Original article
https://doi.org/10.17816/2311-2905-17725

Outcomes of Anterior Cruciate Ligament Reconstruction Using Detached and Non-Detached Autografts: Comparative Analysis

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Abstract

Background. Despite the widespread use of autograft techniques for anterior cruciate ligament (ACL) reconstruction, there remains a need to improve surgical methods aimed at enhancing graft osseointegration, reducing inflammatory responses, and preventing bone tunnel widening. Particular attention has been drawn to techniques that preserve the tibial insertion and ACL remnant. A systematic comparison of these approaches based on objective functional and morphological parameters is necessary.

The aim of the study — to conduct a comparative analysis of short-term and early outcomes of different anterior cruciate ligament reconstruction techniques.

Methods. The study included 112 patients stratified into four groups based on the type of ACL reconstruction performed: D — detached graft; N — non-detached graft; D+S — detached graft with remnant preservation; N+S — non-detached graft with remnant preservation. Clinical outcomes were evaluated at 6 and 12 months using the Lysholm score, IKDC, and KOOS, as well as MRI-based Signal-to-Noise Quotient (SNQ) and CT-based bone tunnel widening. Statistical analysis included one-way and multivariate ANOVA (MANOVA), as well as Principal Component Analysis (PCA).

Results. The comparative analysis revealed statistically significant differences between the groups across all evaluated parameters ($p < 0.05$), according to the ANOVA test. The best functional outcomes (Lysholm, KOOS, IKDC) and morphological indicators (SNQ ratio, bone tunnel widening) were observed in the N+S group. MANOVA and PCA confirmed spatial separation of groups, with a distinct cluster formed by N+S patients, indicating the superiority of this technique. All intergroup differences were statistically significant ($p < 0.05$).

Conclusion. The results suggest that the use of non-detached autografts in combination with preservation of anterior cruciate ligament remnant offers substantial potential for improving surgical outcomes in knee joint instability. However, large-scale randomized trials with long-term follow-up are needed to confirm these findings.

Keywords: anterior cruciate ligament; ACL; ACL rupture; non-detached graft; ACL remnant preservation.

Cite as: Kotelnikov G.P., Shcherbatov N.D., Kudashev D.S., Zuev-Ratnikov S.D. Outcomes of Anterior Cruciate Ligament Reconstruction Using Detached and Non-Detached Autografts: Comparative Analysis. *Traumatology and Orthopedics of Russia*. 2025;31(3):50-60. (In Russian). https://doi.org/10.17816/2311-2905-17725.

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Submitted: 30.06.2025. Accepted: 30.07.2025. Published online: 14.08.2025.

Научная статья
УДК 616.758.3-089.819
https://doi.org/10.17816/2311-2905-17725

Сравнительный анализ результатов реконструкции передней крестообразной связки различными способами с применением свободных и несвободных аутотрансплантатов

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Реферат

Актуальность. Несмотря на широкое применение аутопластики передней крестообразной связки (ПКС), сохраняется потребность в совершенствовании методик, направленных на улучшение остеоинтеграции трансплантата, снижение воспалительной реакции и профилактику расширения костных тоннелей. Особый интерес представляют технологии с сохранением тибиального прикрепления и культи ПКС. Их сравнительная оценка на основе объективных функциональных и морфологических показателей требует систематизированного анализа.

Цель исследования — провести сравнительный анализ ближайших и ранних результатов применения различных способов реконструкции передней крестообразной связки.

Материал и методы. В исследование включены 112 пациентов, стратифицированных на четыре группы по типу выполняемой операции: D — свободный трансплантат; N — несвободный трансплантат; D+S — свободный трансплантат с сохранением культи; N+S — несвободный трансплантат с сохранением культи. Оценка результатов проводилась в сроки 6 и 12 мес. после операции с использованием шкал Lysholm, IKDC, KOOS, а также по данным МРТ (индекс SNQ) и МСКТ (расширение костных тоннелей). Применялись методы одно- и многофакторного дисперсионного анализа (ANOVA, MANOVA) и PCA.

Результаты. Сравнительный анализ показал статистически значимые различия между группами по всем исследуемым показателям ($p < 0,05$) по данным ANOVA-теста. Наилучшие функциональные результаты по шкалам Lysholm, KOOS и IKDC, а также морфологические показатели (индекс SNQ и степень расширения костных каналов) зафиксированы в группе N+S. MANOVA и PCA показали пространственное разделение групп с выраженным кластером пациентов группы N+S, отражающим преимущество данной техники. Различия между группами статистически значимы ($p < 0,05$).

