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Original Research

Evaluation of Blood Loss in Conventional vs MAKOplasty Total Knee Arthroplasty

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ABSTRACT

Background: Primary total knee arthroplasty (TKA) has been historically associated with considerable blood loss. Allogenic transfusions, the standard of care for blood loss following TKA, carry inherent risks. With the expanding use of robotic technology in TKA, one theoretical advantage is decreased blood loss and postoperative blood transfusions requirements. The purpose of this study was to compare postoperative hemoglobin levels and the percentage of patients requiring a transfusion of allogenic packed red blood cells after conventional TKA (CTKA) vs robot-assisted TKA (RATKA).

Methods: This is a retrospective review of 486 consecutive patients undergoing either CTKA or RATKA between October 30, 2018, and June 25, 2020, by a single fellowship-trained arthroplasty surgeon. Mako SmartRobotics (Stryker, Kalamazoo, MI) was used for RATKA cases. Primary outcomes included preoperative vs postoperative hemoglobin values and postoperative blood transfusion rates between the 2 groups.

Results: The mean hemoglobin on postoperative day 1 was 10.7 gm/dl (±1.3) in the CTKA group and 10.9 gm/dl (±1.3) in the RATKA group, $P = .24$. The largest decline in hemoglobin from preoperative to within 2 days postoperatively was 3.1 gm/dl (±1.1) in the CTKA group and 3.1 gm/dl (±1.1) in the RATKA group, $P = .92$. The percentage of patients requiring a blood transfusion was 1.1% in the CTKA group and 1.3% in the RATKA group, $P = .79$.

Conclusions: RATKA and CTKA groups did not have significant differences in postoperative hemoglobin changes or the need for postoperative blood transfusions.

Introduction

Primary total knee arthroplasty (TKA) is one of the most frequently performed elective surgeries for the treatment of degenerative joint disease of the knee [1] with an anticipated annual volume of 1.26 million procedures in the United States by the year 2030 [2]. Primary TKA, however, has been historically associated with a considerable amount of blood loss, with over half of patients requiring a blood transfusion within the first 3 days postoperatively [3]. Allogenic blood transfusions are the standard of care for the treatment of blood loss in TKA [4,5] but carry uncommon risks of infection, immune-mediated reactions, circulatory overload, and lung injury [5]. In patients undergoing TKA, allogenic transfusions have been associated with increased length of hospital stay [6], higher total cost of admission [6], increased risk of deep surgical site infection [7], and an increase in 30-day mortality [8].

Due to concerns over blood loss after TKA, multimodal blood management strategies have been developed over the past decade [9]. These include preoperative hemoglobin optimization, use of regional anesthesia, tourniquet application, stringent postoperative transfusion criteria, and administration of perioperative tranexamic acid (TXA) [5,10]. In addition to blood management programs, preliminary literature has shown that robot-assisted TKA (RATKA) when compared to conventional TKA (CTKA) results in significant decreases in perioperative blood loss and rates of postoperative blood transfusion [11–15].

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Theoretical causes of increased blood loss from CTKA are instrumentation of the femoral canal for intramedullary guide placement [16], excessive bone resection, and iatrogenic soft-tissue trauma [17,18]. In terms of blood loss, a major advantage of some robotic systems is the use of small-diameter bone pins as opposed to intramedullary instrumentation and an automatic-stop function of the saw blade if deviation occurs outside of a predefined cutting window [17]. As blood loss after TKA continues to be problematic, and with the increasing use of robotic technology during TKA [14], we sought to evaluate the impact of a single RATKA system, Mako SmartRobotics (Stryker, Kalamazoo, MI), on blood loss compared to manual techniques.

Primary aims of this study were twofold: 1) to identify changes in postoperative hemoglobin values in CTKA vs RATKA patients, and 2) to identify the percentage of patients receiving postoperative allogenic packed red blood cell (PRBC) transfusions following CTKA vs RATKA. Secondary aims included comparison of patient demographics and characteristics. We hypothesize that based on the inherent differences in RTKA vs CTKA, patients treated with CTKA will have a larger decline in postoperative hemoglobin values and higher rates of postoperative PRBC transfusions.

