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Estimation of Blood Loss in Total Knee Arthroplasty with and without Tourniquet

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Total knee arthroplasty (TKA) without a tourniquet can reduce the risk of large venous emboli, but is associated with increased blood loss. To provide an accurate estimate of this blood loss, we divided 136 patients who underwent primary TKA into four groups based on the type of operation: 1) bilateral TKA with tourniquet; 2) bilateral TKA without tourniquet; 3) unilateral TKA with tourniquet; and 4) unilateral TKA without tourniquet. Blood loss was estimated by calculating the fall in hemoglobin and total blood volume corrected for Japanese. A small difference in intraoperative blood loss was seen between unilateral TKA without tourniquet (308 ml) and bilateral TKA without tourniquet (411 ml). Total blood loss was 879 ml in unilateral TKA with tourniquet, 1165 ml in unilateral TKA without tourniquet, 1458 ml in bilateral TKA with tourniquet and 1823 ml in bilateral TKA without tourniquet. Uni- and bilateral TKAs without a tourniquet were thus associated with an increased blood loss. Performing TKA without a tourniquet should thus be reconsidered to avoid venous thromboembolism.

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Introduction

Prevention of venous thromboembolism (VTE) after total knee arthroplasty (TKA) is a very important issue. Risk factors of VTE in TKA have not been identified, with the exception of prior VTE and aging,[1] but TKA per se is reportedly a significant risk factor for VTE.[2] Clinically, use of a pneumatic tourniquet is considered one of the most important risk factors for the occurrence of symptomatic VTE. Parmet *et al.* demonstrated that use of a tourniquet during TKA is associated with a greater risk of ultrasound-detected VTE.[3] Furthermore, Kato *et al.* recommended that TKA should be performed without a tourniquet to reduce the risk of large venous emboli.[4] We recently reported that use of a tourniquet in TKA represents a risk factor for pulmonary thromboembolism (PTE).[5,6] In those study, PTE was detected in 2 (40.0%) of 5 patients who underwent bilateral TKAs with tourniquet, 1 (7.1%) of 14 patients who underwent unilateral TKA with tourniquet, 3 (7.1%) of 42 patients who underwent bilateral TKAs without tourniquet, and no patients who underwent unilateral TKA without tourniquet. Conversely, a tourniquet also minimizes intraoperative blood loss. Several studies have discussed the management of blood loss in unilateral TKA without using a tourniquet,[7,8] but none have examined this issue with bilateral TKAs. Sehat *et al.* reported that in TKA, total blood loss comprises "visible" blood loss from the surgical field and wound drainage, and "invisible" loss into tissues.[9]

The aim of the present study was to provide an accurate estimate of "invisible" intraoperative blood loss in TKA with and without use of a tourniquet, using an objective method of calculating blood loss.

Materials and Methods

Patients

Primary TKA using cementless procedures was performed in 210 patients between May 2000 and April 2003 at Nagasaki Red

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Cross Atomic Bomb Memorial Hospital (Nagasaki, Japan). These patients were eligible for enrolment in the study and provided signed informed consent. Of these, 73 patients who received intraoperative blood transfusion at Days 0, 1 and 2 were excluded from the study. Blood transfusion was provided for patients with clinical symptoms related to acute blood loss such as shock, hypotension, tachycardia, and those with preoperative hemoglobin level <10.0 mg/dl, postoperative hemoglobin level <7.0 mg/dl and elderly patients >85 years old. Furthermore, another patient who underwent bilateral TKAs with a tourniquet was also excluded due to the development of postoperative infection. As a result, 136 patients were enrolled for further analysis. Among these, underlying pathology was rheumatoid arthritis in 41 patients (7 men, 34 women) and osteoarthritis in 95 patients (16 men, 79 women). Mean age of all patients was 71 years (range, 29-87 years).

