International Orthopaedics (2019) 43:2083–2091
https://doi.org/10.1007/s00264-018-4174-6

ORIGINAL PAPER

The effect of post-operative limb positioning on blood loss and early outcomes after primary total knee arthroplasty: a randomized controlled trial

Yuangang Wu[1] · Yi Zeng[1] · Canfeng Li[1] · Jian Zhong[1] · Qinsheng Hu[1] · Fuxing Pei[1] · Bin Shen[1]

Received: 9 June 2018 / Accepted: 18 September 2018 / Published online: 23 October 2018

Abstract

Introduction The purpose of this study was to investigate the benefits of three different post-operative limb positions in primary total knee arthroplasty (TKA).

Methods The trial was a single-surgeon, randomized, controlled trial, and 135 patients following primary TKA were randomized into three groups: group A (45 patients who were treated with the hip fixed at 50° and knee flexed at 90° for 6 hours post-operatively), group B (45 patients who were treated with the hip elevated at 30° and knee flexed at 45° for 6 hours post-operatively), and group C (45 patients in whom the affected knee was fully extended after surgery). Tranexamic acid was used in all patients.

Results The total blood loss and hidden blood loss in group A (921 ± 209 mL, 597 ± 213 mL) were significantly less than in groups B (1125 ± 222 mL, 784 ± 229 mL) and C (1326 ± 291 mL, 915 ± 301 mL) and less in group B compared with group C. The drain volume in groups A (158 ± 35 mL) and B (174 ± 45 mL) was significantly lower than in group C (249 ± 31 mL). The maximum haemoglobin drop in group A (3.1 ± 0.5 g/dL) was statistically significantly less than in groups B (3.6 ± 0.7 g/dL) and C (4.3 ± 0.4 g/dL). The range of motion (ROM) in groups A (102 ± 3°, 105 ± 2°) and B (100 ± 3°, 104 ± 2°) was significantly better than in group C (98 ± 3°, 102 ± 2°) at the time of discharge and one month after surgery; it was also significantly less for group A (104.9 ± 2.1%, 108.0 ± 2.4%) compared with groups B (106.7 ± 3.1%, 108.3 ± 2.7%) and C (108.4 ± 3.2%, 110.6 ± 3.0%) with post-operative knee swelling. No differences in transfusion requirements and complications were observed among the three groups.

Conclusions The affected knee flexion position was superior to the use of a fully extended position for blood management, but it only contributed to better early functional recovery up to three months post-operatively in TKA. In addition, by fixing the affected knee at a high flexion position of 90°, patients could achieve less blood loss, lower knee swelling, and better early results for ROM and patient satisfaction than the other two groups.

Keywords Total knee arthroplasty · Limb positions · Blood loss · Range of motion

Yuangang Wu and Yi Zeng contributed equally to this work and should be considered as equal first authors.

Level of evidence: Therapeutic Level I

✉ Bin Shen
shenbin_1971@163.com

Yuangang Wu
wuyuangang23@163.com

Yi Zeng
zengyigd@126.com

Canfeng Li
licanfeng87@163.com

Jian Zhong
icetear6@163.com

Qinsheng Hu
huqinsheng@hotmail.com

Fuxing Pei
doctorpei888@126.com

[1] Department of Orthopaedic Surgery, West China Hospital, West China Medical School, Sichuan University, Chengdu, Sichuan Province 610041, China

Introduction

Osteoarthritis (OA) is the most common form of arthritis, affecting approximately 27 million adults in the USA and 25% of people aged 25–74 suffering from pain and deformity [1]. Total knee arthroplasty (TKA) has become a successful surgical procedure and is performed in the USA more than 400,000 times per year [2]. However, TKA often causes a large amount of peri-operative bleeding, and transfusions may potentially increase the risk of post-operative infections, immune reactions, and costs [3–5]. Since TKA is usually performed in elderly patients with complex comorbidities, the management of fast-tracks after surgery is usually performed to reduce morbidity to accelerate recovery and shorten the hospital stay [6]. The core concept of fast-tracking in TKA is blood management and functional improvement, and various strategies to reduce blood loss and enhance recovery after surgery have been well described [7–14].