Заключение. Полученные данные позволяют утверждать, что применение несвободных трансплантатов в сочетании с техникой сохранения культи передней крестообразной связки обладает значительным потенциалом в плане улучшения результатов хирургического лечения нестабильности коленного сустава. В то же время для окончательной верификации выявленных закономерностей требуется проведение широкомасштабных рандомизированных исследований с пролонгированным периодом наблюдения.

Ключевые слова: передняя крестообразная связка; ПКС; разрыв ПКС; несвободный трансплантат; сохранение культи ПКС.

Для цитирования: Котельников Г.П., Щербатов Н.Д., Кудашев Д.С., Зуев-Ратников С.Д. Сравнительный анализ результатов реконструкции передней крестообразной связки различными способами с применением свободных и несвободных аутотрансплантатов. *Травматология и ортопедия России*. 2025;31(3):50-60. https://doi.org/10.17816/2311-2905-17725.

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Рукопись получена: 30.06.2025. Рукопись одобрена: 30.07.2025. Статья опубликована онлайн: 14.08.2025.

INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction of the knee joint remains one of the most common surgical interventions in contemporary orthopedics, aimed at restoring anteromedial knee stability [1, 2, 3, 4]. Despite substantial progress in surgical techniques, graft materials, and approaches to ACL reconstruction, the challenge of achieving optimal and predictable long-term clinical and functional outcomes remains relevant [5, 6]. The conventional technique of ACL autoplasty using a detached hamstring tendon (DHT) is often associated with insufficient biological integration of the graft, pronounced tunnel widening, and variability in clinical results, which may not always meet the expectations of both surgeons and patients [7, 8].

In recent years, growing attention has been directed toward advanced methods that include preservation of the ACL remnant (such as the Single Antero-Medial Bundle Biological Augmentation, SAMBBA technique) and the use of non-detached hamstring tendon (NDHT) grafts, which retain the native tibial insertion of the semitendinosus [9, 10, 11, 12]. These techniques are expected to enhance revascularization, promote ligamentization, and facilitate improved osseointegration, as suggested by early preclinical and clinical observations from independent studies [13, 14, 15, 16]. Nevertheless, comparative data on the long-term clinical and morphological outcomes of these surgical strategies remain limited, highlighting the need for systematic analysis of their potential benefits and limitations.

The aim of the study – to conduct a comparative analysis of short-term and early outcomes of different anterior cruciate ligament reconstruction techniques.

METHODS

Study design

The study design corresponds to a single-center, open-label, randomized prospective clinical trial with parallel groups and was developed in accordance with the CONSORT 2010 (CONsolidated Standards of Reporting Trials) guidelines. The study was conducted at the Department of Traumatology and Orthopedics No. 2 of the Clinics of Samara State Medical University from 2023 to 2024. A total of 121 patients with verified ACL injuries were enrolled in the study.

Inclusion criteria: age ≥ 18 years; ACL injury of any duration confirmed by clinical examination and MRI findings; preserved ACL remnant as verified by MRI.

Exclusion criteria: associated injuries to other knee ligaments (posterior cruciate ligament, medial or lateral collateral ligaments) with instability; stage III-IV knee osteoarthritis (according to the Kellgren-Lawrence classification); body mass index (BMI) ≥ 35 kg/m^2; trophic disorders and/or purulent-inflammatory processes in the target joint area.

Withdrawal criteria: absence of the ACL remnant during arthroscopy, poor patient compliance during the follow-up period, and failure to adhere to postoperative recommendations.

All patients were informed in advance by the orthopedic trauma surgeon about the treatment options and the possible risks and outcomes of surgery. Each patient signed an informed consent form to participate in the study and undergo surgery.

The follow-up period included 6 and 12 months postoperatively. Clinical outcomes were evaluated using the Lysholm, IKDC, and KOOS scoring systems. Imaging parameters included the SNQ index (based on MRI) and bone tunnel widening (based on MSCT).

Patients

Initially, 121 patients were enrolled; however, 9 (7.4%) were excluded: 8 (6.6%) due to intraoperatively confirmed absence of the ACL remnant and 1 (0.8%) due to poor compliance and violation of postoperative rehabilitation protocols. As a result, the final analysis included 112 patients (92.6% of the initial cohort). Stratified randomization was used to allocate patients into four equal groups of 28 individuals, each receiving a different ACL reconstruction technique.