According to the operative procedure, each patient was assigned to one of the following groups: 1) bilateral TKA with tourniquet (n=11); 2) bilateral TKA without tourniquet (n=42); 3) unilateral TKA with tourniquet (n=41); and 4) unilateral TKA without tourniquet (n=42). Patients receiving bilateral TKA with tourniquet underwent surgery between May 2000 and February 2001, while those receiving bilateral TKA without tourniquet underwent surgery between March 2001 and April 2003. Similarly, patients receiving unilateral TKA with tourniquet and unilateral TKA without tourniquet underwent surgery from May 2000 to February 2001 and from March 2001 to April 2003, respectively. Clinical profiles of each group are summarized in Table 1.

All procedures were performed by two surgeons (M.N. and M.K.) using similar surgical techniques. A skin incision was made at the center of the knee joint. A medial parapatellar approach for genu varum was performed through the retinaculum, capsule and synovium. For cases with genu valgum, the lateral approach was applied. An intramedullary guide was used for the femur and an extramedullary guide was used for the tibia. When lateral release was necessary, blood supply from the superior or inferior geniculate artery was preserved. Partial synovectomy was performed and included the suprapatellar bursa only to avoid impingement. A 3-mm suction drain was placed deep into the retinaculum of the knee joint. The drain was removed 24-48 h after operation, when the tube became clogged with coagulate or when volume of suction fluid (blood) was <50 ml in 6 h. Full weight-bearing was started immediately after the procedure. None of the patients required drain replacement. A NexGen Total Knee System (Zimmer, Inc., Warsaw, Indiana, USA) was used in 122 cases (77 unilateral, 45 bilateral), and the posterior cruciate ligament (PCL) was retained in these cases. The LCS Total Knee System (Depuy International, Leeds, UK) with PCL sacrifice was used in 14 cases (6 unilateral, 8 bilateral).

Unilateral TKA was performed under spinal anesthesia, whereas bilateral TKA was conducted under general anesthesia (using hypotensive anesthesia).

None of the patients had experienced previous VTE or had advanced malignancy. No patients received perioperative anticoagulant therapies such as oral administration of warfarin or aspirin, venous injection of heparin, or subcutaneous injection of low-molecular-weight heparin from 7 days preoperatively to 14 days postoperatively, excluding those patients who developed PTE postoperatively. Furthermore, no foot pump was required by any patients after surgery. For the purposes of pain control, diclofenac (a non-steroidal anti-inflammatory drug) was used orally or in suppository form in all patients during the early postoperative period.

Measurement of hemoglobin

Hemoglobin was measured pre- and postoperatively (Days 1, 3 and 7) at 09:00. Minimum postoperative hemoglobin value was defined as the lowest value during 1 week without blood transfusion. Maximum decrease in hemoglobin was defined as (preoperative

Table 1. Clinical profiling of patients who underwent total knee arthropathy (TKA).

Intraoperative tourniquet	Unilateral TKA with (n=41)	Unilateral TKA without (n=42)	Bilateral TKA with (n=11)	Bilateral TKA without (n=42)	Total (n=136)
RA/OA	20/21	14/28	1/10	6/36	41/95
Male/Female	3/38	7 : 35	2/9	11/31	23/113
Age (years)*	(63, 66, 73)	(64, 71, 77)	(70, 73, 76)	(68, 72, 76)	(64, 71, 75)
	29-84	42-87	65-80	53-84	29-87
Weight (kg)*	(47.5, 55.0, 61.5)	(46.5, 53.8, 61.5)	(46.5, 50.0, 64.0)	(55.8, 60.9, 69.6)	(49.5, 57.0, 64.4)
	41.0-71.0	36.0-81.0	42.0-66.0	41.0-90.0	36.0-90.0
Height (m)*	(1.44, 1.50, 1.55)	(1.44, 1.48, 1.55)	(1.43, 1.49, 1.50)	(1.48, 1.52, 1.58)	(1.45, 1.50, 1.56)
	133-161	1.37-1.67	1.40-1.64	1.39-1.73	1.33-1.73
BMI (kg/m^2)*	(21.4, 24.9, 27.9)	(21.7, 24.3, 26.9)	(20.7, 24.5, 28.1)	(23.6, 26.6, 30.6)	(22.3, 25.4, 28.4)
	17.3-32.7	15.7-32.0	18.7-30.2	19.7-36.8	15.7-36.8
TBV (L)	(3.15, 3.68, 4.08)	(3.11, 3.51, 4.10)	(3.11, 3.28, 4.18)	(3.67, 4.10, 4.69)	(3.28, 3.76, 4.29)
	2.68-4.76	2.24-5.17	3.00-4.46	2.60-5.73	2.24-5.73

