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Hidden blood loss and its risk factors between high tibial osteotomy and unicompartmental knee arthroplasty for knee osteoarthritis: a retrospective study

Tao Yu[2], Yiqi Chen[2], Ziye Yang[2], Hao Chen[2], Zhenyu Shen[2], Enxing Xue[1] and Dengying Wu[1*]

Abstract

Purpose The aim of our study was to compare the hidden blood loss (HBL) between patients treated with unicompartmental knee arthroplasty (UKA) and high tibial osteotomy (HTO) and to identify predictors of HBL in this cohort.

Methods We conducted a retrospective study including 91 patients who had knee osteoarthritis, of which 31 cases (male/female: 12/19) received HTO and 60 cases (male/female: 24/36) received UKA, from January 2021 to January 2023. Demographics, clinical information and laboratory values were collected and compared. Recording preoperative and postoperative hematocrit and estimating intraoperative blood loss by surgeon to calculate HBL according to Nadler, Gross and Sehat formula. Effect sizes were determined using Cohen's *d* and Glass rank biserial correlation coefficient to assess clinical difference in the data. The Spearman correlation analysis was used to investigate an association between patient's characteristics and HBL. Multiple linear regression analysis was used to confirm independent risk factors of HBL.

Results The HBL and TBL of the HTO group (534.49 ± 336.05 ml, 639.65 ± 337.81 ml, respectively) are significantly higher than that in the UKA group (359.42 ± 263.51 ml, 408.76 ± 283.50 ml, respectively; $P=0.008$, $P=0.001$). Effect size analysis indicated moderate clinical significance (Cohen's *d* [95% CI] = 0.604 [0.160, 1.045] for HBL, 0.762 [0.312, 1.208] for TBL). The multiple linear regression analysis suggested post-operative hemoglobin values and hemoglobin loss were independent risk factors for HBL in the UKA and HTO groups.

Conclusion This study provides new insights into the comparative blood loss between HTO and UKA procedures, highlighting that HBL and TBL are significantly higher in HTO than in UKA. The moderate clinical significance of this difference emphasize the need for careful management of post-operative anemia, particularly in patients undergoing HTO, where blood loss may be more pronounced. Its risk factors should be paid more attention during the perioperative period.

Clinical trial number Not applicable.

*Correspondence:
Dengying Wu
wudy0577@163.com

Full list of author information is available at the end of the article

Keywords Osteoarthritis, Knee, Osteotomy, Risk factors, Arthroplasty, Retrospective studies

Introduction

Knee osteoarthritis (KOA) is a prominent global cause of disability, with main characteristics including cartilage damage, knee pain, functional disorders, and joint instability [1]. The aim of the management of KOA is to relieve pain, enhance knee function, and improve overall quality of life [2]. Based on the disease progression, the management should be personalized. Self-management program and pharmacologic interventions are mostly applied to mild-to-moderate KOA patients [3, 4]. High tibial osteotomy (HTO) and unicompartmental knee arthroplasty (UKA) are surgical interventions that may be indicated for moderate unicompartmental KOA if non-surgical interventions fail, whereas TKA is the primary treatment for symptomatic late-stage KOA. High tibial osteotomy was first conducted in 1958 to correct a varus deformity as a globally recognized treatment option for KOA, particularly for young and active patients [5, 6]. Unicompartmental knee arthroplasty (UKA) is an alternative to total knee arthroplasty (TKA) or HTO for medial compartment KOA, which was first introduced in the 1970s [7]. Ordinarily, UKA was used for elderly patients with absence of ligament instability, and unicompartmental KOA [8].

Since the concept of hidden blood loss (HBL) was first put forward by Sehat [9], multiple studies have provided evidence for HBL in a range of orthopedic surgical procedures [10, 11]. Foss et al. found that HBL, ranging from 547 ml to 1473 ml, was in excess of intraoperative blood loss after the surgery for fracture of the hip [10]. Wen et al. observed that the amount of HBL was 261 ml, or 50% of the total blood loss in anterior cervical fusion surgery [11]. Hidden blood loss may occur due to bleeding into tissues, residual in dead space or hemolysis. The amount and proportion of HBL vary across different surgical procedures. However, HBL has not received enough attention because of little amount of intraoperative blood loss.

To provide references for clinical practice and address the scarcity of research on the HBL and its risk factors between HTO and UKA, this study aims to compare the HBL between patients treated with UKA and HTO, and to identify predictors of HBL in these patient group.

Materials and methods

Our study has been reviewed and approved by the Ethics Committee of our hospital. After reviewing the medical record of all patients with KOA from January 2021 to January 2023, 91 patients were included in the analysis. Of these patients, 60 patients (male/female: 24/36) received UKA and 31 patients (male/female: 12/19) received HTO. This project has been approved by the Medical Ethics Committee of the Second Affiliated Hospital of Wenzhou Medical University (Approval No: 2022-K-155-01) and conducted in accordance with the ethical standards of the Declaration of Helsinki. The procedures were all performed by orthopedic surgeons skilled in both distinct surgical techniques.