Recently, postoperative knee limb positioning has been demonstrated that it can be used as a simple and a cost-effective way to minimize blood loss and improve the range of motion (ROM) [11]. Early recovery and improvement of ROM play an important role in TKA and are also the best indicators to assess the success of TKA [15]. However, published studies have shown that different limb positioning protocols have inconsistent effects on functional outcomes after TKA. Some studies have indicated that flexion of the knee after surgery can reduce knee swelling and provide other beneficial effects during early rehabilitation [13, 16, 17], but other studies have failed to prove any benefit from post-operative knee flexion and have not recommended it as part of post-operative management [18]. In recent years, surgical techniques and fast-track after-surgery guidelines have made great strides in TKA, but the optimal flexion position in TKA has not been adequately evaluated, and controversy exists regarding the management of flexion time on blood loss and ROM associated with TKA. To our knowledge, no study has directly and concurrently compared high-flexion (90°), mild-flexion (45°), and extension routes (0°) of knee limb positioning administration in TKA administration in primary TKA. This study was therefore designed as a randomized controlled to compare the effectiveness and safety of three different limb positions in patients following primary TKA by evaluating: (1) blood loss, including total blood and hidden blood loss; (2) drain volume, transfusion requirements, and maximum haemoglobin (Hb) drop; (3) ROM, knee swelling ratio, and patient satisfaction; and (4) wound-related complications and thromboembolic events.

Materials and methods

This randomized controlled trial was approved by the institutional ethics committee in our hospital and informed consent was obtained before the study. All consecutive patients with primary TKA with end-stage osteoarthritis were enrolled. The exclusion criteria were as follows: patients with an age less than 18 and greater than 85, patients with a history of thrombotic disease, patients with infection, patients on anticoagulant therapy, and patients with pre-operative anaemia and an allergy to tranexamic acid. Patients were randomly assigned to three groups containing 45 patients with a list generated by a computer at an allocation ratio of 1:1:1 in each group. Group A was treated with the hip fixed at 50° and knee flexed at 90° for six hours post-operatively. Group B contained 45 patients treated with the hip elevated at 30° and knee flexed at 45° for six hours post-operatively. In group C, the affected knee was fully extended after the surgery. The knee flexion was achieved in group A and group B by putting a high pillow beneath the operated knee, which was measured through the protractor to determine the exact angle. The high pillow was removed at six hours post-operatively.

All patients were given intra-operatively 10 mg/kg tranexamic acid (Chongqing Lummy Pharmaceutical Co., Ltd., China) ten minutes before the skin incision; the method of administration of tranexamic acid is described by Patel et al. [19]. The surgeons and those assessing data were blinded to the group assignments.

Intra-operative protocol

All patients underwent general anaesthesia, which was administered by the same anaesthetists. All TKA procedures were performed by one senior orthopaedic surgeon under general anaesthesia. The standard midline skin incision was performed using a medial parapatellar approach, and the patella was everted. All the patients were treated with the same implant, a posterior stabilized fixed bearing P.F.C TKA (DePuy, TN, USA). A tourniquet was applied to all the patients from the skin incision until the prosthesis was installed at 250 mmHg. The implant used was the cemented posterior-stabilized prosthesis in each patient. The drainage tube was clamped for four hours and removed 24 hours post-operatively. After surgery, the patients were transferred to the anaesthesia recovery room until they were completely awake and then they were sent to the inpatient ward for further nursing. A cold pack was applied to the surgical site for two to three days. A daily gait rehabilitation programme and full weight bearing were employed by a physiotherapist at the first day after surgery.

Thrombosis prevention and screening

All patients were given subcutaneous low molecular weight heparin (LMWH, 0.2 mL, 2000 IU; Clexane, Sanofi-Aventis, France) at six hours post-operatively, repeated with a full dose at 24 hours intervals (0.4 mL, 4000 IU) until discharge. After discharge, rivaroxaban (10 mg; Xarelto, Bayer, Germany) was

administered orally for 15 days to prevent thrombosis if there was no bleeding. An intermittent pneumatic compression device was routinely applied on the calves of patients until they could walk.

Doppler ultrasound (Philips Ultrasound_lnc, iU22, USA) examination was used to assess deep vein thrombosis (DVT) at the time of discharge and at one, three and six month follow-up assessments, or at any time with clinically suspected DVT. Pulmonary embolism (PE) was diagnosed based on clinical symptoms and chest computed tomography (CT) scans.

Criteria for transfusions

Blood transfusions were planned in all patients with Hb level < 7 g/dL or a Hb level of 7 to 10 g/dL with symptoms of anaemia (e.g. mental states and palpitations), and the senior doctor decided on the need for blood transfusions.

Outcome measures

The primary outcomes were evaluated, including the total blood loss (calculated by the Gross formula [9]), hidden blood loss, ROM, and patient satisfaction. The secondary outcomes were transfusion requirements, drain volume, and maximum Hb drop. DVT and/or PE and wound-related complications were carefully recorded. The ROM and swelling ratio were assessed by the attending surgeon in the office by a nurse who was not involved in the study. The swelling ratio was defined as the average circumference of the superior patellar pole and the inferior patellar pole after the operative limb divided by the pre-operative circumference. Maximum Hb drop was defined as the difference between the pre-operative Hb level and the lowest post-operative Hb level, as well as the lowest pre-transfusion Hb level. The satisfaction score was divided into a three-point scale: very satisfied, generally satisfied, and poorly satisfied. The total follow-up time point of this study was six months post-operatively. The patients, investigators, and statisticians were all blinded during the study.

