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Internal brace augmentation reconstruction VS standard anterior cruciate ligament reconstruction : A randomized controlled clinical trial study protocol.

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Abstract:

Introduction: Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries in sports, and the gold standard for treating ACL rupture is tendon graft reconstruction. Recently, internal brace technology has been gradually applied to ligament repair, but there is still a lack of relevant in vivo clinical evidence for the use of internal brace technology in ACL reconstruction. We conducted a randomized controlled trial to investigate the clinical efficacy of internal brace technology in ACL reconstruction.

Methods and analysis: This is a randomized, parallel controlled trial of patients with ACL rupture who underwent inpatient surgery at the Department of Orthopedics, Xiangya Hospital, Central South University. All study subjects were assigned to the test and control groups according to the random number table method. The test group underwent ACL reconstruction using the internal brace technique, and the control group underwent standard ACL reconstruction, with uniform postoperative rehabilitation in both groups. Patient-reported outcomes were preoperative baseline and postoperative recovery at 1, 3, 6, 12, and 24 months. The primary outcome was International Knee Documentation Committee (IKDC) function from baseline (ACL rupture) to 6 months postoperatively. Secondary outcomes included (I) other patient outcome reporting metrics, the Lysholm knee score (LKS), the Knee Injury and Osteoarthritis Outcome Score (KOOS), and the Visual Analog Scale (VAS), (II) the use of the Kneelax3 knee stabilizer to assess knee stability, (III) the occurrence of adverse events, such as graft refraction or symptomatic instability, postoperative infection, and contralateral injury, and (IV) magnetic resonance images at 12 and 24 months after ACL reconstruction.

Ethics and dissemination: This trial was approved by the Medical Ethics Committee of Xiangya Hospital of Central South University on October 26, 2021. Data will be published in peer- reviewed journals and presented at national and international conferences.

Trial registration number: ChiCTR2200057526.

Strengths and limitations of this study:

- Internal Brace augmentation reconstruction is the standard ACL reconstruction with Internal Brace technology.
- Randomization divided the included patients into Internal Brace augmentation reconstruction group and standard ACL reconstruction group.
- Prospective follow-up and data collection to comparatively analyze the need for enhanced reconstruction of Internal Brace.
- The study has a standard and detailed rehabilitation training program.
- This trial was conducted in a single center and the data lacked generalizability.

Key words:

anterior cruciate ligament (ACL), anterior cruciate ligament reconstruction, internal brace, study protocol.

Introduction

Anterior cruciate ligament (ACL) rupture is one of the most common ligament injuries in the knee, mainly in young people who participate in sports. If not actively treated after injury, joint instability and other phenomena often occur, which will reduce the quality of life and increase the risk of osteoarthritis[1-3]. Over the past few decades, the incidence of ACL ruptures has been estimated at approximately 30 to 52 cases per 100,000 person-years(4). ACL injuries occur in more than 175,000 people in the United States each year, and approximately 100,000 of those people undergo surgery(5-7). A 41-year-old miner successfully performed the world's first ACL repair surgery, and the function of the knee joint was very good after surgery(8). With the continuous development of surgical techniques, the current mainstream surgical method is to perform ACL reconstruction under arthroscopy(9). In recent years, a Japanese study found that for rugby players under the age of 20 after ACL reconstruction, the redisruption rate of ACL reconstruction grafts after returning to the field was 23%(10). At the same time, other studies have also shown that the revision rate of ACL reconstruction with allogeneic tendon in adolescents can reach 35%(11); however, the effect after revision is not as good as that of primary ACL reconstruction(12).

Internal brace technology was promoted in 2010, which uses braided ultrahigh molecular weight polyethylene (UHMWPE) polyester suture tape and knotless bone anchors to reinforce ligament strength, also known as an auxiliary stabilizing structure for recovery of motion after ligament repair, which helps prevent secondary damage, (13)such as anterior and posterior cruciate ligament, medial and lateral collateral ligament repair of the knee(13-15), and ankle and elbow ligament strengthening repair(16, 17). Enhanced collateral ligament repair and reconstruction with internal brace improves limb biomechanics, including greater stiffness and maximum load, while facilitating early rehabilitation in the motor and biomechanical environment (12, 14). Reinforced ligament repair offers unique advantages over traditional reconstruction techniques, including smaller bores and implants, no risk of disease transmission from allografts, and no risk of tunnel convergence during the procedure (14, 18, 19). Therefore, ACL reinforcement is an alternative method for supporting ACL grafts in a synergistic load-sharing manner with primary tension on the graft and high-strength suture tape.

In the case of ACL reconstruction, the internal brace ligament augmentation technique helps prevent a variety of failure scenarios, including creep and irreversible stretching, traumatic tears, and slippage of the tendon-bone interface(20, 21). In addition, these failures can be avoided when the graft is small or vulnerable(20, 21). In 2018, in an in vitro trial, Dr. Pat Smith found that ACL reconstruction combined with independent suture tape significantly reduced graft elongation and allowed the grafted ligaments to accept higher ultimate disruption loads, thereby reducing the risk of rerupture of the graft(20). Preliminary short-term studies have shown that the use of the internal brace technique can significantly improve functional recovery after ACL reconstruction and improve patient quality of life, but there are only a few medical institutions that use ACL reconstruction combined with the internal brace technique, and there is a lack of relevant in vivo clinical evidence.

This study will fill this gap by exploring whether internal brace technology can improve

the outcome of patients with ligament injuries and provide a new option for patients with ACL injuries.

Methods and analysis

Study setting

This was a randomized parallel-controlled trial of patients with ACL rupture who were hospitalized in the Department of Orthopedics at Xiangya Hospital of Central South University from 03/2022 to 03/2023. The Medical Ethics Committee of Xiangya Hospital of Central South University approved the ethical application related to this study and has filed it (ethical approval number: 202110478). All subjects signed the informed consent form before the operations.

Eligibility criteria

The inclusion criteria are as follows: (1) age of 16-45 years; (2) unilateral knee MRI showing unilateral knee ACL fracture; (3) combined meniscal injury that does not interfere with the standard postoperative rehabilitation program after intraoperative management; (4) combined grade III or lower cartilage injury that does not interfere with the standard postoperative rehabilitation program; (5) satisfaction of 24 months of follow-up; (6) no previous injury to the healthy knee; (7) informed consent of the subject and signing of relevant documents.

The inclusion criteria are as follows: (1) age of <16 years or >45 years; (2) previous ACL reconstruction or bilateral ACL injury; (3) MRI revealed posterior cruciate ligament (PCL), medial collateral ligament (MCL), or lateral collateral ligament (LCL) injury; (4) grade IV cartilage injury or unstable longitudinal meniscus tear requiring repair that interferes with standard rehabilitation protocols after surgical management; (5) patients who cannot meet 24 follow-up visits; (6) patients with severe underlying medical conditions that make surgery inadvisable, or patients with mental illness, pregnancy during planned trials, or other conditions that are not conducive to late follow-up.

Participant selection:

Patients diagnosed with ACL rupture by clinicians through physical examination and MRI imaging evaluation were assigned to the trial and control groups according to the time of admission according to the random number table method after final confirmation of ACL rupture under arthroscopy. The trial group was reconstructed using ACL reconstruction with the internal brace technique, and the control group was reconstructed using ACL reconstruction without the internal brace technique. Preoperative assessment of patients was performed before surgery, and a uniform rehabilitation program was performed after surgery. The protocol (version 1.0, March, 2022) inclusion start date was March 2022, with an expected cutoff date of March 2023. The follow-up period is 2 years, with the last follow-up expected in March 2025 (the exact end date is based on the inclusion of the last subject), and the specific technical route is shown in **Fig. 1.**

Study sample

IKDC score consists of three aspects: 1) symptoms, including pain, stiffness, swelling, interlocking/jamming, and playing with a tender leg; 2) motion and daily activities; and 3) current knee function and knee function before the knee injury (not included in the total score), which is the main outcome indicator of this study, based on which the sample size required for this trial was estimated. The minimum clinically important

difference (MCID) of the IKDC scale was reported to be between 8.8 and 15.6[22-24], we set δ to 10, and the overall sample standard deviation was set to 13 based on the relevant literature[22-24]. To satisfy the test efficacy (1-β) of 0.8 and the test level α of 0.05, the sample size calculated for each group was 27 according to the following formula, and considering a 20% lost visit rate, 32 patients were included in each group with a total of 64 patients included.

Randomization and Concealed Grouping

All eligible subjects were included after screening by inclusion and exclusion criteria, and the subjects enrolled were randomly assigned to the ACL reconstruction with internal brace technique group (combined group, n=32) and the standard ACL reconstruction group (simple group, n=32) using the random number table method. The occurrence of adverse events was recorded throughout the follow-up. All data were collected by 2 physicians who were unaware of the grouping. During postoperative rehabilitation, all subjects were given a uniform standard rehabilitation program by a professionally trained and relevant rehabilitation physician or clinician, and the rehabilitation therapist was not aware of the patient's intraoperative condition.

Interventions and surgical techniques

In all cases, all inside ACL reconstruction was performed using autologous semitendinosus tendons with the aid of knee arthroscopy. Semitendinosus tendons were braided with sutures (0 FiberWire Suture, Arthrex) to form four strands of ACL grafts (all between 7.5 and 10 mm in diameter, supplemented with semimembranous tendons less than 7.5 mm in diameter). In the ACLR group, the braided graft femoral end and tibial segment were suspended and fixed with a TightRope (ACL TightRope RT Implant, Arthrex), and in the ACLR with internal brace group, a separate wire tape (2 mm FiberTape, Arthrex) was added to the ACLR group, and the suture was fixed with a knotless bone anchor (4.75-mm PEEK SwiveLock, Arthrex) distally and a TightRope suspension proximally as in the graft. **Fig. 2**.

The procedure was as follows: the patient was anesthetized, a tourniquet was applied to the affected limb, routine surgical disinfection of the knee was performed, a sterile surgical sheet was placed, the semitendinosus tendon was palpated, a straight incision was made medial to the tibial tuberosity, the semitendinosus tendon was removed with a tendon extractor, 10 ml of ropivacaine was injected at the tendon extraction site, and then, the removed semitendinosus tendon was braided into 4 strands using the GraftLink (Arthrex) technique(25). A conventional knee arthroscopic approach was performed on the anteromedial and anterolateral sides of the affected knee to explore the injured structures and remove the remaining portion of the ACL. The knee was flexed to the extreme, and the femoral tract was created at the footprint of the ACL stop at the lateral femoral condyle and the tibial tract at the footprint of the ACL start. The graft and two TightRope titanium plates were pulled into the knee cavity and pulled out through the femoral and tibial tracts, respectively. The tabs were flipped, the tab rings were tightened, and the titanium plates were fixed. In the ACLR with internal brace group, the femoral end of the FiberTape wire band was fixed with a TightRope ring, the wire band was tensioned in the extended position, and the tibial end was fixed independently with a knotless bone anchor (4.75-mm PEEK SwiveLock, Arthrex).

All patients received a uniform training and rehabilitation program after surgery, and

the entire rehabilitation process was divided into 7 phases. The first 3 phases focused on controlling swelling and restoring range of motion, which usually required 4 weeks. Detailed rehabilitation plan can be found in **Table 1**. Phases 4-5 focused on restoration of quadriceps muscle strength control, balance and core strength restoration training, and phases 6-7 were gradually resumption of various sports activities, from daily activities to professional activities or contact sports. Detailed rehabilitation plan can be found in **Table 2** and **Table 3.**

Table 1. phases 1-3 of the post-ACL reconstruction rehabilitation program

Phase	Movement Exercises	Gait Exercises	Manipulative Massage	Rehabilitation Goals	Precautions
Phase 1 (within 1 week)	(1) Bed heel against the bed for flexion and extension sliding; supine position, the affected leg bends the hip, flexes the knee and places the heel on the wall for flexion and extension sliding; sitting position, legs on the floor, the healthy leg is placed in front of the affected leg and assists the affected leg in flexing the knee. (2) Ankle pump exercises (the affected leg is elevated, and the foot performs upward hooking and downward stepping movements, as well as rotational movements). (3) Anterior thigh muscle tensing exercises with the knee in the straight position (can be combined with neuromuscular electrical stimulation or biofeedback exercises). (4) Hip muscle group training. (5) Pillow clamping of the legs for medial thigh muscle group strength training. (6) The brace is locked in the 0° position, and the affected leg is lifted in the supine, prone and prone positions for muscle strength training. (7) Passive knee extension exercises: prone position with the affected knee extended out of the bed for suspension or supine position with the affected leg in a slightly elevated heel position and the knee joint suspended. (8) In the above weight-bearing exercise position, weight transfer training (front-to-back and left-to-right) can be performed. (9) Continuous passive movement apparatus training with increased knee flexion by 5°to 10°/day.	(1) Flat and step gait training with the support of a knee protection brace and double crutches. (2) Cold compresses after training to reduce edema.	(1) Push the patella in all directions. (2) Manipulation of the posterior thigh muscles of the affected limb or sitting and standing to pull the muscles to relieve their spasm.	Active mobility of the knee joint reaches 0°to 90°. (1) The anterolateral thigh muscles can be tightened better. (2) The affected limb can be fully weight bearing with the help of braces and crutches. (3) Edema control is good. (4) Good wound healing.	(1) Brace locked in 0° position, crutches, and weight-bearing exercises within tolerable range. (2) Wear the brace at night and lock it in the 0° position while sleeping with the affected leg elevated.
Phase 2 (1-2 weeks)	(1) Fixed cycling exercises (from small to full range of pedal rotation). (2) Tightening exercises and 90° muscle strength exercises for the anterior thigh muscles in the straight position.	(1) The healthy leg stands outside the treadmill with weight, and the	(1) Manipulation to push the patella treatment.	The active mobility of the knee joint reaches 0°to 120°. (1) Straight leg elevation; anterior	(1) Weight-bearing exercises within tolerable

	(3) Standing balance training on the affected leg with a single leg wearing a support. (4) Balance training on a balance board with forward and backward weight transfer. (5) Continuous passive activity equipment training. (6) Start small partial weight-bearing squat exercises (within 30° of knee flexion). (7) Passive straightening exercises with the heel slightly elevated and the knee hanging in the air. (8) Straight leg raises training (all directions). (9) Terminal angle knee extension training in the standing position using an elastic band.	affected leg simulates walking on the treadmill. (2) The affected leg crosses the obstacle training and simulates walking.	(2) Manipulation of the posterior thigh muscle group for relaxation and stretching exercises.	thigh muscles can be tightened with force. (2) With crutches, the patient can walk normally with a nonlocking brace.	limits. (2) Transition from double to single crutch. (3) When the strength of the anterior thigh muscle group is well exercised, the locking brace can be gradually dispensed (the anterior thigh muscle group can be unlocked to more than 30° only when it can contract forcefully to keep the straight leg elevated).
Phase 3 (2-4 weeks)	(1) Fixed bicycle training gradually increases the resistance to improve exercise endurance. (2) Tightening exercises for the anterior thigh muscle group in the straight position and muscle strength exercises in the range of 60°to 90° until the muscle strength of both legs is equal. (3) 0°to 60° squat training, gradually increasing the resistance strength (for patients with meniscal repair, squat to the target angle on the healthy leg before shifting the weight to the middle of the two legs). (4) Stand with both legs on a balance board for balance training in multiple directions. (5) Single-leg standing balance training on the affected leg (with eyes closed and open and on a support surface with different degrees of softness). (6) Straight leg raise training in the standing position, which can increase the resistance appropriately.	Exercise with rope tied around the waist or on a treadmill for forward and backward gait training.	(1) Manipulation to push the patella treatment. (2) Manipulation of the surgical scar. (3) Manipulative passive knee flexion or extension angle exercises.	The knee joint moves to an active full angle, in line with the healthy side leg. (1) Normal gait can be achieved without any walking aid. (2) Self-care of daily life (may have some difficulty in walking up and down steps).	Fully weight bearing; normal gait can be achieved without the aid of a brace or walker at 3 weeks postoperatively.

Table2: Phases 4-5 of the post-ACL reconstruction rehabilitation program

Phase	Movement Exercises	Gait Exercises	Manipulative Massage	Rehabilitation Goals	Precautions
Phase 4 (4-8 weeks)	(1) Fixed cycling training: gradually increasing the resistance. (2) Squat training: Double leg transition to a single leg (0°to 60°), gradually increasing resistance. (3) Lunge training (0°to 60°). (4) Step training: centripetal and centrifugal contraction of the anterior thigh muscles (knee does not exceed 60°). (5) Tiptoe training: Double leg transition to single leg. (6) Swing exercise: the affected leg stands on one leg, and the healthy leg is strapped with an elastic band and swings, transitioning from front-to-back swing to lateral swing and then to rotation or random direction movement. (7) Rotational stability training: static lunge stance, lateral pull pulley exercise. (8) Exercise with rope tied around the waist to provide resistance; walking exercises in the forward and backward, left and right directions. (9) Walking exercises on the treadmill in 4 directions. (10) Balance board training: a variety of support surfaces, double-legged standing. (11) Single-leg stand for ball tossing exercises. (12) Core training: supine or prone position for bridge exercise, standing pull pulley.	Go around obstacles at normal walking speeds on different surfaces.	Manual method to loosen surgical scars.	(1) Center of gravity in the middle, squatting bilaterally to 60° (no more than 60°). (2) Knee in good condition (slight pain and effusion, no instability). (3) The circumference at the upper edge of the patella is 10 cm within a 1 to 2 cm difference between the legs. (4) The affected limb can maintain balance for > 30 seconds while standing on one leg with little body sway.	(1) Do not participate in sports with high impact on the joints, such as running, jumping. (2) Do not participate in sports with high lateral stress on the joints. (3) Try not to squat deeply (limit to 0°to 60°).
Phase 5 (8-12 weeks)	(1) Squat training: transition from double to single leg (0°to 60°), gradually increasing resistance. (2) Lunge training (0°to 60°). (3) Tiptoe training: double-leg transition to single-leg. (4) Increasing the strength of the posterior lateral muscle group with plyometric training. Core muscle strength training. ① Combined strength training with balance training (throwing and catching balls on balance board, small squat on balance board, etc.) ② Advanced balance function training (affected leg standing on one leg, hand or opposite foot to touch objects on the ground or lateral pulling elastic band) ③ Swimming training, in addition to breaststroke. Additionally, care should be taken not to stir the leg at a deep squatting angle or to use a splint when swimming. ④ Cycling training every other day.	——	——	(1) The thigh circumference of both legs is close to the same (within 1 cm of each other). (2) The affected limb squats down to 60° on one leg. (3) The affected limb can stand on one leg to maintain balance for 60 seconds. (4) Little, if any, edema with activity.	Patellar tendonitis may occur.

Table 3: Phases 6-7 of the post-ACL reconstruction rehabilitation program

Phase	Movement Exercises	Gait Exercises	Manipulative Massage	Rehabilitation Goals	Precautions
Phase 6 (12-16 weeks)	(1) Jogging movement: multiple directions for running. (2) Increasing the speed of all sports. (3) Skateboard training, slow walking in the water and other forms of exercise can be carried out.	——	——	(1) Squat down to 60° on one leg with the affected limb and repeat 20 times. (2) The affected leg can stand on one leg to maintain balance for at least 60 seconds. (3) Vertical or horizontal jump with both legs with good landing position. (4) Single-leg jump: 80% of the ability of the healthy leg is achieved.	Avoid wrong movements or posture. (1) Landing with the knee joint too straight. (2) The knee joint is turned outward or inward when landing. (3) When landing or bouncing, the healthy leg always takes the lead, and the affected leg does not.
Phase 6 (12-16 weeks)	(1) Jogging movement: multiple directions for running. (2) Increasing the speed of all sports. (3) Skateboard training, slow walking in the water and other forms of exercise can be carried out.	——	——	(1) Squat down to 60° on one leg with the affected limb and repeat 20 times. (2) The affected leg can stand on one leg to maintain balance for at least 60 seconds. (3) Vertical or horizontal jump with both legs with good landing position. (4) Single-leg jump: 80% of the ability of the healthy leg is achieved.	Avoid wrong movements or posture. (1) Landing with the knee joint too straight. (2) The knee joint is turned outward or inward when landing. (3) When landing or bouncing, the healthy leg always takes the lead, and the affected leg does not.

Baseline indicators and observations

Baseline and preoperative patient characteristics included the subject's sex, age, affected limb (left or right), cause of injury (playing basketball, other sports such as soccer), smoking status (yes or no), time from injury to surgery (fresh injury or old rupture), whether the injury was accompanied by cartilage and meniscal damage, time of surgery, and degree of ACL fracture (partial or total).

Study endpoints

Primary outcome/endpoint: The IKDC scores changes in knee function from preoperative to 6 months postoperative. The IKDC is a commonly used tool to evaluate outcomes after various knee surgeries, including ACL reconstruction(26). The IKDC knee score consists of a knee assessment (10 entries) and a knee ligament checklist (8

entries), covering joint pain, motor level and daily activity ability, with a total score of 0 to 100. The IKDC can address knee symptoms, function and physical activity. The IKDC assesses symptoms, function and physical activity of the knee. Patients were evaluated with the questionnaire preoperatively and at follow-up visits at 1, 3, 6, 12, and 24 months postoperatively.

