Original Article

Four Methods for Calculating Blood-loss after Total Knee Arthroplasty

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Abstract

Background: Currently, various calculation methods for evaluating blood-loss in patients with total knee arthroplasty (TKA) are applied in clinical practice. However, different methods may yield different results. The purpose of this study was to determine the most reliable method for calculating blood-loss after primary TKA.
Methods: We compared blood-loss in 245 patients who underwent primary unilateral TKA from February 2010 to August 2011. We calculated blood-loss using four methods: Gross equation, hemoglobin (Hb) balance, the Orthopedic Surgery Transfusion Hemoglobin European Overview (OSTHEO) formula, and Hb-dilution. We determined Pearson's correlation coefficients for the four methods.
Results: There were large differences in the calculated blood-loss obtained by the four methods. In descending order of combined correlation coefficient based on calculated blood-loss, the methods were Hb-balance, OSTHEO formula, Hb-dilution, and Gross equation.
Conclusions: The Hb-balance method may be the most reliable method of estimating blood-loss after TKA.

Key words: Arthroplasty; Blood-loss; Calculation Method; Knee Replacement

Introduction

Total knee arthroplasty (TKA) is an extremely effective intervention for symptomatic osteoarthritis. However, it is associated with large amounts of perioperative blood-loss and high rates of transfusion.[1-3] Blood-loss may come from the osteotomized surface of the distal femoral and proximal tibial bones, release of the soft tissue injury area, and dredging of the marrow cavity.[3,4] Chronic anticoagulant medication use and early rehabilitation of joint function have also resulted in postoperative anemia, which are common concerns for postoperative complication after TKA surgery.[3-6]

Currently, various calculation methods for evaluating blood-loss in TKA patients are applied in clinical practice. However, different calculation methods may yield different results.[1-14] In this study, we compared four methods that are commonly used to calculate the amount of blood-loss after primary TKA. Our goals were to provide theoretical support for the most reliable method and an experimental model to improve blood management in clinical practice.

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Methods

We retrospectively studied 245 consecutive patients who underwent TKA from February 2010 to August 2011. Of them, 29 were males and 216 were females with a mean age of 65.6 years (range: 56–78 years). The average body mass index (BMI) was 28.61 kg/m^2 (range: 17.45–40.15 kg/m^2). The preoperative hemoglobin (Hb) was 131.25 g/L (range: 97–171 g/L). Inclusion criteria included primary TKA, no previous history of coagulation disorders, normal coagulant function preoperatively, and availability of complete medical record data. Exclusion criteria included revisions, bilateral joint arthroplasty procedures, active intravascular clotting disorders, and acute large hemorrhage. The most common

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comorbidities of the cohort were hypertension (116 cases), diabetes (39 cases), cardiovascular disease (11 cases), and cerebrovascular disease (5 cases). The study was carried out in accordance with the ethical standards described by the Local Ethics Committee of National Health Commission and was approved by the Ethics Committee of Peking University Third Hospital.

Calculation methods for evaluating blood-loss

We calculated the amount of blood-loss after primary TKA in the same group of patients using four common calculation methods: Gross equation (method 1), Hb-balance (method 2), Orthopedic Surgery Transfusion Hemoglobin European Overview (OSTHEO) formula (method 3), and Hb-dilution (method 4) [Table 1]. Demographic data, BMI, preoperative diagnosis, type of anesthesia, medical comorbidities, preoperative autologous blood donation, allogeneic blood transfusion, and pre- and post-operative complete blood count (CBC) including hematocrit (Hct); and Hb levels were evaluated.

Perioperative management

All procedures were primary and unilateral. All patients underwent a standard operation using a medial parapatellar approach. All TKAs were performed under tourniquet pressure, which was released at the end of the procedure after application of a pressure bandage. Wound drainage was connected to an autologous blood transfusion system (CBC II ConstaVac Blood Conservation Kit; Stryker, USA) as the tourniquet was deflated. The drained blood was autofiltered and retransfused during the 1st 6 h after the operation. Six hours later, the amount of drainage was recorded. The drain was removed 48 h after surgery. Low-molecular-weight heparin 4000–6000 U subcutaneously or aspirin 150 mg orally was administered postoperatively. Hb concentration was monitored and patients with Hb <80 g/L received red blood cell (RBC) transfusion. The amount of transfusion was recorded. When the anesthesia wore off, patients were instructed to exercise the ankle joint and perform muscular contraction exercises. Venous ultrasound of the lower limbs was performed in all patients to rule out deep vein thrombosis (DVT). Patients can ambulate with mobility aids 2–3 days after the operation and the stitches were removed 2 weeks after surgery. The complications after the surgery were readily managed by the appropriate measures, including DVT (calf muscular venous thrombosis, 63 cases), cerebral infarction (3 cases), urinary tract infection (2 cases), and pulmonary infection (2 cases).

