Prospective, randomised, controlled study on the efficacy and safety of different strategies of tranexamic acid with total blood loss, blood transfusion rate and thrombogenic biomarkers in total knee arthroplasty: study protocol

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ABSTRACT

Introduction Total knee arthroplasty (TKA) is a common and highly effective orthopaedic procedure for treating end-stage knee osteoarthritis. Tranexamic acid (TXA) has become a routine part of perioperative care in TKAs. The best practices regarding the delivery method of TXA in TKA remain controversial. Plasminogen activator inhibitor-1 (PAI-1), thrombin–antithrombin (TAT) complexes and prothrombin fragment F1+2 (F1+2) have been demonstrated to be elevated in patients with venous thromboembolism (VTE). The aim of this trial was to investigate the most efficacious delivery method of TXA (comparison of intravenous and topical applications and comparison of three topical applications) and to evaluate the safety of TXA strategies by investigating the effect of TXA on the plasma D-dimer, PAI-1, TAT and F1+2 levels.

Methods and design This trial is a prospective, randomised, controlled study that will evaluate the efficacy and safety of strategies of TXA. A total of 250 patients undergoing primary TKA will be randomly allocated to five treatment groups for different TXA applications. The primary outcome is total blood loss. The secondary outcomes are blood transfusion rate, drainage volume, plasma D-dimer, PAI-1, TAT and F1+2 levels, maximum haemoglobin drop, wound complications, VTE and length of hospital stay.

Ethics and dissemination This study’s protocol is in accordance with the declaration of Helsinki. The ethics committee of the General Hospital of Ningxia Medical University approved this study (approval ID: 2020–505). The results of this study will be disseminated in international peer reviewed journals.

Trial registration number ChiCTR2000030624.

INTRODUCTION

Total knee arthroplasty (TKA) is a common and highly effective orthopaedic procedure for treating end-stage knee osteoarthritis, which can reconstruct joint alignment, alleviate pain and improve joint function. It was estimated that, from 2005 to 2030, the demand for primary total knee arthroplasties is projected to grow by 673% to 3.48 million procedures.1 However, TKA involves substantial blood loss and blood transfusion requests, which can lead to transfusion-associated complications such as disease transmission and immunological reactions, increasing burden on the healthcare system.2–5

Tranexamic acid (TXA), an indirect fibrinolytic inhibitor, has become a routine part of perioperative care in primary total knee arthroplasties.6 7 TXA can be delivered topically, intravenously or by combined application.8–10 For the patients undergoing TKA, topical TXA can be delivered with irrigation, periarticular soft tissue injection or injection
The study aimed to compare the efficacy of various strategies of TXA (comparison of intravenous and topical applications and comparison of three topical administrations) with TBL, BTR, and drainage volume. Prothrombin fragment F1+2 (F1+2) is produced when prothrombin is cleaved to form thrombin, which then acts on fibrinogen. Thrombin–antithrombin (TAT) complexes are formed after thrombin acts on fibrinogen to form fibrin clot and is then inactivated. Plasminogen activator inhibitor-1 (PAI-1) is a single-chain glycoprotein composed of 379 amino acids with a molecular weight of 47 kDa. In recent years, many investigations reported findings regarding potential associations between PAI-1 rs1799889 A/G polymorphism and VTE. A meta-analysis has supported that PAI-1 rs1799889 polymorphism may serve as one of the predisposing factors of VTE in both Caucasians and East Asians. Therefore, plasma D-dimer, PAI-1, TAT, and F1+2 levels could be used to monitor perioperative VTE and to evaluate the safety of TXA administration.

This is the first prospective, randomised, controlled study on the efficacy and safety of various administrations of TXA on total blood loss (TBL), blood transfusion rate (BTR) and D-dimer, PAI-1, TAT and F1+2 levels of TKA.

Objectives
This study aimed to compare the efficacy of various strategies of TXA (comparison of intravenous and topical applications and comparison of three topical applications) with TBL, BTR and drainage volume.