Material and methods

This is a retrospective review from an urban academic center of 486 consecutive patients treated by a single fellowship-trained arthroplasty surgeon. All patients underwent either CTKA or RATKA from October 30, 2018, to June 25, 2020. RATKA was performed using Mako SmartRobotics (Stryker, Kalamazoo, MI). A posterior stabilized, Triathlon Total Knee System (Stryker, Kalamazoo, MI) was utilized in all patients. The electronic medical record was used to identify patient age, body mass index (BMI), American Society of Anesthesiology (ASA) score, preoperative hemoglobin values, postoperative hemoglobin values on postoperative day 1, the biggest decrease in hemoglobin values from the preoperative stage to within 2 days postoperatively, need for a postoperative PRBC transfusion, perioperative use of tranexamic acid (TXA), and the use of postoperative anticoagulation. Allogenic PRBC transfusion(s) was given to patients if postoperative hemoglobin levels fell below 7 g/dl.

Currently, it is our institution's total joints protocol to administer 1 dose of 1300-mg oral TXA within 2 hours of surgery start and another dose of 1300-mg oral TXA postoperatively. At the initiation of our study, TXA was not administered to patients with any remote history of cerebrovascular accident, thromboembolic disease, myocardial infarction, or cardiac stent placement. Over the time course of our study, limited literature was published to suggest TXA use in patients of higher comorbidity does not increase the risk of thromboembolic events [19,20]. Therefore, our TXA indications expanded, and TXA was not administered to patients with a history of cerebrovascular accident, thromboembolic disease, myocardial infarction, or cardiac stent placement within 6 months of surgery. TXA was also not given to any patient on active anticoagulation therapy or a history of colorblindness. Per protocol at the time of this study, patients were provided postoperative venous thromboembolism (VTE) prophylaxis in the form enoxaparin 40 mg subcutaneous daily, starting on postoperative day 1 and continued throughout hospital stay. Patients were discharged with aspirin 325 mg twice a day for 30 days. Exceptions to this VTE protocol were patients with a history of atrial fibrillation, deep venous thrombosis (DVT), pulmonary embolism, or cancer who were already prescribed an antiplatelet or anticoagulant medication(s). In these patients, the medication(s) was discontinued prior to surgery according to the American Academy of Orthopedic Surgeons guidelines and restarted on postoperative day 1 without any additional VTE prophylaxis.

All patients over the age of 18 years undergoing primary TKA for either degenerative or inflammatory arthritis were included in this study. We excluded patients undergoing revision or conversion procedures and those with a history of blood dyscrasias predisposing them to increased bleeding. All procedures were performed via the medial parapatellar approach, and a tourniquet was used in all patients. The tourniquet was inflated immediately prior to incision and deflated prior to closure of knee joint capsule, and any actively bleeding vessels were addressed using electrocautery.

Statistical analysis

Statistical analysis was performed using SPSS software (version 25; IBM, Armonk, NY). Demographic analysis using *t*-test for equality of means was performed to determine differences in age, BMI, ASA score, and preoperative hemoglobin. Pearson's chi square analysis was used to determine differences in gender, perioperative TXA administration, and the use of postoperative anticoagulation between CTKA and RATKA groups. A t-test for equality of means was used to determine differences in hemoglobin values on postoperative day 1, the change in hemoglobin values from preoperative to postoperative day 1, and the largest change in hemoglobin values from the preoperative stage to within 2 days postoperatively. Pearson's chi square was used to determine differences in the rate of blood transfusion between the 2 groups.

We performed a subgroup analysis to compare blood loss outcomes of patients who received perioperative TXA and who underwent CTKA vs RATKA. Subgroup analysis was also utilized to compare blood loss outcomes in patients who did not receive TXA and who underwent CTKA vs RATKA.

