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COMPARATIVE ANALYSIS OF ARTHROSCOPIC TECHNIQUES OF ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION IN ADOLESCENTS

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Background. According to the considerably contradictory information across the international literature, both the anatomical and transtibial reconstruction of the anterior cruciate ligament (ACL), under similar conditions, yield good functional results from treatment. Therefore, it is important to evaluate the comparative effectiveness and the prospects of certain methods of ACL reconstruction. The purpose of this study was to analyze the possibilities and advantages of anatomical technologies for the reconstruction intervention.

Aim. To compare the outcomes of ACL reconstructions among adolescent children using different methods.

Materials and methods. The outcomes of 94 arthroscopic reconstructions of the ACL in adolescents were analyzed. The patients were categorized into 3 groups: Group 1 included 32 patients (34%) who underwent isometric plastic surgery of the ACL, wherein the femoral canal was formed using the transtibial technique. Group 2 included 30 patients (32%) who underwent anatomical plastic surgery of the ACL, with the formation of the femoral canal through additional anteromedial arthroscopic access. Group 3 included 32 patients (34%) who underwent the "all-inside" anatomical reconstruction of the ACL.

Results. A comparative analysis of the outcomes of reconstruction of the ACL among adolescents revealed that the anterior-posterior and rotational stability of the knee joint was better in group 3 patients than in groups 1 and 2 patients. In fact, the group 3 patients showed a significantly less positive pivot-shift (0 degree to 87.5%; I+ the extent of 12.5%) — than the group 1 patients (0 degree — 46.8%; I+ degree — 25%; II+ degree and 21.9%; III+ degree and 6.3%), followed by the group 2 patients (0 degree to 86.6%; I+ degree 6.7%; II+ degree of 6.7%).

Conclusion. Considering the safety aspects of intra-articular structures and for the better anatomical orientation of the femoral canal, the all-inside method of ACL reconstruction yielded better outcomes of postoperative anterior-posterior and rotational stability of the knee joint.

Keywords: anterior cruciate ligament; adolescents; growth zone.

СРАВНИТЕЛЬНЫЙ АНАЛИЗ АРТРОСКОПИЧЕСКИХ МЕТОДИК РЕКОНСТРУКЦИИ ПЕРЕДНЕЙ КРЕСТООБРАЗНОЙ СВЯЗКИ У ДЕТЕЙ ПОДРОСТКОВОГО ВОЗРАСТА

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Обоснование. В зарубежной и отечественной литературе достаточно много противоречивой информации, согласно которой как анатомическая, так и транстибиальная реконструкция передней крестообразной связки при прочих равных условиях позволяют получить хорошие функциональные результаты лечения. Однако сравнительная эффективность и перспективность отдельных методов реконструкции передней крестообразной связки остаются весьма актуальными темами. Необходимость проанализировать возможности и преимущества анатомических технологий реконструкции передней крестообразной связки и определила цель настоящего исследования.

Цель — сравнительный анализ результатов реконструкции передней крестообразной связки различными методами у детей подросткового возраста.

Материалы и методы. Проанализированы результаты 94 артроскопических реконструкций передней крестообразной связки у детей подросткового возраста. Все пациенты разделены на три группы. В первой группе (32 пациента — 34 %) использовали изометрическую пластику передней крестообразной связки, при которой бедренный канал формировали с помощью транстибиальной методики. Во второй группе (30 пациентов — 32 %) применяли анатомическую пластику передней крестообразной связки с формированием бедренного канала через дополнительный переднемедиальный артроскопический доступ. В третьей группе (32 пациента — 34 %) выполняли реконструкцию передней крестообразной связки по типу all inside — все изнутри.

Результаты. С помощью сравнительного анализа результатов реконструкции передней крестообразной связки у детей подросткового возраста установлено, что у пациентов третьей группы переднезадняя и ротационная стабильность коленного сустава оказались лучше нежели у пациентов первой и второй групп. У пациентов третьей группы значительно реже регистрировали положительный pivot-shift-тест (0 степень — 87,5%; I+ степень — 12,5 %), чем у пациентов первой (0 степень — 46,8%; I+ степень — 25 %; II+ степень — 21,9%; III+ степень — 6,3 %) и второй групп (0 степень — 86,6 %; I+ степень — 6,7 %; II+ степень — 6,7 %).