Moreover, this work aimed to clarify the safety of TXA strategies by investigating the effect of TXA on the plasma D-dimer, PAI-1, TAT and F1+2 levels, and by comparing the wound complications, length of hospital stay (LOS), deep vein thrombosis (DVT) and pulmonary embolism (PE).

METHODS AND ANALYSIS

Trial design
The study is a prospective, randomised, controlled study with a 6-month follow-up involving 250 patients undergoing TKA. The study compares TBL, BTR and drainage volume between different administrations of TXA (comparison of intravenous and topical applications and comparison of three topical applications) to determine the most effective strategy of TXA. The study also investigates the safety of TXA strategies in terms of the effect of TXA on the plasma D-dimer, PAI-1, TAT and F1+2 levels, wound complications, LOS, DVT and PE. Randomisation will be performed with a 1:1:1:1 allocation into five groups: placebo group, intravenous group, topical irrigation (TI) group, peritubular tissue injection (PI) group and and drainage injection (DI) group.

Study setting
The study is performed in the General Hospital of Ningxia Medical University, a tertiary A hospital. All TKA procedures will be performed by one surgeon (QJ) who has previously performed a minimum of 1000 TKA procedures. A training manual will be produced to educate and train the study team, including anaesthesiologists, nurses and clinical research coordinators before starting the trial.

This trial is registered online (chictr.org.cn). The study protocol construction follows the SPIRIT 2013 and the Consolidated Standards of Reporting Trials (CONSORT) statements. A CONSORT flow diagram of the trial is summarised in figure 1.

Sample size calculation
A previous study based on an analysis of a national database with 7133 primary TKA procedures has indicated that the TBLs of intravenous TXA application, topical TXA application and control group were 850±410 mL, 970±470 mL and 1200±640 mL, respectively. Based on these data, the sample size was calculated by PASS V.15.0 (NCSS, LLC, Kaysville, Utah, USA), with one-way analysis of variance (ANOVA) F-tests. We calculated a total of 39 patients per group to provide a power of 80% to detect it at a significance level of 5%. Considering factors such as loss of follow-up, we expanded the sample size by about 30%; therefore, there will be a minimum of 50 patients in each group.

Patient and public involvement
No patients were involved in the study.

Patient enrolment and eligibility criteria
Patient enrolment in this study will occur during the preoperative outpatient visit; the decision to perform the TKA is made by the surgeon according to good clinical practice. A total of 250 consecutive eligible patients will be enrolled in this trial. A detailed list of inclusion and exclusion criteria is presented in box 1.

Randomisation, blinding and quality control
A computer-based randomisation system will be used to screen and randomise the patients 1 day before operation. Randomisation allocation forms will be sealed in non-transparent envelopes by a person not involved in the study. The envelopes will be kept in a locked cabinet at the surgical unit. Single envelopes will be opened and thus patients will be randomised by the anaesthesia nurse no earlier than 2 hours prior to the surgery. Patients, anaesthesiologists and research assistants collecting data
will be blinded to group allocation. The implementation of the study, data completeness and accuracy will be supervised by the Office of Scientific Research at General Hospital of Ningxia Medical University.

**Intervention**

All TKA procedures will be performed by one surgeon (QJ), under general anaesthesia, with tourniquets. A standard midline skin incision and medial parapatellar arthrotomy approach will be used. Standard surgical techniques for intraoperative haemostasis will be performed. All output will be measured and recorded in millilitres. All drains will be clamped for 2 hours and removed 24 hours after placement.

For patients in the placebo group, 100 mL normal saline (NS) will be applied intravenously 10 min prior to skin incision, and 100 mL NS will be applied intravenously at 3 and 6 hours postoperatively.

For patients in the intravenous group, 1 g of TXA in 100 mL NS will be applied intravenously 10 min prior to skin incision, and 1 g of TXA in 100 mL NS will be applied intravenously at 3 and 6 hours postoperatively.