A power analysis was performed with power set at 0.80 and an alpha set at 0.05. It was determined that a minimum sample size of 273 patients would be required to detect a small effect (d = 0.2).

Results

A total of 486 patients were included in the study, of which 187 (38.5%) underwent CTKA, while 299 (61.5%) underwent RATKA. There were no significant differences in age, ASA scores, gender, preoperative hemoglobin values, or the use of postoperative anticoagulation between the 2 groups (Table 1). The mean age of the CTKA group was 60.0 (±9.3) years, and the mean age of the RATKA group was 59.5 (±9.8) years, $P = .51$. Both groups had identical ASA scores, 2.6 (±0.5), $P = .49$. There were 138 (73.8%) female patients in the CTKA group and 205 (68.6%) female patients in the RATKA, $P = .24$. The mean preoperative hemoglobin in the CTKA group was 13.3 (±1.4) gm/dl, while the mean preoperative hemoglobin in the RATKA group was 13.4 (±1.5) gm/dl, $P = .37$. There was no significant difference in the type of postoperative DVT prophylaxis administered ($P = .27$) or cases of dual medications for DVT prophylaxis ($P = .74$) between the 2 groups.

Significant differences were noted between the 2 groups in terms of BMI and perioperative TXA (Table 1). Patients undergoing RATKA had a statistically significant lower BMI, mean 35.5 (±7.6), than patients undergoing CTKA, mean 37.8 (±9.3), $P < .01$. A significantly higher percentage of patients in the RTKA group, 259 of 299 (87%), received perioperative TXA compared to the CTKA, 146 of 187 (78.1%), $P = .01$.

Between the 2 groups, there were no significant differences in hemoglobin levels on postoperative day 1, change in hemoglobin levels from preoperative to postoperative day 1, the largest decline in hemoglobin from the preoperative stage to within 2 days postoperatively, and the percentage of patients requiring a blood

Table 1
Demographics of all patients undergoing TKA.

Characteristic	CTKA (n = 187)	RATKA (n = 299)	*P* value
	Mean, std dev	Mean, std dev	
Age (y)	60.0 + 9.3	59.5 + 9.8	.51[a]
BMI (kg/m^2)	37.8 + 9.3	35.5 + 7.6	<.01[a]
ASA score	2.6 + 0.5	2.6 + 0.5	.49[a]
Preoperative Hb (gm/dl)	13.3 ± 1.4	13.4 ± 1.5	.37[a]
	Number (percent)	Number (percent)	
Gender n (%)			.24[b]
Female	138 (73.8%)	205 (68.6%)	
Male	49 (26.2%)	94 (31.4%)	
Perioperative TXA, n (%)			.01[b]
Yes	146 (78.1%)	259 (86.6%)	
No	41 (21.9%)	40 (13.4%)	
Postoperative DVT prophylaxis			.27[b]
None	1 (0.5%)	1 (0.3%)	
Enoxaparin (Lovenox)	169 (90.4%)	282 (94.3%)	
Apixaban (Eliquis)	7 (3.7%)	4 (1.3%)	
Aspirin	3 (1.6%)	2 (0.6%)	
Warfarin (Coumadin)	1 (0.5%)	0 (0.0%)	
Rivaroxaban (Xarelto)	3 (1.6%)	3 (1.0%)	
Clopidogrel (Plavix)	2 (1.1%)	7 (2.3%)	
Dabigatran (Pradaxa)	1 (0.5%)	0 (0.0%)	
Dual anticoagulants			.74[b]
Yes	8 (4.3%)	11 (3.7%)	
No	179 (95.7%)	288 (96.3%)	

Hb, hemoglobin; std dev, standard deviation.
[a] *t*-test.
[b] Pearson's chi square Test.