Secondary outcomes/endpoints: LKS, KOOS (including knee symptoms, pain, activities of daily living, sports and recreational activities, and quality of life), VAS, Lachman test, MRI imaging data, and assessment of knee stability using the Kneelax3 knee stability meter.

(1) Kneelax3 (MONITORED REHAB SYSTEMS B.V. Model: KNEELAX3, The Netherlands): preoperatively and 1, 3, 6, 12 and 24 months postoperatively; the Kneelax3 arthrometer was used for the assessment of knee stability.

(2) Lysholm knee score: This scoring system consists of 8 questions on a scale of 0-100, with higher scores representing better functional status of the patient. The main tendency is toward activities of daily living, and patients were assessed by questionnaires before surgery and at 1-, 3-, 6-, 12-, and 24-month postoperative follow-up visits(27).

(3) KOOS score: The KOOS consists of 5 subscales: pain, other knee symptoms, activities of daily living (ADL), function in sport and recreation (Sport/Rec), and knee-related quality of life (QOL)(28). Patients were given one week to consider before answering the questions, and each question had five alternative boxes with scores ranging from 0 to 4. Standard scores were calculated for each subscale (100 for no symptoms and 0 for extreme symptoms), and patients were assessed with questionnaires before surgery and at follow-up visits at 1, 3, 6, 12, and 24 months after surgery.

(4) VAS score: This is the visual analog pain scoring method, which is more sensitive and comparable. In this trial, a 100-mm VAS pain score (including resting state score, 30-min postwalk score and overall pain level in the past month) was used(29). This protocol only assesses pain at rest, with 0 representing no pain and 100 representing the most severe pain. Patients were evaluated with questionnaires at preoperative and postoperative follow-up visits at 1, 3, 6, 12, and 24 months.

(5) Lachman test: This is a test used to assess ACL function with the patient in the supine or prone position with the knee flexed at approximately a 30° angle(30). The examiner uses one hand to immobilize the thigh, while the other hand attempts to move the tibia forward. Positive results suggest that patients with ACL injuries be tested preoperatively and at follow-up visits at 1, 3, 6, 12, and 24 months postoperatively.

(6) MRI assessment: MRI was performed at 12 and 24 months postoperatively to assess the patient's reconstructed ACL.

Patient termination and withdrawal criteria

Patients may withdraw from this trial at any time. Patients may withdraw from the study for the following reasons.

(1) Surgical failure: 1) occurrence of infection, 2) no secondary rupture of the reconstructed ligament (rupture of the ligament, rupture of the internal brace augmentation line and both in the trial group, rupture of the reconstructed ligament in the control group), 3) knee instability: patient self-reported knee instability, or Lachman test (+) or Kneelax3 knee arthrometer test revealed a 3-mm difference in comparison with the healthy side.

(2) Patient withdrawal from the trial: All subjects had the right to withdraw from the

trial at any time during the study. A subject was withdrawn from the trial if any of the following occurred during the trial: 1) withdrawal of informed consent by the subject; 2) a person who, in the opinion of the investigator, is no longer suitable for continuation of the clinical trial; 3) a woman who becomes pregnant during the clinical trial; 4) death of the subject; or 5) the subject is lost to follow-up.

(3) Trial termination:

1) The clinical trial institution and the investigator find that the risks to patients of continuing the clinical trial exceed the possible benefits; 2) the ethics committee finds that the rights of the subjects cannot be protected; 3) the sponsor requests termination of the trial for various reasons; and 4) the national administrative authority requests termination.

The time and reason for withdrawal from the trial were recorded in detail on the case report form; data were not collected for subjects who also withdrew from the trial or after the subject was deemed surgical failure, but subjects who withdrew from the trial due to adverse events had to be followed up until the adverse events stabilized or resolved or until the investigator deemed that further follow-up was no longer necessary.

Data management

The trial used an electronic data collection (EDC) system for data management. The investigator or investigator-authorized research staff completed the electronic Case Report Form (eCRF) through the EDC system in an accurate, timely, complete and standardized manner based on the original information from the subjects. Questionnaire checking, data cleaning and summarization were performed in a timely manner after each follow-up visit. The follow-up survey is proposed to adopt the electronic questionnaire system of questionnaire star and on-site questionnaire survey, and the results of the on-site survey will be saved in time and organized in the database later. The data are entered by the investigator or the investigator's authorized researcher into the EDC according to their respective accounts. The data administrator verifies the reliability, completeness, and accuracy of the data in the EDC. If any questionable data are found, a challenge can be issued in the system, and the investigator or the investigator's delegated researcher verifies, corrects, or answers the query. When all data have been entered into the database and all queries have been resolved, the database will be locked by the data administrator. If there is a problem found after the database is locked and there is a need to correct it, the process of unlocking and relocking the data should be followed. After the database is locked, the data manager submits the data to the statistical analyst for statistical analysis as scheduled.

Statistical analysis

(1) Statistical design: This trial was a randomized controlled clinical trial.

(2) Principles of Statistical Analysis: All statistical analyses were performed in SAS version 9.4 or later, R version 3.3.2 or later, or SPSS24. All statistical tests were performed using two-sided tests, and P values less than or equal to 0.05 were considered statistically significant for the differences tested (unless otherwise specified).

1) Summary statistics for continuous variables: including the mean, standard deviation, median, minimum, maximum, lower quartile (Q1), and upper quartile (Q3); summary statistics for categorical variables, including the number of cases and percentage of each category.

2) Between-group comparisons of demographic baseline characteristics: Group comparisons for continuous variables will be made using independent samples t test

(chi-square, normal distribution) or Wilcoxon rank sum test depending on data distribution, and chi-square test or the exact probability method for categorical variables (if chi-square test is not applicable).

(3) Completion and demographic analyses

Baseline analyses were based on the full analysis set (FAS). The enrollment and completion status of the trials were summarized, and the reasons for noncompletion are described in a detailed table. Subjects' demographic characteristics were described and compared to measure the comparability of the two groups. Validity reporting data were accepted only if the baseline was balanced between groups; otherwise, validity data were subject to correction before reporting.

(4) Patient-reported outcome validity evaluation indices

The outcome validity evaluation will be based on the FAS and the per-protocol set (PPS). The statistical description and inference of the data will be based on the characteristics of the data and the selection of applicable descriptive indicators and hypothesis testing methods.

Primary patient-reported outcome: comparison of IKDC knee scores at 6 months (±2 weeks) postoperatively in the trial and control groups. We will use a linear regression model for analysis to correct for some possible confounding factors, such as age, sex, and cause of injury. Preoperative baseline IKDC scores were used as predictors when conducting the analysis, and IKDC at 6 months (±2 weeks) was used as an indicator of posttreatment outcomes.

Secondary patient-reported outcomes

1) Because IKDC scores were measured at multiple different time points during patient follow-up, we were able to use a linear mixed model to compare changes over time between the trial and control groups.

2) Anterior tibial translation distance is measured by the Kneelax3 knee stability meter, and comparisons of anterior tibial translation distance between the test and control groups at the same postoperative time points with the same force will be performed using either an independent samples t test (chi-square, normally distributed) or a Wilcoxon rank sum test. A linear mixed model will also be used to compare and analyze the evolution of these consecutive results over time in both groups.

3) Here, the comparative analysis of failure rate and infection rate in the control group versus the test group during the main 6 months will be performed using the chi-square test or the t test.

4) Linear regression of continuous outcomes from baseline to 24 months, such as the Lysholm knee score, KOOS score (including knee symptoms, pain, activities of daily living, sports and recreational activities, quality of life), Lachman test, and pain visual analog score (VAS) protocols, will be used to compare and analyze the evolution of these continuous outcomes over time in the two groups using linear mixed models.

5) The morphology and signal intensity of the postoperative ACL will be assessed using MRI methods, and the different treatments will be compared at different time points using chi-square tests.

Analysis of safety indicators

The safety evaluation was based on the safety set (SS) analysis dataset. The internationally accepted MedDRA term set classification was used for adverse event coding, and the types of adverse events, frequency, severity, and relationship to internal brace enhancement line generation and surgery were summarized by group. A detailed list of the various adverse events is provided, with special notation for subjects who discontinued the trial because of adverse events and for those who experienced serious

adverse events. The proportion of patients who developed complications between treatments was compared using a chi-square test.

Patient and public involvement

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

Discussion

This trial was conducted as a prospective randomized controlled trial to investigate the clinical efficacy of ACL reconstruction with or without the internal brace technique. In this 2-year follow-up study, the subjective, objective, and functional outcomes of patients who underwent ACL reconstruction with the application of the internal brace technique or ACL reconstruction alone were compared. The hypothesis of this study is that ACL reconstruction with the internal brace technique will prove to be more stable than ACL reconstruction alone in the early postoperative period, with a lower incidence of secondary injury, reduced duration and extent of pain, and an earlier return to preinjury activity levels, but there may be no significant difference between the two groups regarding patient-reported outcome indicators as recovery time increases.

ACL rupture is a very common knee injury in the athletic population and has been extensively studied over the years. Studies as early as the late 20th century have shown that ACLR is superior to ACL repair(31, 32). The ACL is an important structure for maintaining knee stability, preventing anterior tibial displacement and limiting intratibial rotation(33), making ACL reconstruction surgery the gold standard of treatment for patients recovering motion or performing rotational activities after an ACL rupture in the knee(34). The recovery of knee function after surgery depends on the ability of the ACL graft to withstand appropriate loads during rehabilitation and after return to sports. The tendon graft implanted in the human knee joint survives in the intra-articular environment and gradually in the ligaments. The graft is fragile and vulnerable to reinjury during the preremodeling phase prior to ligamentization(35), so a careful rehabilitation program should be developed to prevent reinjury during the rehabilitation period. Several studies have found a higher probability of rerupture or secondary revision for athletes and adolescents or for ACL reconstruction using either autologous tendons or allogeneic tendons(10, 36). Therefore, a surgical approach that increases the structural strength of the graft and protects it during the early stages of graft ligamentization is of great importance.

The biomechanical properties of the intra-articular reconstructed ligaments were found to improve at 8 weeks postoperatively for the FiberTape suture applied in a rabbit model. Additionally, during this period, FiberTape did not adversely affect bone tunnel healing or cause a long-term increase in indicators of inflammation(12). In a dog model, no severe inflammation or immune response, bone erosion, or premature OA development was observed at 6 months postoperatively(37). The results of these studies will support the biocompatibility and safety of intra-articular suture tape for ACLR enhancement.

A study of load sharing after ACL graft enhancement by suture tape reported that load sharing began at 200 N and 300 N for 7-mm and 9-mm grafts, respectively. The final peak load (400 N) would be shared by 31% (7-mm graft) and 20% (9-mm graft) by the suture tape(38). Suture tape ligament augmentation may potentially protect biological

grafts from excessive peak loading and elongation. After ACL reconstruction in the early recovery phase, suture band augmentation increases ACL graft stiffness by 104% and the ultimate breaking load by 57%, which will reduce the graft failure rate in clinical situations.

A recent systematic review paper by Christopher et al. concluded from biomechanical, animal and clinical studies that the application of suture tape augmentation in ACL reconstruction increases its biomechanical stability(39). Therefore, in this randomized controlled trial, we will conduct a prospective observational comparison as well as a long-term follow-up to truly elucidate the clinical efficacy of internal bracing in ACL reconstruction.

Abbreviations

Anterior cruciate ligament (ACL)
International Knee Documentation Committee (IKDC)
the Knee Injury and Osteoarthritis Outcome Score (KOOS)
Lysholm knee score (LKS)
Visual Analog Scale (VAS)
ultrahigh molecular weight polyethylene (UHMWPE)
Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT)
activities of daily living (ADL)
sport and recreation (Sport/Rec)
quality of life (QOL)
medial collateral ligament (MCL)
minimum clinically important difference (MCID)
electronic Case Report Form (eCRF)
safety set (SS)

Ethics and dissemination

The trial was approved by the Medical Ethics Committee of Xiangya Hospital of Central South University on October 26, 2021 with the ethics number "202110478" and prospectively registered in the China Clinical Trials Registry on March 14, 2022 with the registration number: ChiCTR2200057526. All subjects signed an informed consent form before participating in this trial and we will protect the patients from any invasion of their private privacy. All investigators will keep the study results confidential until after the data are made public, and no data related to the database will be released by the investigators without the approval of the principal investigator. We will publish the findings and data in peer-reviewed journals, and present them at national and international conferences.

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Author contributions

WF-X and YS-L established the study design, WH-L conceived the design and wrote the draft manuscript; D-L, ZJ-C, and LY-P were involved in data acquisition, analysis, and interpretation; and WQ-X, HF-J, and X-L designed the rehabilitation protocol. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests regarding the present study.

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References

1. Patterson BE, Culvenor AG, Barton CJ, Guermazi A, Stefanik JJ, Morris HG, et al. Worsening Knee Osteoarthritis Features on Magnetic Resonance Imaging 1 to 5 Years After Anterior Cruciate Ligament Reconstruction. Am J Sports Med. 2018;46(12):2873-83.
2. Suter LG, Smith SR, Katz JN, Englund M, Hunter DJ, Frobell R, et al. Projecting Lifetime Risk of Symptomatic Knee Osteoarthritis and Total Knee Replacement in Individuals Sustaining a Complete Anterior Cruciate Ligament Tear in Early Adulthood. Arthritis Care Res (Hoboken). 2017;69(2):201-8.
3. Filbay SR, Culvenor AG, Ackerman IN, Russell TG, Crossley KM. Quality of life in anterior cruciate ligament-deficient individuals: a systematic review and meta-analysis. Br J Sports Med. 2015;49(16):1033-41.
4. Moses B, Orchard J, Orchard J. Systematic review: Annual incidence of ACL injury and surgery in various populations. Res Sports Med. 2012;20(3-4):157-79.
5. Griffin LY, Albohm MJ, Arendt EA, Bahr R, Beynnon BD, Demaio M, et al. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. Am J Sports Med. 2006;34(9):1512-32.

6. de Sa D, Shanmugaraj A, Weidman M, Peterson DC, Simunovic N, Musahl V, et al. All-Inside Anterior Cruciate Ligament Reconstruction-A Systematic Review of Techniques, Outcomes, and Complications. J Knee Surg. 2018;31(9):895-904.
7. Di Benedetto P, Di Benedetto E, Fiocchi A, Beltrame A, Causero A. Causes of Failure of Anterior Cruciate Ligament Reconstruction and Revision Surgical Strategies. Knee Surg Relat Res. 2016;28(4):319-24.
8. Robson AW. VI. Ruptured Crucial Ligaments and their Repair by Operation Ann Surg. 1903;37(5):716-8.
9. Vaishya R, Agarwal AK, Ingole S, Vijay V. Current Trends in Anterior Cruciate Ligament Reconstruction: A Review. Cureus. 2015;7(11):e378.
10. Takazawa Y, Ikeda H, Saita Y, Kawasaki T, Ishijima M, Nagayama M, et al. Return to Play of Rugby Players After Anterior Cruciate Ligament Reconstruction Using Hamstring Autograft: Return to Sports and Graft Failure According to Age. Arthroscopy. 2017;33(1):181-9.
11. Ellis HB, Matheny LM, Briggs KK, Pennock AT, Steadman JR. Outcomes and revision rate after bone-patellar tendon-bone allograft versus autograft anterior cruciate ligament reconstruction in patients aged 18 years or younger with closed physes. Arthroscopy. 2012;28(12):1819-25.
12. Soreide E, Denbeigh JM, Lewallen EA, Thaler R, Xu W, Berglund L, et al. In vivo assessment of high-molecular-weight polyethylene core suture tape for intra-articular ligament reconstruction: an animal study. Bone Joint J. 2019;101-b(10):1238-47.
13. Lubowitz JH, MacKay G, Gilmer B. Knee medial collateral ligament and posteromedial corner anatomic repair with internal bracing. Arthrosc Tech. 2014;3(4):e505-8.
14. Gilmer BB, Crall T, DeLong J, Kubo T, Mackay G, Jani SS. Biomechanical Analysis of Internal Bracing for Treatment of Medial Knee Injuries. Orthopedics. 2016;39(3):e532-7.
15. Heusdens CHW, Hopper GP, Dossche L, Roelant E, Mackay GM. Anterior cruciate ligament repair with Independent Suture Tape Reinforcement: a case series with 2-year follow-up. Knee Surg Sports Traumatol Arthrosc. 2019;27(1):60-7.
16. Nishimura A, Nakazora S, Senga Y, Kitaura Y, Fukuda A, Kato K, et al. Arthroscopic Internal Brace Augmentation With Arthroscopic Modified Broström Operation for Chronic Ankle Instability. Arthrosc Tech. 2021;10(4):e995-e1000.
17. Wilk KE, Arrigo CA, Bagwell MS, Rothermich MA, Dugas JR. Repair of the Ulnar Collateral Ligament of the Elbow: Rehabilitation Following Internal Brace Surgery. J Orthop Sports Phys Ther. 2019;49(4):253-61.
18. van Eck CF, Limpisvasti O, ElAttrache NS. Is There a Role for Internal Bracing and Repair of the Anterior Cruciate Ligament? A Systematic Literature Review. Am J Sports Med. 2018;46(9):2291-8.
19. Cook JL, Smith P, Stannard JP, Pfeiffer F, Kuroki K, Bozynski CC, et al. A Canine Arthroscopic Anterior Cruciate Ligament Reconstruction Model for Study of Synthetic Augmentation of Tendon Allografts. J Knee Surg. 2017;30(7):704-11.
20. Bachmaier S, Smith PA, Bley J, Wijdicks CA. Independent Suture Tape Reinforcement of Small and Standard Diameter Grafts for Anterior Cruciate Ligament

Reconstruction: A Biomechanical Full Construct Model. Arthroscopy. 2018;34(2):490-9.
21. Bedi A. Editorial Commentary: Buckle Up Surgeons: "Safety Belt" Reinforcement of Knee Anterior Cruciate Ligament Reconstruction Grafts. Arthroscopy. 2018;34(2):500-1.
22. Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). Arthritis Care Res (Hoboken). 2011;63 Suppl 11(0 11):S208-28.
23. Irrgang JJ, Anderson AF, Boland AL, Harner CD, Neyret P, Richmond JC, et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form. Am J Sports Med. 2006;34(10):1567-73.
24. Li YL, Ning GZ, Wu Q, Wu QL, Li Y, Hao Y, et al. Single-bundle or double-bundle for anterior cruciate ligament reconstruction: a meta-analysis. Knee. 2014;21(1):28-37.
25. Lubowitz JH. All-inside anterior cruciate ligament graft link: graft preparation technique. Arthrosc Tech. 2012;1(2):e165-8.
26. Greco NJ, Anderson AF, Mann BJ, Cole BJ, Farr J, Nissen CW, et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form in comparison to the Western Ontario and McMaster Universities Osteoarthritis Index, modified Cincinnati Knee Rating System, and Short Form 36 in patients with focal articular cartilage defects. Am J Sports Med. 2010;38(5):891-902.
27. Briggs KK, Lysholm J, Tegner Y, Rodkey WG, Kocher MS, Steadman JR. The reliability, validity, and responsiveness of the Lysholm score and Tegner activity scale for anterior cruciate ligament injuries of the knee: 25 years later. Am J Sports Med. 2009;37(5):890-7.
28. Collins NJ, Prinsen CA, Christensen R, Bartels EM, Terwee CB, Roos EM. Knee Injury and Osteoarthritis Outcome Score (KOOS): systematic review and meta-analysis of measurement properties. Osteoarthritis Cartilage. 2016;24(8):1317-29.
29. Wewers ME, Lowe NK. A critical review of visual analogue scales in the measurement of clinical phenomena. Res Nurs Health. 1990;13(4):227-36.
30. Coffey R, Bordoni B. Lachman Test. StatPearls. Treasure Island (FL): StatPearls Publishing
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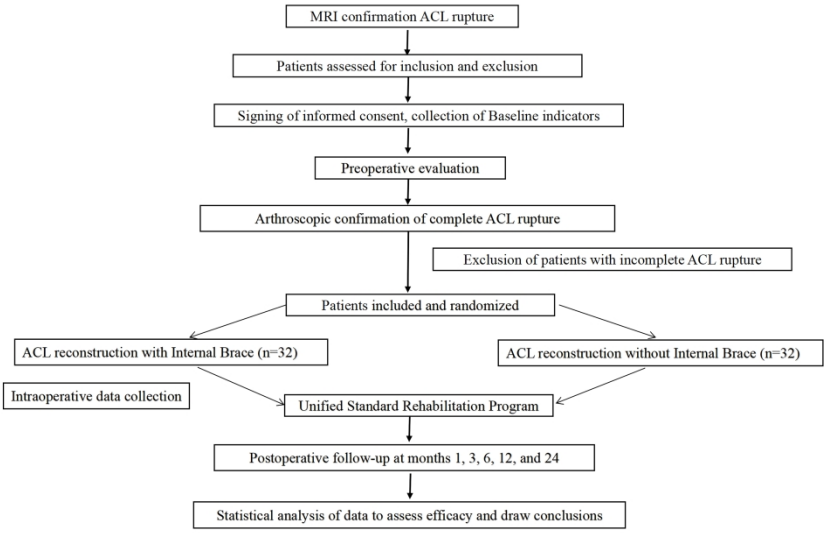
31. Engebretsen L, Benum P, Fasting O, Mølster A, Strand T. A prospective, randomized study of three surgical techniques for treatment of acute ruptures of the anterior cruciate ligament. Am J Sports Med. 1990;18(6):585-90.
32. Grøntvedt T, Engebretsen L, Benum P, Fasting O, Mølster A, Strand T. A prospective, randomized study of three operations for acute rupture of the anterior cruciate ligament. Five-year follow-up of one hundred and thirty-one patients. J Bone

Joint Surg Am. 1996;78(2):159-68.
33. Noyes FR. The function of the human anterior cruciate ligament and analysis of single- and double-bundle graft reconstructions. Sports Health. 2009;1(1):66-75.
34. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. Br J Sports Med. 2011;45(7):596-606.
35. Claes S, Verdonk P, Forsyth R, Bellemans J. The "ligamentization" process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. Am J Sports Med. 2011;39(11):2476-83.
36. Wright RW, Gill CS, Chen L, Brophy RH, Matava MJ, Smith MV, et al. Outcome of revision anterior cruciate ligament reconstruction: a systematic review. J Bone Joint Surg Am. 2012;94(6):531-6.
37. Smith PA, Bozynski CC, Kuroki K, Henrich SM, Wijdicks CA, Cook JL. Intra-Articular Biocompatibility of Multistranded, Long-Chain Polyethylene Suture Tape in a Canine ACL Model. J Knee Surg. 2019;32(6):525-31.
38. Bachmaier S, Smith PA, Argintar EH, Chahla J, Higgins LD, Wijdicks CA. Independent Suture Augmentation With All-Inside Anterior Cruciate Ligament Reconstruction Reduces Peak Loads on Soft-Tissue Graft. A Biomechanical Full-Construct Study. Arthroscopy. 2022;38(1):88-98.
39. C EAM, Huntington LS, Tulloch S. Suture Tape Augmentation of Anterior Cruciate Ligament Reconstruction increases biomechanical stability: A Scoping Review of Biomechanical, Animal, and Clinical Studies. Arthroscopy. 2022.