*Data are expressed as (1^{st} quartile, median, 3^{rd} quartile) minimum-maximum

hemoglobin level - minimum hemoglobin level).

Measurement of intra- and postoperative blood loss

"Intraoperative blood loss" was defined as the sum of the weight change in surgical gauzes and the fluid level of suction reservoirs, and "measured postoperative blood loss" was defined as the total volume collected in the closed-drainage system. Finally, "measured total blood loss" was determined as the sum of "intraoperative blood loss" and "measured postoperative blood loss".

Calculation formulae

Total blood loss was calculated using the following formula: total blood volume (TBV) × (1 - postoperative minimum hemoglobin / preoperative hemoglobin).[10] TBV was defined as (0.168 H^3 + 0.050 W + 0.444) L for Japanese men, and (0.250 H^3 + 0.063 W - 0.662) L for Japanese women, where H was height in meters and W was weight in kilograms.[11] Calculated blood loss was defined as TBV × (1 - postoperative minimum hemoglobin / postoperative hemoglobin).[12] Postoperative blood loss was also determined as (total blood loss - intraoperative blood loss).

Statistical analysis

Data are expressed as median (range). Differences in blood loss between the four patient groups were examined for statistical significance using the Mann-Whitney rank-sum test. Values of P <0.05 denoted the presence of a significant difference. SPSS for Windows version 11.0 software (SPSS, Chicago, IL) was used for all analyses.

Results

Profiling and perioperative blood loss are shown in Table 2. No differences were seen between pre- and postoperative minimum hemoglobin levels between uni- and bilateral TKA groups. Operation times were significantly longer for uni- and bilateral TKA without tourniquet groups compared to the respective tourniquet groups (p<0.001, p=0.005, respectively).

Intraoperative blood loss was significantly greater in uni- and bilateral TKA without tourniquet groups than in the respective tourniquet groups (p<0.001, p<0.001, respectively). However, no significant difference in intraoperative blood loss was seen between unilateral TKA without tourniquet (308 ml) and bilateral TKA without tourniquet (411 ml).

Measured and calculated total blood losses in uni- and bilateral TKA without tourniquet were significantly greater than those in the respective tourniquet groups (p<0.001, 0.002, 0.001 and 0.004, respectively). Calculated postoperative blood loss did not differ significantly between unilateral TKA without tourniquet and unilateral TKA with tourniquet (p=0.45) or between bilateral TKA without tourniquet and bilateral TKA with tourniquet (p=0.98). Calculated total blood losses in unilateral TKA with tourniquet and unilateral TKA without tourniquet were 879 ml and 1165 ml, respectively. Calculated total blood losses in bilateral TKA with tourniquet and bilateral TKA without tourniquet were 1458 ml and 1823 ml, respectively. Small differences in calculated total blood loss were thus seen between unilateral TKA with tourniquet and unilateral TKA without tourniquet (286 ml) and between bilateral TKA with tourniquet and bilateral TKA without tourniquet (365 ml).

"Invisible" losses represent 75.0% and 42.3% of total losses in

Table 2. Bleeding events in patients who underwent TKA with and without tourniquet.

