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Comparison of component positioning in robot-assisted and conventional total hip arthroplasty

Robot-yardımlı ve konvansiyonel total kalça artroplastisinde komponent yerleşiminin karşılaştırılması

Yusuf Onur Kızılay [1], Murat Kezer [1]

[1] Osmangazi Aritmi Hospital, Department of Orthopedics and Traumatology, Osmangazi, Bursa, Turkey

ORCID ID of the author(s)
YOK: 0000-0001-8373-3426
MK: 0000-0001-6684-1636

Corresponding author/Sorumlu yazar:
Yusuf Onur Kızılay
Address/Adres: Osmangazi Aritmi Hastanesi, Ortopedi ve Travmatoloji Kliniği, Ulu Mahallesi, Ulubatlı Hasan Blv. 48-62, 16220 Osmangazi, Bursa, Türkiye
e-Mail: onurkizilay@yahoo.com

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Abstract

Aim: For primary total hip arthroplasty, many authors reported that inappropriate component positioning may lead to unfavorable results and complications. In the last two decades, robotic systems were developed to improve component positioning in total hip arthroplasty. However, there are few reports in the literature concerning its efficacy. In this study, we aimed to compare the accuracy of component positioning between robot-assisted and conventional total hip arthroplasty.

Methods: In this retrospective cohort study, forty-four patients were operated using robot-assisted surgery (RAS), and 60 patients were operated using primary conventional manual arthroplasty (CMA). Measurements were done in standing orthogonal antero-posterior x-ray (AP) views to evaluate acetabular inclination, anteversion, and leg length discrepancy. Results were compared between RAS and CMA groups.

Results: The average deviation from desired acetabular inclination was 8^{o} in the CMA group, 4.7^{o} in the RAS group, between which the difference was statistically significant (P=0.023). Concerning acetabular inclination, 72% of the patients in the CMA group remained in the safe zone described by Lewinnek while 94% of the patients in the RAS group remained in the same safe zone. The mean deviation from desired anteversion was 6.7^{o} in the CMA group and 5.6^{o} in the RAS group. The difference between two groups was not significant (P=0.209). The two groups were similar in terms of leg length discrepancy (P=0.238).

Conclusion: We achieved more consistent acetabular component positioning with robot-assisted total hip arthroplasty compared with conventional total hip arthroplasty. Thus, more patients remained within Lewinnek's safe zone in the robot-assisted surgery group.

Keywords: Total hip arthroplasty, Robot-assisted, Component positioning

Öz

Amaç: Total kalça artroplastisinde protez komponentlerinin uygun olarak yerleştirilmemesi istenmeyen sonuçlara ve komplikasyonlara yol açabilmektedir. Son 20 yılda protez komponentlerinin daha doğru yerleştirilebilmesi için robotik sistemler total kalça artroplastisinde kullanılmaya başlanmıştır. Buna rağmen literatürde robotik sistemlerin uygun protez komponent yerleşimine sebep olduğuna dair kısıtlı sayıda yayın bulunmaktadır. Bu sebeple mevcut çalışmada robot-yardımlı ve konvansiyonel total kalça artroplastisinde komponent yerleşiminin doğruluğu karşılaştırılmaya çalışılmıştır.

Yöntemler: Mevcut retrospektif kohort çalışmasında, 44 hastaya robot-yardımlı total kalça artroplastisi (RYA), 60 hastaya ise konvansiyonel total kalça artroplastisi (KTKA) uygulandı. Tüm vakalar primer artroplasti vakasıydı. Ameliyat sonrası kontrollerde ayakta basarak çekilen bacak uzunluk grafilerinde asetabuler inklinasyon, anteversiyon ve bacak uzunluk farkı ölçümleri yapıldı. Bu sonuçlar her iki grup arasında karşılaştırıldı.

Bulgular: Amaçlanan inklinasyondan ortalama sapma KTKA grubunda 8^{o}, RYA grubunda 4,7^{o} idi ve aradaki fark istatistiksel olarak anlamlıydı (P=0,023). Asetabuler inklinasyon parametresinde KTKA grubundaki hastaların %72'si Lewinnek tarafından tanımlanan güvenli aralıkta bulunurken RYA grubundaki hastaların %94'ü aynı güvenli aralıkta yer aldı. Amaçlanan anteversiyondan ortalama sapma KTKA grubunda 6,7^{o} iken, bu değer RYA grubunda 5,6^{o} idi. İki grup arasındaki fark istatistiksel açıdan anlamlı değildi (P=0,209). Ortalama bacak uzunluk farkı KTKA grubunda 8 mm iken bu değer RYA grubunda 6mm idi. Bacak uzunluk parametresi bakımından iki grup arasında istatiksel açıdan anlamlı fark bulunamadı (P=0,238).

