Does robotic assisted technology improve the accuracy of acetabular component positioning in patients with DDH?

Yixin Zhou, Hongyi Shao, Yong Huang, Wang Deng, Dejin Yang and Tao Bian

Abstract

Background: Accurate positioning of the acetabular component is key in performing total hip arthroplasty (THA). However, reconstruction of the acetabulum in the setting of developmental dysplasia of the hip (DDH) is a challenge. Robotic assisted THA has the potential to improve the accuracy of implantation of the acetabular cup in cases with DDH. The purpose of this study was to assess whether robotic technology improves the accuracy of acetabular component positioning in patients with DDH. Material and methods: We included 59 THAs using robotic assisted technology from June 2019 to January 2020 as the study group. These were compared to conventional THAs without robotic technology after control for age, gender, body mass index (BMI), Crowe type and operation date. Radiographic measurements were taken by 2 blinded orthopaedic residents. The percentage of hips within the Lewinnek and Collanan safe zones were calculated, along with acetabular rotation centers for the “target zone.” Surgical time and perioperative bleeding were also compared between both groups. Results: One patient suffered dislocation in conventional group while no dislocation occurred in robotic group. The acetabular components of the robotic assisted group had more cases located within the Lewinnek ($p = 0.013$) and Collanan ($p = 0.008$) safe zones than conventional group (94.9% vs 79.7% and 74.6% vs 50.8%). There were 7 cases in conventional group and 4 cases in robotic group that had more lateral or more superior rotational centers of THA, but did not reach statistical significance ($p = 0.342$). No statistical difference was detected between groups with regards to blood loss ($p = 0.098$) and surgical time ($p = 0.602$). Conclusion: Robot assisted technology can assist surgeons with implanting acetabular cups more in Lewinnek and Collanan safe zone than conventional techniques without additional blood loss and surgical time.

Level of Evidence: Therapeutic Level III.

Keywords

arthroplasty, dysplasia, hip, robotic assisted technology

Date received: 26 January 2021; Received revised 20 May 2021; accepted: 27 May 2021

Introduction

Accurately positioning the acetabular component is a key step in total hip arthroplasty (THA). In fact, malposition is related to dislocation, poly wear and leg length discrepancy.1–3 As defined by Lewinnek, the optimal inclination and anteversion of the acetabular component is 40° ± 10° and 15° ± 10°, respectively, and is still widely accepted by arthroplasty surgeons today.4,5 Collanan et al.6 later
redefined the acetabular safe zone with a narrower inclination ranging from 30°–45° in order to mitigate the risk of bearing surface wear. In addition to the orientation of the cups, the rotational center should also be reconstructed to the most anatomic position possible in order to decrease the contact stress and restore a normal walking gait, which may potentially decrease the risk of aseptic loosening. In this regard, Watts et al. reported a higher incidence of aseptic loosening and cup revision when the postoperative hip center was more than 10 mm superior or lateral to the approximate center of the femoral head in DDH cases.

Reconstructing the acetabulum in the setting of DDH is a challenge in THA as a result of the inherent bone deficiency, particularly in cases with Crowe III or IV type hips. The morphological variation of the acetabulum makes it difficult to locate the native center of the acetabulum during THA. In primary hip osteoarthritis, the acetabulum rim coincides with the target angle of prosthetic reconstruction, which can guide surgeons with respect to cup implantation. However, in patients with DDH, the acetabulum can be retroverted or anteverted, thereby potentially resulting in malpositioning of the cup.

Robotic assisted THA is an emerging technology which has the potential to improve the accuracy of implant positioning in total joint arthroplasty, including the hip. Domb et al. compared cup positioning between robotic assisted and conventional THA and found that the robotic group was more likely to be implanted within the safe zone. Subsequently, they reported a large cohort of cases of THA and demonstrated the robotic assisted technology can improve the accuracy of implant positioning via both anterior and posterior approaches. Even obesity was a challenge for surgeons to fully expose the hip in THA, robotics could help surgeons to implant cups accurately. However, to our knowledge, no available study to date has compared the results of robotic assisted to conventional THA in patients with DDH. We therefore hypothesized that robotic assisted THA would improve the accuracy of acetabular component positioning in DDH patients without increasing surgical time or blood loss.

