Journal of Anesthesia (2019) 33:399–407
https://doi.org/10.1007/s00540-019-02644-2

ORIGINAL ARTICLE

Intraoperative hemorrhage in revision total hip arthroplasty: a retrospective single-center study

Kana Saito[1,2] · Yu Kaiho[2] · Toru Tamii[1,2,3] · Tadaho Nakamura[1,3,4] · Eri Kameyama[1,5] · Masanori Yamauchi[2]

Received: 1 February 2018 / Accepted: 14 April 2019 / Published online: 29 April 2019

Abstract

Purpose The amount of intraoperative hemorrhages and factors associated with hemorrhages and transfusions during revision total hip arthroplasty (reTHA) have not been identified for Japanese patients. We aimed to clarify the amount of intraoperative hemorrhages, and to elucidate the factors associated with hemorrhages and transfusions during reTHA in Japanese patients.

Methods We retrospectively reviewed patients who underwent reTHA ($n=48$) and primary total hip arthroplasty (pTHA) ($n=615$) in a single hospital and extracted data regarding hemorrhage, transfusion, patient comorbidities, and surgical anesthesia. We defined massive blood loss (MBL) as a hemorrhage comprising more than half of the circulating blood volume within 3 h. The odds ratio (OR) and 95% confidence interval (CI) were estimated using a multivariate logistic regression analysis.

Results There was a significant difference in hemorrhages between reTHA and pTHA patients (1790 g versus 625 g; $p<0.001$). Among patients with reTHA, MBL was significantly associated with younger age (OR 0.91; 95% CI 0.84–1.00; $p=0.04$) and lower body mass index (BMI) (OR 0.69; 95% CI 0.53–0.91; $p=0.01$). Although not significant, the incidence of MBL tended to be higher for patients with hyperlipidemia (OR 4.88; 95% CI 0.99–24.1; $p=0.051$). Furthermore, the need for allogeneic transfusion was significantly associated with the number of prepared autologous blood packs (OR 0.15; 95% CI 0.07–0.55; $p=0.002$).

Conclusion Although this study was limited by its small population and a possibility of underestimating the hemorrhage, hemorrhages in reTHA patients was two times greater than that in pTHA patients. Younger age and lower BMI increased the risk of MBL in reTHA. Preparing autologous blood decreased the risk of intraoperative allogeneic transfusion.

Keywords Revision total hip arthroplasty · Hemorrhage · Transfusion

Introduction

Massive blood loss (MBL) during surgery causes a high incidence of complications and often requires blood transfusions, which can cause adverse effects [1, 2]. Hip joint surgeries are regarded as major invasive procedures that can result in MBL [3]. Among hip joint surgeries, revision total hip arthroplasty (reTHA) is a challenging surgical procedure compared to primary total hip arthroplasty (pTHA) because perioperative complications and unexpected incidents at the time of surgery are much more common in reTHA [4, 5].

Retrospective reTHA studies have reported the amount of hemorrhages and incidence of transfusions [6–8]. One of those reported significantly greater hemorrhage in men and older patients [7]. This study also showed that dual-component surgery and a lower preoperative hemoglobin (Hb) concentration were associated with transfusion [7].

✉ Tadaho Nakamura
tadahonakamura@tohoku-mpu.ac.jp

1 Department of Anesthesia, Tohoku Rosai Hospital, Sendai, Japan

2 Department of Anesthesiology and Perioperative Medicine, Tohoku University Graduate School of Medicine, Sendai, Japan

3 Department of Pharmacology, Tohoku University Graduate School of Medicine, Sendai, Japan

4 Division of Pharmacology, Faculty of Medicine, Tohoku Medical and Pharmaceutical University, 1-15-1 Fukumuro, Miyagino-ku, Sendai, Miyagi 983-8536, Japan

5 Department of Anesthesia, Minami Soma General Hospital, Minamisōma, Japan

However, these studies were conducted in Western countries and did not mention racial distributions or differences [6–8]. For other major surgeries, non-white, non-black race was identified as an independent predictor of perioperative transfusion in major vascular surgery [9]. Furthermore, Stentz et al. reported that Asian American women were 1.7 times more likely to receive a transfusion than Caucasian women among patients undergoing myomectomy [10]. These results indicate that Asian race may become a risk factor for transfusion.

We assume that it is essential to determine associated risk factors for hemorrhage and transfusion during reTHA for those of East Asian descent to provide those patients with an optimal perioperative environment. Therefore, the aims of this study are to clarify the amount of intraoperative hemorrhages, and to elucidate the factors associated with hemorrhages and transfusions during reTHA in Japan.

Methods

This study conformed with the ethical principles of the Declaration of Helsinki and was approved by the institutional ethical committee of Tohoku Rosai Hospital in Sendai, Japan (2014/1/9, Tohokurin number 14-29). The committee also exempted the study from requiring patient consent for the analysis of sensitive data.