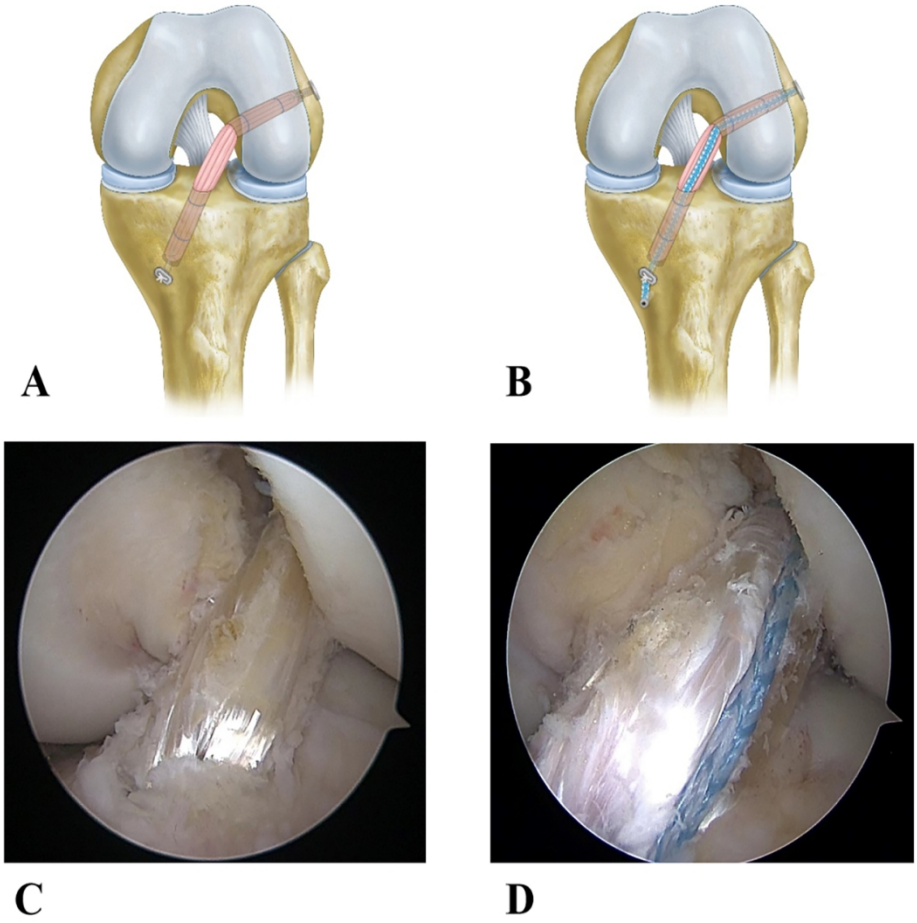
Fig.1 Study Flow Diagram.

Fig.2 A and B are the models of the control group and test group, respectively. C and D are the pictures of the control group and test group after intraoperative arthroscopic ACL reconstruction, respectively.



Study Flow Diagram.

862x485mm (157 x 157 DPI)



A and B are the models of the control group and test group, respectively. C and D are the pictures of the control group and test group after intraoperative arthroscopic ACL reconstruction, respectively.

253x253mm (138 x 138 DPI)

Reporting checklist for protocol of a clinical trial.

Based on the SPIRIT guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

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		Reporting Item	Page Number
Administrative information			
Title	#1	Descriptive title identifying the study design, population, interventions, and, if applicable, trial acronym	1
Trial registration	#2a	Trial identifier and registry name. If not yet registered,	2

		name of intended registry	
Trial registration: data set	#2b	All items from the World Health Organization Trial Registration Data Set	2
Protocol version	#3	Date and version identifier	4
Funding	#4	Sources and types of financial, material, and other support	11
Roles and responsibilities: contributorship	#5a	Names, affiliations, and roles of protocol contributors	1
Roles and responsibilities: sponsor contact information	#5b	Name and contact information for the trial sponsor	11
Roles and responsibilities: sponsor and funder	#5c	Role of study sponsor and funders, if any, in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication, including whether they will have ultimate authority over any of these activities	11
Roles and responsibilities: committees	#5d	Composition, roles, and responsibilities of the coordinating centre, steering committee, endpoint adjudication committee, data management team, and other individuals or groups overseeing the trial, if applicable (see Item 21a for data monitoring committee)	11

Introduction			
Background and rationale	#6a	Description of research question and justification for undertaking the trial, including summary of relevant studies (published and unpublished) examining benefits and harms for each intervention	3
Background and rationale: choice of comparators	#6b	Explanation for choice of comparators	3
Objectives	#7	Specific objectives or hypotheses	3
Trial design	#8	Description of trial design including type of trial (eg, parallel group, crossover, factorial, single group), allocation ratio, and framework (eg, superiority, equivalence, non-inferiority, exploratory)	2
Methods: Participants, interventions, and outcomes			
Study setting	#9	Description of study settings (eg, community clinic, academic hospital) and list of countries where data will be collected. Reference to where list of study sites can be obtained	4
Eligibility criteria	#10	Inclusion and exclusion criteria for participants. If applicable, eligibility criteria for study centres and	4

		individuals who will perform the interventions (eg, surgeons, psychotherapists)	
Interventions: description	#11a	Interventions for each group with sufficient detail to allow replication, including how and when they will be administered	5-6
Interventions: modifications	#11b	Criteria for discontinuing or modifying allocated interventions for a given trial participant (eg, drug dose change in response to harms, participant request, or improving / worsening disease)	5-6
Interventions: adherance	#11c	Strategies to improve adherence to intervention protocols, and any procedures for monitoring adherence (eg, drug tablet return; laboratory tests)	5-6
Interventions: concomitant care	#11d	Relevant concomitant care and interventions that are permitted or prohibited during the trial	5-6
Outcomes	#12	Primary, secondary, and other outcomes, including the specific measurement variable (eg, systolic blood pressure), analysis metric (eg, change from baseline, final value, time to event), method of aggregation (eg, median, proportion), and time point for each outcome. Explanation of the clinical relevance of chosen efficacy and harm outcomes is strongly recommended	6-7
Participant timeline	#13	Time schedule of enrolment, interventions (including any run-ins and washouts), assessments, and visits for participants. A schematic diagram is highly recommended	6-7

		(see Figure)	
Sample size	#14	Estimated number of participants needed to achieve study objectives and how it was determined, including clinical and statistical assumptions supporting any sample size calculations	4
Recruitment	#15	Strategies for achieving adequate participant enrolment to reach target sample size	4
Methods: Assignment of interventions (for controlled trials)			
Allocation: sequence generation	#16a	Method of generating the allocation sequence (eg, computer-generated random numbers), and list of any factors for stratification. To reduce predictability of a random sequence, details of any planned restriction (eg, blocking) should be provided in a separate document that is unavailable to those who enrol participants or assign interventions	4-5
Allocation concealment mechanism	#16b	Mechanism of implementing the allocation sequence (eg, central telephone; sequentially numbered, opaque, sealed envelopes), describing any steps to conceal the sequence until interventions are assigned	4-5
Allocation: implementation	#16c	Who will generate the allocation sequence, who will enrol participants, and who will assign participants to	4-5

		interventions	
Blinding (masking)	#17a	Who will be blinded after assignment to interventions (eg, trial participants, care providers, outcome assessors, data analysts), and how	4-5
Blinding (masking): emergency unblinding	#17b	If blinded, circumstances under which unblinding is permissible, and procedure for revealing a participant's allocated intervention during the trial	4-5
Methods: Data collection, management, and analysis			
Data collection plan	#18a	Plans for assessment and collection of outcome, baseline, and other trial data, including any related processes to promote data quality (eg, duplicate measurements, training of assessors) and a description of study instruments (eg, questionnaires, laboratory tests) along with their reliability and validity, if known. Reference to where data collection forms can be found, if not in the protocol	7
Data collection plan: retention	#18b	Plans to promote participant retention and complete follow-up, including list of any outcome data to be collected for participants who discontinue or deviate from intervention protocols	7
Data management	#19	Plans for data entry, coding, security, and storage,	7

		including any related processes to promote data quality (eg, double data entry; range checks for data values). Reference to where details of data management procedures can be found, if not in the protocol	
Statistics: outcomes	#20a	Statistical methods for analysing primary and secondary outcomes. Reference to where other details of the statistical analysis plan can be found, if not in the protocol	8-9
Statistics: additional analyses	#20b	Methods for any additional analyses (eg, subgroup and adjusted analyses)	8-9
Statistics: analysis population and missing data	#20c	Definition of analysis population relating to protocol non-adherence (eg, as randomised analysis), and any statistical methods to handle missing data (eg, multiple imputation)	8-9
Methods: Monitoring			
Data monitoring: formal committee	#21a	Composition of data monitoring committee (DMC); summary of its role and reporting structure; statement of whether it is independent from the sponsor and competing interests; and reference to where further details about its charter can be found, if not in the protocol. Alternatively, an explanation of why a DMC is not needed	7
Data monitoring: interim analysis	#21b	Description of any interim analyses and stopping guidelines, including who will have access to these interim results and make the final decision to terminate	7

		the trial	
Harms	#22	Plans for collecting, assessing, reporting, and managing solicited and spontaneously reported adverse events and other unintended effects of trial interventions or trial conduct	7
Auditing	#23	Frequency and procedures for auditing trial conduct, if any, and whether the process will be independent from investigators and the sponsor	7
Ethics and dissemination			
Research ethics approval	#24	Plans for seeking research ethics committee / institutional review board (REC / IRB) approval	10
Protocol amendments	#25	Plans for communicating important protocol modifications (eg, changes to eligibility criteria, outcomes, analyses) to relevant parties (eg, investigators, REC / IRBs, trial participants, trial registries, journals, regulators)	10
Consent or assent	#26a	Who will obtain informed consent or assent from potential trial participants or authorised surrogates, and how (see Item 32)	10
Consent or assent: ancillary studies	#26b	Additional consent provisions for collection and use of participant data and biological specimens in ancillary studies, if applicable	Not applicable
Confidentiality	#27	How personal information about potential and enrolled	7

		participants will be collected, shared, and maintained in order to protect confidentiality before, during, and after the trial	
Declaration of interests	#28	Financial and other competing interests for principal investigators for the overall trial and each study site	11
Data access	#29	Statement of who will have access to the final trial dataset, and disclosure of contractual agreements that limit such access for investigators	10
Ancillary and post trial care	#30	Provisions, if any, for ancillary and post-trial care, and for compensation to those who suffer harm from trial participation	7
Dissemination policy: trial results	#31a	Plans for investigators and sponsor to communicate trial results to participants, healthcare professionals, the public, and other relevant groups (eg, via publication, reporting in results databases, or other data sharing arrangements), including any publication restrictions	10
Dissemination policy: authorship	#31b	Authorship eligibility guidelines and any intended use of professional writers	10
Dissemination policy: reproducible research	#31c	Plans, if any, for granting public access to the full protocol, participant-level dataset, and statistical code	10
Appendices			
Informed consent	#32	Model consent form and other related documentation	10

materials		given to participants and authorised surrogates	
Biological specimens	#33	Plans for collection, laboratory evaluation, and storage of biological specimens for genetic or molecular analysis in the current trial and for future use in ancillary studies, if applicable	Not applicable

BMJ Open

Internal brace augmentation reconstruction VS standard anterior cruciate ligament reconstruction:A randomized controlled clinical trial study protocol.

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Primary Subject Heading:	Sports and exercise medicine
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Keywords:	Knee < ORTHOPAEDIC & TRAUMA SURGERY, Orthopaedic sports trauma < ORTHOPAEDIC & TRAUMA SURGERY, Orthopaedic & trauma surgery < SURGERY, Clinical trials < THERAPEUTICS, Adult orthopaedics < ORTHOPAEDIC & TRAUMA SURGERY

Internal brace augmentation reconstruction VS standard anterior cruciate ligament reconstruction : A randomized controlled clinical trial study protocol.

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Abstract:

Introduction: Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries in sports, and the gold standard for treating ACL rupture is tendon graft reconstruction. Recently, internal brace technology has been gradually applied to ligament repair, but there is still need to be more relevant in vivo clinical evidence for using internal brace technology in ACL reconstruction (ACLR). We conducted a randomized controlled trial to investigate the clinical efficacy of internal brace technology in ACLR.

Methods and analysis: This is a randomized, parallel controlled trial of patients with ACL rupture who underwent inpatient surgery at the Department of Orthopedics, Xiangya Hospital, Central South University. All study subjects were assigned to the test and control groups according to the random number table method. The test group underwent ACLR using the internal brace technique, and the control group underwent standard ACLR, with uniform postoperative rehabilitation in both groups. Patient-reported outcomes were preoperative baseline and postoperative recovery at 1, 3, 6, 12, and 24 months. The primary outcome was International Knee Documentation Committee (IKDC) function from baseline (ACL rupture) to 6 months postoperatively. Secondary outcomes included (I) other patient outcome reporting metrics, the Lysholm knee score (LKS), the Knee Injury and Osteoarthritis Outcome Score (KOOS), and the Visual Analog Scale (VAS), (II) the use of the Kneelax3 knee stabilizer to assess knee

stability, (III) the occurrence of adverse events, such as graft refraction or symptomatic instability, postoperative infection, and contralateral injury, and (IV) magnetic resonance images at 12 and 24 months after ACLR.

Ethics and dissemination: This trial was approved by the Medical Ethics Committee of Xiangya Hospital of Central South University on October 26, 2021. Data will be published in peer-reviewed journals and presented at national and international conferences.

Trial registration number: ChiCTR2200057526.

Strengths and limitations of this study:

- This study aims to demonstrate the clinical superiority of the Internal brace compared to conventional ACL reconstruction (ACLR) through a 2-year follow-up period.
- This study will fill an existing gap regarding the efficacy of the internal brace in ACL reconstruction by providing robust and high-quality evidence on its role and impact.
- The study has a standard and detailed rehabilitation program to ensure a smooth recovery after ACLR.
- This trial was conducted in a single centre, and data lacked generalizability.

Keywords:

Anterior cruciate ligament (ACL), Anterior cruciate ligament reconstruction (ACLR), Internal brace, Study protocol.

Introduction

A 41-year-old miner successfully performed the world's first ACL repair surgery, and the function of the knee joint was very good after surgery[1]. ACL rupture is one of the most common ligament injuries in the knee, mainly in young people who participate in sports. If not actively treated after injury, joint instability and other phenomena often occur, reducing the quality of life and increasing the risk of osteoarthritis[2-4]. Over the past few decades, ACL ruptures have been estimated at approximately 30 to 52 cases per 100,000 person-years[5]. ACL injuries occur in more than 175,000 people in the United States annually, and approximately 100,000 undergo surgery[6-8]. With the continuous development of surgical techniques, the current mainstream surgical method is to perform ACLR under arthroscopy[9]. In recent years, a Japanese study found that for rugby players under the age of 20 after ACLR, the re-disruption rate of ACLR grafts after returning to the field was 23%[10]. At the same time, other studies have also shown that the revision rate of ACLR with an allogeneic tendon in adolescents can reach 35%[11]; however, the effect after revision is not as good as that of primary ACLR[12].

Internal brace technology was promoted in 2010, which uses braided ultrahigh molecular weight polyethene (UHMWPE) polyester suture tape and knotless bone anchors to reinforce ligament strength, also known as an auxiliary stabilizing structure for recovery of motion after ligament repair, which helps prevent secondary damage, [13]such as anterior and posterior cruciate ligament, medial and lateral collateral ligament repair of the knee[13-15], and ankle and elbow ligament strengthening repair[16 17]. Enhanced collateral ligament repair and reconstruction with an internal brace improve limb biomechanics, including greater stiffness and maximum load, while facilitating early

rehabilitation in the motor and biomechanical environment [12 14]. Reinforced ligament repair offers unique advantages over traditional reconstruction techniques, including smaller bores and implants, no risk of disease transmission from allografts, and no risk of tunnel convergence during the procedure [14 18 19]. Therefore, ACL reinforcement is an alternative method for supporting ACL grafts synergistically, load-sharing manner with primary tension on the graft and high-strength suture tape.

In the case of ACLR, the internal brace ligament augmentation technique helps prevent various failure scenarios, including creep and irreversible stretching, traumatic tears, and slippage of the tendon-bone interface[20 21]. In addition, these failures can be avoided when the graft is small or vulnerable[20 21]. In 2018, in an in vitro trial, Dr Pat Smith found that ACLR combined with independent suture tape significantly reduced graft elongation and allowed the grafted ligaments to accept higher ultimate disruption loads, thereby reducing the risk of re-rupture of the graft[20]. Preliminary short-term studies have shown that using the internal brace technique can significantly improve functional recovery after ACLR and improve patient quality of life. However, only a few medical institutions use ACLR combined with the internal brace technique, and there needs to be more relevant in vivo clinical evidence.

This study will fill this gap by exploring whether internal brace technology can improve the outcome of patients with ligament injuries and provide a new option for patients with ACL injuries.

Methods and analysis

Study setting

This was a randomized parallel-controlled trial conducted under the guidance of the CONSORT statement[22] and included patients with ACL rupture who were hospitalized in the Department of Orthopedics at Xiangya Hospital of Central South University from 01/03/2022 to 28/02/2023. The Medical Ethics Committee of Xiangya Hospital of Central South University approved the ethical application related to this study and has filed it (ethical approval number: 202110478). All subjects signed the informed consent form before the operations.

Eligibility criteria

The inclusion criteria are as follows: (1) age of 16-45 years; (2) unilateral knee MRI showing unilateral knee ACL fracture; (3) combined meniscal injury that does not interfere with the standard postoperative rehabilitation program after intraoperative management; (4) combined grade III or lower cartilage injury that does not interfere with the standard postoperative rehabilitation program; (5) meet the 24 months of follow-up; (6) no previous injury to the healthy knee; (7) informed consent of the subject and signing of relevant documents.

The exclusion criteria are as follows: (1) age of <16 years or >45 years; (2) previous ACLR or bilateral ACL injury; (3) MRI revealed posterior cruciate ligament (PCL), medial collateral ligament (MCL), or lateral collateral ligament (LCL) injury; (4) grade IV cartilage injury or unstable longitudinal meniscus tear requiring repair that interferes with standard rehabilitation protocols after surgical management; (5) patients who cannot meet 24 follow-up visits; (6) patients with severe underlying medical conditions that make surgery inadvisable, or patients with mental illness, pregnancy during planned trials, or other conditions that are not conducive to late follow-up.

Participant selection:

Patients diagnosed with ACL rupture by clinicians through physical examination and MRI imaging evaluation were randomly allocated to the trial and control groups after final confirmation of ACL rupture under arthroscopy and agreeing to participate in this study. The trial group was reconstructed using ACLR with the internal brace technique, and the control group was reconstructed using ACLR without the internal brace technique. Preoperative assessment of patients was performed before surgery, and a uniform rehabilitation program was performed after surgery. The protocol (version 1.0, March 2022) inclusion start date was March 2022, with an expected cutoff date of March 2023. The follow-up period is 2 years, with the last follow-up expected in March 2025 (the exact end date is based on the inclusion of the last subject), and the specific technical route is shown in **Fig. 1.**

Study sample

IKDC score consists of three aspects: 1) symptoms, including pain, stiffness, swelling, interlocking/jamming, and softening legs; 2) motion and daily activities; and 3) Current knee function, but knee function prior to knee injury does not count towards the total score, which is the main outcome indicator of this study, based on which the sample size required for this trial was estimated. IKDC scores are continuous measurement data, and this study compares statistical differences between the means ± standard deviations of the two groups. The minimum clinically important difference (MCID) of the IKDC scale was reported to be between 8.8 and 15.6[23-25], we set δ to 10, and the overall sample standard deviation was set to 13 based on the relevant literature[23-25]. To satisfy the power of a test (1-β, β means type II error) of 0.8 and the test level α (type I error) of 0.05, the sample size calculated for each group was 27 according to the following formula, and considering a 20% lost visit rate, 33 patients were included in each group with a total of 66 patients included.