Statistical analysis

The sample size of the current study was calculated according to the study by Yang et al. [20]. This study determined the power of 0.80 and the alpha value of 0.05, requiring 20 patients in each group. Considering the potential exclusion, more than 20 patients in each group were enrolled in our study. One-way ANOVA and Tukey's post hoc test were used to compare the quantitative data, such as total blood loss, hidden blood loss, ROM, drain volume, knee swelling ratio, maximum Hb drop, and post-operative hospital stay. Pearson's chi-square test or Fisher's exact test was used for comparing qualitative data, such as patient satisfaction, transfusion requirements, DVT and/or PE, and wound-related complications. All analyses were performed using SPSS version 22.0 and statistical significance was defined as $P < 0.05$.

Results

Patient demographics

During the study period from December 2015 to December 2016, 147 patients with unilateral primary TKA were enrolled. Of them, 12 patients were excluded for the following reasons: six declined to participate, two had infection, one had thrombosis, and three had anaemia symptoms. Thus, 135 patients were finally included, and 45 patients were randomized to each group (Fig. 1). No significant differences were observed between groups in terms of age, gender, BMI, American Society of Anaesthesiologists, pre-operative haemoglobin, pre-operative haematocrit, pre-operative platelet counts, pre-operative ROM, tourniquet time, duration of surgery, and post-operative hospital stay. Table 1 summarizes the baseline characteristics of the three groups.

Blood loss

Table 2 summarizes the outcomes of blood loss. There was no difference in intra-operative blood loss in the three groups. Total blood loss was significantly lower in group A (921 ± 209 mL) and group B (1125 ± 222 mL) compared to group C (1326 ± 291 mL) ($P < 0.001$, $P < 0.001$). Differences in total blood loss were also detected between groups A and B ($P < 0.001$). Hidden blood loss was less in group A (597 ± 213 mL) and group B (784 ± 229 mL) compared to group C (915 ± 301 mL) ($P < 0.001$ and $P = 0.038$), and statistically significant differences were found between groups A and B ($P = 0.002$) in hidden blood loss. Among 45 patients in each group, 2 in group A, 4 in group B, and 7 in group C required

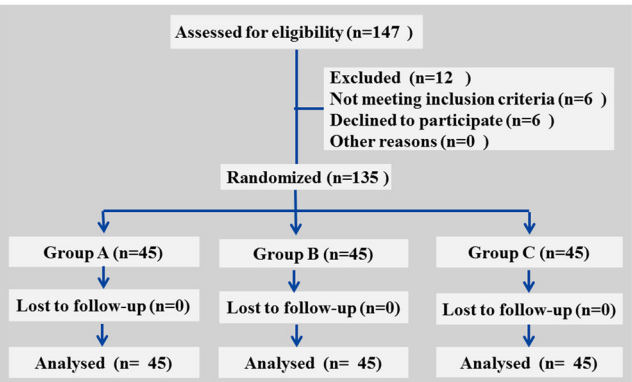

Fig. 1 A flow diagram shows the patients assessed and included among three groups

Table 1 Pre-operative demographics

Demographics	Group A ($n = 45$)	Group B ($n = 45$)	Group C ($n = 45$)	P value
Age* (y)	67.2 ± 3.4	66.7 ± 4.8	66.0 ± 3.2	0.373
Gender# (M/F)	17/28	15/30	19/26	0.685
Side# (R/L)	20/25	18/27	22/23	0.698
Weight* (kg)	65.4 ± 5.1	65.0 ± 4.9	64.1 ± 4.6	0.439
Height* (m)	1.6 ± 0.6	1.6 ± 0.7	1.6 ± 0.6	0.610
BMI* (kg/m^2)	24.0 ± 2.2	24.2 ± 2.4	23.5 ± 1.7	0.250
ASA#				0.867
I	12	14	11	0.771
II#	25	21	26	0.535
III#	8	10	8	0.827
Pre-op. Hb* (g/dL)	13.3 ± 0.6	13.4 ± 0.6	13.4 ± 0.5	0.879
Pre-op. Hct* (%)	39.7 ± 1.1	39.8 ± 1.4	39.7 ± 1.3	0.949
Pre-op. PLT* counts (× 10^9)	183.2 ± 37.7	189.9 ± 29.8	187.3 ± 38.0	0.650
Pre-op. ROM*	94 ± 4	94 ± 3	94 ± 3	0.435
Pre-op. knee circumference*	39.4 ± 0.6	39.6 ± 0.8	39.6 ± 0.8	0.481
Tourniquet time*	44.0 ± 2.9	44.0 ± 2.9	43.6 ± 3	0.734
Duration of surgery*	67.2 ± 3.2	68.1 ± 3.5	68.0 ± 2.8	0.421

y years, *M* male, *F* female, *R* right, *L* left, *BMI* body mass index, *ASA* American Society of Anesthesiologists, *Preop.* preoperative, *ROM* range of motion, *Hb* haemoglobin, *Hct* haematocrit, *PLT* platelet