	Unilateral TKA			Bilateral TKA		
Intraoperative tourniquet	with (n=41)	without (n=42)	p	with (n=11)	without (n=42)	p
Preoperative Hb (mg/dl)	(11.2, 12.1, 13.3) 9.1-14.6	(11.7, 13.1, 13.5) 9.6-15.2	0.059	(11.3, 12.5, 12.9) 10.4-15.3	(12.7, 13.3, 14.1) 10.8-16.2	0.037
Postoperative minimum Hb (mg/dl)	(7.8, 9.1, 10.0) 6.4-11.2	(7.7, 8.4, 9.1) 5.6-13.0	0.082	(6.3, 7.1, 8.4) 6.0-10.0	(6.9, 7.2, 8.0) 5.7-9.5	0.363
Operation time (minutes)	(72, 79, 88) 55-120	(84, 97, 110) 64-188	<0.001	(152, 163, 181) 126-259	(176, 188, 216) 146-289	0.005
Intraoperative blood loss (ml)*†	(0, 0, 4.5) 0-46	(179, 308, 440) 60-793	<0.001	(0, 0, 71) 0-169	(266, 409, 528) 105-1231	<0.001
Measured total blood loss (ml)*†	(114, 220, 308) 8-739	(442, 672, 865) 130-1223	<0.001	(209, 329, 602) 130-1159	(731, 987, 1157) 438-2084	0.001
Calculated total blood loss (ml)*	(724, 879, 1229) 369-2019	(1001, 1165, 1563) 421-2221	0.002	(1220, 1458, 1639) 980-1928	(1517, 1823, 2192) 1093-2548	0.004
Postoperative total blood loss (ml)*	(724, 875, 1229) 345-2014	838 (133-1655) 133-1655	0.452	(1147, 1458, 1554) 963-1928	(1077, 1420, 1817) 614-2112	0.983
Blood transfusion (unit)*‡	(0, 0, 0) 0-4.0	(0, 0, 0) 0-4.0	0.951	2.0 0-4.0	2.0 0-8.0	0.762

* Data are expressed as (1st quartile, median, 3rd quartile) minimum-maximum

† Volume of blood loss during operation was recorded by suction system and surgical gauze.

‡ Japanese unit of packed red blood cells is not a universal standard

unilateral TKA with tourniquet and unilateral TKA without tourniquet, respectively, and 77.4% and 44.7% of total losses in bilateral TKA with tourniquet and bilateral TKA without tourniquet, respectively. Finally, no significant difference in volume of blood transfusion was seen between unilateral TKA with tourniquet and unilateral TKA without tourniquet (p=0.951), or between bilateral TKA with tourniquet and bilateral TKA without tourniquet (p=0.762).

Discussion

Most orthopedic surgeons use a pneumatic tourniquet in TKA to reduce intraoperative blood loss and maintain a bloodless surgical field. Harvey *et al.* reported that use of the tourniquet may theoretically increase the risk of deep vein thrombosis (DVT) through venous stasis, direct trauma to the vessel wall, and increased platelet adhesion in valve pockets secondary to distal limb ischemia.[7] Furthermore, Parmet *et al.* reported that the incidence of PTE after TKA with tourniquet is higher than that without tourniquet.[3] We recently reported the plasma levels of D-dimer, a sensitive serum marker of VTE (defined as the combination of DVT and PTE), were significantly higher in patients with tourniquet than in those without tourniquet, in both unilateral and bilateral TKAs.[5] Causes of PTE after TKA include surgical factors such as tourniquet use and intramedullary guide into the femur, and patient-related risk factors such as existence of DVT and hypercoagulable status.[13] When TKA is performed without a tourniquet, thrombosis and fat embolism may not be suddenly released into the pulmonary arteries.

The major problem associated with TKA without a tourniquet is increased blood loss, but few studies have attempted to evaluate this matter. To estimate blood loss, several calculation formulae have been developed[10,14,15] and used in various studies to estimate total blood loss in unilateral TKA.[8,9,12,16] These formulae calculate the maximum decrease in hemoglobin or hematocrit based on pre- and postoperative values and total blood volume normalized to the weight and height of the patient. The present study estimated blood loss by calculating decreases in hemoglobin and total blood volume corrected for Japanese individuals.[11]

Gross reported that linear formulae, which imply that the fraction decrease in hemoglobin is equal to the fraction of total blood volume that has been lost, overestimate hemoglobin loss because each milliliter of shed blood contains progressively less hemoglobin, particularly in patients with an initial hematocrit >45%. Use of a logarithmic approximation formula was thus recommended.[10] Bourke and Smith reported that within physiological ranges, differences between linear and logarithmic formulae are clinically negligible.[14] The present study therefore applied a linear formula due to the advantage of mathematical simplicity. Hemoglobin level was used because of the utility as a criterion for blood transfusion.