Заключение. Методика реконструкции передней крестообразной связки методом all inside за счет безопасности для внутрисуставных структур и более оптимальной анатомической ориентации бедренного канала позволяет добиться лучших результатов послеоперационной переднезадней и ротационной стабильности коленного сустава.

Ключевые слова: передняя крестообразная связка; дети; ростковая зона.

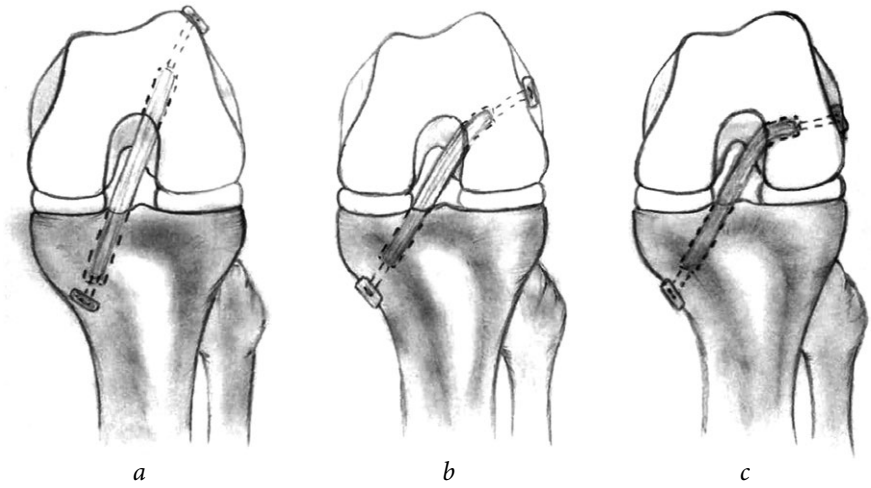
Anterior cruciate ligament (ACL) injury was considered a rare condition in patients with incomplete growth, but recent literature indicated an increasing incidence of this disease. In 2014, Dodwell et al. [1] reported that the incidence of ACL recovery per 100,000 population aged 3 to 20 years in New York increased nearly three times over a 20-year period from 17.6 in 1990 to 50.9 in 2009, and the peak incidence was registered in late adolescence. Many studies have associated the increase in ACL injury incidence with higher activity level during childhood, as well as with earlier sport specialization and fixation on year-round training and competition.

Anatomical risk factors for ACL injury in children include an unexpressed intercondylar fossa, insufficient ACL volume, thickness of the lateral intercondylar ridge, and pronounced posterior tilt of the ACL [2, 3]. In addition, increased quadriceps angle, anteversion, and greater generalized ligamentous laxity are associated with an increased risk of ACL injury. The incidence of ACL injuries is 2–9 times higher in girls than in boys [4–6]. This discrepancy occurs because girls often have the aforementioned anatomical risk factors.

Conservative management of ACL injuries in pediatric patients is associated with 50% dropout of athletes. Numerous studies have shown that the incidence of meniscal tears is higher in pediatric patients who underwent surgery later after ACL injury than in those who were treated immediately after ACL injury [7–9].

Many surgeons worry that surgical treatment may damage the epiphyseal plate and lead to impaired growth and deformities of the limb; therefore, patients and surgeons either choose conservative treatment or postpone ACL reconstruction until growth is complete. However, because nonoperative treatment and delayed ACL reconstruction are associated with worse outcomes [10–14] and surgical methods of ACL reconstruction are constantly improving, an increasing number of surgeons are eager to perform early ACL reconstruction in adolescent patients. One review presented 1867 adolescent patients with functioning growth zones, with history of ACL reconstruction, and without early revision or early reoperation associated with postoperative complications [15].