*Analysed by the one-way ANOVA

Analysed by the Pearson chi-square test or the Fisher exact test

transfusion, which was not statistically significant in the three groups ($P = 0.672$, $P = 0.160$, and $P = 0.334$). Drain volume and the maximum Hb drop were significantly lower in group A and group B compared with group C ($P < 0.001$, $P < 0.001$ and $P < 0.001$, $P < 0.001$, respectively), which was statistically significant between groups A and B in the maximum Hb drop ($P < 0.001$).

Knee function

ROM increased in all patients compared to pre-operative levels. It was significantly better in group A compared with group C at the time of discharge, one and three months after surgery ($P < 0.001$, $P < 0.001$, and $P = 0.027$), and similar differences were found between groups B and C at the time of discharge

Table 2 Intra-operative and post-operative clinical outcomes

Clinical outcomes	Mean and standard deviation			P value			
	Group A ($n = 45$)	Group B ($n = 45$)	Group C ($n = 45$)	A vs. B vs. C	A vs. B	A vs. C	B vs. C
Intra-operative blood loss* (mL)	165 ± 33	167 ± 28	162 ± 20	0.667	0.943	0.839	0.646
Drain volume* (mL)	158 ± 35	174 ± 45	249 ± 31	< 0.001	0.112	< 0.001	< 0.001
Hidden blood loss* (mL)	597 ± 213	784 ± 229	915 ± 301	< 0.001	0.002	< 0.001	0.038
Total blood loss* (mL)	921 ± 209	1125 ± 222	1326 ± 291	< 0.001	< 0.001	< 0.001	< 0.001
Transfusion requirements#	2	4	7	0.198	0.672	0.160	0.334
Maximum Hb drop* (g/dL)	3.1 ± 0.5	3.6 ± 0.7	4.3 ± 0.4	< 0.001	< 0.001	< 0.001	< 0.001
Post-operative hospital stay* (days)	4.9 ± 1.0	5.3 ± 1.5	5.4 ± 1.1	0.169	0.389	0.160	0.858

Hb haemoglobin

*Analysed by the one-way ANOVA

Analysed by the Pearson chi-square test or the Fisher exact test

and one month after surgery ($P = 0.006$ and $P = 0.001$). Additionally, patients in group A had better ROM scores than patients in group B at the time of discharge and one month after surgery ($P < 0.001$ and $P = 0.001$) (Fig. 2 and Appendix Tables 5 and 6). There were no significant differences in ROM among the three groups at six months after surgery.

The knee swelling ratio in group A was significantly lower than group B at day one after surgery ($P = 0.013$), and it was less in groups A and B compared with group C at day one after surgery ($P < 0.001$ and $P = 0.015$), at the time of discharge ($P < 0.001$ and $P < 0.001$), and at one month after surgery ($P = 0.004$ and $P = 0.028$). No statistically significant difference was found at the three and six month follow-up time points among the three groups (Fig. 3 and Appendix Tables 5 and 6).

Post-operative hospital stay and patient satisfaction

The median post-operative hospital stay was 4.9 ± 1.0 days in group A, 5.3 ± 1.5 days in group B, and 5.4 ± 1.1 days in group C, without a significant difference (Table 2).

The satisfaction ratings of patients in group A were significantly higher than those of groups B and C at the time of discharge ($P = 0.031$ and $P < 0.001$). At one month after surgery, a difference was still observed between groups A and C ($P = 0.002$). No significant differences were found among the three groups at three and six months after surgery. Patient satisfaction is summarized in Table 3.

Complications

No clinical DVT and/or PE events were found in all patients. Doppler ultrasound examination showed that five in group A, six in group B, and three in group C developed intramuscular venous thrombosis. Superficial infections were found in two in group A, one in group B, and one in group C. No deep infection was noted among the three groups. Wound exudate occurred in four in group A, three in group B, and one in group C. All wound-related complications were ultimately managed by wound care, dressing augmentation, and antibiotic treatment. Table 4 summarizes the outcomes of complications.