In the first group (D), surgical intervention was performed using the standard technique involving a double-loop detached hamstring tendon (DHT) autograft harvested from the semitendinosus (ST) and gracilis (G) tendons, with complete removal of the ACL remnant.

In the second group (N), during ACL reconstruction, the autograft from the ST and

G tendons was left with its native tibial attachment intact (NDHT), but similar to the first group, the residual ACL remnant was resected.

In the third group (D+S), a detached autograft was also used; however, the SAMBBA technique (Single Antero-Medial Bundle Biological Augmentation) was additionally applied. This approach involves preservation of the residual anteromedial bundle stump of the ACL, which was augmented with the autograft.

In the fourth group (N+S), the autograft was left non-detached, retaining its tibial insertion, and the SAMBBA technique was similarly employed to preserve the native ACL remnant.

Among the 112 patients, 72 (64.3%) were male and 40 (35.7%) female. The mean age was 30.5±9.3 years (range 18-45). ACL injury of the left knee was found in 52 (46.4%) patients, and of the right knee – in 60 (53.6%) patients, with a left-to-right ratio of 1:1.15. The mean time from injury to surgery was 6.0±1.4 months. Demographic and baseline clinical characteristics of the groups are presented in Table 1.

No statistically significant differences between groups were found in terms of age, sex, or time from injury to surgery ($p > 0.05$).

Table 1

Stratified randomization of patients into groups

Group	Number of patients	Sex (M/F)	Age, years (M±SD)	Side of injury (right/left)	Time from injury to surgery, months (M±SD)
D	28	18/10	28.0±9.2	16/12	6.1±1.4
N	28	17/11	31.0±8.9	15/13	5.9±1.6
D+S	28	18/10	29.0±9.5	16/12	6.2±1.5
N+S	28	19/9	32.0±8.7	16/12	6.0±1.3

According to the ANOVA test results, between-group differences were not statistically significant in terms of sex ($p = 0.9597$), side of injury ($p = 0.9912$), and time from injury to surgery ($p = 0.3019$). The difference in age approached the threshold of statistical significance ($p = 0.0547$).

Surgical technique

Arthroscopic reconstruction of the ACL was performed under spinal anesthesia using standard approaches. The initial stage included a diagnostic arthroscopy with inspection of the ACL remnant and intra-articular structures. Therapeutic procedures were then carried out as required, including arthrolysis, debridement, and partial meniscectomy. Subsequently, femoral and tibial bone tunnels were created according to the anatomical footprints of the native ACL. The entry point for the femoral tunnel aperture was determined with reference to the Blumensaat line and the lateral intercondylar ridge (“resident's ridge”) using an offset guide included in the standard instrument set for anterior cruciate ligament reconstruction. Femoral fixation was achieved using a cortical suspensory device (ULTRABUTTON Adjustable Fixation Device, Smith & Nephew), while tibial fixation was performed using a bioabsorbable interference screw (Smith & Nephew). The arthroscopic view of the preserved ACL remnant and the placed autograft is shown in Figure 1.

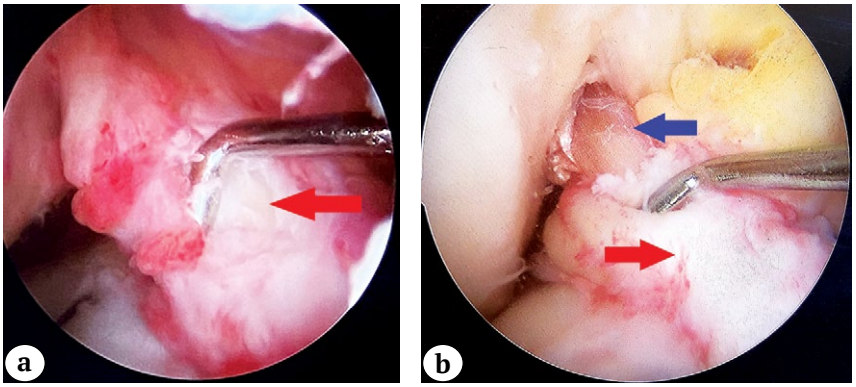

Figure 1. Arthroscopic view:
a — ACL remnant (indicated by the red arrow);
b — fixed autograft (indicated by the blue arrow) with preserved ACL remnant

All patients followed an identical postoperative rehabilitation protocol regardless of group allocation.