**Material and methods**

A case-control study was conducted after institutional review board approval was obtained. From June 2019 to January 2020, 146 patients underwent primary THA using robotic assisted technology. Among them, 65 cases in 63 patients were diagnosed with DDH. Two cases (2 patients) who underwent previous hip surgery prior to the THA were excluded, in addition to another 3 cases (3 patients) who had missing or low quality postoperative anteroposterior radiographs. Subsequently, 60 cases in 58 patients defined the study cohort. The robotic assisted THA group was matched with the conventional THA group in a 1:1 ratio. The matching criteria included an age within 3 years, the same gender, a body mass index (BMI) within 3 kg/m², the same Crowe type and an operation date no more than 1 year apart. If more than one potential control was identified, the patient who was closest in terms of age was selected, followed by BMI and then operation date. We were unable to match one 16-year-old patient with a BMI of 18 with any control case. Finally, 59 cases in 57 patients who underwent robotic assisted THA and 59 cases in 59 patients who underwent conventional THA were included. Both the robotic assisted and conventional THA were performed by three experienced surgeons. All of them perform more than 100 conventional THAs annually and had more than 10 years surgical experience. Among these, 36 cases were of Crowe type I, 13 cases were type II or III and 10 cases were type IV. There was no statistical difference detected between age, gender, BMI and the laterality of surgery between the robotic and conventional groups (Table 1).

**Surgical technique**

For the conventional THAs, component position and size were templated, and the level of the neck cut and leg lengths were planned on pre-operative plain radiographs. Typically, the cups were implanted with the intent of achieving a radiographic inclination angle of 40° and 20° of radiographic anteversion. The intent was to reconstruct the center of rotation at the anatomic center. If Crowe type II/III hips had boney deficiency at the acetabular roof, consideration was given to reconstruct the center of rotation slightly superiorly to optimize coverage. For robotic THAs, patients underwent CT scans of the involved hip and knee pre-operatively for 3-D planning and templating purposes (Figure 1). The MAKO robotic hip system (Stryker Inc. Fort Lauderdale, Florida) was utilized to determine component position and size, with the same principles as the conventional group in pre-operative planning. Given that the robotic system can provide more morphologic information and surgeons are able to template more accurately, the templated cup position was adjusted no more than 5° in the directions of inclination or anteversion depending on the acetabular morphology.

The surgeries in both groups were performed in the decubitus position using the posterior lateral approach. In robotic group, the haptic arm of robotic system was used to...
ream and implant the cup (Figure 2). In conventional group, the cup was implanted based on a guide jig attached to the handle, as well as intra-articular landmarks including the transverse acetabular ligament and the acetabular rim. In Crowe type IV cases where re-location of the hip was difficult, a subtrochanteric osteotomy was performed according to the technique described by D.J. Berry. If the femoral anteversion was more than $30^\circ$ or it was retroversion, modular stem or Wagner cone stem was used to adjust it.

**Radiographic measurements**

Mimics software 20.0 (Materialise, Leuven, Belgium) was used to perform the radiographic measurements, including inclination and anteversion of the acetabular cups. Prior to the measurements, a line passing both sides of the inferior tear drop was created as a reference. Then, a concentric ellipse and a line that bisected the long axis of the ellipse was then created to fit the opening of the cup. We were then able to calculate the anteversion with the axes of the ellipse. The inclination was then measured between long axis and the reference line (Figure 3). We also ascertained that the cups were not retroverted with post-operative cross-table lateral radiographs.

Anatomic acetabular centers of rotation were difficult to find in some DDH cases. In such cases, the approximate femoral head center (AFHC), which was described by Ranawat et al. as the rotational cup center, was utilized (Figure 4). Watt et al. suggested that the acetabular component was in non-anatomic position when the center was positioned superior or lateral by more than 1 cm, which would increase failure rate in cementless THA. We measured the distance and direction between the center of the acetabular component to AFHC for analysis.

All of the radiographs were measured by two orthopaedic residents (Dr. W.D and Dr. T.B), who were blinded to the groups. They measured the first 20 cases of both groups respectively and then re-measured them 4 weeks later to evaluate inter-observer and intra-observer reliabilities. The agreement of the data between the two residents were calculated as the interobserver correlation coefficient and the agreement of the data between the two measurements were calculated as the intra-observer correlation coefficient. The intra-observer and inter-observer ICC for the acetabular inclination measurements were 0.987 and 0.979, respectively, while for acetabular anteversion they were 0.951 and 0.944, respectively. Each of these values indicates satisfactory correlation.