Sonuç: Çalışmamızda konservatif kalça artroplastisi ile karşılaştırıldığında robot-yardımlı total kalça artroplastisi ile daha tutarlı asetabuler komponent yerleşimi elde edildi. Buna ek olarak robotik cerrahi grubunda daha fazla oranda hasta Lewinnek tarafından tarif edilen güvenli aralıkta yer aldı.

Anahtar kelimeler: Total kalça artroplastisi, Robot-yardımlı, Komponent pozisyonu

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Introduction

Regarding stability, function and survival time of the prosthesis, component positioning is crucial in any type of arthroplasty. For total hip arthroplasty, many authors have reported that inappropriate component positioning and improperly adjusted femoral offset increased the risk for dislocation, abductor limping and early polyethylene wear [1–4]. In 1978 Lewinnek and his colleagues defined a safe zone for the acetabular component position. They concluded that there is four times higher risk of dislocation with acetabular component positioning out of 40 ± 10 degrees of inclination and 15 ± 10 degrees of anteversion [5].

Many techniques have been used to improve component positioning, some of which include preoperative templating, rigid patient positioning, external alignment rods, reference pins, compasses, and intraoperative fluoroscopy. However, many authors have reported that prosthetic components might be placed improperly despite using all of these techniques [6–10]. In 2011, a retrospective study at a tertiary hospital demonstrated that among 1823 hips, 63% of the acetabular cups were within the abduction safe zone, 79% of the acetabular cups were within the version safe zone and only 50% of the acetabular cups were within both safe zones [11].

In the last two decades, many Orthopedics clinics started to employ robotic systems in joint replacement surgery to prevent component malpositioning [12]. However, early systems showed similar radiological and clinical results with high technical complications compared with conventional hip arthroplasty [13]. In 2008, a surgeon research team started to work on a new robotic system named MAKO™ (Stryker Mako Surgical Corporation, Fort Lauderdale, FL), in order to improve results of robot-assisted total hip arthroplasty [14]. This robotic system was based on a navigation system and a robotic surgical arm that gives the surgeon haptic feedback during the operation. Also, the new system allowed surgeon to personalize the procedure for each patient on preoperative computed tomography images of the patient's hip joint using a special software called "RIO™" (Stryker Mako Surgical Corporation, Fort Lauderdale, FL). This robotic system was introduced in 2011. Preliminary results showed precise component positioning in total hip arthroplasty [15, 16]. Despite early superior results, there is limited information in the literature related to this topic. It is still questionable that robot-assisted systems help the surgeons to place prosthetic components more precisely.

In this study, we aimed to compare component positioning between robot-assisted surgery and conventional total hip arthroplasty.

Materials and methods

We conducted this retrospective cohort study in accordance with the Declaration of Helsinki, and we obtained a written informed consent from all patients before the operation, along with the local ethical research committee approval.

We performed 104 primary total hip arthroplasties between the 2017 and 2018, among which 44 patients underwent robot-assisted surgery (RAS), and 60 patients underwent conventional manual arthroplasty (CMA). Patients with minimum follow-up period of 1-year were included in our study. Patients with shorter follow-ups and bilaterally operated patients were excluded. Overall, we included thirty-four patients treated with RAS and 32 patients treated with CMA.