Randomization and Concealed Grouping

Using a computer-generated random number list, all eligible subjects were randomly assigned in a 1:1 ratio to the ACLR the endoprosthesis technique group (combined group, n=33) and the standard ACL reconstruction group (simple group, n=33) after screening by inclusion and exclusion criteria, with no restrictions on either study group. Randomization was carried out by an investigator who was not further involved in the study. The allocation results were sealed in opaque envelopes and kept by the study coordinator. On the day of surgery, one envelope per patient was given to the surgeon by the study coordinator. Subjects and physicians included in the study were informed of the grouping, but neither the rehabilitators who instructed the patients on rehabilitation nor the data collectors who conducted the follow-up visits were aware of the grouping of the patients.

Interventions and surgical techniques

In all cases, all inside ACLR was performed using autologous semitendinosus tendons with the arthroscopy. Semitendinosus tendons were braided with sutures (0 FiberWire Suture, Arthrex) to form four strands of ACL grafts (all between 7.5 and 10 mm in diameter, supplemented with semimembranous tendons less than 7.5 mm in diameter). In the ACLR group, the braided graft femoral end and tibial segment were suspended and fixed with a TightRope (ACL TightRope RT Implant, Arthrex), and in the ACLR

with internal brace group, a separate wire tape (2 mm FiberTape, Arthrex) was added to the ACLR group. The suture was fixed with a knotless bone anchor (4.75-mm PEEK SwiveLock, Arthrex) distally and a TightRope suspension proximally as in the graft—fig. 2.

The procedure was as follows: the patient was anaesthetized, a tourniquet was applied to the affected limb, routine surgical disinfection of the knee was performed, a sterile surgical sheet was placed, the semitendinosus tendon was palpated, a straight incision was made medial to the tibial tuberosity, the semitendinosus tendon was removed with a tendon extractor, 10 ml of ropivacaine was injected at the tendon extraction site, and then, the removed semitendinosus tendon was braided into 4 strands using the GraftLink (Arthrex) technique[26]. A conventional knee arthroscopic approach was performed on the anteromedial and anterolateral sides of the affected knee to explore the injured structures and remove the remaining portion of the ACL. The knee was flexed to the extreme, and the femoral tract was created at the footprint of the ACL stop at the lateral femoral condyle and the tibial tract at the footprint of the ACL start. The graft and two TightRope titanium plates were pulled into the knee cavity and pulled out through the femoral and tibial tracts, respectively. The tabs were flipped, the tab rings were tightened, and the titanium plates were fixed. In the ACLR with an internal brace group, the femoral end of the FiberTape wire band was fixed with a TightRope ring, the wire band was tensioned in the extended position, and the tibial end was fixed independently with a knotless bone anchor (4.75-mm PEEK SwiveLock, Arthrex).

All patients received a uniform training and rehabilitation program after surgery, and the entire rehabilitation process was divided into 7 phases. The first 3 phases focused on controlling swelling and restoring range of motion, which usually required 4 weeks. A detailed rehabilitation plan can be found in **Table 1**. Phases 4-5 focused on restoring quadriceps muscle strength control and balance and core strength restoration training, and phases 6-7 were gradually resumption of various sports activities, from daily activities to professional activities or contact sports. A detailed rehabilitation plan can be found in **Table 2** and **Table 3.**

Table 1. Phases **1-3 of the post-ACLR rehabilitation program**

Phase	Movement Exercises	Gait Exercises	Manipulative Massage	Rehabilitation Goals	Precautions
Phase 1 (within 1 week)	(1) Bed heel against the bed for flexion and extension sliding; supine position, the affected leg bends the hip, flexes the knee and places the heel on the wall for flexion and extension sliding; sitting position, legs on the floor; the healthy leg is placed in front of the affected leg and assists the affected leg in flexing the knee. (2) Ankle pump exercises (the affected leg is elevated, and the foot performs upward hooking and downward stepping movements, and rotational movements). (3) Anterior thigh muscle tensing exercises with the knee in the straight position (can be combined with neuromuscular electrical stimulation or biofeedback exercises). (4) Hip muscle group training. (5) Pillow clamping of the legs for medial	(1) Flat and step gait training with the support of a knee protection brace and double crutches. (2) Cold compresses after training to reduce oedema.	(1) Push the patella in all directions. (2) Manipulation of the posterior thigh muscles of the affected limb or sitting and standing to pull the muscles to relieve	Active mobility of the knee joint reaches 0°to 90°. (1) The anterolateral thigh muscles can be tightened better. (2) The affected limb can be fully weight-bearing with the help of braces and crutches.	(1) Brace locked in 0° position, crutches, and weight-bearing exercises within a tolerable range. (2) Wear the brace at night and lock it in the 0° position while sleeping with the affected leg elevated.

	thigh muscle group strength training. (6) The brace is locked in the 0° position, and the affected leg is lifted in the supine, prone and prone positions for muscle strength training. (7) Passive knee extension exercises: prone position with the affected knee extended out of bed for suspension or supine position with the affected leg in a slightly elevated heel position and the knee joint suspended. (8) weight transfer training (front-to-back and left-to-right) can be performed in the above weight-bearing exercise position. (9) Continuous passive movement apparatus training with increased knee flexion by 5°to 10°/day.		their spasm.	(3) Edema control is good. (4) Good wound healing.	
Phase 2 (1-2 weeks)	(1) Fixed cycling exercises (from small to a full range of pedal rotation). (2) Tightening and 90° muscle strength exercises for the anterior thigh muscles in the straight position. (3) Standing balance training on the affected leg with a single leg wearing a support. (4) Balance training on a balance board with forward and backward weight transfer. (5) Continuous passive activity equipment training. (6) Start small partial weight-bearing squat exercises (within 30° of knee flexion). (7) Passive straightening exercises with the heel slightly elevated and the knee hanging in the air. (8) Straight leg raises training (all directions). (9) Terminal angle knee extension training in the standing position using an elastic band.	(1) The healthy leg stands outside the treadmill with weight, and the affected leg simulates walking on the treadmill. (2) The affected leg crosses the obstacle training and simulates walking.	(1) Manipulation to push the patella treatment. (2) Manipulate of the posterior thigh muscle group for relaxation and stretching exercises.	The active mobility of the knee joint reaches 0°to 120°. (1) Straight leg elevation; anterior thigh muscles can be tightened with force. (2) the patient can walk normally with crutches with a nonlocking brace.	(1) Weight-bearing exercises within tolerable limits. (2) Transition from double to single crutch. (3) When the strength of the anterior thigh muscle group is well exercised, the locking brace can be gradually dispensed (the anterior thigh muscle group can be unlocked to more than 30° only when it can contract forcefully to keep the straight leg elevated).
Phase 3 (2-4 weeks)	(1) Fixed bicycle training gradually increases the resistance to improve exercise endurance. (2) Tightening exercises for the anterior thigh muscle group in the straight position and muscle strength exercises in the range of 60°to 90° until the muscle strength of both legs is equal. (3) 0°to 60° squat training, gradually increasing the resistance strength (for patients with meniscal repair, squat to the target angle on the healthy leg before shifting the weight to the middle of the two legs). (4) Stand with both legs on a balance board for balance training in multiple directions. (5) Single-leg standing balance training on the affected leg (with eyes closed and open and on a support surface with different degrees of softness). (6) Straight leg raise training in the standing position can increase resistance appropriately.	Exercise with a rope tied around the waist or on a treadmill for forward and backward gait training.	(1) Manipulation to push the patella treatment. (2) Manipulation of the surgical scar. (3) Manipulative passive knee flexion or extension angle exercises.	The knee joint moves to an active full angle, aligning with the healthy side leg. (1) Normal gait can be achieved without any walking aid. (2) Self-care of daily life (may have difficulty walking up and down steps).	Fully weight bearing; normal gait can be achieved without a brace or walker at 3 weeks postoperatively.

Table2: Phases 4-5 of the post-ACLR rehabilitation program

Phase	Movement Exercises	Gait Exercises	Manipulative Massage	Rehabilitation Goals	Precautions

Phase 4 (4-8 weeks)	(1) Fixed cycling training: gradually increasing the resistance. (2) Squat training: Double leg transition to a single leg (0°to 60°), gradually increasing resistance. (3) Lunge training (0°to 60°). (4) Step training: centripetal and centrifugal contraction of the anterior thigh muscles (knee does not exceed 60°). (5) Tiptoe training: Double leg transition to a single leg. (6) Swing exercise: The affected leg stands on one leg, and the healthy leg is strapped with an elastic band and swings, transitioning from front-to-back swing to lateral swing and then to rotation or random direction movement. (7) Rotational stability training: static lunge stance, lateral pull pulley exercise. (8) Exercise with a rope tied around the waist to provide resistance; walking exercises in the forward and backward, left and right directions. (9) Walking exercises on the treadmill in 4 directions. (10) Balance board training: various of support surfaces, double-legged standing. (11) Single-leg stand for ball tossing exercises. (12) Core training: supine or prone position for bridge exercise, standing to pull pulley.	Go around obstacles at normal walking speeds on different surfaces.	Manual method to loosen surgical scars.	(1) Center of gravity in the middle, squatting bilaterally to 60° (no more than 60°). (2) Knee in good condition (slight pain and effusion, no instability). (3) The circumference at the upper edge of the patella is 10 cm , within a 1 to 2 cm difference between the legs. (4) The affected limb can maintain balance for > 30 seconds while standing on one leg with little body sway.	(1) Do not participate in sports with a high impact on the joints, such as running or jumping. (2) Do not participate in sports with high lateral stress on the joints. (3) Avoid squatting deeply (limit to 0°to 60°).
Phase 5 (8-12 weeks)	(1) Squat training: transition from double to single leg (0°to 60°), gradually increasing resistance. (2) Lunge training (0°to 60°). (3) Tiptoe training: double-leg transition to single-leg. (4) Increasing the strength of the posterior lateral muscle group with plyometric training. Core muscle strength training. ① Combined strength training with balance training (throwing and catching balls on the balance board, small squats on the balance board, etc.) ② Advanced balance function training (affected leg standing on one leg, hand or opposite foot to touch objects on the ground or lateral pulling elastic band) ③ Swimming training, in addition to breaststroke. Additionally, care should be taken not to stir the leg at a deep squatting angle or to use a splint when swimming. ④ Cycling training every other day.	——	——	(1) The thigh circumference of both legs is close to the same (within 1 cm of each other). (2) The affected limb squats to 60° on one leg. (3) The affected limb can stand on one leg to maintain balance for 60 seconds. (4) Little, if any, oedema with activity.	Patellar tendonitis may occur.

Table 3: Phases 6-7 of the post-ACLR rehabilitation program

Phase	Movement Exercises	Gait Exercises	Manipulative Massage	Rehabilitation Goals	Precautions
Phase 6 (12-16 weeks)	(1) Jogging movement: multiple directions for running. (2) Increasing the speed of all sports. (3) Skateboard training, slow walking in the water and other forms of exercise can be carried out.	——	——	(1) Squat down to 60° on one leg with the affected limb and repeat 20 times. (2) The affected leg can stand on one leg to maintain balance for at least 60 seconds. (3) Vertical or horizontal jump with both legs with a good landing position. (4) Single-leg jump: 80% of the ability of the healthy leg is achieved.	Avoid wrong movements or posture. (1) Landing with the knee joint too straight. (2) The knee joint is turned outward or inward when landing. (3) When landing or bouncing, the healthy leg always takes the lead, and the affected leg does not.

Phase 6 (12-16 weeks)	(1) Jogging movement: multiple directions for running. (2) Increasing the speed of all sports. (3) Skateboard training, slow walking in the water and other forms of exercise can be carried out.	——	——	(1) Squat down to 60° on one leg with the affected limb and repeat 20 times. (2) The affected leg can stand on one leg to maintain balance for at least 60 seconds. (3) Vertical or horizontal jump with both legs with a good landing position. (4) Single-leg jump: 80% of the ability of the healthy leg is achieved.	Avoid wrong movements or posture. (1) Landing with the knee joint too straight. (2) The knee joint is turned outward or inward when landing. (3) When landing or bouncing, the healthy leg always takes the lead, and the affected leg does not.

Baseline indicators and observations

Baseline and preoperative patient characteristics included the subject's sex, age, affected limb (left or right), cause of injury (playing basketball, other sports such as soccer), smoking status (yes or no), time from injury to surgery (fresh injury or old rupture), whether the injury was accompanied by cartilage and meniscal damage, time of surgery, and degree of ACL fracture (partial or total).

Study endpoints

Primary outcome/endpoint: The IKDC scores changes in knee function from preoperative to 6 months postoperative. The IKDC is a commonly used tool to evaluate outcomes after knee surgeries, including ACLR[27]. The IKDC knee score consists of a knee assessment (10 entries) and a knee ligament checklist (8 entries), covering joint pain, motor level and daily activity ability, with a total score of 0 to 100. The IKDC can address knee symptoms, function and physical activity. The IKDC assesses symptoms, function and physical activity of the knee. Patients were evaluated with the questionnaire preoperatively and at follow-up visits at 1, 3, 6, 12, and 24 months postoperatively.

Secondary outcomes/endpoints: LKS, KOOS (including knee symptoms, pain, activities of daily living, sports and recreational activities, and quality of life), VAS (For pain assessment), Lachman test, MRI imaging data, and assessment of knee stability using the Kneelax3 knee stability meter.

(1) Kneelax3 (MONITORED REHAB SYSTEMS B.V. Model: KNEELAX3, The Netherlands): preoperatively and 1, 3, 6, 12 and 24 months postoperatively; the Kneelax3 arthrometer was used for the assessment of knee stability.

(2) LKS: This scoring system consists of 8 questions on a scale of 0-100, with higher scores representing a better patient's functional status. The main tendency is toward activities of daily living, and patients were assessed by questionnaires before surgery and at 1, 3, 6, 12, and 24 months of postoperative follow-up visits[28].

(3) KOOS score: The KOOS consists of 5 subscales: pain, other knee symptoms, activities of daily living (ADL), function in sport and recreation (Sport/Rec), and knee-related quality of life (QOL)[29]. Patients were given one week to consider before answering the questions, and each question had five alternative boxes with scores ranging from 0 to 4. Standard scores were calculated for each subscale (100 for no

symptoms and 0 for extreme symptoms), and patients were assessed with questionnaires before surgery and at follow-up visits at 1, 3, 6, 12, and 24 months after surgery.

(4) VAS score: The visual analogue pain scoring method is more sensitive and comparable. In this trial, a 100-mm VAS pain score (including resting state score, 30-min post-walk score and overall pain level in the past month) was used[30]. This protocol only assesses pain at rest, with 0 representing no pain and 100 representing the most severe pain. Patients were evaluated with questionnaires at preoperative and postoperative follow-up visits at 1, 3, 6, 12, and 24 months.

(5) Lachman test: This assesses ACL function with the patient in the supine or prone position with the knee flexed at approximately a 30° angle[31]. The examiner uses one hand to immobilize the thigh while the other attempts to move the tibia forward. Positive results suggest that patients with ACL injuries be tested preoperatively and at follow-up visits at 1, 3, 6, 12, and 24 months postoperatively.

(6) MRI assessment: MRI was performed at 12 and 24 months postoperatively to assess the patient's reconstructed ACL.

Patient termination and withdrawal criteria

Patients may withdraw from this trial at any time. Patients may withdraw from the study for the following reasons.

(1) Surgical failure: 1) occurrence of infection, 2) no secondary rupture of the reconstructed ligament (rupture of the ligament, rupture of the internal brace augmentation line and both in the trial group, rupture of the reconstructed ligament in the control group), 3) knee instability: patient self-reported knee instability, or Lachman test (+) or Kneelax3 knee arthrometer test revealed a 3-mm difference in comparison with the healthy side.

(2) Patient withdrawal from the trial: All subjects had the right to withdraw at any time during the study. A subject was withdrawn from the trial if any of the following occurred during the trial: 1) withdrawal of informed consent by the subject; 2) a person who, in the opinion of the investigator, is no longer suitable for continuation of the clinical trial; 3) a woman who becomes pregnant during the clinical trial; 4) death of the subject; or 5) the subject is lost to follow-up.

(3) Trial termination:

1) The clinical trial institution and the investigator found that the risks to patients of continuing the clinical trial exceed the possible benefits; 2) the ethics committee finds that the rights of the subjects cannot be protected; 3) the sponsor requests termination of the trial for various reasons; and 4) the national administrative authority requests termination.

The timing and reasons for withdrawal from the trial were recorded in detail on the case report form; follow-up care is no longer provided for subjects who voluntarily withdraw from the treatment as well as for those for whom follow-up data are not being collected, but subjects who withdrew from the trial due to adverse events or because of surgical failure must be followed up until the adverse events stabilized or resolved or until the investigator deemed that further follow-up was no longer necessary.

Data management

The trial used an electronic data collection (EDC) system for data management. The investigator or investigator-authorized research staff completed the electronic Case Report Form (eCRF) through the EDC system in an accurate, timely, complete and standardized manner based on the original information from the subjects. Questionnaire checking, data cleaning and summarization were performed in a promptly after each follow-up visit. The follow-up survey is proposed to adopt the electronic questionnaire system and on-site questionnaire survey, and the on-site survey results will be saved in time and organized in the database later. The investigator or the investigator's authorized researcher enters the data into the EDC according to their respective accounts. The data administrator verifies the data's reliability, completeness, and accuracy in the EDC. If any questionable data are found, a challenge can be issued in the system, and the investigator or the investigator's delegated researcher verifies, corrects, or answers the query. When all data have been entered into the database, and all queries have been resolved, the database will be locked by the data administrator. If a problem is found after the database is locked and there is a need to correct it, the process of unlocking and relocking the data should be followed. After the database is locked, the data manager submits the data to the statistical analyst for statistical analysis as scheduled.

Statistical analysis

(1) Statistical design: This trial was a randomized controlled clinical trial.

(2) Principles of Statistical Analysis: All statistical analyses were performed in SAS version 9.4 or later, R version 3.3.2 or later, or SPSS24. All statistical tests were performed using two-sided tests, and P values less than or equal to 0.05 were considered statistically significant for the differences tested (unless otherwise specified).

1) Summary statistics for continuous variables: including the mean, standard deviation, median, minimum, maximum, lower quartile (Q1), and upper quartile (Q3); summary statistics for categorical variables, including the number of cases and percentage of each category.

2) Between-group comparisons of demographic baseline characteristics: Group comparisons for continuous variables will be made using independent samples t-test (chi-square, normal distribution) or Wilcoxon rank sum test depending on data distribution, and the chi-square test or the exact probability method for categorical variables (if chi-square test is not applicable).

(3) Completion and demographic analyses

Baseline analyses were based on the full analysis set (FAS). The enrollment and completion status of the trials were summarized, and the reasons for noncompletion are described in a detailed table. Subjects' demographic characteristics were described and compared to measure the comparability of the two groups. Validity reporting data were accepted only if the baseline was balanced between groups; otherwise, validity data were subject to correction before reporting.

(4) Patient-reported outcome validity evaluation indices

The outcome validity evaluation will be based on the FAS and the per-protocol set (PPS). The statistical description and inference of the data will be based on the

characteristics of the data and the selection of applicable descriptive indicators and hypothesis testing methods.

Primary patient-reported outcome: comparison of IKDC knee scores at 6 months (±2 weeks) postoperatively in the trial and control groups. We will use a linear regression model for analysis to correct for possible confounding factors, such as age, sex, and cause of injury. Preoperative baseline IKDC scores were used as predictors when conducting the analysis, and IKDC at 6 months (±2 weeks) was used as an indicator of posttreatment outcomes.

Secondary patient-reported outcomes

1) Because IKDC scores were measured multiple times during patient follow-up, we used a linear mixed model to compare changes over time between the trial and control groups.

2) Anterior tibial translation distance is measured by the Kneelax3 knee stability meter, and comparisons of anterior tibial translation distance between the test and control groups at the same postoperative time points with the same force will be performed using either an independent samples t-test (chi-square, normally distributed) or a Wilcoxon rank sum test. A linear mixed model will also be used to compare and analyze the evolution of these consecutive results over time in both groups.

3) Here, the comparative analysis of failure rate and infection rate in the control group versus the test group during the main 6 months will be performed using the chi-square test or the t-test.

4) Linear regression of continuous outcomes from baseline to 24 months, such as the LKS, KOOS score (including knee symptoms, pain, activities of daily living, sports and recreational activities, quality of life), Lachman test, and pain visual analogue score (VAS) protocols, will be used to compare and analyze the evolution of these continuous outcomes over time in the two groups using linear mixed models.