Inclusion criteria were: (1) age > 30 years, with skeletal maturity; (2) primary single-side KOA; (3) complete medical and imaging data were available; (4) Tranexamic acid is not used for post-operative hemostasis.

Exclusion criteria were: (1) history of knee surgery; (2) severe hematologic disease; (3) combined inflammatory arthropathy; (4) administration of antiplatelet drugs or non-steroidal anti-inflammatory drugs one month before admission; (5) obviously wrong data.

Operative techniques of HTO group

After general anesthesia, the patient lay prostrate on the operating table. Then, the skin of the surgical area was disinfected. A pneumatic tourniquet was applied to the upper thigh to control intraoperative bleeding and enhance the surgical field visibility. The tourniquet was inflated prior to making the incision. The medial proximal tibia was exposed by a transverse incision. The long fibers of the medial collateral ligament were released. A Kirschner wire was inserted into the medial tibial plateau. The osteotomy was opened gradually using chisels and stabilized with a spreading device. The plate was inserted into the transverse incision and pushed distally into a soft tissue tunnel until the long arm lay on the tibial shaft. Then the plate was fixed using screws. C-arm fluoroscopy showed that the force line of the lower limb was satisfactory. After confirming optimal alignment and fixation, the surgical site was irrigated, and hemostasis was achieved. The tourniquet was gradually deflated, and the incision was carefully sutured in layers to ensure proper closure (Fig. 1A and B).

Operative techniques of UKA group

Same pre-operative preparations as in the HTO group were performed, including poisoning, sterilization, and draping, as well as administering appropriate anesthesia. In addition, the lateral radiographs were used to choose the size of the femoral and tibial component. A pneumatic tourniquet was applied to the upper thigh to control intraoperative bleeding and improve surgical visibility. The tourniquet was inflated after patient positioning and before making the incision, ensuring minimal blood flow to the surgical site during the procedure. Medial parapatellar incision was made from the distal pole of the patella to the medial side of the tibial

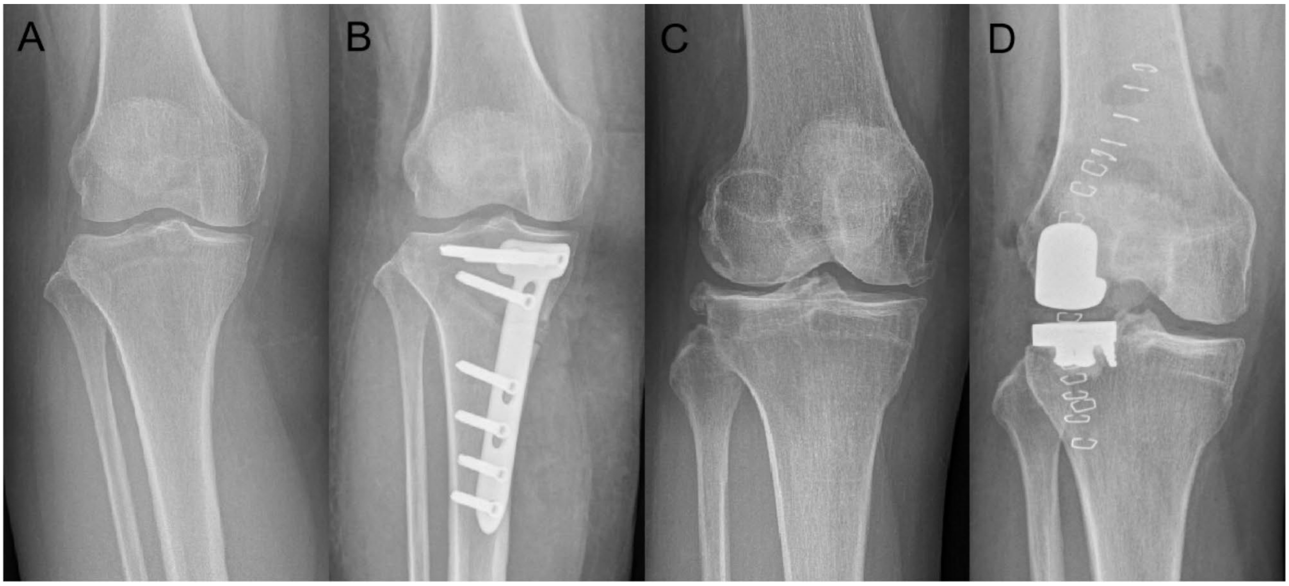

Fig. 1 Radiographic evaluation of HTO. (**A**) Preoperative anteroposterior view and (**B**) Postoperative Lateral view. Radiographic evaluation of UKA. (**C**) Preoperative anteroposterior view and (**D**) Postoperative Lateral view

tuberosity. The synovial cavity is opened, the retinacular fibers were reflected from the tibial, and the leg was flexed to expose the front of the plateau. Using the femoral drill guide, referenced to an intramedullary rod, 2 drill holes were made in the medial femoral condyle along the mechanical axis of the femur. A saw guide, located in the drills, directs the saw for excision of the femur. Bone cement was used to fix the femoral and tibial components. After confirming proper component alignment and joint stability, the wound was irrigated thoroughly to remove any debris and prevent infection. The tourniquet was then deflated slowly, and the surgical area was closely monitored for hemostasis before proceeding with wound closure. Finally, the incision was meticulously sutured in layers (Fig. 1C and D).