**Surgical data collection**

Medical documents were reviewed for all patients. The surgical time from the incision of skin to completion of closure was calculated and recorded. The estimated
blood loss (EBL) was calculated based on the formula described by Good et al.\(^\text{19}\) and Nadler et al.\(^\text{20}\)

### Statistical analysis

The normality of the continual variables was tested using the Shapiro-Wilk test. Continual variables were reported as the mean ± standard deviation (SD). Categorical variables were reported as a frequency (percentage). Continual variables were compared with two independent sample t tests, while categorical variables were compared with the Chi-square or Fisher’s exact test. All statistical analyses were 2-sided and a \(p\) value <0.05 was considered statistically significant. All data were analyzed using the SPSS 19.0 (IBM; Armonk, NY, USA).

### Results

One patient in conventional group suffered dislocation at 3 weeks after surgery with 59.9\(^\circ\) inclination and 22.6\(^\circ\) anteverision while no dislocation occurred in robotic group. The dislocation case used a conventional stem with a measured femoral anteverision of 15\(^\circ\) and the reasons for dislocation may related to acetabular malposition and soft tissue tension. No differences between postoperative inclination and anteverision angles were detected between the robotic group and conventional groups. In robotic group, there were more acetabular components located in the Lewinnek (\(p = 0.013\)) and Collanan (\(p = 0.008\)) safe zones. For the robotic group, there were only 3 Crowe type I cases outside of the Lewinnek safe zone, and 15 cases outside of the Collanan safe zone. For conventional group, 29/36 cases of Crowe type I, 11/13 cases of type II or III and 7/10 cases of type IV were in the Lewinnek safe zone while 30/59 cases were in the Collanan safe zone. There were 7 cases in the conventional group and 4 cases in the robotic group that had more lateral or superior centers of rotation, but this did not reach statistical difference (\(p = 0.342\), Table 2).

There was one intra-operative complication in the conventional group in which there was a femoral side fracture that was treated with cerclage. There were no statistical differences with respect to blood loss between the robotic and conventional groups (1050.5 ml vs. 935.9 ml, \(p = 0.098\), Table 2). We were also unable to detect a statistical difference between surgical times between groups. The average surgical time of the robotic group was shorter than the conventional group (85.3 min Vs 88.6 min, \(p = 0.602\), Table 2).

### Discussion

Suboptimal positioning of the acetabular component may induce hip instability, accelerate polyethylene wear, increase the risk of component loosening and result in a leg length discrepancy.\(^\text{1–3,7,8}\) Previous reports have emphasized that the position of the acetabular cup is variable with freehand techniques and even experienced surgeons can malposition a cup.\(^\text{21,22}\) Robotic technology has been demonstrated as a precise tool to implant acetabular cup,\(^\text{5,13–15}\) which has the potential to be beneficial during THA for patients with DDH given the morphological variation and inherent difficulty often encountered during

---

**Table 2. Outcomes comparison between robotic assisted THA and conventional THA.**

| Outcomes                    | Robotic THA (n = 59) | Manual THA (n = 59) | p Value |
|-----------------------------|----------------------|---------------------|---------|
| Acetabular inclination      | 42.79 ± 4.66         | 43.09 ± 6.18        | 0.762   |
| Acetabular anteverision     | 13.52 ± 3.52         | 15.17 ± 6.98        | 0.108   |
| Lewinnek safe zone          | 94.9% (56/59)        | 79.7% (47/59)       | 0.013   |
| Type I                     | 91.7% (33/36)        | 80.6% (29/36)       |         |
| Type II or III              | 100% (13/13)         | 84.6% (11/13)       |         |
| Type IV                    | 100% (10/10)         | 70.0% (7/10)        |         |
| Collanan safe zone          | 74.6% (44/59)        | 50.8% (30/59)       | 0.008   |
| Type I                     | 69.4% (25/36)        | 50.0% (18/36)       |         |
| Type II or III              | 84.6% (11/13)        | 46.2% (11/13)       |         |
| Type IV                    | 80.0% (8/10)         | 60.0% (6/10)        |         |
| Acetabular center           | 6.8% (4/59)          | 11.9% (7/59)        | 0.342   |
| (10 mm lateral or superior to AFHC) |                  |                     |         |
| Blood loss (ml)             | 1050.5 ± 399.6       | 935.9 ± 344.4       | 0.098   |
| Surgical time (min)         | 85.3 ± 25.7          | 88.6 ± 41.2         | 0.602   |