The risks of damage to the growth zones arising from the drilling of the bone canals during ACL



a *b* *c*

Fig. 1. Scheme of the surgery, axial view: *a,* group 1; *b,* group 2; *c,* group 3

reconstruction are not fully understood. A study has reported that ACL injury may increase the risk of impaired growth regardless of the reconstructive techniques employed [16]. The distal femur and proximal tibia provide more than 60% of the growth of the lower extremity, and they are usually damaged during standard ACL reconstruction with the formation of bone tunnels. The size and orientation of the bone tunnels, as well as the drilling speed, can alter the extent of the damage, and smaller diameters and more vertical tunnels created at slower speeds are more preferable than larger and more inclined tunnels that place the ACL at a biomechanically disadvantageous position [17–20].

Several clinical reports described cases of subsequent leg-length discrepancies or angular deformities after ACL reconstruction in pediatric patients [21–23]. Proponents of transphyseal methods suggest that the formation of bone canals "all-in epiphysis" in the immediate vicinity of the growth zones is more harmful than drilling through a smaller area of the growth zone.

Russian and international literature presents conflicting information, according to which both anatomical and transtibial reconstructions of the ACL, with all other things being equal, can provide good functional results. However, the comparative efficiency and prospects of certain ACL reconstruction methods remain very relevant issues [24]. Moreover, there is a need to analyze the possibilities and advantages of anatomical technologies for ACL reconstruction.

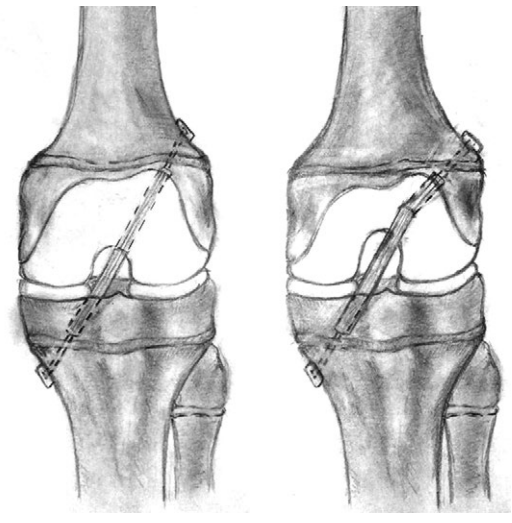
The work aimed to perform a comparative analysis of the results of various ACL reconstruction methods in adolescent patients.

Materials and methods

For this study, the authors analyzed prospectively the results of 94 arthroscopic ACL reconstructions performed in adolescent patients (aged 14–17 years) at the St. Petersburg State Pediatric Medical University in the period from 2015 to 2017.

All patients were distributed into three groups.

In group 1 (n = 32, 34%), isometric ACL grafting was used, in which the femoral canal was created using the transtibial technique. In group 2 (n = 30, 32%), anatomical grafting of the ACL was used with the creation of the femoral canal through an additional anteromedial arthroscopic approach. In group 3 (n = 32, 34%), ACL reconstruction was performed using the "all-inside" anatomical technique (Figs. 1, 2).



a *b*

Fig. 2. Scheme of the surgery, frontal view: *a,* group 1; *b,* groups 2 and 3.

Table 1

Comparative characteristics of the study groups (n = 94)

Parameter	Group 1	Group 2	Group 3	ρ	ρ_1	ρ_2
Количество	32	30	32			
Средний возраст, лет	15.7 ± 0.94	15.3 ± 0.81	15.3 ± 0.82	>0.05	>0.05	>0.05
Женщины	20 (62.5%)	16 (53.3%)	21 (65.6%)	>0.05	>0.05	>0.05
Мужчины	12 (37.5%)	14 (46.7%)	11 (34.4%)			
Спортивная травма	25 (78.1%)	21 (70%)	26 (81.3%)	>0.05	>0.05	>0.05
Бытовая травма	7 (21.9%)	9 (30%)	6 (18.7%)	>0.05	>0.05	>0.05

Note. Here and in other tables, ρ (significance of differences) is the ratio between groups 1 and 2, ρ_1 (significance of differences) is the ratio between groups 1 and 3, and ρ_2 (significance of differences) is the ratio between groups 2 and 3.

