doi: 10.21823/2311-2905-2020-26-2-128-138

Corrugated Suture for Cortical Fixation of a Semitendinosus Tendon Autograft in Anterior Cruciate Ligament Reconstruction: Clinical Results

V.V. Slastinin [1], N.V. Yarygin [1], M.V. Parshikov [1], A.M. Fain [2], M.V. Sychevskiy [1], M.V. Govorov [1]

[1] *A.I. Yevdokimov Moscow State University of Medicine and Dentistry, Moscow, Russian Federation*

[2] *N.V. Sklifosovskiy Scientific Research Institute, Moscow, Russian Federation*

Abstract

The study purpose — to evaluate the clinical results and the condition of bone tunnels after anterior cruciate ligament reconstruction with a semitendinosus tendon graft using cortical fixation and corrugated sutures. ***Materials and Methods.*** The results anterior cruciate ligament reconstruction with a semitendinosus tendon autograft were analyzed in 57 patients aged 18 to 53 years. The patients of the first group (n = 27) underwent anterior cruciate ligament reconstruction with a semitendinosus tendon graft using cortical fixation on the femur and tibia in combination with corrugated sutures at the proximal and distal ends of the graft. The patients of the second group (n = 30) underwent anterior cruciate ligament reconstruction in a similar way, but without the use of corrugated sutures. Clinical results were assessed using the Lysholm and IKDC scales. The degree of bone tunnels widening was evaluated by CT data in 6 months after the surgery. ***Results.*** In the first group, the degree of postoperative bone tunnels widening was significantly lower (for the femoral tunnel by 18% and tibial — by 17%) compared with the second group (for the femoral tunnel by 30% and tibial — by 31%). Scores by the IKDC 2000 and Lysholm scales were higher in the corrugated sutured group. Although, the treatment outcome was interpreted as equally good for both groups. The time for graft preparation was on average 6 minutes longer in the first group. This slightly increased the duration of the surgery. ***Conclusion.*** The anterior cruciate ligament reconstruction with a semitendinosus tendon graft using cortical fixation on the femur and tibia in combination with corrugated sutures ensured the tight contact of the tendon inside the bone tunnels without additional implants and reduced the degree of tunnels widening. This is important for a possible re-grafting. The proposed method does not significantly affect the clinical outcomes.

Keywords: anterior cruciate ligament reconstruction, popliteus ligaments, semitendinosus tendon autograft, corrugated suture.

Cite as: Slastinin V.V., Yarygin N.V., Parshikov M.V., Fain A.M., Sychevskiy M.V., Govorov M.V. [Corrugated Suture for Cortical Fixation of a Semitendinosus Tendon Autograft in Anterior Cruciate Ligament Reconstruction: Clinical Results]. *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia]. 2020;26(2):128-138. (In Russian). doi: 10.21823/2311-2905-2020-26-2-128-138.

Vladimir V. Slastinin; e-mail: slastinin@gmail.com

Received: 19.12.2019. Accepted for publication: 27.03.2020.

Introduction

The integration of the popliteal muscles tendons and bone in the *anterior cruciate ligament* (ACL) reconstruction is one of the main problems: the biological processes occurring at the "tendon graft-bone tunnel" border remain not fully understood [1]. Bone tunnel widening is a well-known phenomenon observed in the patients after ACL repair. Even though this phenomenon does not affect the short-term clinical outcomes, many orthopedic surgeons are unanimous in the opinion that this complication is best to avoid, since it can worsen medium- and long-term outcomes and significantly complicate revisions [2]. The revision ACL grafting sometimes requires an additional stage of treatment in the form of bone grafting in the area of femoral and tibial defects [3]. In 2006, S.A. Rodeo et al. in animal experiments showed that the micro-mobility of the implanted tendon in the area of contact with the bone led to the tunnels widening due to the osteoclasts activation [4]. According to B. Chen et al. study (2007), the tunnel expansion usually occurs within 3 to 6 months after the surgery and remains unchanged after 12 to 24 months [5]. When the *interference screws* (IS) are used to fix the graft, the latter is pressed against the wall of the bone tunnel. This makes it possible to bring the area of close contact to the articular line as much as possible. As a result, the graft mobility is reduced, and synovial fluid cannot spread between the tendon and the bone. But this technology also has some negative sides: the possibility of damage to the graft and the canal walls during screw insertion, poor integration of the screw and often pathological reactions to a foreign body. The complexity of the processes, taking place around the biodegradable fixative, often does not allow predicting the final outcome [6].