Data collection

We reviewed the medical charts of adult patients who underwent total hip arthroplasty (THA) from April 2009 to January 2014 in Tohoku Rosai Hospital, Sendai, Japan to compare hemorrhages that can occur during reTHA with those that can occur during pTHA. The pTHA group included patients who had undergone THA for the first time. The reTHA group included patients who underwent a revision procedure with replacement of dual components. We excluded patients who underwent revision of either only the acetabular or femoral component. All operations were performed by the same two orthopedic surgeons. Data regarding age, sex, height, weight, body mass index (BMI), American Society of Anesthesiologists physical status (ASA-PS) score, type of anesthesia, operative time, anesthesia time, Hb level, hemorrhage, infusion, and transfusion were noted for the reTHA and pTHA groups. The amount of hemorrhages, infusions, and transfusions were counted from the start of surgery until discharge from the operating room. Postoperative hemorrhage after discharge from the operating room was not included in the amount of hemorrhage. We defined MBL as follows: hemorrhage comprising more than half of the circulating blood volume within 3 h [11]. We defined the beginning time of 3 h, which was an important factor for determining MBL, as follows: the time when the first amount of hemorrhage was recorded in the anesthesia chart. If the time between the first hemorrhage in the chart and operating room discharge was shorter than 3 h, the total amount of hemorrhage was counted from the first hemorrhage-recorded time to operating room discharge. The estimated circulating blood volume was calculated using the following equation: body weight (kilogram) × 70 mL.

To evaluate the perioperative factors associated with intraoperative hemorrhage and transfusion in the reTHA group, preoperative medical complications such as asthma, diabetes mellitus, heart disease, hyperlipidemia, hypertension, liver disease, osteoporosis, rheumatoid arthritis, and renal disease were collected from the anesthesia records. Heart disease included coronary artery disease and heart failure. Liver disease included cirrhosis and abnormalities in liver function tests. Renal disease included renal failure and dialysis. We also collected information regarding medications such as anticoagulants, antiplatelet agents, nonsteroidal anti-inflammatory drugs, statins and steroids. In addition, we extracted Hb levels, platelet counts, prothrombin time international normalized ratios (PT-INR), and activated partial thromboplastin times (APTTs) from electronic medical records. Postoperative Hb levels and platelet counts were examined on the first morning after surgery. PT-INR and APTT were measured on the morning of day 4 after surgery. Since anesthesia records were written on paper, we calculated the mean blood pressure (mBP) by converting anesthesia records to PDF files and then plotting intraoperative systolic and diastolic blood pressures (BPs). We calculated mBP according to the following formula: mBP = mean diastolic BP + (mean systolic BP − mean diastolic BP)/3. The intraoperative mean body temperature (mBT) was collected from anesthesia records. Patients under general anesthesia (GA) underwent continuous nasal temperature measurements. However, those under regional anesthesia underwent transient axillary temperature measurements. A body-heating device was used during surgery according to the judgment of the anesthesiologist. The anesthesia method was determined after discussion between the surgeon and anesthesiologist in charge.

Autologous blood was collected from patients younger than 75 years of age whose Hb level exceeded 11 g/dL. For pTHA patients, 800 mL of autologous blood was collected in 400-mL portions on two occasions. For reTHA patients, 1200 mL was collected in 400-mL portions on three occasions if possible. The anesthesiologist comprehensively evaluated each patient and used allogenic or autologous transfusions. Autologous transfusions were preferred over allogeneic transfusions. The standard Hb concentration that indicated the need for a blood transfusion was < 7.0 g/dL.

Statistical analysis

For continuous variables with a normal distribution, the mean (± standard deviation) is reported. For variables that were not normally distributed, the median and interquartile ranges are reported. Continuous variables are described by numeric values, not by cutoff values. Statistical differences in the groups were tested using Student's *t* tests or Wilcoxon's test, when appropriate, for continuous variables; Fisher's exact test was used to evaluate categorical variables. We also performed multivariate logistic regression analysis to compare the least-squares mean for hemorrhages between the groups. To identify perioperative factors associated with MBL or concentrated red cell (CRC) transfusion, we performed a univariate logistic regression analysis first. Then, all preoperative factors with $p < 0.20$ in the univariate analyses were applied as explanatory variables in the multivariate logistic regression analysis of MBL or CRC transfusion as the outcome variable. Odds ratios (ORs) and their 95% confidence intervals (CIs) are reported. All data were analyzed using JMP Pro software (version 12; SAS Inc., Cary, NC, USA), IBM SPSS (version 22.0; IBM Japan, Tokyo, Japan), or STATA 14.2 (Stata Corp., College Station, TX, USA). All statistical tests were two-sided, and differences of $p < 0.05$ were accepted as significant.

