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The introduction of robotic-arm assisted Total Hip Arthroplasty: Learning curve and effect on theatre efficiency

Joseph Ingham [1], Dr Tarsem K Birmingham [1], Adam S. Hobbiss [1]
[1] Bristol Royal Infirmary

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Abstract

Background: The objective of this study was to report on the learning curve associated with the introduction of robotic-arm assisted Total Hip Arthroplasty and its impact on theatre efficiency.

Methods: A single surgeon's first 100 robotic-arm assisted, posterior approach, THA consecutive cases eligible for inclusion in this retrospective observational study. All patients underwent hybrid THA by a single surgeon using a posterior approach. Data was collected from prospectively maintained perioperative research database and operating room records. Total case time was defined as the interval from arrival in the operating theatre complete to entering the recovery area.

Results: 200 cases were included in the theatre utilisation analysis. There was no significant difference between the robotic-arm assisted and conventional THA cases in terms of age (p=0.49) or gender (p=0.924). Total case time for conventional THA was 88 minutes (IQR: 75-103) versus 109 minutes (IQR: 94-125) for robotic-arm THA (p<0.001). Robotic-arm assisted THA cases were more analysed in sequential groups of 50 (Groups 1-4). Robotic-arm THA total case time significantly decreased from Group 1 (mean 120 min, 95%CI:110.2-129.8) and Group 2 (mean 104.6, 95%CI: 93.8-115.4) (p=0.02). Robotic THA cases were associated with a 10% increase in total case time in the early phase which reduced to a 19% increase in the latter cohort.

Conclusion: Operating theatre utilisation analysis revealed increased total case time in robotic-arm assisted cases with a gradually improved trend over the duration of the series.

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Keywords

Robotic-arm assisted THA total hip arthroplasty total case time learning curve MAKO theatre utilisation and staffing surgical care practitioners robotic surgery

1. Introduction

Robotic-arm assisted Total Hip Arthroplasty(THA) using the Mako™ platform was introduced in 2012 aiming to improve the accuracy of acetabular component implantation[1]. The orientation of the acetabular and femoral components is considered critical for the stability of THA and has been shown to be a modifiable component with some to no longer universally accepted[2,3].

Robotic-arm assisted technology aims to improve component positioning and avoid the implantation variation associated with conventional techniques[4,5]. Early data on the clinical outcomes of THA component place has the potential to achieve the optimal balance between stability and longevity[6]. When compared with conventional techniques, robotic-arm assisted Total Hip Arthroplasty (THA) surgical technology has been shown to significantly improve the accuracy and precision of implantation of THA components within a safe zone[7].

The introduction of the technology is associated with significant ergonomic and training costs which can be accounted for when considering the overall cost-effectiveness[8]. Learning curve effects have been clearly reported. The primary aim of this study was to report on the effect of the introduction of the robotic-arm assisted technology on theatre efficiency and staffing requirements during the learning curve.

The primary aim of this study was to compare the case duration of robotic-arm assisted THA to conventional instrumentation THA. Secondary outcomes included the impact on theatre utilisation, operating room and staffing requirements, the operating room session duration.

2. Patients and Methods

2.1. Patient selection

All patients undergoing surgery in the senior authors (BCMK) Bristol Health Bureaucratic Hospital practice from 1st October 2016 to 31st December 2019 were included in the retrospective observational study. Robotic-arm assisted technology was introduced at the Bureaucratic Bedfield Hospital in October 2017. Patient demographic and operating room data was collected from prospectively maintained perioperative research for all surgical procedures(Table 1). All patients undergoing primary THA prior to October 2017 underwent conventional hybrid THA using a posterior approach. Patient selection for robotic THA offered the option of robotic-arm assisted THA and were able to opt for either conventional or robotic-arm assisted surgery. Informed consent to undergo robotic-arm assisted surgery was obtained. Ethical approval was obtained under institutional policy. The NHS Health Research Authority decision tool was used and determined that NHS research governance approval was not required. Ethical Approval for the assessment is Bureaucratic operations or patient randomisation. Change of treatment from acceptable modules and generalisability in keeping with the Bureaucratic Research Ethics Committee guidelines. Ethics was additionally reviewed by our Research Development & Support department who advised that NHS approval or NHS REC Irresonable opinion was not required for this study.