Assessment methods

The outcome assessment was conducted at 6 and 12 months post-op using both clinical and imaging-based evaluation methods. The functional status of the knee joint was assessed using validated clinical scoring systems: the Lysholm Knee Score, the International Knee Documentation Committee Subjective Knee Evaluation Form (IKDC), and the Knee injury and Osteoarthritis Outcome Score (KOOS) [17, 18, 19]. These questionnaires were completed by patients preoperatively and at 6 and 12 months postoperatively.

Instrumental assessment of graft integration and bone tunnel morphology was performed using magnetic resonance imaging (MRI) and multislice computed tomography (MSCT).

MRI was conducted at 6 and 12 months postoperatively to calculate the SNQ (Signal-to-Noise Quotient) index using the following standard formula:

$$SNQ = (SI\ of\ graft - SI\ of\ posterior\ cruciate\ ligament) / SD\ of\ background,$$

where SI stands for signal intensity and SD stands for standard deviation of the background signal measured. Particular attention on MRI was also paid to the accuracy of bone tunnel positioning and the dynamics of graft remodeling (Figure 2).

Figure 2. MRI images 6 months after ACL reconstruction:
a — position of the femoral tunnel (PDE_TSE_SPIR sequence);
b — position of the tibial tunnel (STIR_longTE sequence);
c — intra-articular portion of the ACL autograft (STIR_longTE sequence)

Additionally, MSCT was used to quantify tunnel widening in both the femoral and tibial canals, expressed as a percentage increase relative to the original drilling diameter.

Statistical analysis

To analyze the dynamics of parameters over time (6 and 12 months), a two-way repeated measures analysis of variance (ANOVA) was used, allowing for assessment of both between-group differences and within-group changes over time. To evaluate between-group differences based on the full set of clinical and instrumental scales, a multivariate analysis of variance (MANOVA) was performed, followed by principal component analysis (PCA). Prior to conducting ANOVA and MANOVA, the distribution of quantitative variables was tested for normality using the Shapiro-Wilk test. In cases where deviations from normality were detected, non-parametric methods (Kruskal-Wallis test) were additionally applied. The median (Me) and interquartile range [Q_1; Q_3] were used to describe the sample structure. A post-hoc power analysis was performed based on a sample of 4 groups with 28 patients each, with a significance level of $\alpha = 0.05$ and an effect size of $f = 0.40$; the resulting statistical power was 0.94, indicating a high level of reliability.

All statistical analyses were carried out using IBM SPSS Statistics version 25.0, and graphical visualizations were generated using GraphPad Prism 9.0. A p-value < 0.05 was considered statistically significant.

RESULTS

Throughout the entire follow-up period, improvements in both clinical and instrumental parameters were observed in all four groups; however, the degree of recovery varied significantly depending on the anterior cruciate ligament reconstruction technique used.

Based on the analysis, statistically significant differences were found between the groups across all assessed parameters at both 6 (Table 2) and 12 months of follow-up (Table 3).

After 6 months, the highest functional scores (Lysholm, IKDC, KOOS) and the best instrumental results (the lowest SNQ index and tunnel widening values) were observed in patients from the N+S group. The minimum values were recorded in the D group. By 12 months, the advantage of the N+S group remains in all clinical and morphological criteria: the maximum values of the Lysholm, IKDC, and

Table 2

Comparative dynamics of clinical and instrumental parameters in the study groups at 6 months after ACL reconstruction, Me [Q_1; Q_3], (min-max)

Parameters	Results			
	D (n = 28)	N (n = 28)	D+S (n = 28)	N+S (n = 28)
Lysholm, points	79 [77; 80], (71-89)	82 [80; 84], (75-88)	83 [80; 85], (77-89)	88 [86; 90], (82-92)
IKDC, points	74 [71; 77], (64-89)	78 [75; 81], (68-88)	83 [82; 86], (78-87)	89 [88; 91], (84-93)
KOOS , points	74 [68; 78], (66-79)	81 [74; 84], (72-85)	74 [72; 83], (71-85)	83 [80; 89], (78-92)
SNQ index	8.5 [7.9; 9.1], (7.4-10.2)	7.6 [6.8; 8.1], (6.0-8.9)	6.8 [6.4; 7.2], (4.4-9.3)	5.8 [5.3; 6.3], (4.2-8.5)
Bone tunnel widening, %	31.2 [31.1; 31.3], (31.0-31.5)	26.5 [26.5; 26.6], (26.3-26.8)	25.7 [25.6; 25.8], (25.5-26.0)	20.8 [20.8; 20.9], (20.6-21.0)

p < 0.05 – derived from ANOVA.