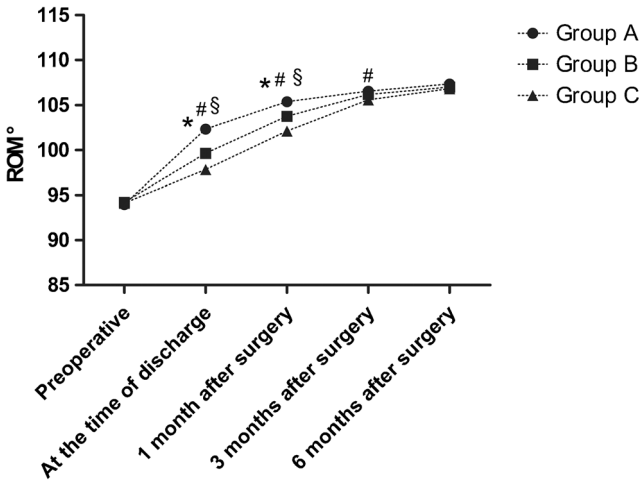

Fig. 2 The ROM scores at each follow-up time point. * indicates values that were significantly different between the groups A and B. # indicates values that were significantly different between the groups A and C. § indicates values that were significantly different between the groups B and C

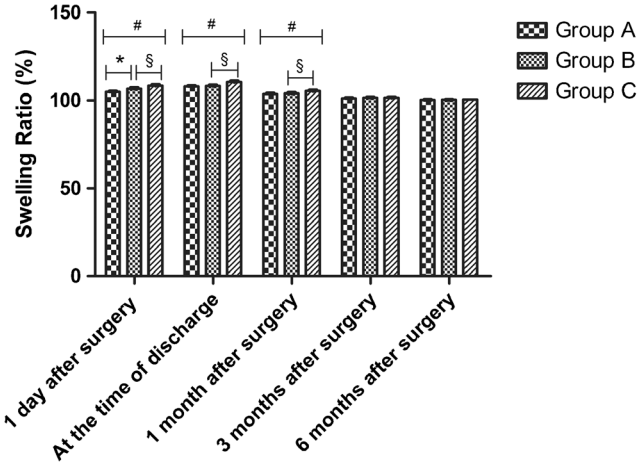

Fig. 3 The results of knee swelling ratio (%) at each follow-up time point. * indicates values that were significantly different between the groups A and B. # indicates values that were significantly different between the groups A and C. § indicates values that were significantly different between the groups B and C

Discussion

The most important finding of the present study was that the affected knee flexion position in the post-operative period of groups A and B can effectively reduce total blood loss and hidden blood loss, decrease maximum Hb drop, drain volume, and knee swelling ratio, and improve early ROM and patient satisfaction compared with the patients in group C. Additionally, it was found that the affected knee in the 90° flexion position had less hidden blood loss, lower results for the knee swelling ratio and drain volumes, and better early ROM and patient satisfaction compared with the other two groups. No significant differences were found in post-operative wound-related complications, DVT, and/or PE among the three groups.

Post-operative flexion management in TKA has proven to be a simple and economical method for reducing post-operative blood loss [21–23]. However, no consensus has been reached on the optimal flexion position for primary TKA. Li et al. [24] reported that 55 consecutive patients had their knee flexed to 30° for 72 hours and found that compared with 55 patients in the full knee extension group, the knee flexion group had significantly less blood loss and showed better results in early rehabilitation following TKA. However, another study of TKA by Ma et al. [18] suggested

Table 3 Patient satisfactions at the each follow-up time point

Demographics	Mean and standard deviation			*P* value			
	Group A ($n = 45$)	Group B ($n = 45$)	Group C ($n = 45$)	A vs. B vs. C	A vs. B	A vs. C	B vs. C
At the time of discharge				0.001	0.031	< 0.001	0.151
Very satisfied	34	22	13				
Generally satisfied	8	18	25				
Poorly satisfied	3	5	7				
At the 1 month after surgery				0.012	0.357	0.002	0.100
Very satisfied	36	30	20				
Generally satisfied	7	12	21				
Poorly satisfied	2	3	4				
At the 3 months after surgery				0.479	0.403	0.187	0.855
Very satisfied	39	34	32				
Generally satisfied	5	9	10				
Poorly satisfied	1	2	3				
At the 6 months after surgery				0.687	0.780	0.368	0.665
Very satisfied	40	38	35				
Generally satisfied	4	5	8				
Poorly satisfied	1	2	2				

P values were analysed by the Pearson chi-square test or the Fisher exact test

that there were no significant differences between the flexion and extension groups among any of the outcomes evaluated. Greater knee flexion may cause curvature of the femoral and popliteal veins and eventually impede venous return. Patients also may have greater discomfort in the high flexion position, and this may be explained by increased pain perception and the limited activity of the wound. As previously reported, the flexion time in the TKA ranged from six to 72 hours post-operatively. In our study, we only wanted to fix patients for six hours compared with long-term knee fixation, which was consistent with the concept of the modern fast-track. Second, if the knee and hip joint flexes for long time, it causes long-term buckling of the lower extremity vein, which impedes venous blood flow. These factors may induce complications such as thrombosis and lower limb swelling. The current results demonstrated that six hours post-operative knee flexion is already sufficient to reduce blood loss.