Data collection

Before the operation, pre-operative data was evaluated and recorded, including age, sex, height, weight, body mass index (BMI), and comorbid diseases (i.e., diabetes, hypertension). Post-operative variables included mean operative time, incisions length, the length of post-operative hospital stay, and intraoperative blood loss. The surgeon and surgical team visually estimate the amount of blood lost based on the appearance of the surgical field, soaking of sponges, and the volume in suction canisters. In addition, laboratory data of hemoglobin (Hb), hematocrit (Hct). In our study, 1st, 3rd, and 5th day after the operation were selected to detect Hct, and then the lowest value of Hct detected among these measurements was selected for calculation.

Calculation of hidden blood loss

Firstly, the Nadler formula was used to calculate the patient blood volume (PBV) [12]:

PBV (L) = height (m)^3 × 0.367 + weight (Kg) × 0.032 + 0.604 (For male patient).
PBV (L) = height (m)^3 × 0.356 + weight (Kg) × 0.033 + 0.183 (For female patient).

Secondly, using the Gross formula, the total blood loss (TBL) was calculated [13]:

TBL (ml) = PBV (L) × (Hctpre − Hctpost) / mean Hct × 1000.

(Hctpre is pre-operative Hct, Hctpost is post-operative Hct, and mean Hct is the average of Hctpre and Hctpost.)

After calculating TBL, HBL was determined according to Sehat formula [14]:

HBL (ml) = TBL (ml) − visible blood loss (VBL) (ml).

(Intraoperative blood loss was measured suction loss plus the weight of loss in swabs. None of patients received blood transfusion during the surgery, and no drainage was placed, therefore, intraoperative blood loss could be regarded as VBL.)

And the percentage of HBL = (HBL / TBL) × 100%.

Data analyses

IBM SPSS Statistics for Windows, version 26.0 (IBM Corp., Armonk, N.Y., USA) was used to analyze the data and statistical significance was set at $P < 0.05$ (two-sided). For *p*-values greater than 0.001, exact values should be reported; for *p*-values less than 0.001, the notation '$P < 0.001$' should be used. Based on baseline characteristics, it was determined whether they were comparable. For continuous variables, the Shapiro-Wilk test was applied to determine whether they followed a normal distribution, when appropriate. Continuous variables with normal distribution were presented as mean ± standard deviation (SD); non-normal variables were reported as median (interquartile range [IQR]). For normally distributed variables, the means were calculated and compared using the independent samples *t*-test (Student's *t*-test); otherwise, the Mann-Whitney *U* test was used for group comparison. Categorical variables were shown as number of cases (sex was reported as male/female ratio). The *Chi*-square test was used to analyze categorical variables. To quantify the magnitude of differences between groups, effect sizes were calculated based on the distribution characteristics of the data. For variables following a normal distribution, effect size was determined using Cohen's *d* [15]. Cohen's $d = 0.2$, 0.5 and 0.8 are defined cut-off values for small, medium and large effect sizes, respectively. For non-normally distributed variables, the effect size was estimated using the Glass rank biserial correlation coefficient [16] via R package "rcompanion" [17], which is appropriate for data analyzed with the Mann-Whitney U test. Values of this coefficient range from – 1 (all values of the second sample are larger than all values of the first sample) to 1 (all values of the second sample are smaller than all values of the first sample). Correlation analysis using Spearman correlation was performed initially to identify variables potentially correlated to the HBL. Any variable where the Spearman correlation had a value of $P < 0.05$ was accepted as a candidate for multivariate linear regression analysis to identify the independent risk factors associated with HBL.

Results

In total, 91 patients were included in our study: 60 patients (male/female: 24/36) treated with UKA and 31 patients (male/female: 12/19) treated with HTO (Figure. 2). The characteristics of patients are shown in Table 1. Compared with the UKA group, patients of HTO are younger ($P < 0.001$). No significant differences are indicated in terms of sex, height, weight, BMI, and comorbid diseases (i.e., diabetes, hypertension) ($P = 0.905$, $P = 0.959$, $P = 0.728$, $P = 0.734$, $P = 0.477$, $P = 0.382$, respectively). As shown in Table 2, perioperative parameters of the patients are recorded. Mean operative time in HTO group was significantly higher than that in UKA group (90 (30) mins vs. 80 (25) mins; $P < 0.001$) and incisions length is lower than that in UKA (8 (4) cm vs. 10 (0) cm; $P < 0.001$). No difference was found in the length of post-operative hospital stay between the two groups ($P = 0.148$).