5) The morphology and signal intensity of the postoperative ACL will be assessed using MRI methods, and the different treatments will be compared at different time points using chi-square tests.

Analysis of safety indicators

The safety evaluation was based on the safety set (SS) analysis dataset. The internationally accepted MedDRA term set classification was used for adverse event coding, and the types of adverse events, frequency, severity, and relationship to internal brace enhancement line generation and surgery were summarized by a group. A detailed list of the various adverse events is provided, with special notation for subjects who discontinued the trial because of adverse events and for those who experienced serious adverse events. The proportion of patients who developed complications between treatments was compared using a chi-square test.

Patient and public involvement

Patients and/or the public were not involved in this research's design, conduct, reporting, or dissemination plans.

Discussion

This trial was conducted as a prospective randomised controlled trial to investigate the clinical efficacy of ACLR with or without the internal brace technique. In this 2-year follow-up study, the subjective, objective, and functional outcomes of patients who underwent ACLR with the application of the internal brace technique or ACLR alone were compared. This study hypothesises that ACLR with the internal brace technique will be more stable than ACLR alone in the early postoperative period, with a lower incidence of secondary injury, reduced duration and extent of pain, and an earlier return to preinjury activity levels. However, there may be no significant difference between the two groups regarding patient-reported outcome indicators as recovery time increases.

ACL rupture is a common knee injury in the athletic population and has been extensively studied. Studies as early as the late 20th century have shown that ACLR is superior to ACL repair[32 33]. The ACL is an important structure for maintaining knee stability, preventing anterior tibial displacement and limiting intratibial rotation[34], making ACLR surgery the gold standard of treatment for patients recovering motion or performing rotational activities after an ACL rupture in the knee[35]. The recovery of knee function after surgery depends on the ability of the ACL graft to withstand appropriate loads during rehabilitation and after return to sports. The tendon graft implanted in the human knee joint survives in the intra-articular environment and gradually in the ligaments. The graft is fragile and vulnerable to reinjury during the pre-remodelling phase prior to ligamentization[36], so a careful rehabilitation program should be developed to prevent reinjury during the rehabilitation period. Several studies have found a higher probability of re-rupture or secondary revision for athletes and adolescents or for ACLR using either autologous tendons or allogeneic tendons[10 37]. Therefore, a surgical approach that increases the structural strength of the graft and protects it during the early stages of graft ligamentization is of great importance.

The biomechanical properties of the intra-articular reconstructed ligaments improved at 8 weeks postoperatively for the FiberTape suture applied in a rabbit model. Additionally, during this period, FiberTape did not adversely affect bone tunnel healing or cause a long-term increase in indicators of inflammation[12]. In a dog model, no severe inflammation or immune response, bone erosion, or premature OA development was observed 6 months postoperatively[38]. The results of these studies will support the biocompatibility and safety of intra-articular suture tape for ACLR enhancement.

A study of load sharing after ACL graft enhancement by suture tape reported that load sharing began at 200 N and 300 N for 7-mm and 9-mm grafts, respectively. The final peak load (400 N) would be shared by 31% (7-mm graft) and 20% (9-mm graft) by the suture tape[39]. Suture tape ligament augmentation may protect biological grafts from excessive peak loading and elongation. After ACLR in the early recovery phase, suture band augmentation increases ACL graft stiffness by 104% and the ultimate breaking load by 57%, reducing the graft failure rate in clinical situations.

A recent systematic review paper by Christopher et al. concluded from biomechanical, animal and clinical studies that applying suture tape augmentation in ACLR increases biomechanical stability[40]. Therefore, in this randomized controlled trial, we will conduct a prospective observational comparison and a long-term follow-up to elucidate the clinical efficacy of internal bracing in ACLR.

Abbreviations

Anterior cruciate ligament (ACL)

Anterior cruciate ligament reconstruction (ACLR)

International Knee Documentation Committee (IKDC)

the Knee Injury and Osteoarthritis Outcome Score (KOOS)

Lysholm knee score (LKS)

Visual Analog Scale (VAS)

ultrahigh molecular weight polyethene (UHMWPE)

Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT)

activities of daily living (ADL)

sport and recreation (Sport/Rec)

quality of life (QOL)

medial collateral ligament (MCL)

minimum clinically important difference (MCID)

electronic Case Report Form (eCRF)

safety set (SS)

Ethics and dissemination

The trial was approved by the Medical Ethics Committee of Xiangya Hospital of Central South University on October 26, 2021, with the ethics number "202110478" and prospectively registered in the China Clinical Trials Registry on March 14, 2022, with the registration number: ChiCTR2200057526. All subjects signed an informed consent form before participating in this trial, and we will protect the patients from any invasion of their private privacy. All investigators will keep the study results confidential until after the data are made public, and the investigators will release no data related to the database without the approval of the principal investigator. We will publish the findings and data in peer-reviewed journals and present them at national and international conferences.

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Author contributions

WF-X and YS-L established the study design; WH-L conceived the design and wrote the draft manuscript; D-L, ZJ-C, and LY-P were involved in data acquisition, analysis, and interpretation; and WQ-X, HF-J, and X-L designed the rehabilitation protocol. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests regarding the present study.

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References

1. Robson AW. VI. Ruptured Crucial Ligaments and their Repair by Operation

Ann Surg 1903;37(5):716-8. [published Online First: 1903/05/01]

2. Patterson BE, Culvenor AG, Barton CJ, et al. Worsening Knee Osteoarthritis Features on Magnetic Resonance Imaging 1 to 5 Years After Anterior Cruciate Ligament Reconstruction. Am J Sports Med 2018;46(12):2873-83. doi: 10.1177/0363546518789685 [published Online First: 2018/09/05]

3. Suter LG, Smith SR, Katz JN, et al. Projecting Lifetime Risk of Symptomatic Knee Osteoarthritis and Total Knee Replacement in Individuals Sustaining a Complete Anterior Cruciate Ligament Tear in Early Adulthood. Arthritis Care Res (Hoboken) 2017;69(2):201-08. doi: 10.1002/acr.22940 [published Online First: 2016/05/24]

4. Filbay SR, Culvenor AG, Ackerman IN, et al. Quality of life in anterior cruciate ligament-deficient individuals: a systematic review and meta-analysis. Br J Sports Med 2015;49(16):1033-41. doi: 10.1136/bjsports-2015-094864 [published Online First: 2015/08/01]

5. Moses B, Orchard J, Orchard J. Systematic review: Annual incidence of ACL injury and surgery in various populations. Res Sports Med 2012;20(3-4):157-79. doi: 10.1080/15438627.2012.680633 [published Online First: 2012/06/30]

6. Griffin LY, Albohm MJ, Arendt EA, et al. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. Am J Sports Med 2006;34(9):1512-32. doi: 10.1177/0363546506286866 [published Online First: 2006/08/15]

7. de Sa D, Shanmugaraj A, Weidman M, et al. All-Inside Anterior Cruciate Ligament Reconstruction-A Systematic Review of Techniques, Outcomes, and Complications. J Knee Surg 2018;31(9):895-904. doi: 10.1055/s-0038-1627446 [published Online First: 2018/03/13]

8. Di Benedetto P, Di Benedetto E, Fiocchi A, et al. Causes of Failure of Anterior Cruciate Ligament Reconstruction and Revision Surgical Strategies. Knee Surg Relat Res 2016;28(4):319-24. doi: 10.5792/ksrr.16.007 [published Online First: 2016/11/29]

9. Vaishya R, Agarwal AK, Ingole S, et al. Current Trends in Anterior Cruciate Ligament Reconstruction: A Review. Cureus 2015;7(11):e378. doi: 10.7759/cureus.378 [published Online First: 2015/12/24]

10. Takazawa Y, Ikeda H, Saita Y, et al. Return to Play of Rugby Players After Anterior Cruciate Ligament Reconstruction Using Hamstring Autograft: Return to Sports and Graft Failure According to Age. Arthroscopy 2017;33(1):181-89. doi: 10.1016/j.arthro.2016.06.009 [published Online First: 2016/08/16]

11. Ellis HB, Matheny LM, Briggs KK, et al. Outcomes and revision rate after bone-patellar tendon-bone allograft versus autograft anterior cruciate ligament reconstruction in patients aged 18 years or younger with closed physes. Arthroscopy 2012;28(12):1819-25. doi: 10.1016/j.arthro.2012.06.016 [published Online First: 2012/10/30]

12. Soreide E, Denbeigh JM, Lewallen EA, et al. In vivo assessment of high-molecular-weight polyethylene core suture tape for intra-articular ligament reconstruction: an animal study. Bone Joint J 2019;101-b(10):1238-47. doi: 10.1302/0301-620x.101b10.Bjj-2018-1282.R2 [published Online First: 2019/10/01]

13. Lubowitz JH, MacKay G, Gilmer B. Knee medial collateral ligament and posteromedial corner anatomic repair with internal bracing. Arthrosc Tech 2014;3(4):e505-8. doi: 10.1016/j.eats.2014.05.008 [published Online First: 2014/10/03]

14. Gilmer BB, Crall T, DeLong J, et al. Biomechanical Analysis of Internal Bracing for Treatment of Medial Knee Injuries. Orthopedics 2016;39(3):e532-7. doi: 10.3928/01477447-20160427-13 [published Online First: 2016/05/03]

15. Heusdens CHW, Hopper GP, Dossche L, et al. Anterior cruciate ligament repair

with Independent Suture Tape Reinforcement: a case series with 2-year follow-up. Knee Surg Sports Traumatol Arthrosc 2019;27(1):60-67. doi: 10.1007/s00167-018-5239-1 [published Online First: 2018/11/02]

16. Nishimura A, Nakazora S, Senga Y, et al. Arthroscopic Internal Brace Augmentation With Arthroscopic Modified Broström Operation for Chronic Ankle Instability. Arthrosc Tech 2021;10(4):e995-e1000. doi: 10.1016/j.eats.2020.11.021 [published Online First: 2021/05/14]

17. Wilk KE, Arrigo CA, Bagwell MS, et al. Repair of the Ulnar Collateral Ligament of the Elbow: Rehabilitation Following Internal Brace Surgery. J Orthop Sports Phys Ther 2019;49(4):253-61. doi: 10.2519/jospt.2019.8215 [published Online First: 2019/03/14]

18. van Eck CF, Limpisvasti O, ElAttrache NS. Is There a Role for Internal Bracing and Repair of the Anterior Cruciate Ligament? A Systematic Literature Review. Am J Sports Med 2018;46(9):2291-98. doi: 10.1177/0363546517717956 [published Online First: 2017/08/08]

19. Cook JL, Smith P, Stannard JP, et al. A Canine Arthroscopic Anterior Cruciate Ligament Reconstruction Model for Study of Synthetic Augmentation of Tendon Allografts. J Knee Surg 2017;30(7):704-11. doi: 10.1055/s-0036-1597618 [published Online First: 2016/12/27]

20. Bachmaier S, Smith PA, Bley J, et al. Independent Suture Tape Reinforcement of Small and Standard Diameter Grafts for Anterior Cruciate Ligament Reconstruction: A Biomechanical Full Construct Model. Arthroscopy 2018;34(2):490-99. doi: 10.1016/j.arthro.2017.10.037 [published Online First: 2017/12/26]

21. Bedi A. Editorial Commentary: Buckle Up Surgeons: "Safety Belt" Reinforcement of Knee Anterior Cruciate Ligament Reconstruction Grafts. Arthroscopy 2018;34(2):500-01. doi: 10.1016/j.arthro.2017.12.009 [published Online First: 2018/02/08]

22. Moher D, Hopewell S, Schulz KF, et al. CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. International journal of surgery (London, England) 2012;10(1):28-55. doi: 10.1016/j.ijsu.2011.10.001 [published Online First: 2011/11/01]

23. Collins NJ, Misra D, Felson DT, et al. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). Arthritis Care Res (Hoboken) 2011;63 Suppl 11(0 11):S208-28. doi: 10.1002/acr.20632 [published Online First: 2012/05/25]

24. Irrgang JJ, Anderson AF, Boland AL, et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form. Am J Sports Med 2006;34(10):1567-73. doi: 10.1177/0363546506288855 [published Online First:

2006/07/28]

25. Li YL, Ning GZ, Wu Q, et al. Single-bundle or double-bundle for anterior cruciate ligament reconstruction: a meta-analysis. Knee 2014;21(1):28-37. doi: 10.1016/j.knee.2012.12.004 [published Online First: 2013/01/12]

26. Lubowitz JH. All-inside anterior cruciate ligament graft link: graft preparation technique. Arthrosc Tech 2012;1(2):e165-8. doi: 10.1016/j.eats.2012.06.002 [published Online First: 2013/06/15]

27. Greco NJ, Anderson AF, Mann BJ, et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form in comparison to the Western Ontario and McMaster Universities Osteoarthritis Index, modified Cincinnati Knee Rating System, and Short Form 36 in patients with focal articular cartilage defects. Am J Sports Med 2010;38(5):891-902. doi: 10.1177/0363546509354163 [published Online First: 2010/01/02]

28. Briggs KK, Lysholm J, Tegner Y, et al. The reliability, validity, and responsiveness of the Lysholm score and Tegner activity scale for anterior cruciate ligament injuries of the knee: 25 years later. Am J Sports Med 2009;37(5):890-7. doi: 10.1177/0363546508330143 [published Online First: 2009/03/06]

29. Collins NJ, Prinsen CA, Christensen R, et al. Knee Injury and Osteoarthritis Outcome Score (KOOS): systematic review and meta-analysis of measurement properties. Osteoarthritis Cartilage 2016;24(8):1317-29. doi: 10.1016/j.joca.2016.03.010 [published Online First: 2016/03/26]

30. Wewers ME, Lowe NK. A critical review of visual analogue scales in the measurement of clinical phenomena. Res Nurs Health 1990;13(4):227-36. doi: 10.1002/nur.4770130405 [published Online First: 1990/08/01]

31. Coffey R, Bordoni B. Lachman Test. StatPearls. Treasure Island (FL): StatPearls Publishing

32. Engebretsen L, Benum P, Fasting O, et al. A prospective, randomized study of three surgical techniques for treatment of acute ruptures of the anterior cruciate ligament. Am J Sports Med 1990;18(6):585-90. doi: 10.1177/036354659001800605 [published Online First: 1990/11/01]

33. Grøntvedt T, Engebretsen L, Benum P, et al. A prospective, randomized study of three operations for acute rupture of the anterior cruciate ligament. Five-year follow-up of one hundred and thirty-one patients. J Bone Joint Surg Am 1996;78(2):159-68. doi: 10.2106/00004623-199602000-00001 [published Online First: 1996/02/01]

34. Noyes FR. The function of the human anterior cruciate ligament and analysis of single- and double-bundle graft reconstructions. Sports Health 2009;1(1):66-75. doi: 10.1177/1941738108326980 [published Online First: 2009/01/01]

35. Ardern CL, Webster KE, Taylor NF, et al. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. Br J Sports Med 2011;45(7):596-606. doi: 10.1136/bjsm.2010.076364 [published Online First: 2011/03/15]

36. Claes S, Verdonk P, Forsyth R, et al. The "ligamentization" process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. Am J Sports Med 2011;39(11):2476-83. doi: 10.1177/0363546511402662 [published Online First: 2011/04/26]

37. Wright RW, Gill CS, Chen L, et al. Outcome of revision anterior cruciate ligament reconstruction: a systematic review. J Bone Joint Surg Am 2012;94(6):531-6. doi: 10.2106/jbjs.K.00733 [published Online First: 2012/03/23]

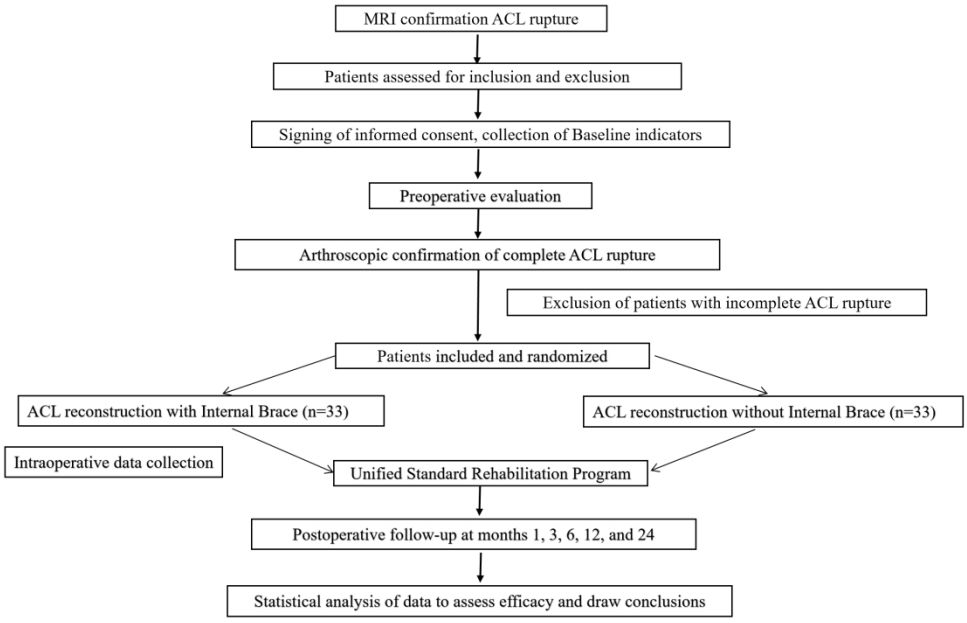
38. Smith PA, Bozynski CC, Kuroki K, et al. Intra-Articular Biocompatibility of Multistranded, Long-Chain Polyethylene Suture Tape in a Canine ACL Model. J Knee Surg 2019;32(6):525-31. doi: 10.1055/s-0038-1655765 [published Online First: 2018/06/01]

39. Bachmaier S, Smith PA, Argintar EH, et al. Independent Suture Augmentation With All-Inside Anterior Cruciate Ligament Reconstruction Reduces Peak Loads on Soft-Tissue Graft. A Biomechanical Full-Construct Study. Arthroscopy 2022;38(1):88-98. doi: 10.1016/j.arthro.2021.09.032 [published Online First: 2021/10/17]

40. C EAM, Huntington LS, Tulloch S. Suture Tape Augmentation of Anterior Cruciate Ligament Reconstruction increases biomechanical stability: A Scoping Review of Biomechanical, Animal, and Clinical Studies. Arthroscopy 2022 doi: 10.1016/j.arthro.2021.12.036 [published Online First: 2022/01/07]

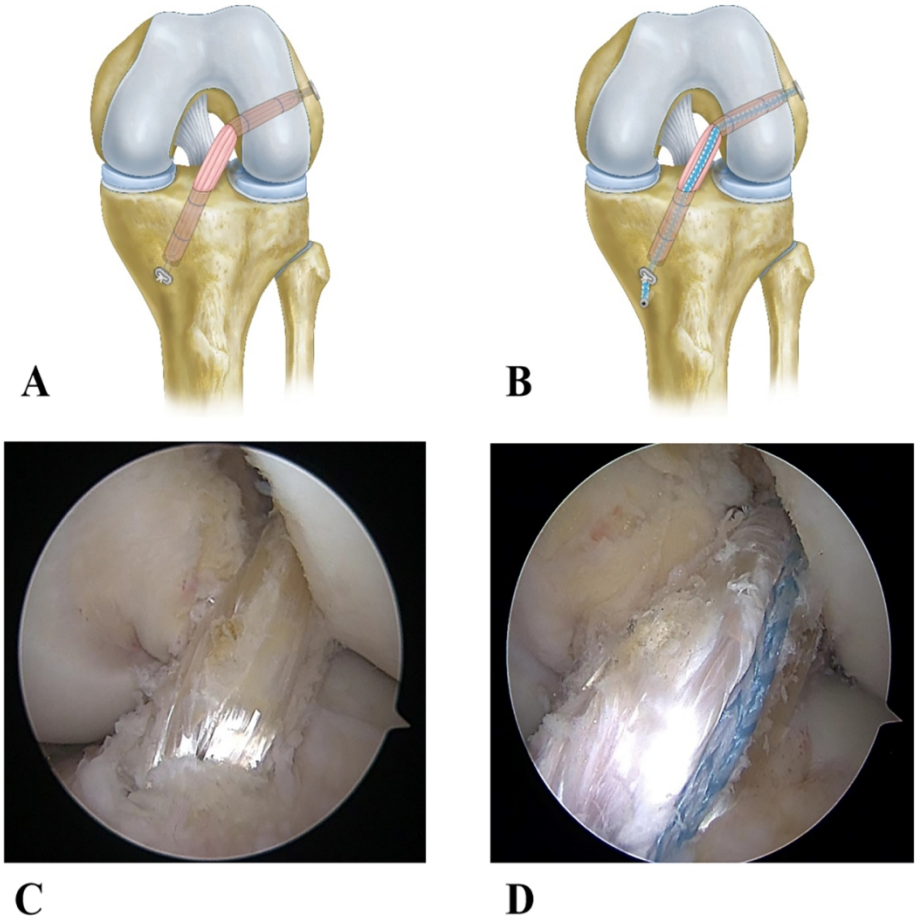
Fig.1 Study Flow Diagram.

Fig.2 A and B are the models of the control group and test group, respectively. C and D are the pictures of the control group and test group after intraoperative arthroscopic ACLR, respectively.



Study Flow Diagram.

