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Is Robotic Arm Assisted Total Hip Arthroplasty More Bone Preserving than Conventional Hip Replacements and Hip Resurfacing?

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Abstract

Background: Total hip arthroplasty (THA) is a common procedure that is increasingly being performed in younger patients. Deep acetabular reaming will result in more bone loss and the need for large acetabular components to be implanted. It can also lead to impingement, loosening, an altered center of rotation, and intraoperative periprosthetic fracture. The purpose of this study is to determine whether the single ream, robotic arm-assisted (RAA) THA can preserve a greater volume of bone stock compared to conventional hip replacement and resurfacing. **Methods:** We prospectively recruited 69 patients who had undergone primary THA using the Stryker Trident Acetabular System® in combination with the Stryker RAA System (MAKO)® and compared their mean reaming weight (g) with that of conventional hip replacement and resurfacing, as measured by Brennan *et al.* Comparison of acetabular reaming during hip resurfacing versus uncemented THA (J Orthop Surg. 2009; 17(1): 42-46). **Results:** The mean reaming weight using the MAKO system was 9.08 g, which was 29% less than the reaming weight using uncemented THA and hip resurfacing of 12.75 g. None of the acetabular cups required screw fixation. During the 35-month follow-up period, there were no complications related to cup placement or positioning. **Conclusions:** The use of RAA THA results in statistically significant preservation of acetabular bone compared to conventional hip replacement and resurfacing. This approach reflects the increased precision offered by RAA single reaming. Surgeons may consider utilizing RAA THA, particularly in younger patients, to better preserve bone stock as this could potentially impact future revision procedures.

Keywords

Arthroplasty, Replacement, Hip

1. Introduction

Total hip arthroplasty (THA) is an increasingly common procedure; 49,764 procedures were performed in Australia in 2018 [1], representing a 108.1% increase in primary total hip replacements completed over those performed in 2003. The 5474 hip revisions that were performed in Australia in 2018 is a 19.5% increase over those completed in 2003. By the year 2030, 52% of primary THAs are projected to be performed in patients younger than 65 years, with the highest increase in patients aged 45 - 55 years [2]. As a consequence, the number of revisions is expected to increase dramatically [2] [3]. Kurtz *et al.* [3] projected a two-fold increase in revisions by 2026. Revision rates appear to be higher in younger patients [4] [5].

Preservation of the acetabulum during primary THA has an impact on both the initial procedure as well as any subsequent revision surgery. Cementless acetabular components rely on adequate press-fit fixation, which is affected by the bone stock after reaming and the occurrences of intraoperative periprosthetic fractures. A malpositioned acetabular component may result in impingement and an altered center of rotation [4] [6]. The loss of bone stock during primary THA may adversely affect any subsequent revisions. Considering the increasing number of young patients undergoing THA and the commensurate incidence of revision, it is incumbent upon surgeons to preserve bone stock whenever possible [7]. Kahlenberg *et al.* [8] studied 108 patients who underwent THA at a mean age of 25.4 years and found that the meantime from the index procedure to revision surgery was 10.1 years. Another consideration for revision surgery is that life expectancy is rising; therefore, the long-term survivorship of the replaced total hip is increasingly relevant [9].

The purpose of this study was to compare the preservation of acetabular bone stock between conventional THA and hip resurfacing vs. robotic arm-assisted (RAA) THA. We hypothesize that the use of a robotic system would allow more accurate reaming, leading to greater preservation of the acetabular bone stock.

2. Materials and Methods

The study was approved by the Hollywood Private Hospital Research Ethics Committee (HPH HREC). Informed written consent was obtained prior to procedure commencement and sample collection.

Brennan *et al.* [7] compared the dry bone weight of the acetabulum after reaming using conventional THA versus hip resurfacing. They found no statistically significant differences between groups. Our study utilized the same trident series acetabular component as Brennan *et al.* and therefore used the data from this study as our control group. The study did not interfere with current surgical practices or flow.