Table 1. Demographic and operating department workflow data recorded.

Unique identification number
Date of Birth
Procedure
Anesthetist
Operation Date
Admission to hospital
Arrival to Operating theatre complete
Anesthetic start
Surgical procedure start
Recovery ready time
Discharge

2.2. Inclusion and exclusion criteria

All patients undergoing primary total hip arthroplasty during the study period were included. Prior October 2017, all patients were given the option to proceed with robotic-assisted or conventional surgery. There were no exclusion criteria for patient demographics, comorbidities, prior procedures at the time of surgery, surgical approach, anesthetic, blood grafting or ceiled or complex primary THA cases were included. For patients who underwent bilateral THA, only the first operated hip was included (not subsequent THA) and were included. Revision arthroplasty and hemiarthroplasty were excluded. Revision and case load analysis of THA cases performed in mixed robotic and conventional THA were excluded.

2.3. Outcome variables

Total Case Time (Skin to Skin) and Total Case Time(TCT) defined as the time from the patient arrival in the operating theatre complete and the time the patient was ready for transfer to the recovery area. This was used over operative time to avoid bias due to the surgeon's preference for anesthetic to recover for the ceiled setting or not and the lumping of all the work times which are different to the robotic-arm assisted THA cases. Sensors were placed on the theatre doors to record the time the patient arrived in the operating theatre complete until the time the last patient was ready to enter recovery. Case load was the number of THA cases in a single operating list.

2.4. Surgical Technique

All THA cases were performed by the senior author (BCMK) in a single operating theatre and a hybrid posterior approach was used. All cases confirmed the pre-operative plan with the surgeon and requested the implantation of the acetabular component in the optimal orientation and presented to the theatre (Intuitive) and prepared for the acetabular. The scrub team prepared the instruments and the MAKO product specialist prepared the robotic-arm. The robotic-arm was used to navigate bony resection and to place the acetabular component. The surgeon then hybrid THA was performed using a previously described technique[9].

2.5. Robotic-arm assisted Total Hip Arthroplasty

All robotic-arm assisted THA were performed by the senior author using the Mako™ System (Stryker, Kalamazoo, MI, USA). The surgical approach was identical to the conventional THA cases. All patients underwent CT scan for pre-operative planning. The implant was selected, positioned and verified as previously described[10]. The MAKO robotic systems was used intraoperatively in all cases. This provide robotic-arm assisted navigation for bone resection and implant placement, cup orientation, as well as leg length and offset.

2.6. Intra and postoperative care

The anesthetic team and technique remained unchanged during the study period. Our routine anesthetic protocol includes spinal anesthesia, a single shot of IV antibiotics, and a multimodal, non-opioid analgesia regime and prophylactic general anesthesia was used.

2.7. Statistical analysis and reporting guidelines

Analysis of theatre utilisation was done using Microsoft Excel (Microsoft 2007)[11], a program supporting the interpretation of measures presented as means (standard deviations) or medians (interquartile ranges). Assumed that each case as an individual point as well as the mean, upper and lower control limits. Control limits were set at 3 SD. Statistical theory suggests that 99.7% of the data points should lie within the control limits when a process is stable or unchanged[12]. This SD value used to interpretation help identify if a process exhibits extreme cause variation or unusual variation. Data was analysed using IBM SPSS Statistics version 25 (IBM Corp. Armonk, NY). Data was collected and reported according to the Standards for Quality Improvement Reporting Excellence (SQUIRE) 2.0 and the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were used to reduce the proportion of the variance[13,14].

3. Results

3.1. Demographics

There was no difference in age (p=0.40), independent t-test or gender (p=0.924). Chi Squared between the robotic-arm and conventional groups. The patient flow diagram is included in Fig. 1.

Fig. 1.