In the grafting by J.H. Lubowitz, the so-called all-inside technique, cortical buttons are used to fix the graft, and the tendon itself is folded in half twice [7]. This method provides the full contact between the walls of the bone tunnels and the graft. The absence of a foreign body in the tunnel ensures good integration [8].

The purpose of this study was to compare and evaluate the clinical outcomes and the condition of the bone tunnels after ACL repair with a graft from the *semitendinosus tendon* (ST) using cortical fixation on the femur and tibia with the technique of cortical fixation of the graft in combination with a modified *corrugated suture* (CS).

Materials and Methods

63 patients (44 men and 19 women) were included in the study. Their ages ranged from 18 to 53 years old. The study was conducted from 2017 to 2019.

Inclusion criteria:

1) ACL rupture, diagnosed clinically, confirmed by MRI;

2) the interval between rupture and reconstruction of the ligament is not more than 1 year;

3) activity on the Y. Tegner scale [9] not less than 5;

4) a healthy contralateral knee.

Exclusion criteria: the presence of a full-thickness articular cartilage defect, menisci tears, and damage to other ligaments of the knee, requiring a change in the rehabilitation protocol.

Three patients were excluded from the study: the 1st — due to a diagnosed full-thickness cartilage defect that required a single-stage mosaic chondroplasty; the 2nd — due to the rupture of the meniscus, which required its suturing and changes in the rehabilitation protocol; the 3rd — due to the insufficient thickness of the graft obtained from the two-fold ST (in this case, an additional collection of the gracilis tendon was performed).

In three patients, it was not possible to track the long-term outcome. The flowchart of the study is shown in Figure 1.

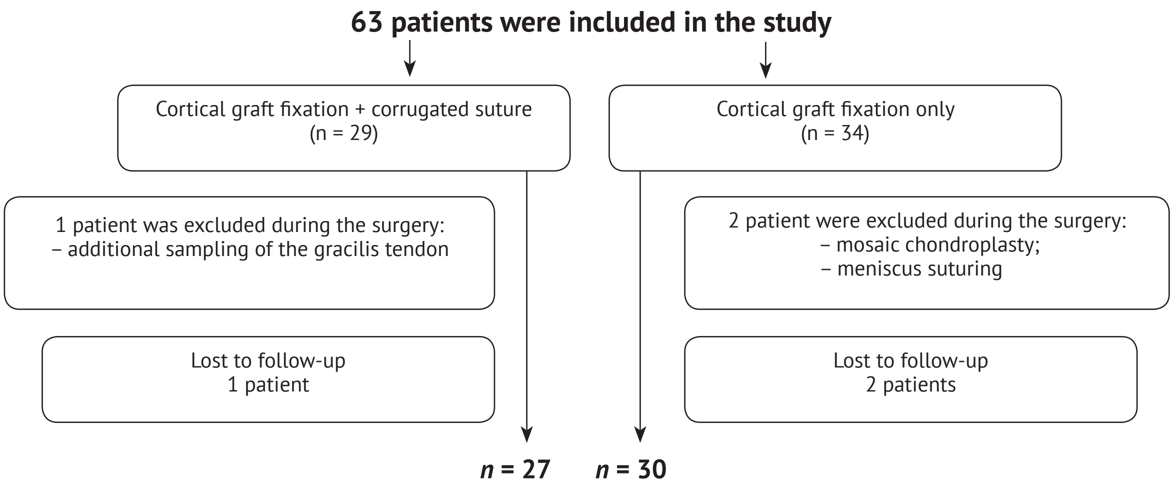

Fig. 1. Flowchart of the study.