Results

Seventy-two reTHAs and 615 pTHAs were performed in our hospital between April 2009 and January 2014. All patients were Mongoloid Japanese. Orthopedic surgeons administered 10 mg of tranexamic acid into the all-operative joint through the drain after wound closure. pTHA did not include any minimally invasive surgery. Among 72 reTHA patients, 23 patients had only acetabular components replaced, and 1 patient had only a femoral component replaced. These 24 patients were excluded from the subsequent analysis. We included 48 patients as the reTHA group; they had both acetabular and femoral components replaced.

The characteristics of the patients in both the reTHA and pTHA groups are shown in Table 1. There were significant differences in height, body weight, ASA-PS, operative time, anesthesia time, postoperative Hb level, and reduction of the Hb level. More than 50% of reTHA patients received GA, whereas almost 90% of pTHA patients received combined spinal and epidural anesthesia.

Intraoperative hemorrhage and the incidence of MBL in the reTHA and pTHA groups are shown in Table 2 and Fig. 1. We found that reTHA patients experienced twice as much hemorrhaging than pTHA patients (reTHA versus [vs.] pTHA: 1790 g vs. 625 g; $p < 0.01$) (Table 2). A multivariate logistic regression analysis involving age, sex, BMI, ASA-PS, and type of anesthesia as covariates also showed that there was a significant difference in hemorrhages between both groups (2138 g vs. 854 g; $F = 202$; $p < 0.01$). Moreover, the incidence of MBL was significantly higher in the reTHA group than the in pTHA group (46% vs. 0.2%; $p < 0.01$) (Table 2). Infusion and transfusion data for both groups are also shown in Table 2. The volumes of total infusion, crystalloids, colloids, and total transfusion, as well as the volumes and frequencies of autologous and allogeneic transfusions were higher in the reTHA group than in the pTHA group. Allogeneic transfused patients, except for one, received only CRC; the one patient lost 5900 g of blood and received fresh–frozen plasma and platelet concentrate. These results indicated that nearly half of the reTHA patients experienced MBL, and that they needed much more transfusions than the pTHA patients. Therefore, we investigated perioperative factors related to MBL or CRC transfusions for reTHA patients.

To establish the association between all variables and MBL, we performed univariate logistic regressions first (Table 3). The univariate analysis identified five significant preoperative variables for increased risk of MBL: age (OR 0.96); body weight (OR 0.91); BMI (OR 0.74); hyperlipidemia (OR 2.78); and preoperative APTT (OR 1.15). These preoperative variables, except for body weight, were included in the multivariate logistic regression analysis. Body weight was excluded so it would not affect multicollinearity.

Intraoperative BP and BT are known to be associated with hemorrhage [12]; however, these variables were excluded from the multivariate logistic regression analysis, because there were no significant differences in mBP and mBT between the MBL and non-MBL groups. There were missing values for intraoperative BT; therefore, we supplemented the values by multiple imputations using STATA 14.2 [13]. The data of the mBT before supplementation with multiple imputations are shown in Table 3. The data after supplementation with multiple imputations included an OR of 0.50 and $p = 0.27$.

Hemorrhage was excluded from the multivariate logistic regression analysis because hemorrhage was used to determine MBL or non-MBL. Although longer operative times, longer anesthesia times, and more total transfusion volumes were significantly associated with the incidence of MBL in the univariate analysis, we did not include these factors in the multivariate logistic regression analysis because they did not have predictive values. There were also significant differences between the MBL and non-MBL groups regarding the postoperative platelet counts and postoperative APTT, but these variables were also excluded from the multivariate logistic regression analysis because they were postoperative variables.

Table 1 Characteristics of patients in the reTHA and pTHA groups

	reTHA ($n=48$)	pTHA ($n=615$)	p value
Age (years)	68.6 ± 11.1	66.2 ± 11.5	0.16
Female sex	42 (88%)	517 (84%)	0.68
Height (cm)	150.5 ± 8.5	153.5 ± 7.9	0.012*[a]
Body weight (kg)	53.6 ± 11.8	57.2 ± 10.5	0.023*[a]
BMI (kg/m^2)	23.5 ± 4.1	24.3 ± 3.9	0.20
ASA-PS			
I	4 (8.3%)	151 (25%)	0.019*[c]
II	43 (90%)	445 (73%)	
III	1 (2.1%)	19 (3.1%)	
Type of anesthesia			< 0.001*[c]
CSEA	12 (25%)	548 (89%)	
GA + Epi	27 (56%)	14 (2.3%)	
GA	5 (10%)	49 (8.0%)	
Others	4 (8.3%)	4 (0.7%)	
Operative time (min) (range)	204.5 (178.25–264.75)	96 (77.5–116)	< 0.001*[b]
Anesthesia time (min) (range)	301 (268.75–354.5)	158 (140–182)	< 0.001*[b]
Hb level (g/dL)			
Preoperative	12.4 ± 1.5	12.2 ± 1.3	0.26
Postoperative	8.0 ± 1.1	9.6 ± 1.3	< 0.001*[a]
Reduction	4.3 ± 1.4	2.6 ± 1.4	< 0.001*[a]