In addition, perioperative parameters regarding hidden blood loss are shown in Table 3. As none of patients had received blood transfusions and no drainage was placed, intraoperative blood loss could be regarded as VBL. The VBL in the UKA group is 49.33 ± 35.60 ml, which is significantly less than that in the HTO group (105.16 ± 72.52 ml) ($P < 0.001$, Cohen's *d* [95% CI] = 1.092 [0.627, 1.552]). The HBL of the HTO group (534.49 ± 336.05 ml) is significantly higher than that in the UKA group (359.42 ± 263.51 ml) ($P = 0.008$, Cohen's *d* [95% CI] = 0.604 [0.160, 1.045]), however, no difference was detected between two groups in the HBL% ($P = 0.715$, Cohen's *d* [95% CI] = 0.081 [-0.353, 0.514]). And the TBL of the HTO group (639.65 ± 337.81 ml) is also more than that in the UKA group (408.76 ± 283.50 ml) ($P = 0.001$, Cohen's *d* [95% CI] = 0.762 [0.312, 1.208]) (Fig. 3).

Table 4 shows the results of correlation analysis between 16 potential risk factors we mentioned earlier and HBL by using Spearman correlation analysis. We excluded risk factors directly associated with HBL (Hct values) and included two risk factors for UKA and three risk factors for HTO in multivariate linear regression analyses to explore the relationship between HBL and these factors. Other factors such as operative time, length of post-operative hospital stay, incisions length, age, sex and BMI were not significantly correlated with HBL. Additionally, considering the impact of confounding variables, age, gender, BMI, height, and weight were also incorporated into the linear regression model. As Table 5 shows, post-operative Hb values ($P = 0.001$) and Hb loss ($P < 0.001$) were independent risk factors for HBL in the UKA group. In the HTO group, post-operative Hb values was negatively correlated with HBL ($P = 0.001$), and Hb loss was positively correlated with HBL ($P < 0.001$). However, comorbid diabetes were not independent risk factors for HBL.

Discussion

Our research aims to compare HBL between patients received UKA and HTO and investigate potential risk factors influencing HBL.

In our study, 91 patients who had KOA were analyzed, of whom 60 (male/female: 24/36) received UKA and 31 (male/female: 12/19) received HTO. We used a relatively reliable method to estimate the HBL. By Nadler, Gross and Sehat formulas [9, 12, 16], respectively, we obtained PBV, TBL and HBL. In accordance with the change in Hct, we can calculate that the average HBL of patients, accounting for 80.59 ± 20.13% and 78.97 ± 19.78% of TBL

