zurakowski D, Rubash H, Freiberg A, Malchau H. 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(2):319-29.

40. Meermans G, Grammatopoulos G, Innmann M, Beverland D. Cup placement in primary total hip arthroplasty: how to get it right without navigation or robotics. *EFORT Open Rev* 2022;7(6):365-74.

41. Hamilton W, Parks N, Huynh C. Comparison of cup alignment, jump distance, and complications in consecutive series of anterior approach and posterior approach total hip arthroplasty. *J Arthroplasty* 2015;30(11):1959–62.

42. McGoldrick N, Antoniades S, El Meniawy S, Kreviazuk C, Beaulé P, Grammatopoulos G. Supine versus lateral position for total hip replacement: accuracy of biomechanical reconstruction. *Arch Orthop Trauma Surg* 2021

43. Brodt S, Jacob B, Windisch C, Seeger J, Matziolis G. Morbidly Obese Patients Undergoing Reduced Cup Anteversion Through a Direct Lateral Approach. *J Bone Joint Surg Am* 2016;98(9):729-34.

44. Elson L, Barr C, Chandran S, Hansen V, Malchau H, Kwon Y-M. Are morbidly obese patients undergoing total hip arthroplasty at an increased risk for component malpositioning? *J Arthroplasty* 2013;28:41-4.

45. Haffer H, Wang Z, Hu Z, Becker L, Müllner M, Hipfl C, Pumberger M, Palmowski Y. Does obesity affect acetabular cup position, spinopelvic function and sagittal spinal alignment? A prospective investigation with standing and sitting assessment of primary hip arthroplasty patients. *J Orthop Surg Res* 2021;16(1):640.

402 46. Gupta A, Redmond J, Hammarstedt J, Petrakos A, Vemula S, Domb B. Does Robotic-
403 Assisted Computer Navigation Affect Acetabular Cup Positioning in Total Hip Arthroplasty in
404 the Obese Patient? A Comparison Study. *J Arthroplasty* 2015;30(12):2204-7.
405 47. Imai N, Takubo R, Suzuki H, Shimada H, Miyasaka D, Tsuchiya K, Endo N. Accuracy of
406 acetabular cup placement using CT-based navigation in total hip arthroplasty: Comparison
407 between obese and non-obese patients. *J Orthop Sci* 2019;24(3):482-7.
408 48. Sharan M, Tang A, Schoof L, Gaukhman A, Meftah M, Sculco P, Schwarzkopf R. Obesity
409 does not influence acetabular component accuracy when using a 3D optical computer
410 navigation system. *J Clin Orthop Trauma* 2020;14(40-44)
411 49. Al-Amiry B, Pantelakis G, Mahmood S, Kadum B, Brismar T, Sayed-Noor A. Does body
412 mass index affect restoration of femoral offset, leg length and cup positioning after total hip
413 arthroplasty? A prospective cohort study. *BMC Musculoskelet Disord* 2019;20(1):422.
414 50. Chee Y, Teoh K, Sabnis B, Ballantyne J, Brenkel I. Total hip replacement in morbidly obese
415 patients with osteoarthritis: results of a prospectively matched study. *J Bone Joint Surg Br*
416 2010;92(8):1066-71.
417 51. Patel A, Albrizio M. Relationship of body mass index to early complications in knee
418 replacement surgery. *Arch Orthop Trauma Surg* 2008;128(1):5-9.
419 52. Meermans G, Konan S, Das R, Volpin A, Haddad F. The direct anterior approach in total
420 hip arthroplasty: a systematic review of the literature. *Bone Joint J* 2017;99-B(6):732-40.
421 53. Manrique J, Paskey T, Tarabichi M, Restrepo C, Foltz C, Hozack W. Total Hip Arthroplasty
422 Through the Direct Anterior Approach Using a Bikini Incision Can Be Safely Performed in
423 Obese Patients. *J Arthroplasty* 2019;34(8):1723-30.
424 54. Jahng K, Bas M, Rodriguez J, Cooper H. Risk Factors for Wound Complications After
425 Direct Anterior Approach Hip Arthroplasty. *J Arthroplasty* 2016;31(11):2583-87.

426 55. Swinnen J, Chao A, Tiwari A, Crozier J, Vicaretti M, Fletcher J. Vertical or transverse
427 incisions for access to the femoral artery: a randomized control study. *Ann Vasc Surg*
428 2010;24(3):336-41.
429 56. Grice E, Segre J. The skin microbiome. *Nat Rev Microbiol* 2011;9(4):9(4):244-53.
430 57. Haverkamp D, Klinkenbijl M, Somford M, Albers G, van der Vis H. Obesity in total hip
431 arthroplasty--does it really matter? A meta-analysis. *Acta Orthop* 2011;82(4):417-22.
432 58. Jameson S, Mason J, Baker P, Elson D, Deehan D, Reed M. The impact of body mass index
433 on patient reported outcome measures (PROMs) and complications following primary hip
434 arthroplasty. *J Arthroplasty* 2014;29(10):1889-98.
435 59. Murgatroyd S, Frampton C, Wright M. The effect of body mass index on outcome in total
436 hip arthroplasty: early analysis from the New Zealand Joint Registry. *J Arthroplasty*
437 2014;29(10):1884-8.
438 60. Committee WotAAoHaKSEB. Obesity and total joint arthroplasty: a literature based
439 review. *J Arthroplasty* 2013;28(5):714-21.
440 61. Group; CCOA, Arnold N, Anis H, Barsoum W, Bloomfield M, Brooks P, Higuera C,
441 Kamath A, Klika A, Krebs V, Mesko N, Molloy R, Mont M, Murray T, Patel P, Strnad G,
442 Stearns K, Warren J, Zajichek A, Piuzzi N. Preoperative cut-off values for body mass index
443 deny patients clinically significant improvements in patient-reported outcomes after total hip
444 arthroplasty. *Bone Joint J* 2020;102-B(6):683-92.
445