"Others" include spinal anesthesia and peripheral nerve block. Postoperative Hb levels were examined on the first morning after surgery. Hb reduction was calculated by subtracting the postoperative Hb from the preoperative Hb. The values with a normal distribution are provided as the mean and standard deviations. The values with non-normal distribution are presented as the median and interquartile range

reTHA revision total hip arthroplasty, *pTHA* primary total hip arthroplasty, *BMI* body mass index, *ASA-PS* American Society of Anesthesiologists physical status, *CSEA* combined spinal and epidural anesthesia, *GA* general anesthesia, *Epi* epidural anesthesia, *Hb* hemoglobin

*$p < 0.05$ between the groups

[a]Student's t test

[b]Wilcoxon's test

[c]Fisher's exact test

Table 2 Intraoperative hemorrhage, incidence of MBL, infusion volume, and transfusion volume for reTHA and pTHA patients

	reTHA ($n=48$)	pTHA ($n=615$)	p value
Hemorrhage (g)	1790 (1312.5–2327)	625 (460–860)	< 0.001*[a]
Incidence of MBL	22 (46%)	1 (0.2%)	< 0.001*[b]
Total infusion (mL)	3675 (2750–4487.5)	1800 (1500–2100)	< 0.001*[a]
Crystalloids (mL)	2500 (1900–3387.5)	1250 (950–1600)	< 0.001*[a]
Colloids (mL)	1000 (1000–1450)	500 (0–1000)	< 0.001*[a]
Total transfusion (mL)	800 (400–1120)	0 (0–400)	< 0.001*[a]
Autologous transfusion (mL)	0 (0–600)	0 (0–400)	< 0.001*[a]
Autologous transfusion (n)	22 (46%)	171 (28%)	0.013*[b]
Allogeneic transfusion (mL)	0 (0–560)	0 (0–0)	< 0.001*[a]
Allogeneic transfusion (n)	19 (40%)	35 (5.7%)	< 0.001*[b]

All prescribed crystalloids were Ringer's solution. Colloids included hydroxyethyl starch and albumin solution. The total transfusion indicated the total volume of allogenic and autologous transfusions. The values with a non-normal distribution are given as the median and interquartile range (first quartile and third quartile)

reTHA revision total hip arthroplasty, *pTHA* primary total hip arthroplasty, *MBL* massive blood loss

*$p < 0.05$ between groups

[a]Wilcoxon's test

[b]Fisher's exact test

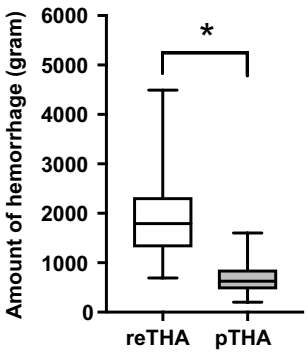

Fig. 1 Amount of hemorrhages in reTHA and pTHA patients. reTHA: revision total hip arthroplasty, pTHA: primary total hip arthroplasty. The bars indicate the median value and 5% and 95% confidence intervals. Boxes indicate the 25th and 75th percentiles, respectively, for each group. reTHA: $n=48$; pTHA: $n=615$; $p<0.05$ according to Levene's test. *$p<0.001$ according to Wilcoxon's test

To determine preoperative factors associated with MBL, multivariate logistic regression analysis with age, BMI, hyperlipidemia, and preoperative APTT as covariates was performed (Table 4). Younger age was associated with the incidence of MBL (OR 0.91; 95% CI 0.84–1.00; $p=0.04$). Lower BMI was also a significant factor that affected the incidence of MBL (OR 0.69; 95% CI 0.53–0.91; $p=0.01$). The incidence of MBL tended to be higher for patients with hyperlipidemia, although it was not statistically significant (OR 4.88; 95% CI 0.99–24.1; $p=0.051$).

To establish the relationship between all variables and CRC transfusion, we performed univariate logistic regression analysis (Table 5). The univariate analysis showed nine significant preoperative variables for the increased risk of CRC transfusion: age (OR 1.05); diabetes mellitus (OR 10); hypertension (OR 4); rheumatoid arthritis (OR 0.16); statins (OR 3.65); steroid medication (OR 5.25); preoperative Hb level (OR 0.77); preoperative platelet count (OR 0.90); and number of prepared autologous blood packs (OR 1.00). We initially planned to forcibly include all these variables; however, nine explanatory variables were too many to perform multivariate logistic regression analysis in 48 reTHA patients. To prevent overfitting, we used a multivariate analysis model of CRC that included the variables with $p<0.10$ in the univariate analysis (five variables: diabetes mellitus, hypertension, statins, the preoperative platelet count, and number of prepared autologous blood packs).