As previously reported, a large amount of bleeding may be mainly due to two factors in TKA: one is the surgical trauma caused by significant blood loss and the other is a hidden blood loss [24–26]. Sehat et al. [27] confirmed an average of 765 mL of hidden blood loss after TKA, accounting for 49% of the total blood loss. Theoretically, hidden blood loss may lead to knee swelling by increasing joint pressure, thus potentially limiting the range of motion of the knee [16, 28]. Good ROM is vital for an optimal result in evaluating the success of TKA [24, 25]. In the current study, the affected knee fixed in the flexion position can effectively improve early ROM compared with the affected knee in an extended position. The affected knee in the flexion position may be a reasonable alternative to extension in improving ROM restoration following primary TKA: first, swelling of the knee suppresses the quadriceps femoris by reducing the afferent

Table 4 Complications at the final follow-up

Complications	Group A ($n = 45$)	Group B ($n = 45$)	Group C ($n = 45$)	*P* value
DVT	0	0	0	–
PE	0	0	0	–
Intramuscular venous thrombosis	5	6	3	0.572
Deep infections	0	0	0	–
Superficial infections	2	1	1	0.773
Wound exudate	4	3	1	0.395

DVT deep venous thrombosis, *PE* pulmonary embolism

P values were analysed by the Pearson chi-square test or the Fisher exact test

activity of intra-capsular receptors, leading to weakness of the quadriceps femoris. Second, swelling may increase the weight of the affected limb and require more strength to perform straight-leg raising exercises. Third, swelling of the knee may cause increased pressure in the joint cavity, and this tension indirectly leads to pain in the wound, which may potentially reduce the patient's confidence and determination to perform the exercise [16]. In our study, for the patients in group A at the one and three months follow-up assessment, ROM had statistically better outcomes than those in the extension group, but no significant difference in ROM was seen among the three groups at six months after surgery. This may be explained by the above reasons that post-operative knee flexion can help to avoid hidden blood loss and improve functional recovery in the early post-operative period.

Satisfactory ratings of patients in our study suggested a better result at the time of discharge and post-operative one month follow-up in group A and group B compared with group C. The potential causes include the following: first, the purpose of TKA was to relieve pain and improve ROM without discomfort to the patient. The results of the study showed that post-operative high flexion achieved adequate improvement in functional outcome and achieved acceptable patient compliance compared with the extension group. Second, the core of enhanced recovery in TKA is blood management because of a large amount of peri-operative blood loss associated with complications that delay the recovery and prolong the length of stay [6]. Although the difference was not statistically significant in median post-operative hospital stay among the three groups, the blood loss, knee swelling, and drain volumes were less for the flexion route than for the extension route; this will be helpful for quadriceps strength recovery and fast recovery, as well as achieving psychological satisfaction. Therefore, these reasons may explain the significantly higher patient satisfaction score at the early time point in the flexion groups.

DVT and/or PE following TKA is a catastrophic complication [10, 29, 30]. Physical and chemical measures for thromboprophylaxis were used in all patients. Although several cases of intramuscular venous thrombosis were examined through the Doppler ultrasound, there were no clinical symptoms of DVT and PE, consistent with the results of other reports that 47% of DVT cases occurred on the first post-operative day. Thus, it is essential to prevent thrombosis in early anticoagulant therapy. However, the benefits of early anticoagulation may be offset by an increased risk of bleeding due to fibrinolysis caused by trauma and tourniquets. Thus, anticoagulation and post-operative bleeding require a delicate balance in TKA to reduce blood loss and prevent thrombosis. No significant difference was found in the incidence of wound-related complications among the three groups.

The current study has the following strengths: first, it was a well-designed and rigorously performed randomized controlled trial that produces less bias. Second, the baseline characteristics of the three groups were comparable and all the surgeries were performed by a senior surgeon. Third, the outcome of our study was the ratings of the patient's satisfaction, which was not explored well in other kinds of literature. Additionally, few studies have compared three different routes of knee limb positioning in TKA at the same time.

This study had some limitations, including the follow-up period for assessing functional outcome and complications was six months. Thus, there was not a sufficiently long time to identify known adverse events. Second, although this study shows a lower incidence of thrombotic and other wound-related complications, a larger sample size is needed to adequately assess the significant differences in these adverse events. Finally, the lack of an optimal time comparison with flexion is another potential limitation.