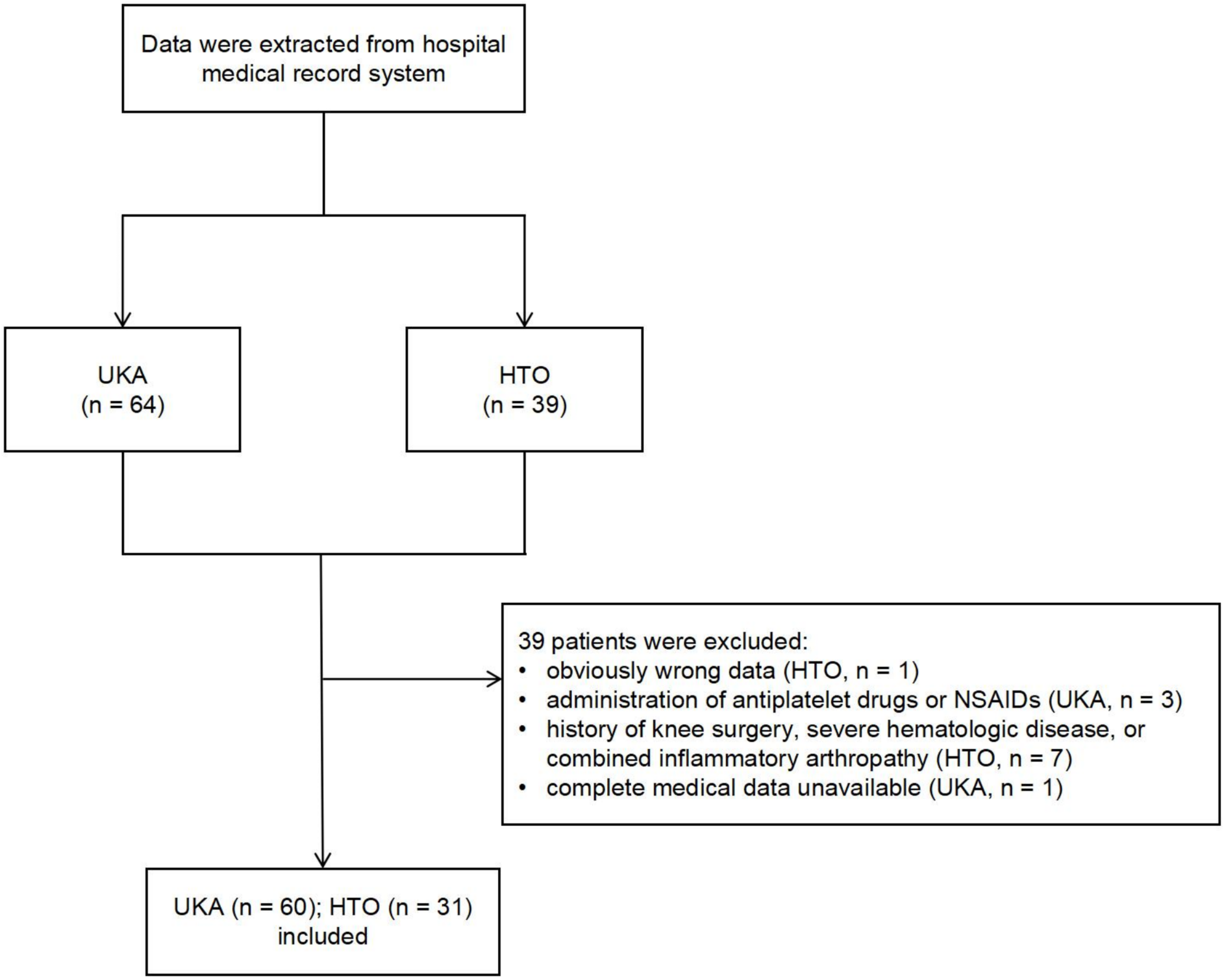

Fig. 2 Patient selection flow chart. UKA, unicompartmental knee arthroplasty; HTO, high tibial osteotomy; NASIDs, non-steroidal anti-inflammatory drugs

Table 1 Characteristics of the patients

	UKA	HTO	*P* value
Number of patients	60	31	
Age (years)	69.37 ± 8.56	57.90 ± 9.12	< 0.001 [a]
Sex (male/female)	24/36	12/19	0.905 [b]
Height (m)	1.61 ± 0.07	1.61 ± 0.09	0.959 [a]
Weight (kg)	66.87 ± 10.73	66.03 ± 10.95	0.728 [a]
BMI	25.97 ± 4.29	25.65 ± 4.12	0.734 [a]
Diabetes	9	3	0.477 [b]
Hypertension	25	10	0.382 [b]

Continuous variables were mean ± SD or median (IQR) and categorical variables were number of cases

BMI, body mass index; UKA, unicompartmental knee arthroplasty; HTO, high tibial osteotomy

[a] Student's *t*-test

[b] *Chi*-square test

Table 2 Perioperative parameters of the patients

	UKA	HTO	*P* value [a]
Mean operative time (min)	80 (25)	90 (30)	< 0.001
Incisions length (cm)	10 (0)	8 (4)	< 0.001
Length of post-operative hospital stay (day)	4.90 (0.36)	5.71 (2.83)	0.148

UKA, unicompartmental knee arthroplasty; HTO, high tibial osteotomy

[a] Mann-Whitney *U* test

in UKA and HTO, indicating that HBL was abundant and accounted for a high proportion. When comparing data between the HTO group and UKA group, we found that HBL in the HTO group (534.49 ± 336.05 ml) was higher than that in the UKA group (359.42 ± 263.51 ml) (Cohen's d [95% CI] = 0.604 [0.160, 1.045]). Similarly, the TBL ($P = 0.001$, Cohen's d [95% CI] = 0.762 [0.312, 1.208]) and intraoperative blood loss ($P < 0.001$, Cohen's d [95% CI] = 1.092 [0.627, 1.552]) was higher in the HTO group. The large clinical significance of difference of TBL and intraoperative blood loss Interestingly, we notice that

Table 3 Perioperative parameters regarding hidden blood loss

	UKA	HTO	*P* value	Effect size (95% CI)
Intraoperative blood loss (ml)	49.33 ± 35.60	105.16 ± 72.52	< 0.001 [a]	1.092 (0.627, 1.552) [c]
Pre-operative Hb values (g/L)	134.27 ± 15.48	140.42 ± 10.72	0.041 [a]	0.460 (0.020, 0.897) [c]
Post-operative Hb values (g/L)	122.60 ± 15.48	121.13 ± 11.48	0.642 [a]	0.103 (-0.331, 0.537) [c]
Hb loss (g/L)	11 (11)	16 (17)	< 0.001 [b]	-0.465 (-0.662, -0.248) [d]
Pre-operative Hct values (%)	41.22 ± 4.28	42.36 ± 3.11	0.192 [a]	0.291 (-0.146, 0.726) [c]
Post-operative Hct values (%)	37.29 ± 4.58	36.16 ± 3.35	0.230 [a]	0.267 (-0.169, 0.702) [c]
Average Hct values (%)	39.25 ± 4.22	39.26 ± 2.88	0.993 [a]	0.002 (-0.082, 0.084) [c]
PBV (L)	4.04 ± 0.54	4.01 ± 0.65	0.826 [a]	0.049 (-0.385, 0.482) [c]
VBL (ml)	49.33 ± 35.60	105.16 ± 72.52	< 0.001 [a]	1.092 (0.627, 1.552) [c]
TBL (ml)	408.76 ± 283.50	639.65 ± 337.81	0.001 [a]	0.762 (0.312, 1.208) [c]
HBL (ml)	359.42 ± 263.51	534.49 ± 336.05	0.008 [a]	0.604 (0.160, 1.045) [c]
HBL %	80.59 ± 20.13	78.97 ± 19.78	0.715 [a]	0.081 (-0.353, 0.514) [c]