Intraoperative BP and BT were excluded from the multivariate logistic regression analysis because they did not have significant differences. All intraoperative and postoperative factors were also excluded from the multivariate logistic regression analysis because they did not have predictive values.

To identify the risk factors of CRC transfusion, we performed a multivariate logistic regression analysis using diabetes mellitus, hypertension, statins, the preoperative platelet count, and number of prepared autologous blood packs as covariates (Table 6). The multivariate logistic regression analysis revealed that the number of prepared autologous blood packs decreased the use of CRC transfusions (OR 0.15; 95% CI 0.07–0.55; $p=0.002$).

Discussion

We performed a single-center, retrospective study to identify hemorrhage and transfusion occurring with reTHA and compared them with those occurring with pTHA performed by the same orthopedic surgeons during the same period in Japanese patients. We found that reTHA patients had significantly greater hemorrhages and needed more transfusions than pTHA patients. The multivariate logistic regression analysis revealed that younger age and lower BMI increased the risk of MBL. We also identified that preparing an autologous transfusion decreased the risk of one requiring a CRC transfusion.

reTHA patients with shorter heights and lighter weights had longer surgical times under GA than did pTHA patients (Table 1). There was a no major difference in the mean age of patients in this study compared to that of previous reports [6, 7, 14]. Compared to previous studies, the proportion of female patients was higher [6, 7]. This might be because of the higher incidence of developmental dysplasia of the hip, which causes osteoarthritis, in Japanese women [15].

We found that the amount of intraoperative hemorrhage was 2.9 times greater, and that the incidence of MBL was significantly higher in the reTHA group than in the pTHA group (Table 2). There were no differences in pTHA hemorrhages in this study when compared with previous studies [12, 16, 17]. For reTHA patients, the reductions of the Hb level were similar to those of dual component revision in a previous study [7]. Therefore, we estimated that the procedural skills of the surgeons in this study were standard.

The multivariate logistic regression analysis showed that younger age was significantly associated with an increased incidence of MBL (Table 4). Since the incidence of prosthetic joint infection seemed higher for younger patients and was an indication for reTHA in our hospital, it might have led to increased hemorrhages in this study. In contrast, Mahadevan et al. reported that older age was identified as an

Table 3 Characteristics of reTHA patients with massive and non-massive blood loss

	MBL ($n=22$)	Non-MBL ($n=26$)	OR	p value
Preoperative factors				
Age (years)	66.2 ± 13.2	70.6 ± 8.8	0.96	0.19*
Female sex	20 (91%)	22 (85%)	1.82	0.52
Height (cm)	149.1 ± 8.2	151.6 ± 8.8	0.97	0.32
Body weight (kg)	48.3 ± 10.6	58.1 ± 11.0	0.91	0.010*
BMI	21.6 ± 3.7	25.2 ± 3.7	0.74	0.006*
Complications				
Asthma	1 (4.5%)	1 (3.8%)	1.19	0.90
Diabetes mellitus	3 (14%)	3 (12%)	1.21	0.83
Heart disease	4 (18%)	5 (19%)	0.93	0.93
Hyperlipidemia	10 (45%)	6 (23%)	2.78	0.11*
Hypertension	13 (59%)	19 (73%)	0.60	0.42
Liver disease	12 (56%)	12 (46%)	1.4	0.56
Osteoporosis	4 (18%)	4 (15%)	1.22	0.80
RA	4 (18%)	4 (15%)	1.22	0.80
Renal disease	1 (4.5%)	2 (7.7%)	0.57	0.66
Medications				
Anticoagulants	1 (4.5%)	2 (7.7%)	0.57	0.66
Antiplatelet agents	1 (4.5%)	4 (15%)	0.26	0.25
NSAIDs	5 (23%)	4 (15%)	1.62	0.52
Statins	6 (27%)	5 (19%)	1.58	0.51
Steroids	2 (9.0%)	2 (7.7%)	1.2	0.86
Hb level (g/dL)	12.5 ± 1.6	12.4 ± 1.5	1.03	0.88
Platelet count ($\times 10^4$)	21.3 ± 5.4	22.4 ± 5.9	0.96	0.49
PT-INR	1.04 ± 0.05	1.05 ± 0.16	0.48	0.78
APTT	30.0 ± 2.3	28.5 ± 4.1	1.15	0.14*
Intraoperative factors				
Mean blood pressure (mmHg)	66.3 ± 1.6	66.9 ± 1.5	0.99	0.77
Mean body temperature (°C)	36.6 ± 0.6 ($n=15$)	36.7 ± 0.3 ($n=22$)	0.77	0.73
Operative time (min)	224.5 (186.75–281.75)	193.5 (169.25–257.25)	1.01	0.050*
Anesthesia time (min)	311 (285.75–393.75)	282.5 (259.5–333)	1.02	0.010*
Amount of hemorrhage (g)	2380.5 (1794–3395)	1410 (1200–1805)	1.00	0.001*
Total transfusion (mL)	800 (280–1132.5)	400 (210–800)	1.00	0.044*
Postoperative factors				
Hb level (g/dL)	7.8 ± 1.3	8.2 ± 1.0	0.77	0.32
Platelet count ($\times 10^4$)	10.9 ± 4.2	13.6 ± 4.3	0.85	0.037*
PT-INR	1.13 ± 0.20	1.10 ± 0.10	4.33	0.48
APTT	31.1 ± 3.8	29.0 ± 3.0	1.21	0.047*