transfusion (Table 2). The mean hemoglobin level on postoperative day 1 was 10.7 gm/dl (±1.3) in the CTKA group and 10.9 gm/dl (±1.3) in the RATKA group, $P = .24$. When comparing hemoglobin values on postoperative day 1 to preoperative hemoglobin values, the CTKA group had a hemoglobin decline of 2.5 gm/dl (±1.1), while the RTKA group also had a hemoglobin decline of 2.5 gm/dl (±1.1), $P = .99$. The largest decline in hemoglobin from preoperative level to within 2 days postoperatively was 3.1 gm/dl (±1.1) in the CTKA group and 3.1 gm/dl (±1.1) in the RATKA group, $P = .92$. The number of patients requiring a blood transfusion in the CTKA group was 2 of the 187 (1.1%), and in the RATKA group, it was 4 of the 299 (1.3%), $P = .79$. One unit each of allogenic PRBCs was given to the 6 patients requiring a blood transfusion.

Further, in a subgroup analysis (Table 3) of patients who received perioperative TXA and underwent CTKA vs RATKA, there were no significant differences in hemoglobin levels on postoperative day 1, change in hemoglobin levels from preoperative to postoperative day 1, the largest decline in hemoglobin from preoperative stage to within 2 days postoperatively, and the percentage of patients requiring a blood transfusion. In all patients who received TXA, the mean hemoglobin level on postoperative day 1 was 10.8 gm/dl (±1.3) in the CTKA group and 10.9 gm/dl (±1.3) in the RATKA group, $P = .35$. When comparing hemoglobin values on postoperative day 1 to preoperative hemoglobin values, the CTKA group had a mean hemoglobin decline of 2.5 gm/dl (±1.1), while the RTKA group also had a hemoglobin decline of 2.5 gm/gl (±1.0), $P = .99$. The largest decline in hemoglobin from preoperative level to within 2 days postoperatively was 3.1 gm/dl (±1.1) in the CTKA group and 3.0 gm/dl (±1.1) in the RATKA group, $P = .78$. The number of patients requiring a blood transfusion in the CTKA group was 1 of the 146 (0.7%), and in the RATKA group, it was 1 of the 259 (0.4%), $P = .59$

A subgroup analysis (Table 3) of patients who did not receive perioperative TXA and underwent CTKA vs RATKA also showed no significant differences in hemoglobin levels on postoperative day 1, change in hemoglobin levels from preoperative to postoperative day 1, the largest decline in hemoglobin from preoperative stage to within 2 days postoperatively, and the percentage of patients requiring a blood transfusion. In all patients who did not receive TXA, the mean hemoglobin level on postoperative day 1 was 10.4 gm/dl (±1.3) in the CTKA group and 10.4 gm/dl (±1.5) in the RATKA group, $P = .99$. When comparing hemoglobin values on postoperative day 1 to preoperative hemoglobin values, the CTKA group had a mean hemoglobin decline of 2.6 gm/dl (±1.2), while the RTKA

Table 2
Blood loss data of all patients undergoing TKA.

Outcome	CTKA (n = 187)	RATKA (n = 299)	*P* value
	Mean, std dev	Mean, std dev	
Hb (gm/dl) POD1	10.7 ± 1.3	10.9 ± 1.3	.24[a]
Δ Hb (gm/dl, preoperative−POD1)	2.5 ± 1.1	2.5 ± 1.1	.99[a]
Largest Δ Hb (gm/dl)[c]	3.1 ± 1.1	3.1 ± 1.1	.92[a]
Blood transfusion, n (%)			.79[b]
Yes	2 (1.1%)	4 (1.3%)	
No	185 (98.9%)	295 (98.7%)	

Hb, hemoglobin; std dev, standard deviation.
[a] *t*-test.
[b] Pearson's chi square Test.
[c] Preoperative Hb value−lowest Hb values within 2 d postoperatively.

Table 3
Perioperative TXA usage: subgroup analysis.