Table 2

Assessment results of the clinical stability of the knee joint before the reconstruction of the anterior cruciate ligament (n = 94)

Degree	Group 1 n = 32	Group 2 n = 30	Group 3 n = 32
Lachman test			
0 (0–2 mm)	0	0	0
I+ (3–5 mm)	7 (21.8%)	5 (16.7%)	5 (15.6%)
II+ (6–10 mm)	10 (31.3%)	11 (36.7%)	11 (34.4%)
III+ (>10 mm)	15 (46.9%)	14 (46.6%)	16 (50%)
Anterior drawer test			
0 (0–2 mm)	0	0	0
I+ (3–5 mm)	19 (59.4%)	20 (66.7%)	18 (56.3%)
II+ (6–10 mm)	10 (31.3%)	8 (26.7%)	11 (34.3%)
III+ (>10 m)	3 (9.7%)	2 (6.6%)	3 (9.4%)
Pivot-shift test			
0 (not determined)	17 (21.9%)	10 (33.3%)	10 (31.3%)
I+ (mild)	11 (34.3%)	10 (33.3%)	11 (34.3%)
II+ (moderate)	10 (31.3%)	8 (26.7%)	8 (25%)
III+ (severe)	4 (12.5%)	2 (6.7%)	3 (9.4%)

No statistically significant differences were found between the groups in terms of sex, age, mechanism, nature of injuries, duration of injury, and postoperative follow-up (Table 1).

The knee joint was assessed through clinical examination (Table 2), radiographic examination, and magnetic resonance imaging, and its function was evaluated using the International Knee Documentation Committee (IKDC) 2000 and Lysholm Knee Scoring Scale. All patients were examined before and after surgery. Clinical and functional results were assessed 12 months after surgery. To assess the knee joint stability, a special KLT Karl Storz instrument was used. The duration of the surgical treatment was also compared in each group.

Results of the clinical study indicating the severity of the anterior–posterior and anterolateral rotational instability of the knee joint prior to ACL reconstruction, obtained using the anterior drawer test, Lachman test, and pivot-shift test in groups 1, 2, and 3, did not differ statistically ($p > 0.05$).

Surgical treatment of patients was performed according to a standard protocol.

In groups 1 and 2, an autograft was formed from the semitendinous (ST) muscle tendon folded in two, and if the required graft diameter was insufficient, a gracilis tendon (ST + G) was added.

In group 3, an autograft was formed from an ST muscle tendon folded in four. To ensure acceptable ACL strength, the graft diameter was 7.5–8 mm in most cases.

In group 1, the tibial canal was first created. Generally, no difficulties were encountered at this stage, since the point of the canal formation was easily visualized during arthroscopy and was determined both by the preserved distal stump of the native ACL and by the posterior edge of the anterior horn of the lateral meniscus located in the field of view of the arthroscope. After placing the guide wire, the tibial canal was drilled through using a cannulated drill corresponding to the diameter of the graft prepared. The canal was drilled out using the outside-in technique.

In group 1, the femoral canal was created isometrically using the transtibial technique and standard Karl Storz guides with an offset of 7–8–9 mm. The notch located behind the proximal edge of the lateral condyle of the femur, the so-called over-the-top zone, was a reference point when setting the offset of the guide. The canal was drilled out to a graft diameter of 30 mm, and the rest of the canal was formed using a through drill with a diameter of 4.5 mm.

In group 2, the femoral canal was created anatomically through an additional anteromedial approach at the site of ACL attachment. The canal center was slightly displaced to the posterior edge of the lateral condyle of the femur from the center of the lateral bifurcation ridge at a distance equal to the radius of the femoral canal +2.0 mm from the posterior edge of the hyaline cartilage of the lateral condyle of the femur. The canal was created at a 60° angle of flexion in the knee joint, and as in group 1, it had a predetermined diameter and length of 30 mm; the rest of the canal was formed using a through drill with a diameter of 4.5 mm. After the creation of the femoral tunnel, the tibial tunnel was created using the same technique as in group 1.

In group 3, the surgical technique consisted of the creation of bone canals from the joint inside out according to the all-inside reconstruction technique. In this group, the femoral tunnel was created anatomically using a standard femoral guide for this ACL reconstruction technique below the lateral intercondylar ridge, in the middle of the distance between the posterior border of the lateral wall of the intercondylar fossa and the lateral bifurcation ridge. The tibial canal was created in the remnants of the native ACL, opposite the posterior cruciate ligament and laterally from the medial intercondylar spine of the tibia.