Statistical analysis

All data analyses were performed using SPSS for Windows, version 16.0 (SPSS Inc., Chicago, IL, USA). The independent samples (or two-sample) *t*-test was used to compare the means of blood-loss obtained using the four calculation methods. Pearson's correlation analysis was applied to measure the similarity in blood-loss between pairwise results yielded by the four methods. An *r*-matrix of

Table 1: The specific computing process of four common calculated methods

Calculated methods	Specific computing process	Index
Method 1: Gross equation[1-3]	$BV = k_1 \times H^3 + k_2 \times W + k_3$ $V_{loss\ total} = BV \times (Hct_{preop} - Hct_{postop})$ For males, $k_1 = 0.3669$, $k_2 = 0.03219$, and $k_3 = 0.6041$, while for females, $k_1 = 0.3561$, $k_2 = 0.03308$, and $k_3 = 0.1833$ Once the mean Hct value is determined, the total blood volume can be further calculated	BV (ml): The patient's blood volume before surgery H (m): Height W (kg): Weight $V_{loss\ total}$ (ml): The total volume of RBC loss Hct_{preop} and Hct_{postop} (ml): The Hct values before and after surgery
Method 2: Hemoglobin balance[1,4,5,7]	$Hb_{loss\ total} = BV \times (Hb_i - Hb_e) \times 0.001 + Hb_t$ $V_{loss\ total} = 1000 \times Hb_{loss\ total}/Hb_i$ Generally, 1 U banked blood is considered to contain 52 ± 5.4 g Hb[5]	$Hb_{loss\ total}$ (g): The loss volume of Hb Hb_i (g/L): The Hb value before surgery Hb_e (g/L): The Hb value after surgery; Hb_t (g): The total volume of blood transfusion
Method 3: OSTHEO formula[8-13]	$V_{loss\ total} = V_{URL} + V_{CRL}$ $V_{URL} = V_{initial} - V_{final}$ $V_{initial} = BV \times Hct_{preop}$ $V_{final} = BV \times Hct_{postop}$ $BV = Z \times k$ For females, k = 2430, while for males, k = 2530 $Z\ (m^2) = 0.0235 \times H^{0.42246} \times W^{0.51456}$ A Hct of 35% indicates the total blood loss volume: Total blood loss volume = Total RBC loss volume (ml)/0.35. When the Hct = 60%, the RBC volume is equal to 250 ml, and when Hct = 100%, the RBC volume is equal to 150 ml/U[12,13] $V_{CRL} = T_{allogeneic} \times 150 + T_{drainage} \times 0.3$	$V_{loss\ total}$: The total RBC loss V_{URL}: Uncompensated RBC loss (URL) V_{CRL}: Compensated RBC loss (CRL). V_{CRL} represents the combination of all the RBCs from various forms of transfusions $V_{initial}$: The RBC volume before surgery (ml) V_{final}: The RBC volume after surgery (ml) Z: The body surface area, *k* is a regular value relating to sex $T_{allogeneic}$: Transfusion volume $T_{drainage}$: The volume of autologous transfusion or drainage A Hct from autologous transfusion after surgery is considered to be 30%
Method 4: Hemoglobin dilution[1,14]	$V_{loss\ total}$ (ml) $= BV \times (Hb_i - Hb_e)/Hb_i$ $Hb_e = Hb_i - Bood_{loss\ total} \times Hb_i/BV$ $Hb_{decrease} = Hb_i - Hb_e = Bood_{loss\ total} \times Hb_i/BV$	$Hb_{decrease}$ (g/L): The decrease in Hb

OSTHEO: Orthopedic Surgery Transfusion Hemoglobin European Overview; Hct: Hematocrit; Hb: Hemoglobin; Preop: Preoperative; Postop: Postoperative; URL: Uncompensated RBC loss; CRL: Compensated RBC loss; RBC: Red blood cell.

Pearson's correlation coefficient for pairwise comparison of blood-loss volume among the four methods was established. The size of the combined correlation coefficient (*r* value) reflected the degree of the relationship between an index and the other indexes, which indicated the relative reliability of the method.[15] The level of statistical significance was set at $P < 0.05$.