The values with a normal distribution are given as the mean and standard deviations. The values with a non-normal distribution are given as the median and interquartile range

reTHA revision total hip arthroplasty, *MBL* massive blood loss, *OR* odds ratio, *BMI* body mass index, *RA* rheumatoid arthritis, *NSAIDs* non-steroidal anti-inflammatory drugs, *Hb* hemoglobin, *PT-INR* prothrombin time international normalized ratio, *APTT* activated partial thromboplastin time

*$p<0.20$ between the groups in the univariate logistic regression analysis

Table 4 Preoperative factors associated with MBL according to the multivariate logistic regression analysis in reTHA patients

Variable	OR (95% CI)	*p* value
Age	0.91 (0.84–1.00)	0.040*
BMI	0.69 (0.53–0.91)	0.010*
Complications		
Hyperlipidemia	4.88 (0.99–24.1)	0.051
APTT, preoperative	1.06 (0.86–1.31)	0.59

Variables with $p < 0.20$ in the univariate logistic regression analysis were entered into the multivariate logistic regression analysis

MBL massive blood loss, *reTHA* revision total hip arthroplasty, *BMI* body mass index, *APTT* activated partial thromboplastin time, *OR* odds ratio, *CI* confidence interval

*$p < 0.05$ between the groups

independent variable with a significant correlation to hemorrhage in reTHA [7]. Reasons for the contrary were unclear, although there might have been several differences between the studies, such as the following: we analyzed the factors associated with MBL but not hemorrhage; we included only reTHA patients who underwent both acetabular and femoral replacements; the indications for reTHA; and patient population.

Patients with hyperlipidemia tended to have a higher incidence of MBL (OR 4.88; 95% CI 0.99–24.1; $p = 0.051$) (Table 4). An observational study showed that the increase in low-density lipoprotein cholesterol level was associated with non-vertebral fractures, including hip and leg fractures [18]. In addition, a high blood cholesterol level was associated with low bone mineral density [19]. These studies led us to assume that hyperlipidemia is associated with reduced bone mass in patients with artificial hip joint implants, resulting in femoral shaft fractures during surgery. In our experience, intraoperative fractures are observed after reaming and implantation of the femoral bone. However, we could not determine the correlation between osteoporosis and MBL.

We performed multivariate logistic regression analysis to identify the factors associated with MBL. First, we performed univariate analysis to screen out the variables that should be ruled out from multivariate logistic regression analysis to avoid overfitting. We identified 5 variables that had a *p* value < 0.20. In terms of the preoperative APTT, the univariate analysis showed an OR of 1.15 and *p* value of 0.14 (Table 3). Next, we performed multivariate logistic regression analysis of MBL, which include variables with a *p* value < 0.20 in univariate analysis (4 variables: age, BMI, hyperlipidemia, and preoperative APTT) in Table 4. The multivariate analysis showed that preoperative APTT was not associated with the incidence of MBL (OR 1.06; CI 0.86–1.31; $p = 0.59$). This result indicated that other variables included in the multivariate analysis such as age, BMI, and hyperlipidemia might exert an influence as a confounding factor on the preoperative APTT. In addition, there was a possibility that factors that we did not include in this study were confounding factors.

We found that the number of prepared autologous blood packs was the only variable that was significantly associated with CRC transfusions (Table 6). In addition, a randomized, controlled study of pTHA patients reported the efficacy of intraoperative autologous transfusion for reducing allogenic CRC transfusion requirements [20]. These results suggested that prepared autologous blood might reduce CRC transfusions required for reTHA patients.

This is the first study to report the amount of hemorrhage specifically in reTHA surgery in the East Asian population. However, this retrospective study was limited by its small population and its use of a single center. Therefore, our results cannot be easily generalized to all other populations. Residual confounding factors not included in this study might influence hemorrhages and transfusions in reTHA patients even after we included all the clinically relevant characteristics in the analysis, using some statistical technics such as multiple imputations. In addition, there was a possibility of underestimating the hemorrhage because postoperative hemorrhage after discharge was not included in the amount of hemorrhage.