The value in the parentheses following Crowe types represented the number of cases in the safe zone; AFHC: approximate femoral head center.
component position between robotic assisted technology. To our knowledge, no study has compared robotic THA and manual THA in cases of DDH. In the current study, we found that robotic assisted technology facilitated more acetabular cups to be implanted in traditional safe zone without evidence of increased surgical time or blood loss. Although, there was one post-operative dislocation in conventional THA group, whose acetabular angle was outside both Lewinnek’s and Callanan’s safe zone, we could not find the statistical difference. However, with robotic technology, 94.9% cases were identified as within Lewinnek’s safe zone and 74.6% in Callanan’s safe zone; these rates were higher than with conventional techniques. Published data had well established the relationship between component outlier and the dislocation rate or the wear rate, so our preliminary radiological results could strongly suggest that robotic assisted THA has potential advantages in complex THAs for DDH patients. Domb et al. compared acetabular component position between robotic assisted technology and traditional techniques, which revealed that with robotic technology, 100% of cups were within Lewinnek’s safe zone and 92% of cups were within Callanan’s safe zone. By comparison, the rates for traditional techniques within those safe zones was 80% and 62%, respectively, which may explain why robotic technology helped us to implant cups more precisely in the current study. In another study, 135 robotic THAs had 97.8% and 94.1% positioning within Lewinnek’s and Callanan’s safe zones, respectively, while 708 conventional THAs had 69.5% and 58.8% positioning, respectively. Our results were similar to those with the exception being that we had more cases with robotic technology outside of Callanan’s safe zone, for which there are 2 potential reasons to explain this result. First, DDH patients have more complex acetabular morphology which can lead to difficult implantation. Secondly, DDH patients have especially high-riding hips and may compromise their own spinopelvic status in the sagittal plane. The MAKO system utilizes the supine functional plane in the pre-operative CT scanner as a reference plane. However, the pelvis may tilt posteriorly, thereby resulting in increased inclination and anteversion, or vice versa postoperatively. Additionally, we used posterior approach and target the average anteversion at 20° to compensate posterior instability which was a little larger than Lewinnek’s and Callanan’s target. Moreover, DDH patients usually needed soft tissue release which may bring difference between preoperative and postoperative position.

Although statistically insignificant, we found more cases of conventional THA than robotic THA in which more superior or lateral hip centers of rotation were encountered. Avoiding deviation of the hip center of rotation laterally and superiorly from the AFHC may facilitate durable fixation, and will increase the dynamic hip range of motion and reduce the hip reaction force. Thus, surgeons pursue restoration of the hip center of rotation as closely as possible to AFHC. Previous studies on the topic of robotic THA have not reported the position of the hip center of rotation. In fact, DDH patients have morphological variation and poor bone stock superiorly, which makes cup implantation difficult. With robotic technology, 3D image-based systems can be utilized for templating and the robotic arm assists with reaming and implanting the cups accurately. This may help to more accurately reconstruct the center of rotation in DDH patients. In the current study, we found that the center of rotation deviated more in the conventional group, but this did not reach the statistical difference for which limited case numbers may be responsible. Large variations in the deliberate elevation of the centers of rotation of the cup as a means of optimizing coverage in DDH patients also contributed to large variations in the measured centers of rotation. Further investigation with larger case numbers will be necessary to ascertain the superiority in reconstructing the center of rotation with the assistance of robotic technology.

Even with increasing use of robotic technology in orthopaedic practices, concerns remain, including potentially longer surgical time and increased blood loss which may result in higher complication rates. In this regard, however, Chen et al. performed a systematic review and detected no statistical difference in surgical time and blood loss between robotic assisted and conventional THAs. Although our data also detected no statistical difference for these variables, it revealed that the average surgical time of robotic group was slightly shorter than the conventional group which was contrary to previous studies. The robotic system helped surgeons to ream the acetabulum to a target position directly and simply. Without sequential reaming, time was likely conserved, especially in severe dysplasia cases. We also did not detect a difference in mean blood loss between groups. There was one-sixth of cases of Crowe types and surgeons were trained in the same