Results

The results of blood-loss volume for each calculation method are shown in Table 2. The methods were listed in descending order by means of calculated blood-loss volume after surgery. There were large differences among the calculated results of blood-loss after primary TKA for the four methods except between methods 1 and 2. The *r*-matrix of Pearson's correlation coefficient, constructed from the pairwise comparisons among the four methods, is shown in Tables 2–4. The larger the combined correlation coefficient (*r* value) was, the greater the degree of the relationship between an index and the other indexes. The combined correlation coefficients (Cr) of the four methods, calculated from the results as shown in Table 4, were Cr 1 = 1.389, Cr 2 = 1.685, Cr 3 = 1.641, and Cr 4 = 1.493.

The results obtained from the different methods varied greatly. When sorted in descending order of the combined correlation coefficient based on the calculated blood-loss yields, the methods were Hb-balance, OSTHEO formula, Hb-dilution, and Gross equation. The Hb-balance method may be the most reliable way to estimate the blood-loss after TKA.

Table 2: BL volume calculate by different methods (*n* = 245, ml)

Methods	Mean volume (SD)	Maximax volume	Minmax volume
Method 1	1127.6 (418.3)	2665.8	225.6
Method 2	1166.8 (482.5)	2449.0	270.9
Method 3	1699.3 (620.8)	3396.9	364.1
Method 4	971.6 (364.3)	2238.4	102.7

SD: Standard deviation; BL: Blood-loss.

Table 3: Results of *t*-tests pairwise comparison among four methods by which BL calculated

Items	Method 1	Method 2	Method 3
Method 2	−0.960	–	–
Method 3	−11.954*	−10.601*	–
Method 4	4.403*	5.053*	15.825*

*$P<0.05$. BL: Blood-loss. "–" represents not applicable.

Table 4: The *r*-matrix of Pearson correlation coefficient of the pairwise BL among four methods

Items	Method 1	Method 2	Method 3	Method 4
Method 1	1	–	–	–
Method 2	0.45371822	1	–	–
Method 3	0.52452683	0.68200108	1	–
Method 4	0.40998630	0.54906037	0.43445062	1

BL: Blood-loss."–" represents not applicable.

Discussion

The present study revealed large differences among the calculations of blood-loss after primary TKA using the four methods. Results for Hb-balance and the Gross equation were similar. However, they were found to be significantly different from the other methods. The OSTHEO formula produced the largest calculated blood-loss while the Hb-dilution method produced the smallest. Among the four calculation methods, Hb-balance method may be the most reliable of the four methods for estimating blood-loss after TKA.

The Hb-balance method is based on the balance of Hb during the perioperative period of primary TKA surgery.[4,16,17] It is regarded as an important method with intuitive expressiveness and high accuracy and often addresses contemporary clinical issues. Many scholars[1,4,5,7] chose this method to investigate the composition and mechanism of blood-loss after TKA surgery, thus that corroborated the clinical utility and rationality of the method. It is a scientifically logical method which widely applied to measure postoperative blood-loss. Our study also supported this view. While it is sometimes necessary to measure the concentration of Hb in postoperative drainage, the complexity of the clinical procedure, and increased medical costs, poor patient compliance limits the use of this method in our clinical practice.

The method described by Gross[2] for calculation of blood-loss after arthroplasty surgery is popular among surgeons. As blood-loss is occurring, the patient's circulating volume will tend to fall. However, the simultaneous shift of fluid into the circulating compartment and fluid administered perioperatively maintain the circulating volume, although with increasingly more dilute blood and the Hct gradually falls. The RBC loss, as hemorrhage, continues logarithmically.[3] In 1980, Ward *et al*.[18] published a mathematical solution to the shift of circulating volume and the concept was taken forward by Gross[2] in 1983. A new linear formula using the patient's average Hct during the perioperative course was proposed. Gross tested this in patients undergoing surgery. It was found that the Gross equation[2] closely approximated the logarithmic one unless there was substantial or brisk hemorrhage causing the formulas to drift from the normal baseline. For this reason, cases with large losses were excluded from this study. Because individual factors such as gender, height, weight, and volume of blood transfusion are taken into consideration, the Gross equation reflects actual postoperative blood-loss to some extent. This results in its extensive application in medical practice. However, the Gross equation does not involve Hb-related factors. Actual blood-loss and anemia are revealed by the calculated perioperative volume and the changing Hct,[19] which may be the limitations of this method.