731x467mm (76 x 76 DPI)



A and B are the models of the control group and test group, respectively. C and D are the pictures of the control group and test group after intraoperative arthroscopic ACLR, respectively.

253x253mm (138 x 138 DPI)

Reporting checklist for protocol of a clinical trial.

Based on the SPIRIT guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

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		Reporting Item	Page Number
Administrative information			
Title	#1	Descriptive title identifying the study design, population, interventions, and, if applicable, trial acronym	1
Trial registration	#2a	Trial identifier and registry name. If not yet registered,	2

		name of intended registry	
Trial registration: data set	#2b	All items from the World Health Organization Trial Registration Data Set	2
Protocol version	#3	Date and version identifier	4
Funding	#4	Sources and types of financial, material, and other support	11
Roles and responsibilities: contributorship	#5a	Names, affiliations, and roles of protocol contributors	1
Roles and responsibilities: sponsor contact information	#5b	Name and contact information for the trial sponsor	11
Roles and responsibilities: sponsor and funder	#5c	Role of study sponsor and funders, if any, in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication, including whether they will have ultimate authority over any of these activities	11
Roles and responsibilities: committees	#5d	Composition, roles, and responsibilities of the coordinating centre, steering committee, endpoint adjudication committee, data management team, and other individuals or groups overseeing the trial, if applicable (see Item 21a for data monitoring committee)	11

Introduction			
Background and rationale	#6a	Description of research question and justification for undertaking the trial, including summary of relevant studies (published and unpublished) examining benefits and harms for each intervention	3
Background and rationale: choice of comparators	#6b	Explanation for choice of comparators	3
Objectives	#7	Specific objectives or hypotheses	3
Trial design	#8	Description of trial design including type of trial (eg, parallel group, crossover, factorial, single group), allocation ratio, and framework (eg, superiority, equivalence, non-inferiority, exploratory)	2
Methods: Participants, interventions, and outcomes			
Study setting	#9	Description of study settings (eg, community clinic, academic hospital) and list of countries where data will be collected. Reference to where list of study sites can be obtained	4
Eligibility criteria	#10	Inclusion and exclusion criteria for participants. If applicable, eligibility criteria for study centres and	4

		individuals who will perform the interventions (eg, surgeons, psychotherapists)	
Interventions: description	#11a	Interventions for each group with sufficient detail to allow replication, including how and when they will be administered	5-6
Interventions: modifications	#11b	Criteria for discontinuing or modifying allocated interventions for a given trial participant (eg, drug dose change in response to harms, participant request, or improving / worsening disease)	5-6
Interventions: adherance	#11c	Strategies to improve adherence to intervention protocols, and any procedures for monitoring adherence (eg, drug tablet return; laboratory tests)	5-6
Interventions: concomitant care	#11d	Relevant concomitant care and interventions that are permitted or prohibited during the trial	5-6
Outcomes	#12	Primary, secondary, and other outcomes, including the specific measurement variable (eg, systolic blood pressure), analysis metric (eg, change from baseline, final value, time to event), method of aggregation (eg, median, proportion), and time point for each outcome. Explanation of the clinical relevance of chosen efficacy and harm outcomes is strongly recommended	6-7
Participant timeline	#13	Time schedule of enrolment, interventions (including any run-ins and washouts), assessments, and visits for participants. A schematic diagram is highly recommended	6-7

		(see Figure)	
Sample size	#14	Estimated number of participants needed to achieve study objectives and how it was determined, including clinical and statistical assumptions supporting any sample size calculations	4
Recruitment	#15	Strategies for achieving adequate participant enrolment to reach target sample size	4
Methods: Assignment of interventions (for controlled trials)			
Allocation: sequence generation	#16a	Method of generating the allocation sequence (eg, computer-generated random numbers), and list of any factors for stratification. To reduce predictability of a random sequence, details of any planned restriction (eg, blocking) should be provided in a separate document that is unavailable to those who enrol participants or assign interventions	4-5
Allocation concealment mechanism	#16b	Mechanism of implementing the allocation sequence (eg, central telephone; sequentially numbered, opaque, sealed envelopes), describing any steps to conceal the sequence until interventions are assigned	4-5
Allocation: implementation	#16c	Who will generate the allocation sequence, who will enrol participants, and who will assign participants to	4-5

		interventions	
Blinding (masking)	#17a	Who will be blinded after assignment to interventions (eg, trial participants, care providers, outcome assessors, data analysts), and how	4-5
Blinding (masking): emergency unblinding	#17b	If blinded, circumstances under which unblinding is permissible, and procedure for revealing a participant's allocated intervention during the trial	4-5
Methods: Data collection, management, and analysis			
Data collection plan	#18a	Plans for assessment and collection of outcome, baseline, and other trial data, including any related processes to promote data quality (eg, duplicate measurements, training of assessors) and a description of study instruments (eg, questionnaires, laboratory tests) along with their reliability and validity, if known. Reference to where data collection forms can be found, if not in the protocol	7
Data collection plan: retention	#18b	Plans to promote participant retention and complete follow-up, including list of any outcome data to be collected for participants who discontinue or deviate from intervention protocols	7
Data management	#19	Plans for data entry, coding, security, and storage,	7

		including any related processes to promote data quality (eg, double data entry; range checks for data values). Reference to where details of data management procedures can be found, if not in the protocol	
Statistics: outcomes	#20a	Statistical methods for analysing primary and secondary outcomes. Reference to where other details of the statistical analysis plan can be found, if not in the protocol	8-9
Statistics: additional analyses	#20b	Methods for any additional analyses (eg, subgroup and adjusted analyses)	8-9
Statistics: analysis population and missing data	#20c	Definition of analysis population relating to protocol non-adherence (eg, as randomised analysis), and any statistical methods to handle missing data (eg, multiple imputation)	8-9
Methods: Monitoring			
Data monitoring: formal committee	#21a	Composition of data monitoring committee (DMC); summary of its role and reporting structure; statement of whether it is independent from the sponsor and competing interests; and reference to where further details about its charter can be found, if not in the protocol. Alternatively, an explanation of why a DMC is not needed	7
Data monitoring: interim analysis	#21b	Description of any interim analyses and stopping guidelines, including who will have access to these interim results and make the final decision to terminate	7

		the trial	
Harms	#22	Plans for collecting, assessing, reporting, and managing solicited and spontaneously reported adverse events and other unintended effects of trial interventions or trial conduct	7
Auditing	#23	Frequency and procedures for auditing trial conduct, if any, and whether the process will be independent from investigators and the sponsor	7
Ethics and dissemination			
Research ethics approval	#24	Plans for seeking research ethics committee / institutional review board (REC / IRB) approval	10
Protocol amendments	#25	Plans for communicating important protocol modifications (eg, changes to eligibility criteria, outcomes, analyses) to relevant parties (eg, investigators, REC / IRBs, trial participants, trial registries, journals, regulators)	10
Consent or assent	#26a	Who will obtain informed consent or assent from potential trial participants or authorised surrogates, and how (see Item 32)	10
Consent or assent: ancillary studies	#26b	Additional consent provisions for collection and use of participant data and biological specimens in ancillary studies, if applicable	Not applicable
Confidentiality	#27	How personal information about potential and enrolled	7

		participants will be collected, shared, and maintained in order to protect confidentiality before, during, and after the trial	
Declaration of interests	#28	Financial and other competing interests for principal investigators for the overall trial and each study site	11
Data access	#29	Statement of who will have access to the final trial dataset, and disclosure of contractual agreements that limit such access for investigators	10
Ancillary and post trial care	#30	Provisions, if any, for ancillary and post-trial care, and for compensation to those who suffer harm from trial participation	7
Dissemination policy: trial results	#31a	Plans for investigators and sponsor to communicate trial results to participants, healthcare professionals, the public, and other relevant groups (eg, via publication, reporting in results databases, or other data sharing arrangements), including any publication restrictions	10
Dissemination policy: authorship	#31b	Authorship eligibility guidelines and any intended use of professional writers	10
Dissemination policy: reproducible research	#31c	Plans, if any, for granting public access to the full protocol, participant-level dataset, and statistical code	10
Appendices			
Informed consent	#32	Model consent form and other related documentation	10

materials		given to participants and authorised surrogates	
Biological specimens	#33	Plans for collection, laboratory evaluation, and storage of biological specimens for genetic or molecular analysis in the current trial and for future use in ancillary studies, if applicable	Not applicable

BMJ Open

Internal brace augmentation reconstruction versus standard anterior cruciate ligament reconstruction : A randomized controlled clinical trial study protocol

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Internal brace augmentation reconstruction versus standard anterior cruciate ligament reconstruction : A randomized controlled clinical trial study protocol

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Abstract:

Introduction: Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries in sports, and the gold standard for treating ACL rupture is tendon graft reconstruction. Internal brace technology is being used nowadays for ligament repair; however, more relevant *in vivo* clinical evidence is required for using internal brace technology in ACL reconstruction (ACLR). We conducted a randomized controlled trial to investigate the clinical efficacy of internal brace technology in ACLR.

Methods and analysis: This randomized, parallel-controlled trial included patients with ACL rupture who underwent inpatient surgery at the Department of Orthopedics, Xiangya Hospital, Central South University. Random number table method was used to assign the participants to either the test or the control group. The test group underwent ACLR using the internal brace technique, whereas the control group underwent standard ACLR. Uniform postoperative rehabilitation protocol was used for both the groups. Patient-reported outcomes included preoperative baseline and postoperative recovery at 1, 3, 6, 12, and 24 months. The primary outcome was International Knee Documentation Committee (IKDC) function from baseline (ACL rupture) to six-months postoperatively. Secondary outcomes included (I) other patient outcome reporting metrics, Lysholm knee score (LKS), Knee Injury and Osteoarthritis Outcome Score (KOOS), and Visual Analog Scale (VAS); (II) the use of Kneelax3 knee stabilizer to assess knee stability; (III) occurrence of adverse events, such as graft refraction or symptomatic instability, postoperative infection, and contralateral injury; and (IV) magnetic resonance images at 12 and 24 months after ACLR.

Ethics and dissemination: This trial was approved by the Medical Ethics Committee of the Xiangya Hospital of Central South University on October 26, 2021. Data will be published in peer-reviewed journals and presented at national and international conferences.

Trial registration number: ChiCTR2200057526.

Strengths and limitations of this study:

- This study aims to demonstrate the clinical superiority of internal braces over conventional ACL reconstruction (ACLR) over a 2-year follow-up period.
- This study will fill an existing gap regarding the efficacy of internal braces in ACLR by providing robust and high-quality evidence of its role and impact.
- This study used a standard and detailed rehabilitation program to ensure smooth recovery after ACLR.
- The single-center design of the trial will result in data to lack generalizability.

Introduction

Anterior cruciate ligament (ACL) rupture is one of the most common knee ligament injuries occurring in young athletes. Mayo-Robson of Leeds performed the first ACL repair in 1895, which was followed by initiation of ACL reconstruction (ACLR) using autologous tissue by Grekow and Hey Groves between 1914-1920.[1] If ACL ruptures are not actively treated after injury, joint instability and other phenomena often occur, which reduces the quality of life and increases the risk of osteoarthritis.[2-4] Over the past few decades, ACL ruptures have been estimated to occur in approximately 30–52 cases per 100,000 person-years.[5] ACL injuries reportedly occur in more than 175,000 people annually in the United States, and approximately 100,000 undergo surgery.[6-8] With the continuous development of surgical techniques, the current mainstream surgical method involves performing ACLR under arthroscopy.[9] A Japanese study reported that the re-disruption rate of ACLR grafts after returning to the field was 23% for rugby players under the age of 20 years.[10] At the same time, other studies have also shown that the revision rate of ACLR with an allogeneic tendon in adolescents can reach 35%;[11] however, the effect after revision is not as good as that of primary ACLR.[12]

Internal brace technology for ligament repair has been promoted since 2010. It uses braided ultrahigh molecular weight polyethene (UHMWPE) polyester suture tape and knotless bone anchors to reinforce ligament strength, also known as an auxiliary stabilizing structure for recovery of motion after ligament repair, which helps prevent secondary damage,[13] such as anterior and posterior cruciate ligament, medial and lateral collateral ligament repair of the knee,[13-15] and ankle and elbow ligament strengthening repair.[16, 17] Enhanced collateral ligament repair and reconstruction with an internal brace improves limb biomechanics, including greater stiffness and maximum load, while facilitating early rehabilitation in motor and biomechanical environments.[12, 14] Reinforced ligament repair offers unique advantages over traditional reconstruction techniques, including smaller bores and implants, no risk of disease transmission from the allografts, and no risk of tunnel convergence during the procedure. [14, 18, 19] Therefore, ACL reinforcement is an alternative method for synergistically supporting ACL grafts and load-sharing, with primary tension on the graft and high-strength suture tape.

In ACLR, the internal brace ligament augmentation technique helps prevent various failure scenarios, including creep and irreversible stretching, traumatic tears, and slippage of the tendon-bone interface.[20, 21] In addition, these failures can be avoided when the graft is small or vulnerable.[20, 21] Smith in an *in vitro* trial conducted in 2018 found that ACLR combined with independent suture tape significantly reduced graft elongation and allowed the grafted ligaments to accept higher ultimate disruption loads, thereby reducing the risk of graft rerupture.[20] Preliminary short-term studies have shown that the internal brace technique can significantly improve functional recovery after ACLR, thereby enhancing the patient's quality of life. However, only a few medical institutions use ACLR combined with internal brace technique, and more relevant in vivo clinical evidence is required.

This study was undertaken with an aim to fill this gap by exploring whether internal brace technology can improve the outcomes of patients with ligament injuries and provide a new option for patients with ACL injuries.

Methods and analysis

Study setting

This randomized parallel-controlled trial will be conducted in accordance with the CONSORT statement.[22] Patients with ACL rupture who were hospitalized in the Department of Orthopedics at Xiangya Hospital of Central South University between March 1, 2022 and February 28, 2023 formed our study population. The Medical Ethics Committee of Xiangya Hospital of Central South University approved the ethical application related to this study and filed it (ethical approval number: 202110478). All patients signed an informed consent form prior to the surgery.

Eligibility criteria

The inclusion criteria were: (1) age: 16-45 years; (2) unilateral knee magnetic resonance imaging (MRI) showing unilateral knee ACL fracture; (3) combined meniscal injury that does not interfere with the standard postoperative rehabilitation program after intraoperative management; (4) combined grade III or lower cartilage injury that does not interfere with the standard postoperative rehabilitation program; (5) a minimum of 24 months of follow-up; (6) no previous injury to the healthy knee; (7) informed consent provided by the participant and signed relevant documents.

The exclusion criteria were: (1) age of <16 years or >45 years; (2) previous ACLR or bilateral ACL injury; (3) MRI revealing posterior cruciate ligament (PCL), medial collateral ligament (MCL), or lateral collateral ligament (LCL) injury; (4) grade IV cartilage injury or unstable longitudinal meniscus tear requiring repair that interferes with standard rehabilitation protocols after surgical management; (5) not meeting the requirement of 24 follow-up visits; (6) patients with severe underlying medical conditions that make surgery inadvisable, or patients with mental illness, pregnancy during planned trials, or other conditions that are not conducive for long-term follow-up.

Participant selection:

Patients diagnosed with ACL rupture by clinicians through physical examination and MRI were randomly allocated to the trial and control groups after final confirmation of ACL rupture under arthroscopy and agreeing to participate in this study. The trial group underwent ACLR with the internal brace technique, while the control group underwent ACLR without the internal brace technique. Preoperative assessment of the patients was performed before surgery, and a uniform rehabilitation program was performed after surgery. The inclusion start date of the protocol (version 1.0, March 2022) was March 2022, with an expected cutoff date of March 2023. The follow-up period is 2 years, with the last follow-up expected in March 2025 (the exact end date will be based on the inclusion of the last participant). The specific technical route is shown in **Fig. 1.**

Study sample

International Knee Documentation Committee (IKDC) score consists of three aspects: 1) symptoms, including pain, stiffness, swelling, interlocking/jamming, and softening of the legs; 2) motion and daily activities; and 3) current knee function. However, knee function prior to knee injury does not count towards the total score, which is the main outcome indicator of this study, based on which the sample size required for this trial was estimated. IKDC scores are continuous measurement data, and this study compares

the statistical differences between the means ± standard deviations of the two groups. The minimum clinically important difference (MCID) of the IKDC scale was reported to range between 8.8-15.6.[23-25] We set δ to 10, and the overall sample standard deviation was set to 13 based on the relevant literature.[23-25] To satisfy the power of a test (1-β, β means type II error) of 0.8 and the test level α (type I error) of 0.05, the sample size calculated for each group was 27 according to the following formula. Considering a 20% lost visit rate, 33 patients were included in each group with a total of 66 patients included in the study.

Randomization and Concealed Grouping

Using a computer-generated random number list, all eligible participants were randomly assigned in a 1:1 ratio to the ACLR endoprosthesis technique group (combined group, n=33) and the standard ACLR group (simple group, n=33), with no restrictions on either group. Randomization was performed by an investigator who was not involved in the study. Allocation results were sealed in opaque envelopes and maintained by the study coordinator. On the day of surgery, one envelope per patient was given to the surgeon by the study coordinator. The participants and physicians included in the study were informed of the grouping, but neither the rehabilitators who instructed the patients on rehabilitation nor the data collectors who conducted the follow-up visits were aware of the grouping.

Interventions and surgical techniques

In all patients, all-inside ACLR was performed using autologous semitendinosus tendons with arthroscopy. Semitendinosus tendons were braided with sutures (0 FiberWire Suture, Arthrex) to form four strands of ACL grafts (all between 7.5-10 mm in diameter, supplemented with semimembranous tendons less than 7.5 mm in diameter). In the ACLR group, the braided graft femoral end and tibial segment were suspended and fixed with a TightRope (ACL TightRope RT Implant, Arthrex). On the other hand, in the ACLR with internal brace group, a separate wire tape (2 mm FiberTape, Arthrex) was added in addition to the components and technique used in the ACLR group. The suture was fixed with a knotless bone anchor (4.75-mm PEEK SwiveLock, Arthrex) distally and a TightRope suspension proximally as in the graft **(Fig. 2)**.

The procedure was as follows: the patient was anesthetized, a tourniquet was applied to the affected limb, routine surgical disinfection of the knee was performed, a sterile surgical sheet was placed, the semitendinosus tendon was palpated, a straight incision was made medial to the tibial tuberosity, the semitendinosus tendon was removed with a tendon extractor, 10 ml of ropivacaine was injected at the tendon extraction site, and the removed semitendinosus tendon was braided into four strands using the GraftLink (Arthrex) technique.[26] A conventional knee arthroscopic approach was used on the anteromedial and anterolateral sides of the affected knee to explore the injured structures and remove the remaining portion of the ACL. The knee was flexed to the extreme, and the femoral tract was created at the footprint of the ACL stop at the lateral femoral condyle and the tibial tract at the footprint of the ACL start. The graft and two TightRope titanium plates were pulled into the knee cavity and removed through the femoral and tibial tracts, respectively. The tabs were flipped, the tab rings were tightened, and the titanium plates were fixed. In the ACLR with an internal brace group, the femoral end of the FiberTape wire band was fixed with a TightRope ring, the wire band was tensioned in the extended position, and the tibial end was fixed independently

with a knotless bone anchor (4.75-mm PEEK SwiveLock, Arthrex).