Conclusions

The current study found that the affected knee flexion position was superior to the use of a fully extended position for blood management, but it only contributed to better early functional recovery up to three months post-operatively in TKA. In addition, by fixing the affected knee at a high flexion position of 90°, patients could achieve less blood loss, lower knee swelling, and better early results for ROM and patient satisfaction than the other two groups.

Acknowledgements The authors would like to thank Dr. Li Chen (chenli930@scu.edu.cn) from Analytical & Testing Center Sichuan University for her help with image processing and data analysis, and I would also like to thank Dr. Shuting Li (447623681@qq.com) from Department of Ultrasonography, West China Hospital, Sichuan University, for providing diagnosis of venous thrombosis.

Funding This study was funded by the National Natural Science Foundation of China Program (No. 81601936, No. 81672219), and it was funded by the Science and Technology Department of Sichuan Province (No.2018HH0141), and it was also funded by the Health Department of Chengdu city, Sichuan Province (No. 18ZD016).

Compliance with ethical standards

This randomized controlled trial was approved by the institutional ethics committee in our hospital and informed consent was obtained before the study.

Competing interests The authors declare that they have no competing interests.

Appendix. ROM and knee swelling ratio (%)

Table 5 The results of ROM at each follow-up time point

Demographics	Mean and standard deviation			*P* value*			
	Group A ($n = 45$)	Group B ($n = 45$)	Group C ($n = 45$)	A vs. B vs. C	A vs. B	A vs. C	B vs. C
At the time of discharge	102 ± 3	100 ± 3	98 ± 3	< 0.001	< 0.001	< 0.001	0.006
1 month after surgery	105 ± 2	104 ± 2	102 ± 2	< 0.001	0.001	< 0.001	0.001
3 months after surgery	107 ± 2	106 ± 2	105 ± 2	0.034	0.573	0.027	0.248
6 months after surgery	107 ± 2	107 ± 2	106 ± 2	0.429	0.680	0.406	0.896

P values were analysed by the one-way ANOVA

Table 6 The results of knee swelling ratio (%) at each follow-up time point

Demographics	Mean and standard deviation			*P* value*			
	Group A ($n = 45$)	Group B ($n = 45$)	Group C ($n = 45$)	A vs. B vs. C	A vs. B	A vs. C	B vs. C
1 day after surgery	104.9 ± 2.1	106.7 ± 3.1	108.4 ± 3.2	< 0.001	0.013	< 0.001	0.015
At the time of discharge	108.0 ± 2.4	108.3 ± 2.7	110.6 ± 3.0	< 0.001	0.832	< 0.001	< 0.001
1 month after surgery	103.7 ± 2.1	104.1 ± 2.6	105.4 ± 2.6	0.003	0.779	0.004	0.028
3 months after surgery	101.2 ± 1.4	101.5 ± 2.4	101.6 ± 1.5	0.495	0.669	0.490	0.956
6 months after surgery	100.3 ± 0.9	100.4 ± 0.2	100.6 ± 0.1	0.586	0.974	0.588	0.723

P values were analysed by the one-way ANOVA

References

1. Lawrence RC, Felson DT, Helmick CG, Arnold LM, Choi H, Deyo RA et al (2008) Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part II. Arthritis Rheum 58:26–35
2. Zeni JA Jr, Axe MJ, Snyder-Mackler L (2010) Clinical predictors of elective total joint replacement in persons with end-stage knee osteoarthritis. BMC Musculoskelet Disord 11:86
3. Hill SR, Carless PA, Henry DA, Carson JL, Hebert PC, McClelland DB et al (2002) Transfusion thresholds and other strategies for guiding allogeneic red blood cell transfusion. Cochrane Database Syst Rev 2:CD002042
4. Madjdpour C, Spahn DR (2005) Allogeneic red blood cell transfusions: efficacy, risks, alternatives and indications. Br J Anaesth 95: 33–42
5. Schreiber GB, Busch MP, Kleinman SH, Korelitz JJ (1996) The risk of transfusion-transmitted viral infections. The Retrovirus Epidemiology Donor Study. N Engl J Med 334:1685–1690
6. Kehlet H (2013) Fast-track hip and knee arthroplasty. Lancet 381: 1600–1602
7. Dennis DA, Kittelson AJ, Yang CC, Miner TM, Kim RH, Stevens-Lapsley JE (2016) Does tourniquet use in TKA affect recovery of lower extremity strength and function? A randomized trial. Clin Orthop Relat Res 474:69–77
8. Wu Y, Zeng Y, Bao X, Xiong H, Hu Q, Li M, Shen B (2018) Comparison of mini-subvastus approach versus medial parapatellar approach in primary total knee arthroplasty. Int J Surg 57:15–21
9. Gross JB (1983) Estimating allowable blood loss: corrected for dilution. Anesthesiology 58:277–280
10. Haas SB, Barrack RL, Westrich G, Lachiewicz PF (2008) Venous thromboembolic disease after total hip and knee arthroplasty. J Bone Joint Surg Am 90:2764–2780
11. Horton TC, Jackson R, Mohan N, Hambidge JE (2002) Is routine splintage following primary total knee replacement necessary? A prospective randomised trial. Knee 9:229–231
12. Kumar A (2009) Perioperative management of anemia: limits of blood transfusion and alternatives to it. Cleve Clin J Med 76(Suppl 4):S112–S118
13. Li B, Wang G, Wang Y, Bai L (2017) Effect of two limb positions on venous hemodynamics and hidden blood loss following total knee arthroplasty. J Knee Surg 30:70–74
14. Wang H, Shen B, Zeng Y (2015) Blood loss and transfusion after topical tranexamic acid administration in primary total knee arthroplasty. Orthopedics 38:e1007–e1016
15. Lin K, Bao L, Wang J, Fujita K, Makimoto K, Liao X (2017) Validation of the Chinese (Mandarin) version of the Oxford knee score in patients with knee osteoarthritis. Clin Orthop Relat Res 475:2992–3004