There were several limitations in this study. First, we had limited cases available for analysis, especially of Crowe types II, III and IV. Inevitably, this likely yields a higher rate of type I error, and made a subgroup analysis impossible. However, to our knowledge, this is the first study to address the advantage of robotic technology for patients with DDH. Second, we compared the rate of outliers which was measured on plain radiographs. Spinopelvic motion could not be considered for variability, but both safe zones, and particularly the Callanan safe zone, was our target and primary objective. As a surgical tool, current robots only assist surgeons with improving implantation accuracy rather than locating the implantation target. Third, we did not compare the final position to the position templated preoperatively. However, both cohorts were DDH patients with the same Crowe types and surgeons were trained in the same
hospital, which helps to minimize potential biases. Further research including the investigation of comparing preoperative templating and true post-operative position may be useful. Finally, only longer follow-up could give the information whether the robotic technology could provide superior clinical results or not. Potential edge loading and subsequent polyethylene wear should be evaluated in future follow-up. Without patients’ specific preoperative planning, robotic assisted technology only brings accurate cup position while clinical benefit is still questionable. 

**Conclusion**

Robot assisted technology can assist surgeons with implanting acetabular cups more accurately within the Lewinnek and Callanan safe zone than conventional techniques without additional blood loss and surgical time. Further studies with a higher volume of patients are necessary to demonstrate further possible advantages in these complicated cases.

**Acknowledgments**

We thank Dr. Hanlong Zheng, and Mrs. Jinqing Zhang to help us for collecting clinical data.

**Declaration of conflicting interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding**

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research received grant from “Beijing Municipal Administration of Hospitals Incubating Program,” code: pX2020019.

**ORCID ID**

Yixin Zhou [https://orcid.org/0000-0002-9682-0577](https://orcid.org/0000-0002-9682-0577)

**Supplemental material**

Supplemental material for this article is available online.

**References**

1. Biedermann R, Tonin A, Krismer M, et al. Reducing the risk of dislocation after total hip arthroplasty: the effect of orientation of the acetabular component. *J Bone Joint Surg Br* 2005; 87(6): 762–769.

2. Little NJ, Busch CA, Gallagher JA, et al. Acetabular polyethylene wear and acetabular inclination and femoral offset. *Clin Orthop Relat Res* 2009; 467(11): 2895–2900.

3. Ng VY, Kean JR and Glassman AH. Limb-length discrepancy after hip arthroplasty. *J Bone Joint Surg Am* 2013; 95(15): 1426–1436.

4. Lewinnek GE, Lewis JL, Tarr R, et al. Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg Am* 1978; 60(2): 217–220.

5. Kamara E, Robinson J, Bas MA, et al. Adoption of robotic vs fluoroscopic guidance in total hip arthroplasty: Is acetabular positioning improved in the learning curve? *J Arthroplasty* 2017; 32(1): 125–130.

6. 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(2): 319–329.

7. Karaismailoglu B, Erdogan F and Kaynak G. High hip center reduces the dynamic hip range of motion and increases the hip load: a gait analysis study in hip arthroplasty patients with unilateral developmental dysplasia. *J Arthroplasty* 2019; 34(6): 1267–1272 e1.

8. Watts CD, Martin JR, Fehring KA, et al. Inferomedial hip center decreases failure rates in cementless total hip arthroplasty for Crowe II and III hip dysplasia. *J Arthroplasty* 2018; 33(7): 2177–2181.

9. Greber EM, Pelt CE, Gilillard JN, et al. Challenges in total hip arthroplasty in the setting of developmental dysplasia of the hip. *J Arthroplasty* 2017; 32(9S): S38–S44.

10. van Bosse H, Wedge JH and Babyn P. How are dysplastic hips different? A three-dimensional CT study. *Clin Orthop Relat Res* 2015; 473(5): 1712–1723.

11. Merle C, Grammatopoulos G, Waldstein W, et al. Comparison of native anatomy with recommended safe component orientation in total hip arthroplasty for primary osteoarthritis. *J Bone Joint Surg Am* 2013; 95(22): e172.

12. Chen AF, Kazarian GS, Jessop GW, et al. Robotic technology in orthopaedic surgery. *J Bone Joint Surg Am* 2018; 100(22): 1984–1992.