In all groups, only suspended extracortical fixators installed at the exit from the created femoral and tibial canals were used. This fixation was selected to reduce aggression on the growth zones and to minimize the frequency of possible epiphysiodesis.

Statistical data analysis was performed using the Statistica 10 package (StatSoft, USA). Descriptive statistical methods were used to display the general characteristics of the baseline parameters, and obtained values are presented as mean ± standard deviation. For variables with normal distribution, group comparisons were performed using Student's *t* test. To determine the statistical significance of the differences between the groups, the Mann–Whitney test was used to analyze quantitative variables and Fisher's exact test was used for nominative ones. The statistical significance of differences in the mean values of the dependent samples was assessed using the paired comparison Wilcoxon test. The p value lower than 0.05 was considered critical.

Results

Comparative analysis of the results of ACL reconstruction in adolescent patients helped establish that the anterior–posterior and rotational stability of the knee joint was higher in group 3 than in groups 1 and 2 (Table 3).

The results of the pivot-shift test, indicating the severity of the anterolateral rotational instability, were registered four times more often in group 1 than in groups 2 and 3 ($p < 0.0001$ and $p < 0.0001$, respectively). Thus, in group 3, the test results showed 0 degrees in 87.5% of the cases and I+ degree in 12.5%; in group 1, they were 0 degrees in 46.8% of the cases, I+ degree in 25%, II+ degree in 21.9%, and III+ degree in 6.3%; in group 2, they were 0 degrees in 86.6% of the cases, I+ degree in 6.7%, and II+ degree in 6.7%.

The results indicating the severity of the anterior–posterior knee instability after ACL reconstruction, obtained using the anterior drawer and Lachman tests, did not differ statistically significantly in groups 2 and 3 ($p > 0.05$).

Table 3

Analysis results of the clinical stability of the knee joint 12 months after reconstruction of the anterior cruciate ligament (n = 94)

Degree	Group 1 n = 32	Group 2 n = 30	Group 3 n = 32
Lachman test			
0 (0–2 mm)	12 (37.5%)	25 (83.3%)	27 (84.4%)
I+ (3–5 mm)	14 (43.7%)	5 (16.7%)	5 (15.6%)
II+ (6–10 mm)	6 (18.8%)	0	0
III+ (>10 mm)	0	0	0
Anterior drawer test			
0 (0–2 mm)	22 (68.8%)	24 (80%)	27 (84.4%)
I+ (3–5 mm)	8 (25%)	5 (16.7%)	5 (15.6%)
II+ (6–10 mm)	2 (6.2%)	1 (3.3%)	0
III+ (>10 mm)	0	0	0
Pivot-shift test			
0 (not determined)	15 (46.8%)	26 (86.6%)	28 (87.5%)
I+ (mild)	8 (25%)	2 (6.7%)	4 (12.5%)
II+ (moderate)	7 (21.9%)	2 (6.7%)	0
III+ (severe)	2 (6.3%)	0	0

Table 4

Results of group comparison according to the IKDC 2000 and Lysholm Knee Scoring Scale before and after reconstruction of the anterior cruciate ligament (n = 94)

Period	Group 1 n = 32	Group 2 n = 30	Group 3 n = 32	ρ	ρ_1	ρ_2
IKDC 2000 Scale						
Before surgery	56.83 ± 0.86	56.34 ± 0.85	55.77 ± 0.77	>0.05	>0.05	>0.05
After 12 months	85.29 ± 1.09	93.45 ± 0.37	98.48 ± 0.27	0.00006	0.00006	0.00006
Lysholm Knee Scoring Scale						
Before surgery	43.94 ± 0.96	44.07 ± 1.03	43.52 ± 0.99	>0.05	>0.05	>0.05
After 12 months	77.0 ± 1.23	85.86 ± 1.45	96.13 ± 0.68	0.00008	0.00006	0.00006

In group 2, the results according to the Lachman test showed 0 degrees in 83.3% of the cases and I+ degree in 16.7%. According to the anterior drawer test, the results were 0 degrees in 80% of the cases, I+ degree in 16.7%, and II+ degree in 3.3%.