Our results suggest that TKA without tourniquet influences operation time, intraoperative blood loss and calculated total blood loss. The operation without tourniquet was 16 min longer for unilateral TKA and 25 min longer for bilateral TKA. Intraoperative blood loss without tourniquet was 308 ml in unilateral TKA and 411 ml in bilateral TKA. Intraoperative blood loss in unilateral TKA without tourniquet was reported as 295 ml by Tetro *et al*.[8] The difference in calculated total blood loss between with and without a tourniquet was <300 ml with unilateral TKA and <400 ml with bilateral TKA. Evaluation of intraoperative blood loss and calculated total blood loss is quite important for the management of blood transfusion in patients who undergo TKA without a tourniquet.

According to our results for calculated total blood loss in TKA (Table 2), necessary transfusion volumes for safe surgical procedures in uni- and bilateral TKA without tourniquet were estimated as approximately 1200 ml and 1800 ml, respectively. Conversely, required transfusion volumes for ordinary procedures in uni- and bilateral TKA with tourniquet were estimated as approximately 800 ml and 1400 ml, respectively. Preparation of autologous red blood cells or allogeneic blood would be needed for these procedures in TKA.

The benefit of tourniquet use for the prevention of blood loss in TKA remains controversial. Harvey *et al*. reported estimated blood losses in unilateral TKA with and without tourniquet of 709 ml and 1493 ml, respectively, and incidence of DVT did not correlate with tourniquet use.[7] Conversely, Tetro *et al*. reported that calculated total blood loss in unilateral TKA with and without tourniquet was 1792 ml and 1499 ml, respectively, and effectiveness of a pneumatic tourniquet to control blood loss in TKA was questionable.[8] In another study, Abdel-Salam *et al*. reported no significant differences between TKA with and without tourniquet with regard to operation time and blood loss, but less postoperative pain was experienced by patients in whom no tourniquet had been used.[17] On the other hand, Wakankar *et al*. concluded that use of a tourniquet is safe and recommended continuation of the current practice.[18]

Sehat *et al.* reported calculated total blood loss in unilateral TKA with tourniquet as 1474 ml.[9] The loss was reported as 1518 ml by Lotke *et al.*[12] and 1426 ml by Good *et al.*[16] In the present study, calculated total blood losses in unilateral TKA with and without tourniquet were 879 ml and 1165 ml, respectively. Differences in these volumes between studies might be due to factors such as hypotensive anesthesia, operation time, re-infusion drain, ethnicity, total blood volume and body size. To the best of our knowledge, this is the first study to estimate blood loss in bilateral TKA without a tourniquet.

In our study, "invisible" loss with and without tourniquet was 75.0% and 42.3% of total loss in unilateral TKA, and 77.4% and 44.7% in bilateral TKA, respectively. Sehat *et al.* indicated that this potential problem must be recognized and addressed when clinically indicated.[9]

The present pilot study showed several limitations. The sample size was relatively small, and the study was neither prospective nor randomized. Furthermore, we included patients with rheumatoid arthritis as well those with osteoarthritis. To reduce the incidence

of postoperative VTE in patients who undergo TKA, further studies are needed to re-evaluate tourniquet use in TKA in terms of blood loss and prevention of VTE.

In conclusion, TKA without tourniquet increased blood loss by less than 400 ml compared to TKA with tourniquet. Postoperative blood loss was the same in both procedures, according to our calculation. If use of a tourniquet during TKA represents a risk factor for VTE following TKA, TKA without tourniquet is safer than TKA with tourniquet in terms of life-threatening VTE. Further countermeasures to minimize intraoperative blood loss during TKA without tourniquet are needed.

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