Hb, Hemoglobin; Hct, Hematocrit; PBV, patient's blood volume, VBL, visible blood loss; TBL, total blood loss; HBL, hidden blood loss; HBL%, the percentage of HBL

[a] Student's *t*-test

[b] Mann-Whitney *U* test

[c] Cohen's *d*

[d] Glass rank biserial correlation coefficient

Notice. PBV represents the average level observed in patients undergoing surgery

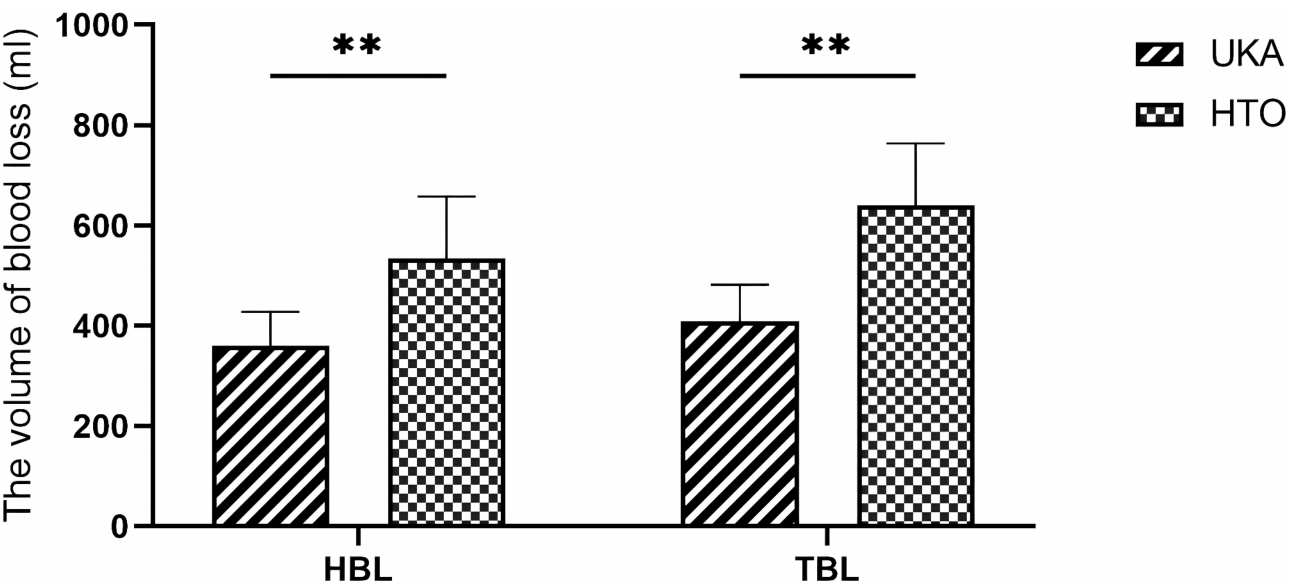

Fig. 3 Comparison of HBL and TBL between two groups. ***P* < 0.01; HBL, hidden blood loss; TBL, total blood loss

there is less preoperative Hb level in HTO group than UKA group and that they had similar preoperative Hct values. Since the calculation of HBL is independent of Hb, the slightly lower preoperative Hb level in the HTO group is unlikely to have affected the study results. The influential factors correlated to the HBL were not confirmed. The multiple linear regression analysis showed post-operative Hb values and Hb loss were independent risk factors for HBL in the both UKA and HTO group. Nonetheless, other potential risk factors such as sex and age showed no correlation with HBL, possibly due to the small sample size.

Several factors may contribute to the higher HBL observed in the HTO group. First, this might be due to the surgical technique itself. Intraoperative release of soft tissue during osteotomy results in recessive blood loss, while bone cement used to fix the femoral and tibial prosthesis in the UKA process can seal the bone surface and reduce bleeding. Additionally, unsealed osteotomy sectioning with dead space in the open wedge osteotomy gap may contribute to further complications in hemostasis due to the creation of a potential space for hematoma formation. Second, HTO has a longer operative and anesthesia time compared to UKA, which may further contribute to increased blood loss.