13. Nodzo SR, Chang CC, Carroll KM, et al. Intraoperative placement of total hip arthroplasty components with robotic-arm assisted technology correlates with postoperative implant position: a CT-based study. *Bone Joint J* 2018; 100-B(10): 1303–1309.

14. Domb BG, El Bitar YF, Sadik AY, et al. Comparison of robotic-assisted and conventional acetabular cup placement in THA: a matched-pair controlled study. *Clin Orthop Relat Res* 2014; 472(1): 329–336.

15. Domb BG, Redmond JM, Louis SS, et al. Accuracy of component positioning in 1980 total hip arthroplasties: a comparative analysis by surgical technique and mode of guidance. *J Arthroplasty* 2015; 30(12): 2208–2218.

16. Gupta A, Redmond JM, Hammarstedt JE, et al. Does robotic-assisted computer navigation affect acetabular cup positioning in total hip arthroplasty in the obese patient? A comparison study. *J Arthroplasty* 2015; 30(12): 2204–2207.

17. Krych AJ, Howard JL, Trousdale RT, et al. Total hip arthroplasty with shortening subtrochanteric osteotomy in Crowe type IV developmental dysplasia: surgical technique. *J Bone Joint Surg Am* 2010; 92(Suppl): 176–187.

18. Ranawat CS, Dorr LD and Inglis AE. Total hip arthroplasty in protrusio acetabuli of rheumatoid arthritis. *J Bone Joint Surg Am* 1980; 62(7): 1059–1065.

19. Good L, Peterson E and Lisander B. Tranexamic acid decreases external blood loss but not hidden blood loss in total knee replacement. *Br J Anaesth* 2003; 90(5): 596–599.
20. Nadler SB, Hidalgo JH and Bloch T. Prediction of blood volume in normal human adults. *Surgery* 1962; 51(2): 224–232.

21. Grammatopoulos G, Alvand A, Monk AP, et al. Surgeons’ accuracy in achieving their desired acetabular component orientation. *J Bone Joint Surg Am* 2016; 98(17): e72.

22. Bosker BH, Verheyen CC, Horstmann WG, et al. Poor accuracy of freehand cup positioning during total hip arthroplasty. *Arch Orthop Trauma Surg* 2007; 127(5): 375–379.

23. Stefl M, Lundergan W, Heckmann N, et al. Spinopelvic mobility and acetabular component position for total hip arthroplasty. *Bone Joint J* 2017; 99-B(1 Supple A): 37–45.

24. Nawabi DH, Meftah M, Nam D, et al. Durable fixation achieved with medialized, high hip center cementless THAs for Crowe II and III dysplasia. *Clin Orthop Relat Res* 2014; 472(2): 630–636.

25. Liu B, Gao YH, Ding L, et al. Computed tomographic evaluation of bone stock in patients with Crowe type III developmental dysplasia of the hip: implications for guiding acetabular component placement using the high hip center technique. *J Arthroplasty* 2018; 33(3): 915–918.

26. El Bitar YF, Stone JC, Jackson TJ, et al. Leg-length discrepancy after total hip arthroplasty: comparison of robot-assisted posterior, fluoroscopy-guided anterior, and conventional posterior approaches. *Am J Orthop (Belle Mead NJ)* 2015; 44(6): 265–269.

27. Lim SJ, Ko KR, Park CW, et al. Robot-assisted primary cementless total hip arthroplasty with a short femoral stem: a prospective randomized short-term outcome study. *Comput Aided Surg* 2015; 20(1): 41–46.

28. Chen X, Xiong J, Wang P, et al. Robotic-assisted compared with conventional total hip arthroplasty: systematic review and meta-analysis. *Postgrad Med J* 2018; 94(1112): 335–341.

29. Siebel T and Kafer W. Clinical outcome following robotic assisted versus conventional total hip arthroplasty: a controlled and prospective study of seventy-one patients. *Z Orthop Ihre Grenzgeb* 2005; 143(4): 391–398.

30. Nakamura N, Sugano N, Nishii T, et al. A comparison between robotic-assisted and manual implantation of cementless total hip arthroplasty. *Clin Orthop Relat Res* 2010; 468(4): 1072–1081.

31. Sharkey P, Parvizi J and Booth R. Robotics in hip and knee arthroplasty: real innovation or marketing ruse. *J Arthroplasty* 2019; 34(10): 2197–2198.