Table 3

Comparative dynamics of clinical and instrumental parameters in the study groups at 12 months after ACL reconstruction, Me [Q_1; Q_3], (min-max)

Parameters	Results			
	D (n = 28)	N (n = 28)	D+S (n = 28)	N+S (n = 28)
Lysholm, points	86 [83; 88], (79-92)	90 [87; 93], (84-96)	91 [89; 93], (85-96)	96 [95; 98], (94-100)
IKDC, points	81 [77; 85], (72-91)	85 [81; 88], (75-94)	89 [87; 92], (81-97)	94 [91; 96], (89-100)
KOOS, points	78 [75; 82], (68-88)	84 [81; 89], (74-94)	91 [89; 93], (82-98)	96 [94; 98], (88-100)
SNQ index	8.5 [7.9; 9.1], (7.4-10.2)	7.6 [6.8; 8.1], (6.0-8.9)	6.8 [6.4; 7.2], (4.4-9.3)	5.8 [5.3; 6.3], (4.2-8.5)
Bone tunnel widening, %	31.2 [31.1; 31.3], (31.0-31.5)	26.5 [26.5; 26.6], (26.3-26.8)	25.7 [25.6; 25.8], (25.5-26.0)	20.8 [20.8; 20.9], (20.6-21.0)

p < 0.05 – derived from ANOVA.

KOOS scales and the lowest SNQ and tunnel widening values. The worst results were observed in the D group. The highest functional scores and the lowest SNQ and tunnel widening values were recorded in the group with non-detached graft and ACL remnant preservation (N+S). The lowest outcomes were observed in the D group (detached graft without remnant preservation), as confirmed by statistically significant pairwise differences ($p < 0.05$) with the other groups (N, D+S, and N+S).

The resulting two-dimensional projection onto the plane of the first two principal components, which together explained the majority of data variance (PC1: 75.6%, PC2: 9.3%), enabled visualization of the spatial distribution of clinical groups in a multiparametric context.

The PCA projection of MANOVA revealed a clear separation of data points corresponding to patients from different groups, most distinctly in the N+S group (non-detached graft + remnant preservation), which formed an isolated cluster distant from the others (Figure 3). This indicated a high degree of differentiation of this group in terms of cumulative clinical indicators (Lysholm, KOOS, SNQ index) at both 6 and 12 months postoperatively. The D and D+S groups showed partial overlap, while the N group was positioned between them and the N+S cluster, reflecting intermediate values.

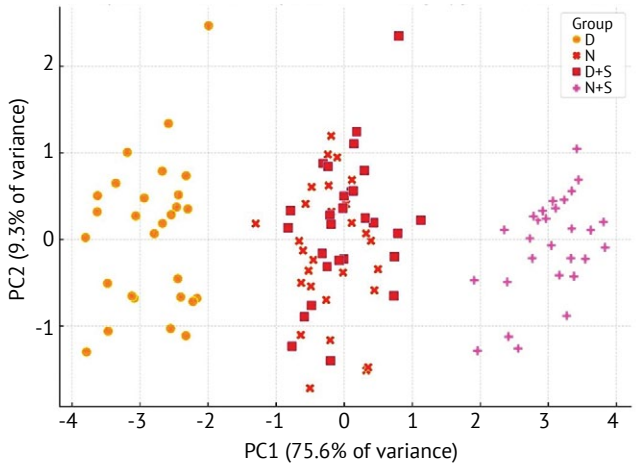

Figure 3. PCA projection of MANOVA: clustering of groups based on combined clinical and instrumental indicators

The observed spatial differentiation in the PCA cluster plot confirmed that clinical features – such as the rate of functional recovery of the knee joint, subjective quality-of-life assessment, and graft integration level – exhibited a consistent distribution depending on the surgical technique applied. These findings emphasized the practical significance of multivariate analysis for prognostic stratification and personalization of surgical tactics.

The results of the PCA projection confirmed that the modified surgical techniques, particularly in the N+S group, lead to qualitatively distinct recovery trajectories, which was further validated by statistically significant differences according to the MANOVA data ($p < 0.001$).