Robot-assisted total hip arthroplasty surgical technique

In the preoperative period, a 3-dimensional pelvis computed tomography was obtained from the patients treated with RAS (Figure 1). The patient-specific virtual 3-D bone model of the pelvis and the proximal femur were created using the MAKO software. The prosthetic components were positioned on the virtual 3-D pelvis bone model for the pre-operative planning (Figure 2). Depth, the center of rotation, inclination, and version of the acetabular cup were determined as needed. Level of the femoral neck osteotomy and best fitting femoral stem, along with the appropriate femoral head were chosen (Figure 2). At this point combined offset and leg length were checked. Few days after preoperative planning, the patient was transferred to the operating room. All patients were operated in lateral decubitus position fixed with rigid patient positioners. An anterolateral approach was employed in all procedures, including the CMA group. After surgical exposure three treaded Steinman pins were introduced into the iliac crest 3 cm posterior from the anterior superior iliac spine to fix the pelvic array. Then femoral array and femoral checkpoint were inserted to the proximal femur. Proximal femur was registered to the system with the navigation probe. After femoral registration, femoral neck cut was performed at the preoperatively planned level. Following the head removal, acetabular checkpoint was inserted into the supra-acetabular region and acetabulum was registered with the navigation probe. From this point, the robotic system was able to locate the true acetabulum in the spatial plane. The acetabulum was reamed with preoperatively planned angles via using the robotic arm with the surgeon in haptic guidance (Figure 3). The acetabular component was positioned and impacted with the robotic arm with the same angles. As the result of consistent reaming, the acetabular cup was nearly always press-fit, and there was no need for acetabular screws in half of the patients. The femoral canal was prepared manually, and preoperative planned sized trial stem and femoral head were placed. After the hip was reduced with the trial components, the position of the prosthetic components, combined offset, combined anteversion and leg length were checked with the help of the software. At this point, the surgeon had the chance to revise the femoral stem or head. If the components were in the desired position, original components were placed, and hip stability was checked. Traditional hemostasis and closure were obtained. The patients were allowed for partial weight bearing with a walker one day after the surgery and full weight bearing at six weeks postoperatively.

Data evaluation

Standard antero-posterior (AP) and lateral x-rays were taken one day after the surgery and a standing orthogonal AP image was obtained to evaluate leg length discrepancy (Figure 4). On the AP standing pelvis view, acetabular cup inclination was measured. The acetabular version was measured as described by Lewinnek [5]. Leg length discrepancy was measured as the distance between the level of the most prominent point of the trochanter minors. Results were compared between RAS and CMA groups.

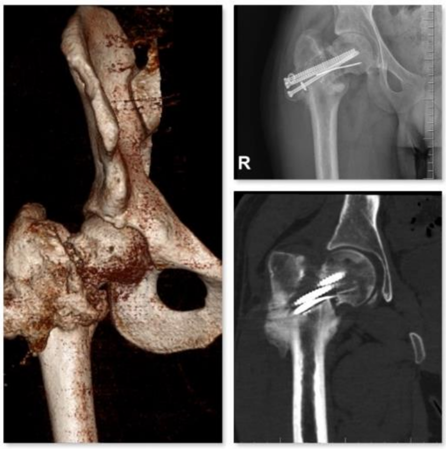

Figure 1: 44 year-old patient with right hip femoral neck fracture non-union. Pre-operative x-rays and 3-D computed tomography views of the patient are illustrated

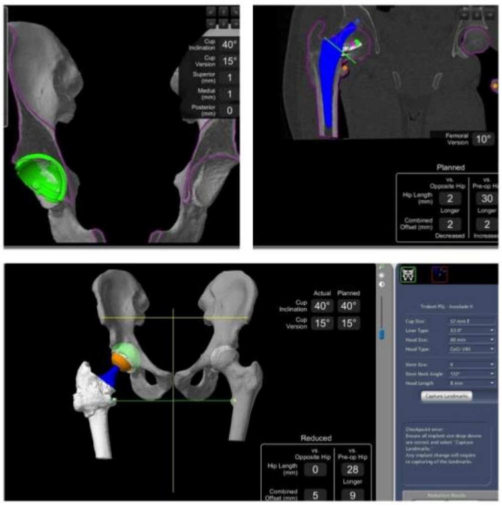
Figure 2: Preoperative planning of the same patient in Figure 1


Figure 3: Reaming of the acetabulum by the surgeon with preoperative defined angles under haptic guidance of the robotic arm

Figure 4: Postoperative orthogonal A-P standing x-ray of the patient demonstrated in Figure 1

Statistical analysis

SPSS 20.0 software was used for statistical analysis, and Kolmogorov-Smirnov test was used for normality analysis. Mean values were compared using Mann Whitney U test. *P*-value under 0.05 was considered statistically significant for all statistical analyses.

Results

The mean age was 64.1 years (min=36, max=87) and 51.7 years (min=32, max=78) in CMA and RAS groups, respectively. The average acetabular inclination was 47.2^o (min=32^o, max=57^o) in the CMA group and 43.7^o (min=36^o, max=58^o) in the RAS group. The difference between average acetabular inclination angle was statistically significant (*P*=0.029). The average deviation from desired acetabular inclination was 8^o (min=0^o, max=17^o) in the CMA group, 4.7^o (min=0^o, max=18^o) in the RAS group, the difference between which was significant (*P*=0.023). Concerning acetabular inclination, 72% of the patients in the CMA group and 94% of the patients in the RAS group remained in the safe zone described by Lewinnek (Figure 5). The average acetabular anteversion was 9.5^o (min=0^o, max=20^o) and 11.2^o (min=3^o, max=20^o) in the CMA and RAS groups, respectively. The difference between acetabular anteversions was not statistically significant (*P*=0.209). The mean deviation from the desired anteversion was 6.7^o (min=0^o, max=15^o) in the CMA group and 5.6^o (min=0^o, max=12^o) in the RAS group (*P*=0.235). While 75% of the patients in the CMA group remained in the Lewinnek's safe zone for acetabular anteversion, the rate was 95% in the RAS group. The mean leg length discrepancy was 8 mm (min=2, max=18) in the CMA group and 6 mm (min=0, max=16) in the RAS group (*P*=0.238). The average surgical time was 70 and 80 minutes in the CMA and RAS groups, respectively (*P*=0.326) (Table 1).