Table 4 Results of spearman correlation analysis for hidden blood loss

Parameters	UKA		HTO	
	r	*P* value	*r*	*P* value
Average Hct values (%)	-0.200	0.126	-0.008	0.965
Post-operative Hct values (%)	-0.412	0.001	-0.443	0.013
Pre-operative Hct values (%)	0.082	0.534	0.415	0.020
Operative time (min)	0.077	0.561	-0.040	0.830
Length of post-operative hospital stay (day)	0.078	0.551	0.144	0.439
Incisions length (cm)	-0.056	0.669	0.090	0.629
Age (years)	0.003	0.980	0.116	0.533
Height (m)	0.022	0.867	0.310	0.090
Weight (kg)	0.112	0.396	0.122	0.512
BMI	0.076	0.564	-0.011	0.951
Pre-operative Hb values (g/L)	0.111	0.400	0.359	0.047
Post-operative Hb values (g/L)	-0.393	0.002	-0.492	0.005
Hb loss (g/L)	0.938	< 0.001	0.910	< 0.001
Sex	-0.153	0.242	-0.178	0.339
Diabetes	-0.031	0.814	0.378	0.036
Hypertension	0.030	0.818	0.212	0.252

Hb, Hemoglobin; Hct, Hematocrit; BMI, body mass index

HBL remains an important yet often overlooked component of blood loss in orthopedic surgeries. Consistent with previous studies [9–11, 18, 19], we found that even with minimal intraoperative blood loss, significant postoperative decreases in Hb and Hct levels were observed, underscoring the clinical relevance of HBL. Studies have shown that HBL accounts for a large proportion of HTO and UKA [20, 21]. Many orthopedic surgery studies (such as TKA and THA) have found that HBL accounts for approximately 50% of the total blood loss [22, 23]. The influencing factors of HBL mostly include Hb loss, operation time, and BMI. Surgical blood loss and the subsequent reduction in Hb levels can negatively impact patient outcomes, potentially leading to delayed wound healing, postoperative anemia, and increased infection risks, especially for those with lower hematopoietic capacity [24]. While allogeneic blood transfusion can correct anemia, it carries risks such as hemolysis and allergic reactions [25, 26]. Therefore, we should not overlook the large number of HBL when performing surgeries to treat KOA. Especially in HTO, we should pay more attention to protecting the deep soft tissue and use tranexamic acid appropriately to reduce HBL [27]. Additionally, sealing the osteotomy gap with gelatin sponges or bone graft (BG) can be considered to further enhance hemostasis and promote healing. Despite the small amount of intraoperative blood loss, the possibility of post-operative anemia should not be ignored.

In our study, we did not employ intra-articular drainage after either procedure, which may have influenced the amount of hematoma accumulation in tissue planes and, consequently, the extent of HBL. The use of closed suction drains in knee surgeries remains controversial. While they can effectively reduce local hematoma, improve wound healing, and lower the postoperative infection rate by facilitating continuous postoperative drainage [28], their potential drawbacks cannot be overlooked. The use of drainage tubes may be associated with an increased risk of transfusion and may interfere with physical therapy, leading to delayed recovery [29, 30]. Although studies indicate that drainage does not significantly reduce total blood loss, it may alleviate postoperative pain and swelling [31, 32]. Conversely, some studies have also found that the use of drainage tubes does not provide substantial benefits for postoperative recovery and blood loss management [33, 34]. Since our study did not involve the use of drainage, future research should explore its impact on HBL and whether drainage reduces

Table 5 Multiple linear regression analysis on risk factors of hidden blood loss after unicompartmental knee arthroplasty (UKA) or high tibial osteotomy (HTO)

	Coefficient B	SE	95% CI for B	*P*
UKA				
Constant	843.421	1933.284	-3035.997 to 4722.839	0.664
Post-operative Hb values (g/L)	-2.839	0.787	-4.419 to -1.259	**0.001**
Hb loss (g/L)	27.718	1.198	25.313 to 30.122	**< 0.001**
HTO				
Constant	857.717	1953.354	-3063.806 to 4779.239	0.662
Post-operative Hb values (g/L)	-2.831	0.796	-4.430 to -1.233	**0.001**
Hb loss (g/L)	27.725	1.210	25.295 to 30.155	**< 0.001**
Diabetes	-4.335	25.236	-54.999 to 46.328	0.864

Multiple linear regression analysis adjusted for all variables in the table and potential cofounders (sex, age, height, weight and BMI). The adjusted R^2 of HTO = 0.931, and the adjusted R^2 of UKA = 0.933

Hb, Hemoglobin; Hct, Hematocrit; BMI, body mass index; SE, standard error

Bold values indicate $P < 0.05$

Table 6 Comparative characters of HTO and UKA

	HTO	UKA
Indications [39–41]	Young and active patients (age < 65 years)	Elder patients (age > 55 years) and low activity requirements
	Anterior cruciate ligament deficiency	Severe osteoarthritis with significant joint space narrowing
	Mechanical malalignment	Acceptable coronal alignment
	Asymmetric varus	Symmetric varus
	Normal range of BMI	Normal range of BMI
	Good range of motion	Good range of motion
	Mild varus malalignment	Mild varus malalignment
	Intact lateral and patellofemoral compartments	Intact lateral and patellofemoral compartments
	Varus deformity less than 10° and valgus deformity less than 5°	Range of motion of at least 90° with a maximum of 5° flexion contracture and coronal deformity less than 15°
Contraindication [39, 42]	Inflammatory arthritis	Inflammatory arthritis
	Medial bone loss	Presence of subchondral bone in an adjacent compartment
	Knee stiffness	Anterior cruciate ligament deficiency
Complications [36, 43]	Lateral hinge fracture	Anemia and thrombosis
	Peroneal nerve injury	Nerve palsy
	Neurovascular injury	Joint swelling
	Superficial infection	Infection
	Nonunion, loss of correction and implant failure	Periprosthetic fracture and functional limitation