Inclusion criteria included non-emergent procedure status, fitness to undergo general anaesthetic, and suitability for follow-up. Exclusion criteria included non-arthritic indications for THA, current hip fracture, and patients under 18 years old.

Specimen collection and bone preparation

Between October 2017 and June 2019, 69 consecutive patients were prospectively enrolled in the study. All patients underwent primary THA using the Stryker Trident Acetabular System® in combination with the Stryker RAA System (MAKO)®. All acetabular implants were uncemented press-fit components. Femoral implants were either Stryker Accolade II (uncemented) or Exeter (cemented) components, depending on the age and co-morbidities of the patients.

Patients were placed in the lateral decubitus position, supported by padded bolsters both anteriorly and posteriorly. All procedures were performed using a posterior (Moore) approach to the hip. After appropriate computer orientation of the osseous anatomy, a cut was made to the femoral neck under robotic guidance. The acetabulum was exposed and reamed using a single reaming technique. A reamer of the same size as that of the final component was used. Care was taken to meticulously retrieve all acetabular reamings. The nursing staff involved was taught the collection process for the femoral head and bone shavings prior to the commencement of the study. The collected specimens were transported to a laboratory facility in separate sterile containers for measurements. The femoral heads were measured using a digital caliper (accurate to 0.01 mm). Acetabular shavings were dehydrated prior to being defatted in 100 mL of a 1:1 solution of diethyl ether and acetone. This process was repeated five times, following the protocol described by Brennan *et al.* [7]. The shavings were then weighed using a digital scale (accurate to within 0.001 g) and reweighed four hours later to ascertain dry mass consistency [10].

Statistical methodology

A statistical power analysis was performed for sample size estimation using G*Power version 3.1 [11]. A medium effect size, using Cohen's (1988) criteria [12], was considered sufficient. With alpha = 0.05 and power = 0.80, the projected number of patients needed was approximately N = 64 for the simplest between group comparison. Thus, our final sample size of 69 was considered sufficient for the current study.

Estimates for the Brennan *et al.* [7] data were obtained using DataThief version 3 [13] to extract data points from their Figure 2. Statistical analyses were conducted using IBM SPSS Statistics version 22. Current data was compared to the combined Brennan *et al.* dataset. To check comparability of the current study patient characteristics with Brennan *et al.* gender and age were compared chi square and one-sample t-tests respectively. For the reaming weight and head size comparisons, a meta-analysis was conducted using Exploratory Software for Confidence Intervals [14]. The Brennan *et al.* datasets were weighted according to the inverse of the variance of their effect size. Results reported include the mean difference between conditions (Mdiff) with 95% between-subjects confidence intervals in square brackets. Effect size is reported in Cohen's d [12].

3. Results

Comparison of data from the current study with the Brennan *et al.* dataset

Table 1 shows a comparison of the current data to the Brennan *et al.* [7] dataset.

AGE: Average age in the current study was significantly higher than in the Brennan *et al.* combined data (M = 60 years vs. M = 65.8), t(68) = 4.36, p < 0.001. In the current data, there was no relationship between age and reaming weight, r = −0.026, p = 0.830.

GENDER: There was no difference in the ratio of males to females between the current study and the Brennan *et al.* combined data, $\chi 2(1) = 1.22$, p = 0.270. In the current data, there was a significant effect of gender on reaming weight, Mdiff = 2.31, 95% CI [0.94, 3.68]), t(67) = 3.37, p = 0.001, d = 0.82, where reaming weight for males (M = 10.38 g) was greater than for females (M = 8.07 g).

HEAD SIZE: In the current data, there was a trend towards a positive relationship between head size and reaming weight, r = 0.221, p = 0.068, where increased reaming weights were associated with larger head size (**Figure 1**). For the meta-analysis, a forest plot showing mean effect sizes and the corresponding 95% CIs are presented in **Figure 2**. The CIs for the current study data overlapped with the Brennan *et al.* combined data, suggesting they did not differ.