Patients receiving TXA (n = 405)	CTKA (n = 146)	RATKA (n = 259)	*P* value
	Mean, std dev	Mean, std dev	
Hb (gm/dl) POD1	10.8 ± 1.3	10.9 ± 1.3	.35[a]
Δ Hb (gm/dl, preoperative–POD1)	2.5 ± 1.1	2.5 ± 1.0	.99[a]
Largest Δ Hb (gm/dl)[c]	3.1 ± 1.1	3.0 ± 1.1	.78[a]
Blood transfusion, n (%)			.59[b]
Yes	1 (0.7%)	1 (0.4%)	
No	145 (99.3%)	258 (99.6%)	
Patients not receiving TXA (n = 81)	CTKA (n = 41)	RATKA (n = 40)	*P* value
	Mean, std	Mean, std	
Hb (gm/dl) POD1	10.4 ± 1.3	10.4 ± 1.5	.99[a]
Δ Hb (gm/dl, preoperative–POD1)	2.6 ± 1.2	2.6 ± 1.1	.99[a]
Largest Δ Hb (gm/dl)[c]	3.2 ± 1.2	3.4 ± 1.3	.51[a]
Blood transfusion, n (%)			.36[b]
Yes	1 (2.4%)	3 (7.5%)	
No	40 (97.6%)	37 (92.5)	

Hb, hemoglobin; std dev, standard deviation; TXA, tranexamic acid.
[a] *t*-test
[b] Pearson's chi square Test.
[c] Preoperative Hb value–lowest Hb values within 2 d postoperatively.

group also had a mean hemoglobin decline of 2.6 gm/gl (±1.1), $P = .99$. The largest decline in hemoglobin from preoperative stage to within 2 days postoperatively was 3.2 gm/dl (±1.1) in the CTKA group and 3.4 gm/dl (±1.3) in the RATKA group, $P = .51$. The number of patients requiring a blood transfusion in the CTKA group was 1 of 41 (2.4%), and in the RATKA group, it was 3 of 40 (7.5%) $P = .36$.

Discussion

Blood loss after TKA has been of a concern for both patients and orthopedic surgeons [3,21]. One proposed advantage of RATKA is decreased blood loss and transfusion requirements, but there is a paucity of literature evaluating blood loss after RATKA compared to CTKA. The purpose of our study was to analyze changes in preoperative vs postoperative hemoglobin level and the rate of postoperative PRBC transfusions in patients undergoing CTKA compared to patients undergoing RATKA. Our retrospective review of 486 patients, the largest study of its kind, found no significant difference in preoperative vs postoperative hemoglobin values during hospital admission between the 2 groups. We also found no significant difference in transfusion rates between the 2 groups.

Contrary to our findings, much of the current literature has shown that CTKA can result in a significant amount of postoperative blood loss requiring transfusion. For example, Hu et al. [3] looked at a series of 304 patients undergoing conventional primary TKA from January 2011 to June 2016 and estimated that total blood loss following CTKA averaged 1346 ml (SD ±671 ml) which accounted for almost 30% of blood volume. Additionally, 51.6% of patients in their study required either an allogenic or autologous blood transfusion by the third postoperative day [3]. Similarly, Klika et al. [6] after review of the Nationwide Inpatient Sample included 4,215,499 patients undergoing CTKA between January 2000 and December 2009 and found an overall rate of allogenic blood product transfusion of 11.91%. Patients in this study who received transfusions had a statistically significant longer hospital stay, higher total cost of admission, and increased risk of postoperative infection [6]. Further, analysis of the 2011 National Surgical Quality Improvement Program data of 13,662 patients who underwent CTKA found a PRBC transfusion rate of 18.3% within 72 hours of surgery, and there was a significantly higher mortality rate for those patients who received blood transfusion [8].

Due to the historically large percentages of patients requiring a blood transfusion, blood management programs have been developed to mitigate the risk of blood loss during TKA. These approaches place emphasis on optimization of preoperative hemoglobin, intraoperative tourniquet use, hypotensive epidural anesthesia, perioperative antifibrinolytics, transfusion of 1 unit of PRBC instead of the traditional 2 units, and withholding transfusions in hemodynamically stable patients with hemoglobin >7 g/dl [22,23]. Implementation of these approaches has reduced the number of patients requiring blood transfusions, with rates varying in the literature [9,23,24]. For example, in a single-institution retrospective review of 674 patients undergoing primary TKA, Lindman and Carlsson [24] found a transfusion rate of 0.45% in patients with optimized perioperative blood loss protocols. Contrary to this, Loftus et al. [23] evaluated 6593 consecutive patients enrolled in a blood management program undergoing either primary or revision total hip arthroplasty or TKA and showed a transfusion rate of 11.7%.