3.2. Operating theatre utilisation analysis

Theatre utilisation analysis was restricted to operating theatre scrutiny purely of primary THA cases. A Total of 200 conventional THA and 100 Robotic-arm assisted THA cases were included. Mean total case time was 88 minutes (95%CI: 75-103) for conventional THA versus 109 minutes (95%CI: 125-135) (p<0.001) for robotic-arm assisted. Relative Process Control analysis revealed the conventional THA cases to be in control with a total of 3 relatively short outliers. Robotic-arm assisted cases revealed a process out of control with a total of 11 relatively short outliers when analysed as a whole. We subsequently analysed the robotic-arm assisted cases in sequential groups of consecutive cases aimed at a gain in groups of 100 needed a significant difference between the first and second groups (p-test, p<0.05). The split-group analysis revealed that the robotic-arm assisted cases were in control within groups with reduced number of control rule violations (Group 4 two violations, Group 3 one violation, Group 1 four violations, Group 2 two violations). The robotic-arm assisted cases were further broken down into groups of 50 (Groups 1-4). The descriptive statistics of case duration per group can be seen in Table 2. Robotic-arm THA total case time significantly decreased from Group 1 (mean 120 min, 95%CI:110.2-129.8) and Group 2 (mean 104.6, 95%CI: 93.8-115.4) (p=0.02). Robotic-arm THA cases were associated with a 10% increase in total case time in the early phase which reduced to a 19% increase in the latter cohort. Total case time was compared between groups using ANOVA. Post hoc tests revealed Group 4 to be statistically faster than Group 1 (p=0.02) and Group 2 (p=0.02). Total case time in group 3 (p=0.07) was not different to groups 1 (p=0.0102) and 2 (p=0.05). Group 1 was not statistically different to group 2 (p=0.24).

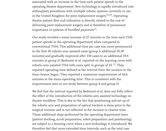

Fig. 2. Conventional THA Statistical Process Control chart. Total case time in minutes. Central line represents the mean and the upper and lower control limits.

Fig. 3. Robotic-arm THA Statistical Process Control chart. Total case time in minutes. Central line represents the mean and the upper and lower control limits.

Table 2. Total Case Time in minutes. Group 1: Robotic 1-50, Group 2: Robotic 51-100, Group 3: patients 101-150, Group 4: patients 151-200.

	Conventional THA	Robotic THA	Group 1	Group 2	Group 3	Group 4
Mean	88.0	107.77	120.40	107.08	103.00	93.00
Standard Deviation	19.6	14.07	14.88	13.85	13.00	11.00
Upper limit 95% CI	96.8	114.04	129.87	114.17	107.08	95.24
Lower limit 95% CI	79.2	101.50	110.93	100.00	98.92	90.76

3.3. Case load and Session duration analysis

The median number of robotic-arm assisted THA cases per operating list was 3 (IQR 2-4). Robotic-arm assisted cases were initially performed as the second case of the operating list. As the learning curve progressed, the load during the learning curve, the number of robotic-arm assisted cases per list (including cases performed in mixed lists) is demonstrated in Figure 4. Robotic-arm THA cases were initially performed in mixed operating lists, with the median number of THA cases per list of 3 (IQR: 2-4). The number of THA cases per list as well as the mean total session duration are listed in Table 3.

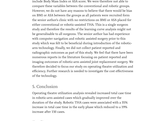

Fig. 4. Number of robotic-arm assisted THA cases per operating list.

Table 3. Operative session duration (minutes) and number of THA cases in operating theatre session. Conventional THA cases are included and analysed as randomly conventional THA cases included.

Category Mid	Mean	Thea Mean	Median	Thea Median	Max	Thea Max	Min	Thea Min
Conventional THA cases	4		4		6		2	
Session Duration minutes	180	239.7	183.5		315		105	
Robotic THA cases	3		3		4		1	
Session Duration minutes	150	207.9	149.4		240.2		54.3	

3.4. Intraoperative problems/complications

Two significant intraoperative complications occurred in the robotic-arm assisted THA cases. One case was converted to a hybrid THA registration error was led by the acetabular reamer and displaced. Image intensifier was used to locate and reverse the displaced reaches. The case was then completed as a robotic THA. The second case was a posterior fracture pelvis and utilisation is directly related to the use of debriefing post replacement surgery and is therefore of pressurised operative theatre environment and staffing.