All patients underwent uniform training and rehabilitation program after surgery. The entire rehabilitation process was divided into seven phases. The first three phases focused on controlling swelling and restoring the range of motion, which usually required four weeks. The detailed rehabilitation plan is presented in **Table 1**. Phases 4-5 focused on restoring quadriceps muscle strength control and balance along with core strength restoration training. Phases 6-7 included gradual resumption of various sports activities, from daily activities to professional activities or contact sports. A detailed rehabilitation plan has been presented in **Tables 2** and **3.**

Table 1. Phases 1-3 of the post-ACLR rehabilitation program

Phase	Movement Exercises	Gait Exercises	Manipulative Massage	Rehabilitation Goals	Precautions
Phase 1 (within 1 week)	(1) Placing the heel against the bed for flexion and extension sliding; supine position, the affected leg bends the hip, flexes the knee and places the heel on the wall for flexion and extension sliding; sitting position, legs on the floor; the healthy leg is placed in front of the affected leg and assists the affected leg in flexing the knee. (2) Ankle pump exercises (the affected leg is elevated, and the foot performs upward hooking and downward stepping movements, along with rotational movements). (3) Anterior thigh muscle tensing exercises with the knee in straight position (can be combined with neuromuscular electrical stimulation or biofeedback exercises). (4) Hip muscle group training. (5) Pillow clamping of the legs for medial thigh muscle group strength training. (6) The brace is locked in 0° position, and the affected leg is lifted in the supine and prone positions for muscle strength training. (7) Passive knee extension exercises: prone position with the affected knee extended out of bed for suspension or supine position with the affected leg in a slightly elevated heel position and the knee joint suspended. (8) Weight transfer training (front-to-back and left-to-right) can be performed in the above mentioned weight-bearing exercise position. (9) Continuous passive movement apparatus training with increased knee flexion by 5°to 10°/day.	(1) Flat and step gait training with the support of a knee protection brace and double crutches. (2) Cold compresses after training to reduce edema.	(1) Pushing the patella in all directions. (2) Manipulation of the posterior thigh muscles of the affected limb or sitting and standing to pull the muscles to relieve their spasm.	Active mobility of the knee joint reaches 0°- 90°. (1) The anterolateral thigh muscles can be tightened better. (2) The affected limb can be fully weight-bearing with the help of braces and crutches. (3) Edema control is good. (4) Good wound healing.	(1) Brace locked in 0° position, crutches, and weight-bearing exercises within a tolerable range. (2) Wearing the brace at night and locking it in 0° position while sleeping with the affected leg elevated.
Phase 2 (1-2 weeks)	(1) Fixed cycling exercises (from small to a full range of pedal rotation). (2) Tightening and 90° muscle strength exercises for anterior thigh muscles in straight position. (3) Standing balance training on the affected leg with a single leg wearing support. (4) Balance training on a balance board with forward and backward weight transfer. (5) Continuous passive activity equipment training. (6) Starting small partial weight-bearing squat exercises (within 30° of knee flexion). (7) Passive straightening exercises with the heel slightly elevated and the knee hanging in air. (8) Straight leg raises training (all directions). (9) Terminal angle knee extension training in the standing position using an elastic band.	(1) The healthy leg stands outside the treadmill with weight, and the affected leg simulates walking on the treadmill. (2) The affected leg crosses the	(1) Manipulation to push the patella treatment. (2) Manipulate of the posterior thigh muscle group for relaxation and stretching exercises.	Active mobility of the knee joint reaches 0°-120°. (1) Straight leg elevation; anterior thigh muscles can be tightened with force. (2) The patient can walk normally using crutches with a nonlocking brace.	(1) Weight-bearing exercises within tolerable limits. (2) Transition from double to single crutch. (3) When the strength of the anterior thigh muscle group is well exercised, the locking brace can be gradually dispensed (the anterior thigh muscle group can be unlocked to more than 30° only when it can

		obstacle training and simulates walking.			contract forcefully to keep the straight leg elevated).
Phase 3 (2-4 weeks)	(1) Fixed bicycle training gradually increases the resistance to improve exercise endurance. (2) Tightening exercises for the anterior thigh muscle group in straight position and muscle strength exercises in the range of 60°-90° until the muscle strength of both legs is equal. (3) 0°-60° squat training, gradually increasing the resistance strength (for patients with meniscal repair, squat to the target angle on the healthy leg before shifting the weight to the middle of the two legs). (4) Stand with both legs on a balance board for balance training in multiple directions. (5) Single-leg standing balance training on the affected leg (with eyes closed and open and on a support surface with different degrees of softness). (6) Straight leg raise training in the standing position can increase resistance appropriately.	Exercise with a rope tied around the waist or on a treadmill for forward and backward gait training.	(1) Manipulation to push the patella treatment. (2) Manipulation of the surgical scar. (3) Manipulative passive knee flexion or extension angle exercises.	The knee joint moves to an active full angle, aligning with the healthy side leg. (1) Normal gait can be achieved without any walking aid. (2) Self-care in daily life (may have difficulty walking up and down steps).	Fully weight bearing; normal gait can be achieved without a brace or walker at three weeks postoperatively.

201

202

203 **Table 2: Phases 4-5 of the post-ACLR rehabilitation program**

Phase	Movement Exercises	Gait Exercises	Manipulative Massage	Rehabilitation Goals	Precautions
Phase 4 (4-8 weeks)	(1) Fixed cycling training: gradually increasing the resistance. (2) Squat training: Transition from double leg to single leg (0°-60°), gradually increasing resistance. (3) Lunge training (0°-60°). (4) Step training: centripetal and centrifugal contraction of the anterior thigh muscles (knee does not exceed 60°). (5) Tiptoe training: Transition from double leg to single leg. (6) Swing exercise: Standing using the affected leg, and the healthy leg is strapped with an elastic band and swings, transitioning from front-to-back swing to lateral swing and then to rotation or random direction movement. (7) Rotational stability training: static lunge stance, lateral pull pulley exercise. (8) Exercise with a rope tied around the waist to provide resistance; walking exercises in forward and backward, left and right directions. (9) Walking exercises on the treadmill in four directions. (10) Balance board training: various support surfaces, double-legged standing. (11) Single-leg stand for ball tossing exercises. (12) Core training: supine or prone position for bridge exercise, standing to pull the pulley.	Go around the obstacles at normal walking speed on different surfaces.	Manual method to loosen surgical scars.	(1) Center of gravity in the middle, squatting bilaterally to 60° (no more than 60°). (2) Knee in good condition (slight pain and effusion, no instability). (3) The circumference at the upper edge of the patella is 10 cm , with a 1-2 cm difference between the legs. (4) The affected limb can maintain balance for > 30 s while standing on one leg with little body sway.	(1) No participation in sports which have a high impact on the joints, such as running or jumping. (2) No participation in sports with high lateral stress on the joints. (3) Avoid squatting deeply (limited to 0°-60°).
Phase 5 (8-12 weeks)	(1) Squat training: transition from double to single leg (0°-60°), gradually increasing resistance. (2) Lunge training (0°-60°). (3) Tiptoe training: Transition from double-leg to single-leg. (4) Increasing the strength of the posterior lateral muscle group with plyometric training. Core muscle strength training. ① Combined strength and balance training (throwing and catching balls on the balance board, and small squats on the balance board) ② Advanced balance function training (affected leg standing on one leg, hand or opposite foot to touch objects on the ground or lateral pulling elastic band) ③ Swimming training, in addition to breaststroke. Additionally, care should be taken not to stir the leg at	——	——	(1) The thigh circumference of both legs is approximately the same (within 1 cm of each other). (2) The affected limb squats to 60° on one leg. (3) The affected limb can stand on one leg to maintain balance for 60 s. (4) Little, if any, edema with activity.	Patellar tendonitis may occur.

	a deep squatting angle or to use a splint when swimming. ④ Cycling training every other day.				

Table 3: Phases 6-7 of the post-ACLR rehabilitation program

Phase	Movement Exercises	Gait Exercises	Manipulative Massage	Rehabilitation Goals	Precautions
Phase 6 (12-16 weeks)	(1) Jogging movement: multiple directions for running. (2) Increasing the speed of all sports. (3) Skateboard training, slow walking in water and other forms of exercise can be carried out.	——	——	(1) Squat down to 60° on one leg with the affected limb and repeat 20 times. (2) The affected leg can stand on one leg to maintain balance for at least 60 s. (3) Vertical or horizontal jump using both legs with a good landing position. (4) Single-leg jump: 80% of the ability of the healthy leg is achieved.	Avoid wrong movements or posture. (1) Landing with the knee joint too straight. (2) The knee joint is turned outward or inward when landing. (3) When landing or bouncing, the healthy leg always takes the lead, not the affected leg.
Phase 6 (12-16 weeks)	(1) Progressive running program. (2) Testing and training of single-leg jumping. (3) Vertical or horizontal jumps, transitioning from double to single leg. (4) Progressive enhancement type training (box jumps, side jumps, standing jumps, deep squat jumps, etc.). (5) Speed and agility training (join professional sports training).	——	——	After 20 weeks, they participate in a professional sports program.	——

Baseline indicators and observations

Baseline and preoperative patient characteristics included sex, age, affected limb (left or right), cause of injury (playing basketball or other sports such as soccer), smoking status (yes or no), time from injury to surgery (fresh injury or old rupture), whether the injury was accompanied by cartilage and meniscal damage, time of surgery, and degree of ACL fracture (partial or total).

Study endpoints

Primary outcome/endpoint: IKDC score changes in knee function from preoperative period to 6 months postoperatively was the primary outcome. The IKDC is a commonly used tool to evaluate outcomes after knee surgery, including ACLR. [27] The IKDC knee score consists of knee assessment (10 entries) and knee ligament checklist (eight entries), covering joint pain, motor level, and daily activity ability, with total score ranging between 0-100. The IKDC can be used to assess knee symptoms, function, and physical activity. The IKDC assesses symptoms, function, and physical activity of the knee. Patients were evaluated using a questionnaire preoperatively and at follow-up visits at 1, 3, 6, 12, and 24 months postoperatively.

Secondary outcomes/endpoints: Lysholm knee score (LKS), Knee Injury and Osteoarthritis Outcome Score (KOOS, including knee symptoms, pain, activities of daily living, sports and recreational activities, and quality of life), Visual Analog Scale (VAS, for pain assessment), Lachman test, MRI data, and assessment of knee stability using the Kneelax3 knee stability meter.

(1) *Kneelax3 (MONITORED REHAB SYSTEMS B.V. Model: KNEELAX3, The Netherlands):* The Kneelax3 arthrometer was used for assessment of knee stability preoperatively and 1, 3, 6, 12, and 24 months postoperatively.

(2) *LKS:* This scoring system consists of eight questions scored on a scale of 0-100, with higher scores representing better functional status of the patient. The main tendency is toward activities of daily living, and patients were assessed using questionnaires before surgery and at 1, 3, 6, 12, and 24 months of postoperative follow-up visits.[28]

(3) *KOOS score:* The KOOS consists of five subscales: pain, other knee symptoms, activities of daily living, function in sports and recreation (Sport/Rec), and knee-related quality of life.[29] Patients were given one week for consideration before answering the questions, and each question had five alternative boxes with scores ranging between 0-4. Standard scores were calculated for each subscale (100 for no symptoms and 0 for extreme symptoms), and patients were assessed using questionnaires before surgery and at follow-up visits at 1, 3, 6, 12, and 24 months after surgery.

(4) *VAS score:* The visual analogue pain scoring method is more sensitive and comparable. In this trial, a 100-mm VAS pain score (including resting-state score, 30-min post-walk score, and overall pain level in the past month) was used.[30] This protocol only assessed pain at rest, with 0 representing no pain and 100 representing the most severe pain. Patients were evaluated using questionnaires before surgery and at 1, 3, 6, 12, and 24 months of postoperative follow-up.

(5) *Lachman test:* This assesses ACL function with the patient in supine or prone position and knee flexed at an angle of approximately 30°.[31] The examiner uses one hand to immobilize the thigh while the other hand attempts to move the tibia forward. Positive results suggest that patients with ACL injuries be tested preoperatively and at follow-up visits at 1, 3, 6, 12, and 24 months postoperatively.

(6) MRI assessment: MRI was performed at 12 and 24 months postoperatively to assess the patient's reconstructed ACL.

Patient termination and withdrawal criteria

Patients could withdraw from the trial at any time due to the following reasons:

(1) Surgical failure: 1) occurrence of infection; 2) no secondary rupture of the reconstructed ligament (rupture of the ligament or the internal brace augmentation line or both in the trial group, rupture of the reconstructed ligament in the control group); and 3) knee instability: self-reported knee instability, or Lachman test (+) or Kneelax3 knee arthrometer test revealing a 3-mm difference in comparison with the healthy side.

(2) Patient withdrawal from the trial: All participants had the right to withdraw at any time during the study period. A participant was withdrawn from the trial if any of the

following occurred during the trial: 1) withdrawal of informed consent by the participant; 2) a person who, in the opinion of the investigator, was no longer suitable for continuation of the clinical trial; 3) a woman who became pregnant during the clinical trial; 4) death of the participant; or 5) the participant was lost to follow-up.

(3) Trial termination:

1) The clinical trial institution and investigator found that the risks to patients by continuing the clinical trial exceeded the possible benefits; 2) the ethics committee found that the rights of the participants could not be protected; 3) the sponsor requested termination of the trial for various reasons; and 4) the national administrative authority requested termination.

The timing and reasons for withdrawal from the trial were recorded in detail in the case report form. Follow-up care was no longer provided for participants who voluntarily withdrew from the treatment, as well as for those for whom follow-up data were not being collected. However, participants who withdrew from the trial due to adverse events or because of surgical failure were to be followed up until the adverse events stabilized or resolved or until the investigator deemed that further follow-up was no longer necessary.

Data management

The trial used an electronic data collection (EDC) system for data management. The investigator or investigator-authorized research staff completed the electronic Case Report Form (eCRF) through the EDC system in an accurate, timely, complete, and standardized manner, based on the original information from the participants. Questionnaire checking, data cleaning, and summarization were performed promptly after each follow-up visit. A follow-up survey is proposed to adopt the electronic questionnaire system and on-site questionnaire survey. The on-site survey results will be saved in time and organized in the database later. The investigator or investigator's authorized researcher will enter the data into the EDC according to their respective accounts. The data administrator verifies the reliability, completeness, and accuracy of the data in the EDC. If any questionable data are found, a challenge can be issued in the system, and the investigator or the investigator's delegated researcher will verify, correct, or answer the query. When all the data have been entered into the database and all queries have been resolved, the database will be locked by the data administrator. If a problem is found after the database is locked and there is a need to correct it, the process of unlocking and relocking the data will be followed. After the database is locked, the data manager will submit the data to the analyst for statistical analysis as scheduled.

Statistical analysis

(1) Statistical design: This was a randomized controlled clinical trial.

(2) Principles of Statistical Analysis: All statistical analyses were performed using SAS version 9.4 or later, R version 3.3.2 or later, or SPSS24(IBM Corporate Headquarters, Armonk, New York, USA). All statistical tests were two-sided tests, and P values ≤ 0.05 were considered statistically significant for the differences tested

(unless otherwise specified).

i) Summary statistics for continuous variables: including the mean, standard deviation, median, minimum, maximum, lower quartile (Q1), and upper quartile (Q3); summary statistics for categorical variables, including the number of cases and percentages of each category.

ii) Between-group comparisons of demographic baseline characteristics: Group comparisons for continuous variables will be made using independent samples t-test (chi-square, normal distribution) or Wilcoxon rank-sum test depending on data distribution, and chi-square test or exact probability method for categorical variables (if chi-square test is not applicable).

(3) Completion and demographic analyses: Baseline analyses were based on full analysis set (FAS). The enrollment and completion status of the trials were summarized and the reasons for non-completion are described in a detailed table. The participants' demographic characteristics were described and compared to measure comparability between the two groups. Validity reporting data were accepted only if the baseline was balanced between the groups; otherwise, the validity data were corrected before reporting.

(4) Patient-reported outcome validity evaluation indices: Outcome validity evaluation will be based on the FAS and the per-protocol set (PPS). The statistical description and inference of the data will be based on the characteristics of the data, the selection of applicable descriptive indicators, and hypothesis testing methods.

Primary patient-reported outcome: Comparison of IKDC knee scores at six-months (±2 weeks) postoperatively in the trial and control groups. We will use a linear regression model for analysis to correct for possible confounding factors such as age, sex, and cause of injury. Preoperative baseline IKDC scores will be used as predictors when conducting the analysis, and IKDC scores at 6 months (±2 weeks) will be used as indicators of post-treatment outcomes.

Secondary patient-reported outcomes

i) Since IKDC scores were measured multiple times during the follow-up period, we will use a linear mixed model to compare the changes over time between the trial and control groups.

ii) The anterior tibial translation distance is measured using the Kneelax3 knee stability meter, and comparisons of the anterior tibial translation distance between the test and control groups at the same postoperative time points with the same force will be performed using either an independent samples t-test (chi-square, normally distributed) or a Wilcoxon rank sum test. A linear mixed model will also be used to compare and analyze the evolution of these consecutive results over time in both groups.

iii) A comparative analysis of failure and infection rates in the control group versus the test group during the main six months will be performed using the chi-square test or t-test.

iv) Linear regression of continuous outcomes from baseline to 24 months, such as LKS, KOOS score (including knee symptoms, pain, activities of daily living, sports and recreational activities, quality of life), Lachman test, and pain VAS protocols, will be used to compare and analyze the evolution of these continuous outcomes over time in

the two groups using linear mixed models.

v) The morphology and signal intensity of the postoperative ACL will be assessed using MRI, and different treatments will be compared at different time points using chi-square test.

Analysis of safety indicators

Safety evaluation will be based on a safety-set (SS) analysis dataset. The internationally accepted Medical Dictionary for Regulatory Activities (MedDRA) term set classification was used for adverse event coding. The types of adverse events, frequency, severity, and relationship with internal brace enhancement line generation and surgery were summarized by group. A detailed list of the various adverse events is provided, with special notations for participants who discontinued the trial because of adverse events and for those who experienced serious adverse events. The proportions of patients who developed complications between treatments were compared using the chi-square test.

Patient and public involvement

Patients and/or the public were not involved in the study design, conduct, reporting, or dissemination plans.

Discussion

This prospective, randomized controlled trial aimed to investigate the clinical efficacy of ACLR with and without the internal brace technique. In this 2-year follow-up study, the subjective, objective, and functional outcomes of patients who underwent ACLR with the internal brace technique or ACLR alone were compared. This study hypothesized that ACLR with internal brace technique would be more stable than ACLR alone in the early postoperative period, with a lower incidence of secondary injury, reduced duration and extent of pain, and earlier return to preinjury activity levels. However, there may be no significant difference between the two groups in terms of patient-reported outcome indicators with increase in recovery time.

ACL rupture is a common knee injury among athletes and has been extensively studied. Studies from as early as the late 20th century have shown that ACLR is superior to ACL repair.[32, 33] The ACL is an important structure for maintaining knee stability, preventing anterior tibial displacement, and limiting intratibial rotation,[34] making ACLR the gold standard treatment for patients recovering motion or performing rotational activities after ACL rupture in the knee.[35] The recovery of knee function after surgery depends on the ability of the ACL graft to withstand appropriate loads during rehabilitation and after returning to sports. Tendon grafts implanted in the human knee joint survive in the intra-articular environment and gradually in the ligaments. The graft is fragile and vulnerable to reinjury during the pre-remodeling phase before ligamentization,[36] so a carefully designed rehabilitation program should be developed to prevent reinjury during the rehabilitation period. Several studies have found a higher probability of re-rupture or secondary revision in athletes and

adolescents or for ACLR using either autologous or allogeneic tendons.[10, 37] Therefore, a surgical approach that increases the structural strength of the graft and protects it during the early stages of graft ligamentization is important.

The biomechanical properties of the intraarticular reconstructed ligaments reportedly improved 8 weeks postoperatively when the FiberTape suture was applied in a rabbit model. Additionally, during this period, FiberTape did not adversely affect bone tunnel healing or cause a long-term increase in indicators of inflammation.[12] In a dog model, no severe inflammation, immune response, bone erosion, or premature osteoarthritis development was observed 6 months postoperatively.[38] The results of these studies support the biocompatibility and safety of intraarticular suture tape for ACLR enhancement.

A study on load sharing after ACL graft enhancement using suture tape reported that load sharing began at 200 N and 300 N for 7-mm and 9-mm grafts, respectively. The final peak load (400 N) was shared by 31% (7-mm graft) and 20% (9-mm graft) when using suture tape.[39] Suture tape ligament augmentation may protect biological grafts from excessive peak loading and elongation. After ACLR in the early recovery phase, suture band augmentation reportedly increases ACL graft stiffness by 104% and the ultimate breaking load by 57%, reducing the graft failure rate in clinical situations.

A recent systematic review by Christopher et al. concluded from biomechanical, animal, and clinical studies that suture tape augmentation in ACLR increased biomechanical stability.[40] Therefore, in this randomized controlled trial, we will conduct a prospective observational comparison and long-term follow-up to elucidate the clinical efficacy of internal bracing in ACLR.

Ethics and dissemination

The trial was approved by the Medical Ethics Committee of Xiangya Hospital of Central South University on October 26, 2021 (ethics number "202110478") and prospectively registered in the China Clinical Trials Registry on March 14, 2022 (registration number: ChiCTR2200057526). All participants signed an informed consent form before participating in this trial, and we will protect the patients from any invasion of their privacy. All investigators will keep the study results confidential until after the data are made public and will release no data related to the database without approval from the principal investigator. We will publish our findings and data in peer-reviewed journals and present them at national and international conferences.

Abbreviations

Anterior cruciate ligament (ACL)

Anterior cruciate ligament reconstruction (ACLR)

International Knee Documentation Committee (IKDC)

the Knee Injury and Osteoarthritis Outcome Score (KOOS)

Lysholm knee score (LKS)

Visual Analog Scale (VAS)

ultrahigh molecular weight polyethene (UHMWPE)

Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT)

activities of daily living (ADL)

sport and recreation (Sport/Rec)

quality of life (QOL)

medial collateral ligament (MCL)

minimum clinically important difference (MCID)

electronic Case Report Form (eCRF)

safety set (SS)

Medical Dictionary for Regulatory Activities (MedDRA)

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Author contributions

WF-X and YS-L established the study design; WH-L conceived the design and wrote the draft manuscript; D-L, ZJ-C, and LY-P were involved in data acquisition, analysis,

and interpretation; and WQ-X, HF-J, and X-L designed the rehabilitation protocol. All the authors have read and approved the final version of the manuscript.

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Competing interests

The authors declare that they have no competing interests.