REAMINGS: Unlike Brennan *et al.* reaming weights in the current data were normally distributed (Shapiro-Wilk test, p = 0.249). For the meta-analysis, a forest plot showing mean effect sizes and the corresponding 95% CIs are presented in **Figure 3**. The CIs for the current study data did not overlap with the Brennan *et al.* combined data, suggesting they differed. The meta-analysis results indicated that the current study and Brennan *et al.*'s effects were not homogeneous (*i.e.* evaluating the same effect), Q = 14.97, df = 2, p < 0.001, I2 = 86.6%, and the current mean reaming weight was on average 28.8% lower than that of the Brennan *et al.* Mdiff = −3.67 g.

Table 1. Characteristics of the current data vs. those cited in Brennan *et al.* [7].

	Brennan *et al.*	Current (robotic)
N	62	69
Gender	M = 37, F = 25	M = 30, F = 39
Age	34 - 88 (*M* = 60)	34 - 87 (*M* = 66)
Femur head diameter (mm)	43 - 57 (*M* = 51)	39.3 - 60.0 (*M* = 48.9)
Reaming weight (g)	*M* = 12.75 *SD* = 5.11	*M* = 9.08 *SD* = 3.03

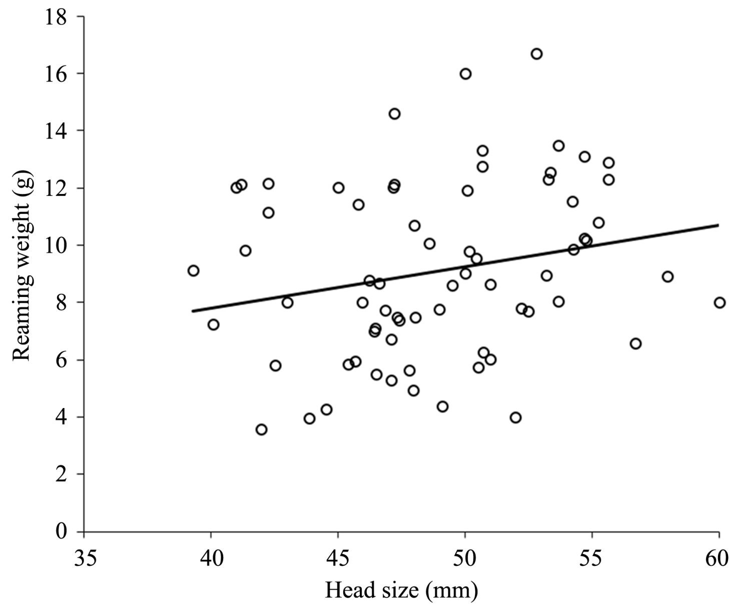

Figure 1. Femoral head size (mm) vs reaming weight (g).

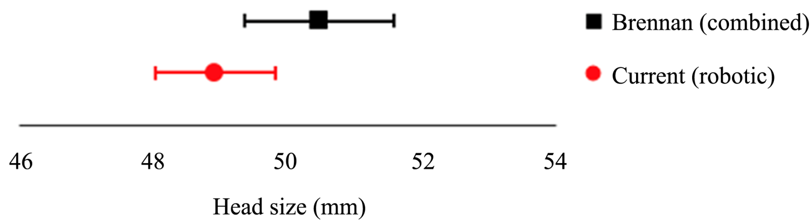

Figure 2. Meta-analysis results for femoral head size (mm) with means and 95% confidence intervals presented.

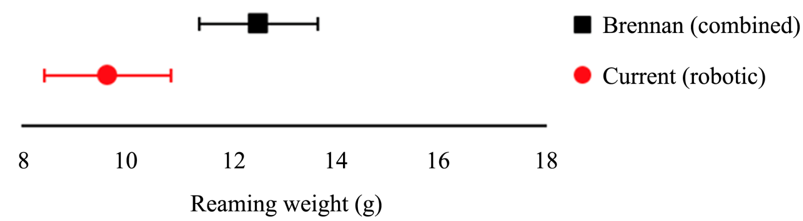

Figure 3. Meta-analysis results for reaming weights (g) with means and 95% confidence intervals presented.