For patients in the TI group, after cementation of the implant, 3 g of TXA diluted in 75 mL NS solution will be irrigated topically to the open joint surfaces 5 min prior to tourniquet release. The surgeon subsequently suctioned away excess study solution without touching the surrounding tissue surfaces.

For patients in the PI group, 3 g of TXA diluted in 75 mL NS solution will be injected to periarticular tissue, including the medial and lateral capsules, the quadriceps muscle tendon and the infrapatellar fat pad, prior to capsule closure.

For patients in the DI group, after wound closure, 3 g of TXA diluted in 75 mL NS solution will be injected into joint cavity through drainage.

As placebo, the patients in the TI, PI and DI groups will also receive 100 mL NS intravenously 10 min prior to skin incision, 3 and 6 hours postoperatively.

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**Box 1 Inclusion and exclusion criteria**

**Inclusion criteria**

1. Undergoing primary total knee arthroplasty of both genders.
2. >18 and <100 years at the time of inclusion.

**Exclusion criteria**

1. Allergy to tranexamic acid.
2. Preoperative hepatic or renal dysfunction.
3. Serious cardiac or respiratory disease, including coronary artery stent placement or bypass.
4. Congenital or acquired coagulopathy, as evidenced by an international normalised ratio of >1.4 or a partial thromboplastin time of >1.4 times normal.
5. A preoperative platelet count of <150,000/mm³.
6. History of a prothrombotic condition.
7. Pregnancy or breast feeding.
8. Diagnosis of inflammatory arthritis.
9. A preoperative haemoglobin level of <100 g/L.
VTE prophylaxis will be standardised according to the institution with low-molecular-weight heparin. All patients will be managed with a comprehensive, multidisciplinary approach to postoperative care, including mechanical prophylaxis prior to discharge, early mobilisation with physical therapy, medical optimisation and regional anaesthesia, if appropriate. All patients will undergo ultrasound examination of the lower extremity blood vessels before discharge. Patients will be considered for blood transfusion if the haemoglobin level is less than 80 g/L with symptoms (defined as syncope, lightheadedness, shortness of breath, fatigue and palpitations).

ASSESSMENTS
Sample collection
Peripheral blood samples will be collected at several time points: 1–3 days prior to operation, second hour, first and third days after the operation, respectively. All samples will be placed on ice and centrifuged at 3500 rpm for 5 min. The plasma will be frozen and stored at −80 °C. Preoperative and postoperative samples will be drawn to assess haemoglobin, haematocrit, D-dimer, PAI-1, TAT and F1+2 levels.

Preoperative phase
Medical data and history, including height, weight, allergies, tobacco use, alcohol use, ASA presurgical physical status class, historical illnesses and surgeries, together with preoperative standard laboratory tests, will be collected from every patient. Imaging examination and surgical planning will be performed for every patient.

Postoperative phase
A total drainage volume of 24 hours will be recorded for each patient. The blood volume and TBL will be calculated using the formula reported by Nadler et al. A maximum haemoglobin drop will be calculated and recorded for each patient. The patients requiring blood transfusion in each group will be recorded. The complications, such as wound complications and VTE, will also be collected. Patients will be discharged within 3–5 days postoperatively, if no complication occurs. The LOS will also be collected. Patients will be invited to the outpatient clinic 2 weeks and 1, 3 and 6 months after the operation to assess and record the complications and mortality. The vascular ultrasonography will also be performed at the follow-up time points.

Outcome measures are presented in Table 1.

Study schedule
This study began on 1 May 2020. It is estimated that this study will be completed by 30 September 2021.

Statistical analysis
The statistical analysis will be performed by using SPSS V.19.0 software. The baseline continuous variables will be summarised using mean±SD or median (IQR) for continuous variables as appropriate. Categorical variables will be summarised using frequency (percentage). Normality of data will be tested by the Kolmogorov-Smirnov test. One-way ANOVA will be used to compare the TBL, drainage volume, plasma D-dimer, PAI-1, TAT and F1+2 levels, maximum haemoglobin drop and LOS between groups. If there is a significant difference, the comparison between groups will be performed by Schefee post hoc analysis test. Repeated-measures ANOVA will be used to compare plasma PAI-1, TAT, F1+2 levels according to time points. \( \chi^2 \) test will be used to compare the BTR, VTE and wound complications between groups.