DISCUSSION

Surgical ACL reconstruction continues to be considered the preferred method for treating anteromedial instability of the knee joint [20, 21, 22]. However, despite the widespread use of conventional technique employing detached autografts, recent years have witnessed the active development of biologically preserving surgical approaches focused on maintaining anatomical structures, including the ACL remnant and the tibial tendon insertion site [23, 24, 25]. This trend reflects the growing demand for achieving anatomical and functional outcomes comparable to those of the native ligament, while simultaneously reducing complication rates and improving graft incorporation into surrounding tissues [26, 27, 28, 29].

According to the literature, non-detached hamstring tendon (NDHT) grafts that preserve the natural tibial attachment demonstrate more favorable outcomes compared to detached tendon grafts (DHT). For example, N. Vari et al. demonstrated that the use of NDHT grafts leads to more reliable restoration of knee joint stability and a lower re-rupture rate, while maintaining comparable functional results [30]. The study by A. Grassi et al., based on magnetic resonance imaging, revealed significant advantages of NDHT graft in terms of graft ligamentization.

In the NDHT group, the authors observed lower SNQ values, reduced graft edema, and less tunnel widening at 4 and 18 months postoperatively [31]. According to A. Ruffilli et al., preservation of the natural tibial tendon insertion site promotes accelerated ligamentization and the formation of structural graft continuity, improving healing and early functional recovery [32].

In parallel, the SAMBBA technique, which includes ACL remnant preservation, not only improves the biomechanics of the graft but also enhances biological integration by maintaining vascular and synovial coverage. Studies by Y. Zhang et al. and B.I. Lee et al. demonstrated that preservation of the ACL remnant reduces bone tunnel widening and graft signal intensity on MRI, which are interpreted as indicators of graft maturation in the later stages of follow-up [33, 34]. G.Y. Ahn et al. also reported that biological augmentation in the form of remnant preservation improves both clinical and imaging outcomes [35].

The results of the present study are consistent with the findings of the aforementioned authors. Patients in the N+S group treated with a combination of NDHT graft and ACL remnant preservation achieved the most favorable outcomes across all clinical scales (Lysholm, IKDC, KOOS) and instrumental assessments (SNQ index, bone tunnel widening) at both 6 and 12 months postoperatively. These findings confirm the effectiveness of biologically sparing techniques compared to traditional ACL reconstruction using a detached graft.

Additionally, multivariate analysis of variance (MANOVA), with visual representation via principal component analysis (PCA), revealed that patients in the N+S group formed a distinct cluster, clearly separated from the other groups. The key features contributing to this separation were high scores on functional scales (Lysholm, KOOS), a high percentage of patients rated as IKDC grade A, as well as the lowest SNQ index values and minimal tunnel widening. These characteristics reflect the most favorable clinical and morphological recovery trajectory in patients who underwent ACL reconstruction with preservation of both the tibial tendon insertion and the ACL remnant.

Study limitations

Despite the statistically significant results obtained, this study has several limitations. It was conducted as a single-center observation, which may reduce external validity and limit the generalizability of the findings to other clinical populations. Although the study design included randomization, the lack of blinding could have introduced potential bias in the interpretation of subjective outcome measures. Additionally, the follow-up period was limited to 12 months, which restricts the assessment of long-term clinical and morphological outcomes. Finally, despite the stratified allocation of patients into groups, the potential influence of concomitant factors – such as the level of physical activity or adherence to rehabilitation protocols – was not fully accounted for.

Future multicenter blinded randomized trials with extended follow-up periods are needed to confirm and expand upon these findings.

CONCLUSION

The findings of this study suggest that the use of non-detached grafts in combination with anterior cruciate ligament remnant-preserving techniques holds substantial potential for improving the outcomes of surgical treatment for knee joint instability. At the same time, large-scale randomized controlled trials with long-term follow-up are necessary to definitively validate these results.

DISCLAIMERS

Author contribution

Kotelnikov G.P. — scientific guidance, editing the manuscript.
Shcherbatov N.D. — data acquisition, analysis and interpretation, drafting the manuscript.
Kudashev D.S. — editing the manuscript.
Zuev-Ratnikov S.D. — study concept and design.
All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

Funding source. This study was not supported by any external sources of funding.

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

Ethics approval. The study was approved by the local bioethics committee of Samara State Medical University, Samara, Russia, protocol No 269, 13.09.2023.

Consent for publication. The authors obtained written consent from patients to participate in the study and publish the results.

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