In conclusion, we found that hemorrhages occurred two times more often with reTHA than with pTHA in Japanese patients. In addition, younger age and lower BMI increased the risk of MBL, and preparing autologous transfusions decreased the risk of CRC transfusions. Finally, hyperlipidemia might be associated with increased hemorrhages. This retrospective single-center study was limited by its small population and a possibility of underestimating the hemorrhage.

Table 5 Characteristics of reTHA patients with or without CRC administration

	CRC ($n=19$)	Non-CRC ($n=29$)	OR	p value
Preoperative factors				
Age (years)	71.8 ± 2.5	66.5 ± 2.0	1.05	0.12*
Female sex	18 (95%)	24 (83%)	3.75	0.25
Height (cm)	149.1 ± 2.0	151.3 ± 1.6	0.97	0.39
Body weight (kg)	52.9 ± 2.7	54.1 ± 2.2	0.99	0.74
BMI	23.7 ± 0.9	23.4 ± 0.8	1.02	0.75
Complications				
Asthma	0 (0%)	2 (6.9%)	1	–
Diabetes mellitus	5 (26%)	1 (3.5%)	10	0.044*
Heart disease	3 (16%)	6 (21%)	0.72	0.67
Hyperlipidemia	8 (42%)	8 (28%)	1.9	0.30
Hypertension	16 (84%)	16 (57%)	4	0.06*
Liver disease	9 (47%)	15 (52%)	0.84	0.77
Osteoporosis	4 (21%)	4 (14%)	1.67	0.51
RA	5 (26%)	3 (10%)	3.10	0.16*
Renal disease	3 (16%)	0 (0%)	1	–
Medications				
Anticoagulants	2 (11%)	1 (3.5%)	3.29	0.35
Antiplatelet agents	2 (11%)	3 (11%)	1.02	0.98
NSAIDs	2 (11%)	7 (24%)	0.37	0.25
Statins	7 (37%)	4 (14%)	3.65	0.072*
Steroids	3 (16%)	1 (3.5%)	5.25	0.17*
Hb level (g/dL)	12.1 ± 0.3	12.7 ± 0.3	0.77	0.19*
Platelet count ($\times 10^4$)	20.1 ± 1.3	23.0 ± 1.0	0.90	0.084*
PT-INR	1.04 ± 0.03	1.04 ± 0.02	0.92	0.97
APTT	29.8 ± 0.8	28.8 ± 0.6	1.08	0.37
Number of prepared autologous blood packs	0.26 ± 0.20	1.84 ± 0.16	0.19	< 0.001*
Intraoperative factors				
Mean blood pressure (mmHg)	67.2 ± 1.7	66.3 ± 1.4	1.02	0.67
Mean body temperature (°C)	36.7 ± 0.4 ($n=13$)	36.6 ± 0.5 ($n=24$)	1.32	0.72
Operative time (min)	216 (177–284)	200 (178.5–243.5)	1.01	0.11*
Anesthesia time (min)	331 (266–396)	286 (269.5–322.5)	1.01	0.024*
Amount of hemorrhage (g)	1842 (1600–3310)	1490 (1200–2150)	1.00	0.015*
Total transfusion volume (mL)	560 (560–1120)	400 (0–800)	1.00	0.02*
Volume of used autologous blood (mL)	0 (0–0)	400 (0–800)	1.00	0.004*
Postoperative factors				
Hb level (g/dL)	8.1 ± 0.3	7.9 ± 0.2	1.19	0.51
Platelet count ($\times 10^4$)	10.8 ± 1.0	13.4 ± 0.8	0.86	0.054*
PT-INR	1.11 ± 0.03	1.11 ± 0.03	1.02	0.99
APTT	30.3 ± 0.8	29.8 ± 0.7	1.04	0.62

The values with a normal distribution are given as the mean and standard deviations. The values with a non-normal distribution are given as the median and interquartile range. One pack of prepared autologous blood contains 400 mL of blood

reTHA revision total hip arthroplasty, *CRC* concentrated red cell, *OR* odds ratio, *BMI* body mass index, *RA* rheumatoid arthritis, *Hb* hemoglobin, *PT-INR* prothrombin time international normalized ratio, *APTT* activated partial thromboplastin time

*$p < 0.20$ between the groups in the univariate logistic regression analysis

Table 6 Preoperative factors associated with CRC according to the multivariate logistic regression analysis in reTHA patients

Variables	OR (95% CI)	*p* value
Complications		
Diabetes mellitus	0.52 (0.29–9.42)	0.66
Hypertension	1.37 (0.15–12.5)	0.78
Statins	9.76 (0.70–137)	0.091
Platelet count, preoperative	0.88 (0.73–1.06)	0.19
Number of prepared autologous blood packs	0.15 (0.048–0.45)	0.001*