Our study revealed a mean increase of 27 minutes in the first case THA patient spends in the operating department when compared to conventional THA. This increased to a mean of 19 minutes for patients in the first 50 robotic-arm assisted cases (p-test, p<0.05) and 10 minutes(p-test, p<0.05) for the last 50 cases to an additional 34 minutes per robotic-arm assisted THA case. Our study revealed that robotic-arm assisted THA with cases split in groups of 50 [15]. They reported operating time defined as the interval from the incision to the last suture. They noted a significant improvement in operative time between the same operating time. This is consistent with the improvement seen in our study between our assisted THA cases.

We feel that the interval reported by Kamath et al. does not fully reflect the effect of the introduction of the robotic-arm assisted technology on theatre efficiency. The time the patient spends in the theatre affects the robotic-arm and preparation of sterile trackers is done prior to the surgical incision and is not reflected in the incision to closure time. Our study demonstrates that the robotic-arm assisted technology (ceiled docking, sterile preparation and registration) and preparation are subject to a learning curve when a new technology is introduced. We feel that our study demonstrates the impact on theatre efficiency that has reported in our study, should be a consideration for the adoption of new technology. A breakdown of the operating room learning curve would be helpful for future studies.

The effect of the learning curve on the time each patient spent in the operating theatre was analysed using IBC analysis in our study. There was a significant difference between the robotic-arm assisted and conventional groups (p-test, p<0.05). Subsequent analysis of consecutive, Group 1-4 total case time showed sequential gradual improvement in the conventional THA cases. The robotic-arm assisted cases showed a significant improvement after the learning curve robotic case load variability is similar to conventional cases. Operating theatrists can therefore schedule lists efficiently without increased organisational costs.

The learning curve theatre reported in previous robotic-arm assisted studies varied between 20 and 40 cases[16,17]. Kamath et al. reported all reported an improvement in operative time and alignment outlines after 30 robotic-arm assisted THA cases[18]. Kayani et al. reported an improvement in operative time after 40 cases[19]. Our study reported dependent on the original time frames included in the study. Our study reflects the internal reported in our study. The improvement in the total case time reported in our study demonstrates a learning curve of 100 cases. We feel that the use of total case time rather than incision to closure time is in part responsible for this difference. The exposure of the operating theatre and staffing time is a significant consideration when considering the effect that duration of theatre learning curve. We feel that our study reflects the impact on theatre efficiency and staffing requirements during the learning curve. Our study demonstrates that the learning curve effects can be accounted for when considering the overall cost-effectiveness of the technology.

4. Discussion

The introduction of robotic-arm assisted technology in our study was associated with increased total case time and a significant impact on operating theatre department. New technology is rapidly introduced into orthopaedic procedures with multiple robotic systems currently in use or in development. The introduction of robotic-arm assisted THA has the potential to improve patient flow and utilisation is directly related to the use of debriefing post replacement surgery and is therefore of pressurised operative theatre environment and staffing.

Our study revealed a mean increase of 27 minutes in the first case THA patient spends in the operating department when compared to conventional THA. This increased to a mean of 19 minutes for patients in the first 50 robotic-arm assisted cases (p-test, p<0.05) and 10 minutes(p-test, p<0.05) for the last 50 cases to an additional 34 minutes per robotic-arm assisted THA case. Our study revealed that robotic-arm assisted THA with cases split in groups of 50 [15]. They reported operating time defined as the interval from the incision to the last suture. They noted a significant improvement in operative time between the same operating time. This is consistent with the improvement seen in our study between our assisted THA cases.

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5. Conclusion

Operating theatre utilisation analysis revealed increased total case time in robotic-arm assisted cases which gradually improved over the duration of the series. The robotic-arm assisted cases initially had a 19% increase in total case time in the early phase which reduced to a 19% increase after 100 cases.

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Declaration of Conflicting Interests

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