In addition to multimodal approaches to blood management in TKA, some literature has shown decreased blood loss and transfusion requirements in RATKA compared to CTKA [11–15]. In a single-institution retrospective review, Khan et al. [11] found a statistically significant reduction in the percentage of patients requiring a blood transfusion who underwent RATKA using the NAVIO surgical system (Smith & Nephew, Watford, England) compared to CTKA. In their cohort of 100 patients, 12% of patients in the CTKA group required blood transfusion compared to 2% of patients in the RATKA group, $P = .01$ [11]. A meta-analysis by Onggo et al. [15] evaluating 2 studies with a total of 80 patients compared RATKA using ROBODOC (Integrated Surgical Systems, Sacramento, CA) to CTKA. They found a statistically significant, lower mean blood loss (mean difference = 286.65 ml, CI = 411.1-162.16, $P < .001$) in patients undergoing RATKA compared to those undergoing CTKA [15].

Blood loss from CTKA is thought to be the result of instrumentation of the femoral canal for intramedullary guide placement [16], excessive bone resection, and iatrogenic soft-tissue trauma [17]. However, the Mako SmartRobotics (Stryker, Kalamazoo, MI) system used in this study does not use intramedullary instrumentation for bony referencing. Excessive bony resection and soft-tissue trauma are also limited as the oscillating saw blade only functions within a

predefined resection window [17]. Based on these inherent differences between RATKA and CTKA, as well as the aforementioned studies by Khan et al. [11] and Onggo et al. [15], we hypothesized that patients treated with CTKA would have a larger decline in postoperative hemoglobin values and higher rates of postoperative PRBC transfusions. Our findings did not support this hypothesis and was not in line with much of the current literature regarding decreased blood loss after RATKA.

Limitations of this study include those inherent to a retrospective study. Also, the majority of our patients were discharged on postoperative day 1 or 2. Cho et al. found that the lowest postoperative hemoglobin values occurred on day 3 following TKA [25]. As such, we may not have captured these values in our postoperative hemoglobin lab values. Further, throughout the course of our study period, the senior author (H.F.D.) increasingly utilized RATKA compared to CTKA. In addition, the use of TXA also increased during our study as its indications expanded. This may explain the significant differences seen in perioperative TXA administration between RATKA and CTKA groups, with higher percentage of patients in the RATKA group receiving perioperative TXA. We recognize this as a cofounding factor and performed a subgroup analysis to account for this difference. With the significant increase in TXA use, we would expect less blood loss and lower transfusion rates in the RATKA. These differences were not observed. Further, the transfusion rate for patients in our study was 1.1% in the CTKA group and 1.3% RTKA group. Although our transfusion rate was lower than that historically reported, it is consistent with studies citing recent trends in transfusions rates with utilization of blood management programs.

Conclusions

In contrast to much of the current literature, this study did not find any significant differences in postoperative blood loss or transfusion rates between RATKA and CTKA. Postoperative blood loss after TKA can be affected by numerous factors such as use of TXA, use of a tourniquet, implant fixation technique, and postoperative DVT prophylaxis. Further large-scale prospective studies addressing these factors are needed to definitively state if there are any significant differences in postoperative blood loss with the use of RATKA.

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Conflict of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Dr. Hussein Darwiche, our senior author, is a paid consultant for Stryker Corporation. However, this relationship did not influence the work reported in this paper. *Updated November 2021.*

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Informed patient consent

The author(s) confirm that informed consent has been obtained from the involved patient(s) or if appropriate from the parent, guardian, power of attorney of the involved patient(s); and, they have given approval for this information to be published in this article.

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