The OSTHEO formula was developed by multiple research centers based on the OSTHEO study.[8-11,20] The OSTHEO study was a prospective study designed to examine blood management practices before, during, and after total knee and total hip arthroplasty in Europe and to determine factors that predicted the risk associated with allogeneic transfusion. Specifically, the study examined various factors related to blood collection and transfusion, including blood wastage, pre- and post-operative Hb evolution, transfusion-associated complications, and predictors of the likelihood of allogeneic transfusion. Better strategies for blood transfusion can be developed if the calculated total blood-loss is known.[9,21] The following demographic data associated with this study were collected: Date of birth, gender, country, height, and weight. Comorbid conditions, baseline Hb level, information concerning transfusion alternatives, the use and route of iron supplementation, and the use and total dose of recombinant human erythropoietin were also recorded.[9-11] Our results confirmed previous findings, yet also highlighted differences specific to European clinical practice. In addition, for the first time, blood usage for these types of surgeries was evaluated by calculating total perioperative blood-loss. A comprehensive blood management program for patients undergoing hip or knee arthroplasties minimizes the requirement for allogeneic transfusion.[9,22,23] Such a program would optimize patient management and would reduce complications associated with anemia and blood transfusions in patients undergoing hip and knee arthroplasty. The OSTHEO formula objectively describes the factors involved in perioperative blood-loss and effectively links to its used-blood management techniques, but the many variables involved make computations too complex. In addition, the blood volume calculated using the classic formula in the Gross equation was 0.35 m^2 less than that calculated using body surface area in the OSTHEO formula [Table 1]. This makes the two numeric variables significantly different ($t = -8.075$, $P = 5.3 \times 10^{-15}$). Its reason may be that the design of the formula itself results in a significant difference. Therefore, different designs of the formula itself may also be one of the reasons for the large deviation of calculated results.

Analysis of Hb-dilution after bleeding is a simple, inexpensive, and noninvasive method for estimating the blood-loss. Blood volume is estimated taking gender, weight, and height into consideration. The Hb concentrations before and after blood-loss were analyzed; assuming a normovolemic subject, the blood-loss volume can be calculated from the difference. Although widely used, this method has never been validated.[6] However, the value obtained using this method has been reported to be much smaller than another method. A study by Meunier *et al*.[14] calculated the blood-loss using the Hb-dilution method and compared the calculated value with the donated blood volume. The authors showed that the Hb-dilution method underestimates true blood-loss by more than 30% after moderate blood-loss of approximately 10% of the total blood volume. This is consistent with our findings in the present study. However, a requirement for correct calculation is a strictly normovolemic patient. Meunier *et al*.[14] demonstrated that blood volume is not fully normalized within a few days after an acute blood-loss. In most studies evaluating perioperative bleeding, the Hb concentration has been analyzed on the 2nd to 4th day after surgery.[2,3,24] The lowest Hb concentration caused by Hb-dilution following redistribution of fluid from the extravascular to the intravascular space was observed on day 6 after blood donation.[14,24-26] However, at this point, the Hb concentration was still higher than expected from blood-loss.[24] Because of this underestimation, the Hb-dilution method is in our opinion not suitable for calculation of the absolute blood-loss volume but can be used to produce a rough estimate.[14] This also suggests a limitation of the Hb-dilution method.

Because of the complexity and variability of the mechanism of perioperative blood-loss from TKA surgery, different calculation methods may lead to different blood-loss determinations. Currently, the specific mechanism of hidden blood-loss formation is still unknown. Many methods are based on certain assumptions and simulation experiments, which may differ greatly from clinical situations. Therefore, future studies should focus on the mechanism of postoperative blood-loss from arthroplasty in order to obtain more reliable calculation methods.

There are some limitations in this study. So far, the mechanisms of blood-loss after TKA have not been very clear. The methods are mainly based on the supported literature and the previous clinical observation. This study is limited by virtue of the retrospective analysis. There was no randomized and blinded control group with four methods in this study. However, we believed that the methods and results in the same patient population in this study did not affect the overall outcomes. Because there is no "gold standard" for calculated method, we used the combined correlation coefficient to evaluate the reliability of the four methods. The size of the combined correlation coefficient (r value) which we chose reflected the degree of relationship between an index and other indexes, which indicated the relative reliability of the method (refer to the statistical method described by Chen).[15] We recognized that this was where the problem of the statistical method used in the manuscript lies.

In conclusion, blood-loss volume calculated using different methods varies greatly. The Hb-balance method may be the most reliable method for estimating blood-loss after TKA.

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Conflicts of interest

There are no conflicts of interest.

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