References

1. Robson AW. VI. Ruptured Crucial Ligaments and their Repair by Operation Ann Surg. 1903;37(5):716-718.
2. Patterson BE, Culvenor AG, Barton CJ, et al. Worsening Knee Osteoarthritis Features on Magnetic Resonance Imaging 1 to 5 Years After Anterior Cruciate Ligament Reconstruction. Am J Sports Med. 2018;46(12):2873-2883.
3. Suter LG, Smith SR, Katz JN, et al. Projecting Lifetime Risk of Symptomatic Knee Osteoarthritis and Total Knee Replacement in Individuals Sustaining a Complete Anterior Cruciate Ligament Tear in Early Adulthood. Arthritis Care Res (Hoboken). 2017;69(2):201-208.
4. Filbay SR, Culvenor AG, Ackerman IN, Russell TG, Crossley KM. Quality of life in anterior cruciate ligament-deficient individuals: a systematic review and meta-analysis. Br J Sports Med. 2015;49(16):1033-1041.
5. Moses B, Orchard J, Orchard J. Systematic review: Annual incidence of ACL injury and surgery in various populations. Res Sports Med. 2012;20(3-4):157-179.
6. Griffin LY, Albohm MJ, Arendt EA, et al. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. Am J Sports Med. 2006;34(9):1512-1532.
7. de Sa D, Shanmugaraj A, Weidman M, et al. All-Inside Anterior Cruciate Ligament Reconstruction-A Systematic Review of Techniques, Outcomes, and Complications. The journal of knee surgery. 2018;31(9):895-904.
8. Di Benedetto P, Di Benedetto E, Fiocchi A, Beltrame A, Causero A. Causes of Failure of Anterior Cruciate Ligament Reconstruction and Revision Surgical Strategies. Knee Surg Relat Res. 2016;28(4):319-324.
9. Vaishya R, Agarwal AK, Ingole S, Vijay V. Current Trends in Anterior Cruciate Ligament Reconstruction: A Review. Cureus. 2015;7(11):e378.
10. Takazawa Y, Ikeda H, Saita Y, et al. Return to Play of Rugby Players After Anterior Cruciate Ligament Reconstruction Using Hamstring Autograft: Return to Sports and Graft Failure According to Age. Arthroscopy. 2017;33(1):181-189.
11. Ellis HB, Matheny LM, Briggs KK, Pennock AT, Steadman JR. Outcomes and revision rate after bone-patellar tendon-bone allograft versus autograft anterior cruciate

ligament reconstruction in patients aged 18 years or younger with closed physes. Arthroscopy. 2012;28(12):1819-1825.
12. Soreide E, Denbeigh JM, Lewallen EA, et al. In vivo assessment of high-molecular-weight polyethylene core suture tape for intra-articular ligament reconstruction: an animal study. Bone Joint J. 2019;101-b(10):1238-1247.
13. Lubowitz JH, MacKay G, Gilmer B. Knee medial collateral ligament and posteromedial corner anatomic repair with internal bracing. Arthrosc Tech. 2014;3(4):e505-508.
14. Gilmer BB, Crall T, DeLong J, et al. Biomechanical Analysis of Internal Bracing for Treatment of Medial Knee Injuries. Orthopedics. 2016;39(3):e532-537.
15. Heusdens CHW, Hopper GP, Dossche L, Roelant E, Mackay GM. Anterior cruciate ligament repair with Independent Suture Tape Reinforcement: a case series with 2-year follow-up. Knee Surg Sports Traumatol Arthrosc. 2019;27(1):60-67.
16. Nishimura A, Nakazora S, Senga Y, et al. Arthroscopic Internal Brace Augmentation With Arthroscopic Modified Broström Operation for Chronic Ankle Instability. Arthrosc Tech. 2021;10(4):e995-e1000.
17. Wilk KE, Arrigo CA, Bagwell MS, Rothermich MA, Dugas JR. Repair of the Ulnar Collateral Ligament of the Elbow: Rehabilitation Following Internal Brace Surgery. J Orthop Sports Phys Ther. 2019;49(4):253-261.
18. van Eck CF, Limpisvasti O, ElAttrache NS. Is There a Role for Internal Bracing and Repair of the Anterior Cruciate Ligament? A Systematic Literature Review. Am J Sports Med. 2018;46(9):2291-2298.
19. Cook JL, Smith P, Stannard JP, et al. A Canine Arthroscopic Anterior Cruciate Ligament Reconstruction Model for Study of Synthetic Augmentation of Tendon Allografts. J Knee Surg. 2017;30(7):704-711.
20. Bachmaier S, Smith PA, Bley J, Wijdicks CA. Independent Suture Tape Reinforcement of Small and Standard Diameter Grafts for Anterior Cruciate Ligament Reconstruction: A Biomechanical Full Construct Model. Arthroscopy. 2018;34(2):490-499.
21. Bedi A. Editorial Commentary: Buckle Up Surgeons: "Safety Belt" Reinforcement of Knee Anterior Cruciate Ligament Reconstruction Grafts. Arthroscopy. 2018;34(2):500-501.
22. Moher D, Hopewell S, Schulz KF, et al. CONSORT 2010 explanation and elaboration: updated guidelines for reporting parallel group randomised trials. International journal of surgery (London, England). 2012;10(1):28-55.
23. Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). Arthritis Care Res (Hoboken). 2011;63 Suppl 11(0 11):S208-228.
24. Irrgang JJ, Anderson AF, Boland AL, et al. Responsiveness of the International

Knee Documentation Committee Subjective Knee Form. Am J Sports Med. 2006;34(10):1567-1573.
25. Li YL, Ning GZ, Wu Q, et al. Single-bundle or double-bundle for anterior cruciate ligament reconstruction: a meta-analysis. Knee. 2014;21(1):28-37.
26. Lubowitz JH. All-inside anterior cruciate ligament graft link: graft preparation technique. Arthrosc Tech. 2012;1(2):e165-168.
27. Greco NJ, Anderson AF, Mann BJ, et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form in comparison to the Western Ontario and McMaster Universities Osteoarthritis Index, modified Cincinnati Knee Rating System, and Short Form 36 in patients with focal articular cartilage defects. Am J Sports Med. 2010;38(5):891-902.
28. Briggs KK, Lysholm J, Tegner Y, et al. The reliability, validity, and responsiveness of the Lysholm score and Tegner activity scale for anterior cruciate ligament injuries of the knee: 25 years later. Am J Sports Med. 2009;37(5):890-897.
29. Collins NJ, Prinsen CA, Christensen R, et al. Knee Injury and Osteoarthritis Outcome Score (KOOS): systematic review and meta-analysis of measurement properties. Osteoarthritis Cartilage. 2016;24(8):1317-1329.
30. Wewers ME, Lowe NK. A critical review of visual analogue scales in the measurement of clinical phenomena. Res Nurs Health. 1990;13(4):227-236.
31. Coffey R, Bordoni B. Lachman Test. StatPearls. Treasure Island (FL): StatPearls Publishing
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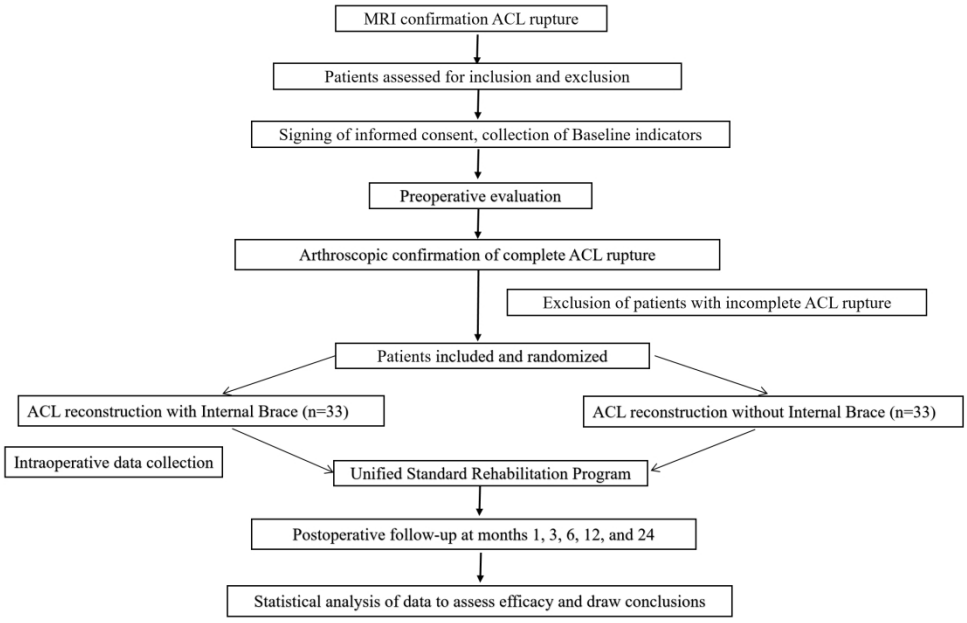
32. Engebretsen L, Benum P, Fasting O, Mølster A, Strand T. A prospective, randomized study of three surgical techniques for treatment of acute ruptures of the anterior cruciate ligament. Am J Sports Med. 1990;18(6):585-590.
33. Grøntvedt T, Engebretsen L, Benum P, et al. A prospective, randomized study of three operations for acute rupture of the anterior cruciate ligament. Five-year follow-up of one hundred and thirty-one patients. J Bone Joint Surg Am. 1996;78(2):159-168.
34. Noyes FR. The function of the human anterior cruciate ligament and analysis of single- and double-bundle graft reconstructions. Sports Health. 2009;1(1):66-75.
35. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. Br J Sports Med. 2011;45(7):596-606.
36. Claes S, Verdonk P, Forsyth R, Bellemans J. The "ligamentization" process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. Am J Sports Med. 2011;39(11):2476-2483.
37. Wright RW, Gill CS, Chen L, et al. Outcome of revision anterior cruciate ligament reconstruction: a systematic review. J Bone Joint Surg Am. 2012;94(6):531-536.
38. Smith PA, Bozynski CC, Kuroki K, et al. Intra-Articular Biocompatibility of Multistranded, Long-Chain Polyethylene Suture Tape in a Canine ACL Model. J Knee Surg. 2019;32(6):525-531.
39. Bachmaier S, Smith PA, Argintar EH, et al. Independent Suture Augmentation With All-Inside Anterior Cruciate Ligament Reconstruction Reduces Peak Loads on Soft-Tissue Graft. A Biomechanical Full-Construct Study. Arthroscopy.

2022;38(1):88-98.
40. C EAM, Huntington LS, Tulloch S. Suture Tape Augmentation of Anterior Cruciate Ligament Reconstruction increases biomechanical stability: A Scoping Review of Biomechanical, Animal, and Clinical Studies. Arthroscopy. 2022.

Figure legends

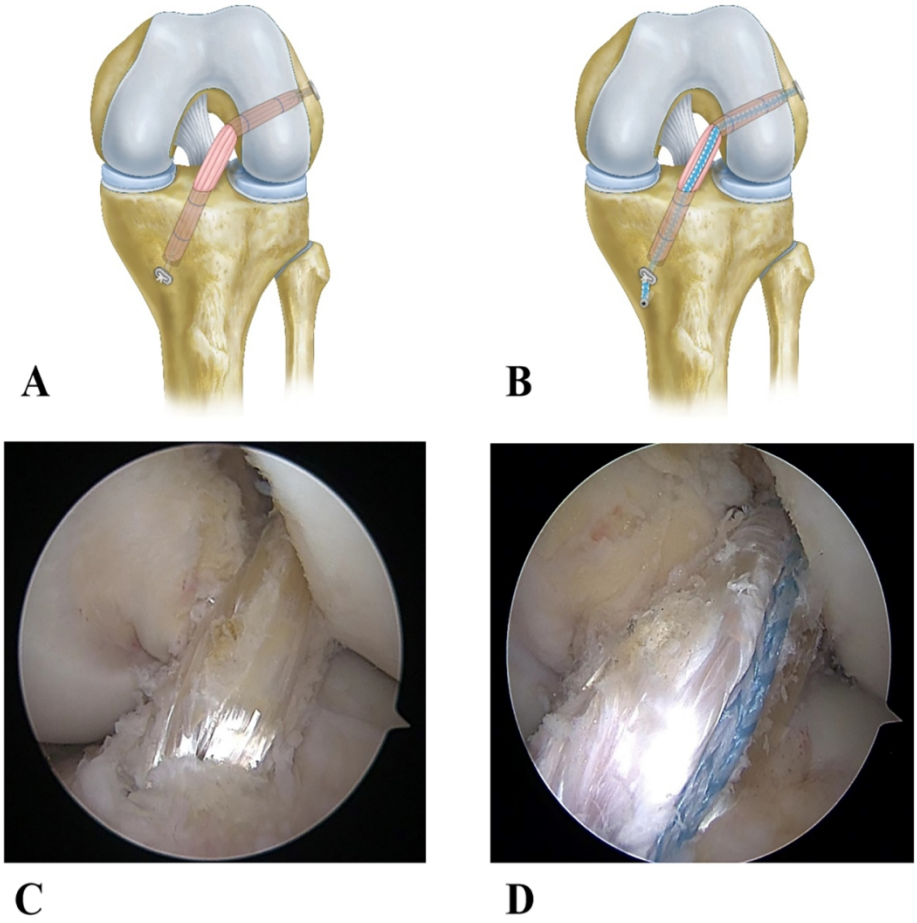
Fig.1 Study Flow Diagram.

Fig.2 A and B are the models of control and test groups, respectively. C and D are the pictures of control and test groups after intraoperative arthroscopic ACLR, respectively.



Study Flow Diagram.

731x467mm (76 x 76 DPI)



A and B are the models of control and test groups, respectively. C and D are the pictures of control and test groups after intraoperative arthroscopic ACLR, respectively.

253x253mm (138 x 138 DPI)

Reporting checklist for protocol of a clinical trial.

Based on the SPIRIT guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

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		Reporting Item	Page Number
Administrative information			
Title	#1	Descriptive title identifying the study design, population, interventions, and, if applicable, trial acronym	1
Trial registration	#2a	Trial identifier and registry name. If not yet registered,	2

		name of intended registry	
Trial registration: data set	#2b	All items from the World Health Organization Trial Registration Data Set	2
Protocol version	#3	Date and version identifier	4
Funding	#4	Sources and types of financial, material, and other support	11
Roles and responsibilities: contributorship	#5a	Names, affiliations, and roles of protocol contributors	1
Roles and responsibilities: sponsor contact information	#5b	Name and contact information for the trial sponsor	11
Roles and responsibilities: sponsor and funder	#5c	Role of study sponsor and funders, if any, in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication, including whether they will have ultimate authority over any of these activities	11
Roles and responsibilities: committees	#5d	Composition, roles, and responsibilities of the coordinating centre, steering committee, endpoint adjudication committee, data management team, and other individuals or groups overseeing the trial, if applicable (see Item 21a for data monitoring committee)	11

Introduction			
Background and rationale	#6a	Description of research question and justification for undertaking the trial, including summary of relevant studies (published and unpublished) examining benefits and harms for each intervention	3
Background and rationale: choice of comparators	#6b	Explanation for choice of comparators	3
Objectives	#7	Specific objectives or hypotheses	3
Trial design	#8	Description of trial design including type of trial (eg, parallel group, crossover, factorial, single group), allocation ratio, and framework (eg, superiority, equivalence, non-inferiority, exploratory)	2
Methods: Participants, interventions, and outcomes			
Study setting	#9	Description of study settings (eg, community clinic, academic hospital) and list of countries where data will be collected. Reference to where list of study sites can be obtained	4
Eligibility criteria	#10	Inclusion and exclusion criteria for participants. If applicable, eligibility criteria for study centres and	4

		individuals who will perform the interventions (eg, surgeons, psychotherapists)	
Interventions: description	#11a	Interventions for each group with sufficient detail to allow replication, including how and when they will be administered	5-6
Interventions: modifications	#11b	Criteria for discontinuing or modifying allocated interventions for a given trial participant (eg, drug dose change in response to harms, participant request, or improving / worsening disease)	5-6
Interventions: adherance	#11c	Strategies to improve adherence to intervention protocols, and any procedures for monitoring adherence (eg, drug tablet return; laboratory tests)	5-6
Interventions: concomitant care	#11d	Relevant concomitant care and interventions that are permitted or prohibited during the trial	5-6
Outcomes	#12	Primary, secondary, and other outcomes, including the specific measurement variable (eg, systolic blood pressure), analysis metric (eg, change from baseline, final value, time to event), method of aggregation (eg, median, proportion), and time point for each outcome. Explanation of the clinical relevance of chosen efficacy and harm outcomes is strongly recommended	6-7
Participant timeline	#13	Time schedule of enrolment, interventions (including any run-ins and washouts), assessments, and visits for participants. A schematic diagram is highly recommended	6-7

		(see Figure)	
Sample size	#14	Estimated number of participants needed to achieve study objectives and how it was determined, including clinical and statistical assumptions supporting any sample size calculations	4
Recruitment	#15	Strategies for achieving adequate participant enrolment to reach target sample size	4
Methods: Assignment of interventions (for controlled trials)			
Allocation: sequence generation	#16a	Method of generating the allocation sequence (eg, computer-generated random numbers), and list of any factors for stratification. To reduce predictability of a random sequence, details of any planned restriction (eg, blocking) should be provided in a separate document that is unavailable to those who enrol participants or assign interventions	4-5
Allocation concealment mechanism	#16b	Mechanism of implementing the allocation sequence (eg, central telephone; sequentially numbered, opaque, sealed envelopes), describing any steps to conceal the sequence until interventions are assigned	4-5
Allocation: implementation	#16c	Who will generate the allocation sequence, who will enrol participants, and who will assign participants to	4-5

		interventions	
Blinding (masking)	#17a	Who will be blinded after assignment to interventions (eg, trial participants, care providers, outcome assessors, data analysts), and how	4-5
Blinding (masking): emergency unblinding	#17b	If blinded, circumstances under which unblinding is permissible, and procedure for revealing a participant's allocated intervention during the trial	4-5
Methods: Data collection, management, and analysis			
Data collection plan	#18a	Plans for assessment and collection of outcome, baseline, and other trial data, including any related processes to promote data quality (eg, duplicate measurements, training of assessors) and a description of study instruments (eg, questionnaires, laboratory tests) along with their reliability and validity, if known. Reference to where data collection forms can be found, if not in the protocol	7
Data collection plan: retention	#18b	Plans to promote participant retention and complete follow-up, including list of any outcome data to be collected for participants who discontinue or deviate from intervention protocols	7
Data management	#19	Plans for data entry, coding, security, and storage,	7

		including any related processes to promote data quality (eg, double data entry; range checks for data values). Reference to where details of data management procedures can be found, if not in the protocol	
Statistics: outcomes	#20a	Statistical methods for analysing primary and secondary outcomes. Reference to where other details of the statistical analysis plan can be found, if not in the protocol	8-9
Statistics: additional analyses	#20b	Methods for any additional analyses (eg, subgroup and adjusted analyses)	8-9
Statistics: analysis population and missing data	#20c	Definition of analysis population relating to protocol non-adherence (eg, as randomised analysis), and any statistical methods to handle missing data (eg, multiple imputation)	8-9
Methods: Monitoring			
Data monitoring: formal committee	#21a	Composition of data monitoring committee (DMC); summary of its role and reporting structure; statement of whether it is independent from the sponsor and competing interests; and reference to where further details about its charter can be found, if not in the protocol. Alternatively, an explanation of why a DMC is not needed	7
Data monitoring: interim analysis	#21b	Description of any interim analyses and stopping guidelines, including who will have access to these interim results and make the final decision to terminate	7

		the trial	
Harms	#22	Plans for collecting, assessing, reporting, and managing solicited and spontaneously reported adverse events and other unintended effects of trial interventions or trial conduct	7
Auditing	#23	Frequency and procedures for auditing trial conduct, if any, and whether the process will be independent from investigators and the sponsor	7
Ethics and dissemination			
Research ethics approval	#24	Plans for seeking research ethics committee / institutional review board (REC / IRB) approval	10
Protocol amendments	#25	Plans for communicating important protocol modifications (eg, changes to eligibility criteria, outcomes, analyses) to relevant parties (eg, investigators, REC / IRBs, trial participants, trial registries, journals, regulators)	10
Consent or assent	#26a	Who will obtain informed consent or assent from potential trial participants or authorised surrogates, and how (see Item 32)	10
Consent or assent: ancillary studies	#26b	Additional consent provisions for collection and use of participant data and biological specimens in ancillary studies, if applicable	Not applicable
Confidentiality	#27	How personal information about potential and enrolled	7

		participants will be collected, shared, and maintained in order to protect confidentiality before, during, and after the trial	
Declaration of interests	#28	Financial and other competing interests for principal investigators for the overall trial and each study site	11
Data access	#29	Statement of who will have access to the final trial dataset, and disclosure of contractual agreements that limit such access for investigators	10
Ancillary and post trial care	#30	Provisions, if any, for ancillary and post-trial care, and for compensation to those who suffer harm from trial participation	7
Dissemination policy: trial results	#31a	Plans for investigators and sponsor to communicate trial results to participants, healthcare professionals, the public, and other relevant groups (eg, via publication, reporting in results databases, or other data sharing arrangements), including any publication restrictions	10
Dissemination policy: authorship	#31b	Authorship eligibility guidelines and any intended use of professional writers	10
Dissemination policy: reproducible research	#31c	Plans, if any, for granting public access to the full protocol, participant-level dataset, and statistical code	10
Appendices			
Informed consent	#32	Model consent form and other related documentation	10

materials		given to participants and authorised surrogates	
Biological specimens	#33	Plans for collection, laboratory evaluation, and storage of biological specimens for genetic or molecular analysis in the current trial and for future use in ancillary studies, if applicable	Not applicable