One pack of prepared autologous blood contained 400 mL. Variables with $p < 0.10$ in the univariate logistic regression analysis were entered in the multivariate logistic regression analysis

reTHA revision total hip arthroplasty, *CRC* concentrated red cell, *OR* odds ratio, *CI* confidence interval

*$p < 0.05$ between the groups

Acknowledgements This study was supported by JSPS KAKEN (Grant number 15K20028 and 17K16753). We acknowledge Dr. Akane Ui and Ms. Akiko Endo, a medical assistant, who helped with data collection.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

References

1. Toy P, Popovsky MA, Abraham E, Ambruso DR, Holness LG, Kopko PM, McFarland JG, Nathens AB, Silliman CC, Stroncek D, National Heart L and BIWG on T. Transfusion-related acute lung injury: definition and review. Crit Care Med. 2005;33:721–6.
2. Auroy Y, Lienhart A, Péquignot F, Benhamou D. Complications related to blood transfusion in surgical patients: data from the French national survey on anesthesia-related deaths. Transfusion. 2007;47:184S–9S.
3. Vera-Llonch M, Hagiwara M, Oster G. Clinical and economic consequences of bleeding following major orthopedic surgery. Thromb Res. 2006;117:569–77.
4. Kerboull L. Selecting the surgical approach for revision total hip arthroplasty. Orthop Traumatol Surg Res. 2015;101:S171–8.
5. Barrack RL. Preoperative planning for revision total hip arthroplasty. Clin Orthop. 2004;420:32–8.
6. Kessler S, Kinkel S, Käfer W, Puhl W, Schochat T. Influence of operation duration on perioperative morbidity in revision total hip arthroplasty. Acta Orthop Belg. 2003;69:328–33.
7. Mahadevan D, Challand C, Keenan J. Revision total hip replacement: predictors of blood loss, transfusion requirements, and length of hospitalisation. J Orthop Traumatol. 2010;11:159–65.
8. Nichols CI, Vose JG. Clinical outcomes and costs within 90 days of primary or revision total joint arthroplasty. J Arthroplast. 2016;31:1400–6.
9. Obi AT, Park YJ, Bove P, Cuff R, Kazmers A, Gurm HS, Grossman PM, Henke PK. The association of perioperative transfusion with 30-day morbidity and mortality in patients undergoing major vascular surgery. J Vasc Surg. 2015;61:1000–9.
10. Stentz NC, Cooney LG, Sammel MD, Shah DK. Association of patient race with surgical practice and perioperative morbidity after myomectomy. Obstet Gynecol. 2018;132:291–7.
11. Irita K. Risk and crisis management in intraoperative hemorrhage: human factors in hemorrhagic critical events. Korean J Anesthesiol. 2011;60:151–60.
12. Schmied H, Kurz A, Sessler DI, Kozek S, Reiter A. Mild hypothermia increases blood loss and transfusion requirements during total hip arthroplasty. Lancet. 1996;347:289–92.
13. Rubin DB, Schenker N. Multiple imputation for interval estimation from surveys with ignorable nonresponse. J Am Stat Assoc. 1985;81:366–74.
14. Salassa T, Hoeffel D, Mehle S, Tatman P, Gioe TJ. Efficacy of revision surgery for the dislocating total hip arthroplasty: report from a large community Registry. Clin Orthop Relat Res. 2014;472:962–7.
15. Hattori T, Inaba Y, Ichinohe S, Kitano T, Kobayashi D, Saisu T, Ozaki T. The epidemiology of developmental dysplasia of the hip in Japan: findings from a nationwide multi-center survey. J Orthop Sci. 2017;22:121–6.
16. Grosflam JM, Wright EA, Cleary PD, Katz JN. Predictors of blood loss during total hip replacement surgery. Arthritis Care Res. 1995;8:167–73.
17. Nuttall GA, Santrach PJ, Oliver WC, Horlocker TT, Shaughnessy WJ, Cabanela ME, Bryant S. The predictors of red cell transfusions in total hip arthroplasties. Transfusion. 1996;36:144–9.
18. Yamauchi M, Yamaguchi T, Nawata K, Tanaka K, Takaoka S, Sugimoto T. Increased low-density lipoprotein cholesterol level is associated with non-vertebral fractures in postmenopausal women. Endocrine. 2015;48:279–86.
19. Kim YH, Nam GE, Cho KH, Choi YS, Kim SM, Han BD, Han KD, Lee KS, Park CH, Kim DH. Low bone mineral density is associated with dyslipidemia in South Korean men: the 2008-2010 Korean National Health and Nutrition Examination Survey. Endocr J. 2013;60:1179–89.
20. Lorentz A, Osswald PM, Schilling M, Jani L. A comparison of autologous transfusion procedures in hip surgery. Anaesthesist. 1991;40:205–13.