DISCUSSION
TKA is an effective treatment option to correct deformity, ameliorate pain and improve quality of life for advanced osteoarthritis of the knee. Since the concept of Enhanced recovery after surgery (ERAS), or fast-track surgery, was introduced in 1997 by Dr Henrik Kehlet, the ERAS has been widely accepted in TKA. Blood management is an inseparable part of all big orthopaedic surgeries, including TKA procedure.

TXA, an antifibrinolytic agent, has received increasing attention; it is shown to have effectively reduced blood loss following TKA. While previous studies have compared TXA administrations between intravenous usage and one or two of three topical usages, and there is no consensus or best practices regarding route of TXA in knee arthroplasty. Therefore, we designed this study to compare the efficacy of different strategies of TXA (comparison of intravenous and topical applications and comparison of three topical applications).

In this study, we conduct plasma D-dimer, PAI-1, TAT and F1+2 levels to evaluate the safety of TXA. Because the sensitivity and specificity of those three markers remain unclear in TKA, we will perform ultrasound examination of the lower extremity blood vessels for each patient to confirm the diagnosis of DVT.

In summary, this study was designed to investigate the most effective administration from intravenous and three

| Table 1 Outcome measures          |
|----------------------------------|
| **Primary outcome**              |
| Total blood loss (mL)            | Blood transfusion rate (mL) |
| Drainage volume (mL)             |                             |
| Plasma D-dimer (mg/L)            | Plasma PAI-1 (ng/mL)        |
| Plasma TAT (ng/mL)               | Plasma F1+2 (ng/mL)         |
| **Secondary outcomes**           |
| Wound complications              |
| Venous thromboembolism           |
| Length of hospital stay (days)   |

F1+2, prothrombin fragment F1+2; PAI-1, plasminogen activator inhibitor-1; TAT, thrombin–antithrombin complexes.
topical applications, and to evaluate the safety of TXA with D-dimer, PAI-1, TAT and F1+2.

Monitoring
An orthopaedic surgeon, an anaesthesiologist, a statistician, a physician and a member from the Office of Scientific Research who are not related to this trial will be involved for the entire duration of the trial to review and ensure protocol compliance, and to make the decision to stop the trial if there are abnormal safety issues or serious complications.

Ethics and dissemination
This study protocol is in accordance with the most recent version of the World Medical Association Declaration of Helsinki. The ethics committee of General Hospital of Ningxia Medical University approved this study (approval ID: 2020–505).

Consent
Details of the study will be explained thoroughly to the potential participants by the study investigator at the preoperative interview. The informed consent form must be signed and provided by all eligible individuals before enrolment. The participants can withdraw from the study without any reason at any time. The privacy of all participants will be strictly protected. Any confidential information, such as name, identification number and hospital administration number will not be exported, and data anonymity will be executed during the process of data analysis and management.

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Contributors YY, ZW and OJ are responsible for the original study planning. YY, XZ and OJ applied for this study’s funding and for the postoperative evaluations of 3 and 12 months. KY, JH and YJ trained the hospital personnel. KY, JH and YJ were responsible for patient recruitment; DD, HY and OJ were responsible for the 24-hour evaluation of the patients. YY and ZW were responsible for controlling patient data deposits and checked the data input. YY, ZW and XZ were experts in outcome prediction models, intensive care and severe complications, and orthopaedic research. All authors participated in the analysis and reporting of the results. FW, as a professional statistician, was consulted for statistical analyses. YY and OJ conceived the study. All authors contributed to refining the study protocol and approving the final manuscript.

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Competing interests
None declared.

Patient and public involvement
Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Patient consent for publication
Not required.

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