In group 3, the results according to the Lachman test were 0 degrees in 84.4% of the cases and I+ degree in 15.6%. According to the anterior drawer test, the results showed 0 degrees in 84.4% and I+ degree in 15.6% of the cases.

Positive results of the anterior drawer test were 1.5 times more often in group 1 than in groups 2 and 3 (0 degrees in 68.8% of the cases, I+ degree in 25.0%, and II+ degree in 6.2%; with $p < 0.0001$ and $p < 0.0001$, respectively).

Positive results of the Lachman test in group 1 were four times more often than that in groups 2 and 3 (0 degrees in 37.5% of the patients, I+ degree in 43.7%, and II+ degree in 18.8%), with $p < 0.0001$ and $p < 0.0001$, respectively.

In group 3, the results of the functional assessment of the knee joint after ACL reconstruction, according to the IKDC 2000 and Lysholm Knee Scoring Scale, differed significantly from those of groups 2 and 1 for the better ($p = 0.00006$ and $p = 0.00006$, respectively) (Table 4).

The functional results in group 2 were statistically significantly higher than that in group 1 ($p = 0.00008$ and $p = 0.00006$ according to the Lysholm Knee Scoring Scale and IKDC 2000, respectively).

Table 5

Duration of surgery in groups 1, 2, and 3

Group	Duration of surgery (mean value ± standard deviation), min	ρ	ρ_1	ρ_2
Group 1	60.03 ± 1.49	0.00006	0.00006	0.00006
Group 2	98.2 ± 0.99			
Group 3	72.3 ± 0.76			

At the final stage of the study, the duration of surgery was compared in all groups. In group 2, the surgery took the maximum time (98.2 ± 0.99 min) for better preparation of the joint for the creation of the femoral canal through the additional anteromedial port. Preparation included removal of a part of the fat pad and creation of the femoral canal through an additional anteromedial approach. The additional anteromedial approach should, in turn, be convenient for the creation of the femoral canal and safe for intra-articular structures, in particular for the medial meniscus and hyaline cartilage of the medial femoral condyle. The duration of surgery was the shortest in group 1 (60.03 ± 1.49 min), since all stages were performed using special guides and the installation of which did not cause technical difficulties. In group 3, the surgery duration was an average (72.3 ± 0.76 min) of the indicators in groups 1 and 2 (Table 5).

Discussion

At present, not only a single priority technique for ACL reconstruction is lacking, but also an ultrastrong graft and an absolutely reliable fixator. Clinics and hospitals worldwide use various techniques for the creation of femoral and tibial canals, all kinds of grafts, and methods of their fixation, but the general principles are dependent on the anatomical nature of the ligament restored, graft isometricity, simplicity, and technical accessibility of the surgical intervention, which ensure maximum safety in the intra- and postoperative periods.

Analysis of the results and contemporary scientific literature present the potential of ACL anatomical reconstruction using the "all-inside" technique and reconstruction using an additional anteromedial access, whose main advantages over the transtibial technique include technical accessibility and reliability in achieving complex stability of the knee joint [25].

According to world literature, the progression of secondary degenerative changes in the knee joint is directly related to the insufficient joint stability after ACL reconstruction [26]. Non-anatomical creation of bone canals leads to the preservation or development of rotational instability; as a result, graft isometry disappears in the postoperative period, which leads to the progression of degenerative changes in the knee joint [27]. The treatment results of group 1 confirm the opinion of leading experts.

Recently, much attention is focused on rare complications associated with ACL reconstruction in patients with incomplete growth. In a review of the Herodicus Society and the ACL study group, Kocher et al. [28] found that 11% of the surgeons reported a growth disorder leading to angular deformities of the lower limbs after ACL reconstruction in adolescent patients. In the present study, majority (80%) of the reported cases of growth impairment occurred on the femoral side, and most cases result in femoral valgus deformities. Kaeding et al. [29] also provide data on the incidence of graft failure (8.2%) after ACL reconstruction in patients aged 10–19 years compared with patients aged 20–29 years (4%) and aged 30–39 years (1.8%).