One deep and one superficial infections, two periprosthetic fractures, and one dislocation occurred in the CMA group. Two deep, one superficial infections, one periprosthetic fracture, and one pulmonary embolism occurred in the RAS group.

Table 1: Parameters in both groups

	Group	n	Mean	SD	*P*-value
Acetabular Inclination	CMA	32	47.2	6.7	0.029
	RAS	34	43.7	5.2	
Acetabular anteversion	CMA	32	9.5	5.8	0.209
	RAS	34	11.2	5.3	
Deviation from desired acetabular inclination	CMA	32	8.0	5.7	0.023
	RAS	34	4.7	4.2	
Deviation from desired acetabular anteversion	CMA	32	6.7	4.4	0.235
	RAS	34	5.6	3.1	
Leg length discrepancy	CMA	32	8.0	5.7	0.238
	RAS	34	6.3	5.2	
Surgical time	CMA	32	70	6.3	0.326
	RAS	34	80	7.8	

SD: Standard deviation, CMA: Conventional manual arthroplasty, RAS: Robot-assisted surgery, AP: Antero-posterior

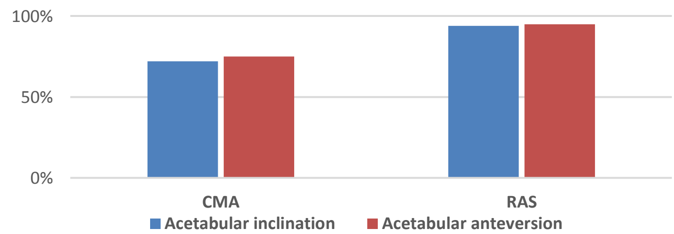

Figure 5: The percentage of the patients that remained in the safe zones described by Lewinnek in both groups (CMA: Conventional manual arthroplasty, RAS: Robot-assisted surgery)

Discussion

Total hip arthroplasty is one of the most frequently performed orthopedic procedures. Every year, the demand for primary total hip arthroplasty is increasing and is estimated to grow by 174% by 2030. Furthermore, the number of revision arthroplasty procedures performed is expected to double by the year 2026 in the United States [17]. For this reason, the survival of the prosthesis became more important nowadays. It is well established that appropriate component positioning and restoration of the femoral offset is crucial concerning the joint stability and early wear [18–22]. Many techniques have been employed to improve component positioning in hip arthroplasty. It is not always possible to achieve appropriate component positioning despite these methods. After the 20th century, robotic systems have been employed in arthroplasty to improve component positioning. However, preliminary results didn't show better functional results compared with conventional techniques [23].

Different robotic systems have been utilized in arthroplasty. A relatively newer technology called "MAKO" is a robotic system used in clinical practice for unicompartmental - total knee and total hip arthroplasty. MAKO is an image-based robotic system that uses preoperative CT in surgical planning to help determine component sizing, positioning, and bone resection. These parameters are confirmed and adjusted intra-operatively based on the patient's specific kinematics before any surgical resection. This system provides haptic feedback during surgery and prevents resection outside of the surgeon's plan [24]. In 2012 Domb and colleagues reported preliminary results of the MAKO system in total hip arthroplasty. They reported that 100% of the patients operated with the MAKO system remained in Lewinnek's safe zone, while this rate was only 82% in patients operated with conventional arthroplasty [25].

For 2 years, we have been utilizing MAKO™ robotic system in arthroplasty surgery. In our study, the mean age was 64.1 and 51.7 years in CMA and RAS groups, respectively. Based on this fact, we believe that younger patients with higher demands are more interested in novel techniques promising higher functional results and longer survival of the arthroplasty.