None of the acetabular cups in our study required screw fixation. During the 35-month follow-up period, we had no complications related to cup placement or positioning, and no dislocations were observed.

4. Discussion

There is a growing body of evidence to support the use of RAA THA [15] [16] [17] [18] [19], which allows for accurate planning and execution with precise implant placement and assessment of cup position [15] [20]. Evaluation of the intraoperative cup position is also easier with RAA THA. This approach is particularly useful for less-experienced surgeons to achieve more reproducible results [18] [21], especially in obese patients [22]. In addition to cup orientation, RAA systems allow for accurate planning and execution of the reaming depth, which influences the position of the rotational center of the reamer in the horizontal direction. If the reaming depth is too deep or too shallow, it may affect the survivorship of the prosthesis by changing the torque of the reconstructed hip [23], and the extreme thinning of the anterior and posterior walls of the femur after reaming may complicate the implantation [24]. The enhanced preservation of the bone after RAA THA, as demonstrated in this study, is likely a reflection of the increased precision of the planning and execution of the acetabular reaming process.

Bayliss *et al.* [25] investigated the lifetime risk of revision surgery following THA, highlighting an increased risk in younger patients. For patients aged 50 - 54 years, the lifetime risk is 29%, compared with around 5% in patients aged 70 years or older. By the year 2030, 52% of primary THAs are projected to be performed in patients younger than 65 years, with the largest increase in patents aged 45 - 55 years [2]. As a consequence, the number of revisions is expected to increase dramatically [2] [3]. Loughead *et al.* [24] expressed concerns about the impact of increased acetabular reaming on subsequent revision surgery. Vendittoli *et al.* [26] expressed similar concerns, noting that in young and active adults, all efforts should be made to minimize the loss of acetabular bone during the initial arthroplasty.

Fluoroscopic guidance is another technique that can control reaming depth intraoperatively. Surgical staff may also benefit from robotic assistance compared to fluoroscopic guidance, with radiation exposure 74% lower in robot-assisted kyphoplasty procedures compared to fluoroscopy-guided approaches [27].

A deficiency in the acetabular bone stock presents a major challenge in revision hip arthroplasty, as the availability of the remaining acetabular bone stock plays an important role in the success of the revision [28] [29]. Our study highlights the acetabulum-preserving potential of RAA THA. Its single ream technique removed 29% less bone than conventional THA and resurfacing, which rely on sequential reaming, as the depth of reaming is guided by the surgeon's experience. While significantly more bone was removed from male (10.38 g) than female (8.07 g) patients, this finding likely reflects gender differences in bone mineral density rather than changes in the total volume of bone removed [30].

This study was performed at a single institution and by a single surgeon; both are limitations of the study design. All planning and surgeries were performed by an experienced orthopedic surgeon who was trained in robotics; the level of accuracy achieved may differ if a less-experienced surgeon were involved. There is also the potential limitation of unconscious bias, as the analysis was performed by the surgical team, however, strict predetermined protocols were followed to attempt to reduce such bias. No patient-reported outcome measures (PROMs) were investigated. Although none of the acetabular cups required screw fixation, no complications related to cup placement or positioning, and no dislocations during the duration of the study and the 35-month follow-up period were observed, future studies should incorporate PROMs. The use of a historical data set [7] as a control group may limit the conclusions of the current study. We endeavored to meticulously replicate the methods used by Brennan *et al.* in an attempt to mitigate this. Future studies should ideally be controlled and prospective in nature.

5. Conclusion

RAA THA leads to significant preservation of the acetabulum compared to conventional techniques. This outcome is a reflection of the increased precision of the planning and execution of the RAA acetabular reaming process. This is a significant finding, especially considering the increasing number of younger patients receiving hip replacements, as they are more likely to require revision surgery. Preservation of bone stock during primary THA is a desirable goal in the context of a potential future revision. Achieving this result may lead to an easier revision of THA and improved outcome for the patient.

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Conflicts of Interest

The authors have no conflicts of interest to disclose.

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