According to most authors specializing in arthroscopic surgery, early untimely loading, which is a characteristic of young patients striving for early recovery and return to previous sports loads, is the main cause of ACL graft damage and recurrence of knee joint instability. This has nothing in common with the channel formation, graft type, and method of its fixation. The recurrence rate of knee instability in these groups can increase up to 28%. The risk of graft rupture or rupture of the ligament of the opposite joint is 30–40 times higher in adolescents who returned to sports after ACL reconstruction than in healthy adolescents [30].

Moreover, this study revealed that transtibial creation of the femoral canal is simple and safe in terms of the damage to the femoral growth zone,

but it also has disadvantages, that is, the point of the femoral canal formation is not anatomically located, which in turn leads to the preservation of rotational instability in the postoperative period, despite the preservation of the graft isometric property.

The creation of the femoral canal through an additional anteromedial approach helped achieve anatomical positioning of the ACL graft and obtain optimal results of knee joint stability. However, this technique involves aggressive resection of a part of Hoffa's fat pad and the deepest possible flexion of the limb in the knee joint. Even if all stages of surgery are performed, complications associated with damage to the medial meniscus and superficial hyaline cartilage are difficult to avoid completely.

Owing to the safety of intra-articular structures and better anatomical orientation of the femoral canal, the all-inside ACL reconstruction technique helps achieve the best postoperative anterior–posterior and rotational stability of the knee joint. Although the femoral canal was created transphyseally with this ACL reconstruction method, no complications associated with damage to the growth zones (this may be caused by a short follow-up period of 12 months) were recorded in this study. The results obtained are consistent with world data. We believe this offers a number of advantages over other methods.

After ACL reconstruction, up to the incorporation of the graft into the bone canals, joint stability is primarily determined by consistency of the fixators. The close contact of the graft with the canal walls, as well as complete filling of the canals with the graft, contributed to the incorporation. This may occur because with such an arrangement of the ACL graft, the possibility of penetration into the channels of the synovial fluid decreases, and the graft had sufficient contact area with the bone canal walls. These conditions persist only in cases where the bone canals were created using the all-inside ACL reconstruction technique. This reconstruction technique can be recommended for adolescent patients (aged 14–17 years).

Conclusion

The results of the functional assessment of the knee joint 12 months after ACL reconstruction, estimated according to IKDC 2000 (98.48 ± 0.27 in group 3, 93.45 ± 0.37 in group 2, and 85.29 ± 1.09 in group 1) and Lysholm Knee Scoring Scale (96.13 ± 0.68 in group 3, 85.86 ± 1.45 in group 2, and 77.0 ± 1.23 in group 1), differed statistically significantly for the better from the results obtained in groups 2 and 1 ($p = 0.00006$ and $p = 0.00006$, respectively). Therefore, the anatomical "all-inside" creation of the femoral and tibial canals, which provides better functional results, should be the preferred approach to the stabilization of the knee joint in adolescent patients.

For ACL reconstruction in adolescent patients, the use of a double or a quadruple ST muscle tendon is recommended. To ensure acceptable ACL strength, the graft diameter must be at least 7.5–8 mm. A significant increase in the graft size can lead to its impingement in the intercondylar fossa of the femur.

When performing surgeries in adolescent patients, the main fixing elements are the extracortical systems to ensure minimal risk of iatrogenic epiphysiodesis.

Additional information

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Conflict of interests. The authors declare no conflict of interest.

Ethical statement. The study was conducted in accordance with the ethical standards of the Declaration of Helsinki of the World Medical Association as amended by the Ministry of Health of Russia and approved by the ethical committee of the R.R. Vreden Russian Scientific Research Institute of Traumatology and Orthopedics (protocol No. 17/1 dated 10/11/2018). Patient representatives signed informed consent to participate in the study and publish the data without identification of personality.

Author contributions

M.R. Salikhov developed the concept and design of the article, collected the literature data and the clinical material, analyzed and interpreted the data obtained, and edited the text.

V.V. Avramenko collected literature data and clinical material, edited the text, and coordinated with the research participants.

All authors have made a significant contribution to the research and preparation of the article and have read and approved the final version before its publication.

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