HTO, high tibial osteotomy; UKA, unicompartmental knee arthroplasty; BMI, body mass index

hidden blood loss by converting it into measurable postoperative loss and assess its overall influence on clinical outcomes.

Comparative characters of HTO and UKA are presented in Table 6. HTO and UKA are two commonly employed surgical interventions for KOA. Although both procedures have distinct indications and contraindications, there is a degree of overlap in the patient populations that may benefit from either surgery. The timing of surgery and the decision between HTO and UKA should be carefully individualized, based on the patient's specific condition and clinical needs. As a result, for patients seeking higher post-operative activity levels, HTO can be considered a treatment option for KOA, but it should not replace UKA when the indications are appropriately evaluated. However, for patients with lower blood volume or with anemia, HBL from this procedure should be considered. For patients with higher BMI, HTO offers certain advantages by preserving the natural proprioception of the knee joint. Compared to UKA, HTO is a more suitable option for younger patients, providing better stability, and a lower risk of osteolysis. In terms of long-term functional recovery, HTO demonstrates superior outcomes over UKA [35]. However, UKA generally has a shorter postoperative recovery time. HTO is not recommended for patients with knee flexion deformities. Most studies suggest that the complication rate of HTO is higher than that of UKA, including joint swelling, nerve damage, infection, and fractures [36, 37]. Anemia is also a more common complication after UKA [38], while there is a lack of research on hemorrhagic complications related to HTO surgery. We also need to consider patients who have subjective indications for surgery or with poor coagulation function. For these patients, HBL should be carefully evaluated as it may significantly impact perioperative management, postoperative recovery, and overall surgical outcomes. Therefore, the surgical decision between HTO and UKA must not only account for the patient's anatomical and clinical presentation but also consider the potential risks of HBL, with an emphasis on perioperative blood management.

While this study offers important insights into the role of HBL in KOA surgeries, it has several limitations. First, the imbalanced and relatively small sample size and single-center study design limits the statistical power and generalizability of the results. In addition, the reliance on pre-existing medical records introduces the potential for selection bias and information bias, as data collection was not originally intended for research purposes. Furthermore, there may be other latent factors influencing HBL that were not addressed in this study. Lastly, the method used to calculate HBL, while reliable, may still have some inherent error when compared with actual blood loss measurements. Future studies should incorporate larger, multicenter datasets and adopt prospective study designs to minimize selection and information biases inherent in retrospective research. Additionally, they should explore additional risk factors influencing HBL to provide a more comprehensive understanding of its determinants and clinical impact. Investigating strategies to minimize HBL, such as optimizing perioperative hemostatic measures, remains an important area for further research.

Conclusion

In conclusion, the perioperative HBL is much higher than VBL and should not be ignored, in both procedures. HTO has higher TBL and HBL than those of UKA. Compared with UKA, we should pay more attention to the post-operative anemia status of patients undergoing HTO surgery. We suggest that for patients who meet the indications for both procedures and have low Hb levels pre-operatively, UKA might be more suitable than HTO. In addition, adequate management of the risk factors will help to reduce patients' perioperative HBL.

Abbreviations

HBL	Hidden blood loss
UKA	Unicompartmental knee arthroplasty
HTO	High tibial osteotomy
TKA	Total knee arthroplasty
KOA	Knee osteoarthritis
PBV	Patient blood volume
VBL	Visible blood loss
SD	Standard deviation
TBL	Total blood loss
HB	Hemoglobin
HCT	Hematocrit
BMI	Body mass index

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Author contributions

All authors had full access to the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Conceptualization, Tao Yu and Dengying Wu; Formal Analysis, Yiqi Chen and Zhenyu Shen; Data Curation, Hao Chen and Ziye Yang; Writing - Original Draft, Tao Yu; Writing - Review & Editing, Tao Yu and Dengying Wu; Supervision, Dengying Wu and Enxing Xue;

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Data availability

The data of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the ethical standards of the Declaration of Helsinki and with approval from the Institutional Review Board of Second Affiliated Hospital and Yuying Childrens Hospital of Wenzhou Medical University (Approval No: 2022-K-155-01). Written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Orthopaedics, The Second Affiliated Hospital, Yuying Childrens Hospital of Wenzhou Medical University, Wenzhou, Zhejiang Province, China
[2]The Second School of Medicine, Wenzhou Medical University, Wenzhou, Zhejiang Province, China

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