16. Li B, Wen Y, Liu D, Tian L (2012) The effect of knee position on blood loss and range of motion following total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 20:594–599
17. Zeng Y, Si H, Li C, Wu Y, Shen B (2018) Effect of knee flexion position and combined application of tranexamic acid on blood loss following primary total knee arthroplasty: a prospective randomized controlled trial. Int Orthop 42:529–535
18. Ma T, Khan RJ, Carey Smith R, Nivbrant B, Wood DJ (2008) Effect of flexion/extension splintage post total knee arthroplasty on blood loss and range of motion—a randomised controlled trial. Knee 15: 15–19
19. Patel JN, Spanyer JM, Smith LS, Huang J, Yakkanti MR, Malkani AL (2014) Comparison of intravenous versus topical tranexamic acid in total knee arthroplasty: a prospective randomized study. J Arthroplast 29:1528–1531
20. Yang Y, Yong-Ming L, Pei-jian D, Jia L, Ying-ze Z (2015) Leg position influences early blood loss and functional recovery following total knee arthroplasty: a randomized study. Int J Surg 23:82–86
21. Antinolfi P, Innocenti B, Caraffa A, Peretti G, Cerulli G (2014) Post-operative blood loss in total knee arthroplasty: knee flexion versus pharmacological techniques. Knee Surg Sports Traumatol Arthrosc 22:2756–2762
22. Ong SM, Taylor GJ (2003) Can knee position save blood following total knee replacement? Knee 10:81–85
23. Panni AS, Cerciello S, Vasso M, Del Regno C (2014) Knee flexion after total knee arthroplasty reduces blood loss. Knee Surg Sports Traumatol Arthrosc 22:1859–1864
24. Wu Y, Yang T, Zeng Y, Si H, Li C, Shen B (2017) Effect of different postoperative limb positions on blood loss and range of motion in total knee arthroplasty: an updated meta-analysis of randomized controlled trials. Int J Surg 37:15–23
25. Fu X, Tian P, Li ZJ, Sun XL, Ma XL (2016) Postoperative leg position following total knee arthroplasty influences blood loss and range of motion: a meta-analysis of randomized controlled trials. Curr Med Res Opin 32:771–778
26. Huang GP, Jia XF, Xiang Z, Ji Y, Wu GY, Tang Y et al (2016) Tranexamic acid reduces hidden blood loss in patients undergoing total knee arthroplasty: a comparative study and meta-analysis. Med Sci Monit 22:797–802
27. Sehat KR, Evans R, Newman JH (2000) How much blood is really lost in total knee arthroplasty?. Correct blood loss management should take hidden loss into account. Knee 7:151–155
28. Faldini C, Traina F, De Fine M, Pedrini M, Sambri A (2015) Postoperative limb position can influence blood loss and range of motion after total knee arthroplasty: a systematic review. Knee Surg Sports Traumatol Arthrosc 23:852–859
29. Wu Y, Yang T, Zeng Y, Si H, Cao F, Shen B (2017) Tranexamic acid reduces blood loss and transfusion requirements in primary simultaneous bilateral total knee arthroplasty: a meta-analysis of randomized controlled trials. Blood Coagul Fibrinolysis 28:501–508
30. Gillette BP, DeSimone LJ, Trousdale RT, Pagnano MW, Sierra RJ (2013) Low risk of thromboembolic complications with tranexamic acid after primary total hip and knee arthroplasty. Clin Orthop Relat Res 471:150–154