In the CMA group, we used preoperative templating, rigid patient positioning, external guides, and intraoperative fluoroscopy to improve component positioning. However, there is an 8° deviation of desired acetabular cup inclination in the CMA group, compared with 4.7° in the RAS group. Although this seems like a minor difference, it was statistically significant. Thus, only 72% of the patients in the CMA group were within Lewinnek's safe zone compared with 94% in the RAS group. In terms of acetabular anteversion, there was mean 6.7° and 5.6° of deviation from desired values in the CMA and RAS groups, respectively, which was not significantly different. The rate of staying within Lewinnek's safe zone was 75% in the CMA group and 95% in the RAS group. For leg length discrepancy, there was an average of 8 mm difference between the most prominent level of trochanter minors in the CMA group. This value was 6mm in the RAS group, which was similar.

In our study, there was a significant difference between both groups in acetabular inclination values but anteversion angles were alike**.** This may be due to mean values being used for statistical analysis. When we projected the results to safe zones described by Lewinnek we realized an apparent difference between two groups**.** This is probably because there were more extreme cup positions in terms of inclination and anteversion in the CMA group. On the other hand, it is questionable that the robotic system might be inferior in measuring cup version. However, Redmond et al. reported that correlation between the robotic system and postoperative radiographs was within 10° for 95.9% of cases for inclination and 99.3% for anteversion [26]. Our study revealed similar results with Domb et al. [27]. They reported that patients operated with the MAKO system via posterior hip approach remained 97.7% within Lewinnek's safe zone. There is limited information in the literature comparing intra-operative accuracy and post-operative implant position of the MAKO hip system. Nodzo et al. [28] demonstrated that there was a significant correlation between intra-operative and post-operative cup angles. They showed 1.6° error in inclination and 0.8° error in anteversion respectively for intra-operative and post-operative acetabular cup angles.

In 2012, Nawabi and colleagues [16] compared manual and robot-assisted total hip arthroplasty implantation in a cadaveric model. They found that error for manual implantation compared to robotic assistance was five times higher for cup inclination and 3.4 times higher for cup anteversion. Error for the robot-assisted system was within 3° for cup placement and within 1 mm for leg length equalization. In our study, deviation from the desired acetabular inclination and anteversion were higher than the Nawabi and colleagues' study. We thought that this is the result of the long learning curve of the technique. Several authors reported that robotic systems provide more accuracy compared with standard hip arthroplasty [29–31].

Published data regarding limb length discrepancy after MAKO robot-assisted total hip replacement is limited. In a study, the radiographic discrepancy was 5 mm or less in 89.6% of robot-assisted posterior total hip replacements, with none greater than 1 cm. Results were similar in the conventional arthroplasty group, and the difference was not significant compared with the robot-assisted group [32]. Similarly, in our study, both CMA and RAS group demonstrated less than 1 cm leg length discrepancy.

Although the MAKO robotic system seems to be accurate for component positioning, there are limited data regarding the clinical and functional outcomes of this system. Bukowski and Colleagues reported that robot-assisted cohort demonstrated significantly higher mean postoperative UCLA scores, higher mean postoperative modified Harris Hip Scores (mHHS), and a more significant percentage of patients with mHHS of 90 to 100 points compared with the conventional group at a minimum one-year follow-up [33]. However, Banchetti and colleagues [34] were unable to demonstrate improved patient-reported outcomes with robot-assisted surgery. More studies are needed to show clinical benefits and improvement of the patient reported outcomes after robot-assisted surgery.

Complications are another issue regarding robot-assisted hip arthroplasty. A recent meta-analysis demonstrated that compared with conventional THA, robot-assisted THA was associated with longer surgical time (not significant), lower intraoperative complication rates, better cup placement, stem placement and global offset, and a higher rate of heterotopic ossifications. Functional scores, limb length discrepancy, rates of revision, and stress shielding were similar in the two groups. The relative amount of blood loss was unclear [29]. Similarly, we could not demonstrate a difference in complications between CMA and RAS groups.

In our study, the robot-assisted system showed better results in terms of prosthetic component positioning and leg-length discrepancy. However, results were not statistically significant, despite acetabular inclination.

Limitations

There were some limitations in our study. Patient numbers were relatively small and follow-up time was short. We did not measure hip offset and true clinical leg length discrepancy. In addition, we did not compare patient-reported outcomes. This study was mainly based on radiographic measurements.

Conclusion

Our study demonstrated more accurate component positioning with robot-assisted hip arthroplasty without increased complication rates. We thought that robot-assisted surgery is a valuable tool to achieve preoperatively planned component positioning. However, long-standing studies are required to prove this technique's patient reported and long-term outcomes, and effects on prosthetic survival.

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