The patients were divided into two groups. The patients of the 1st group underwent ACL repair by ST grafting with cortical fixation on the femur and tibia in combination with CS at the proximal and distal ends of the graft. The previously developed original technique was experimentally justified [10]. The patients of the 2nd group underwent ACL grafting with the cortical fixation of the ST graft on the femur and tibia, but without CS. In both cases, the TightRope RT fixator (Arthrex Inc., USA) was used on the femur, and ABS ButtonRound (Arthrex Inc., USA) on the tibia. The grafts were sutured with FiberWire 2# threads (Arthrex Inc., USA).

In 6 months after the surgery, CT of the knee was performed.

The surgical fixation technique using a corrugated suture

The ST was taken from a longitudinal approach along the anterior-inner surface of the lower leg and washed in 4% chlorhexidine solution to prevent postoperative infection [11]. Next, a four-bundle graft was composed on a preparation table. The technique of four-bundle graft formation is described in detail in the works of J.H. Lubowitz [7]. With moderate pulling the sutures 1 and 2, fastened in the fixators of the preparation table, the graft from a round shape became elongated. The bundles were positioned so that the contact area of the free ends of the tendon was covered by them. Then, the distal and proximal circular sutures were formed, and consequently — the CS.

Figure 2 shows a scheme of the prepared tendon before and after immersion of the proximal CS (5) into the graft.

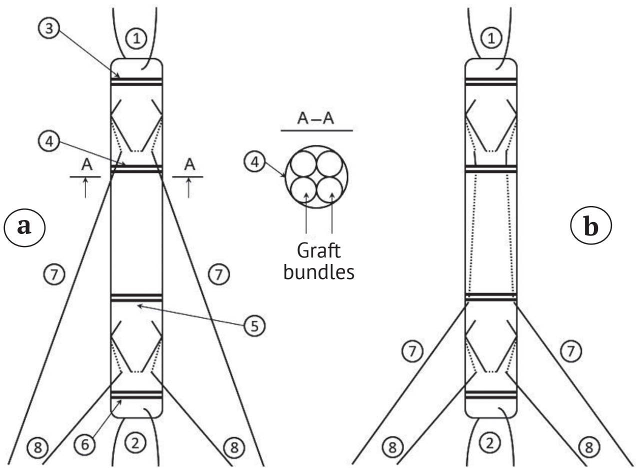

Fig. 2. Scheme of the four-bundle semitendinosus tendon graft prepared by modified method:
a — view after corrugated sutures formation and before the proximal corrugated suture immersion into the graft; b — view after the proximal corrugated suture immersion into the graft;
1 — thread of femoral cortical fixator;
2 — thread of cortical fixation at the tibia;
3, 4, 5, 6 — circular sutures;
7 — thread of the proximal corrugated suture;
8 — thread of the distal corrugated suture.

Figure 3 shows a scheme of the proximal corrugated suture formation.

Below, a detailed description of the stages is presented. The distal CS was formed similarly. Figure 4 shows a graft prepared according to the developed technique.

The femoral tunnel was formed through the anteromedial arthroscopic port. To immerse the graft, the port was reamed out to a depth of 20 mm. The through tibial tunnel was formed traditionally, focusing on the location of the ACL stump, which we tried to preserve as much as possible. Also, to objectify the correct location of the femoral and tibial tunnels, an electron-optical converter was used during the operation. The localization of the femoral tunnel was assessed using the quadrant method described by M. Bernard et al. [12]. Its center was worked out by calculating the distance from the Blumensaat line in the proximal-distal direction. The h axis is a line drawn perpendicular to the Blumensaat line. It starts from the roof of the intercondylar fossa and ends at the lower edge of the *lateral condyle of the femur* (LCF); the t axis is a line drawn parallel to the Blumensaat line, starting from the posterior and ending at the anterior edge of the LCF [13]. The localization of the tibial tunnel was determined using the Amis and Jakob line. This is the distance between the anterior edge of the tibial plateau to the center of the tunnel, expressed as a percentage of the anteroposterior size of the tibial proximal part [14]. For calculations and positioning of the tunnels during the surgery, we used the templates made by ourselves according to the S. Kumar et al. method [15].

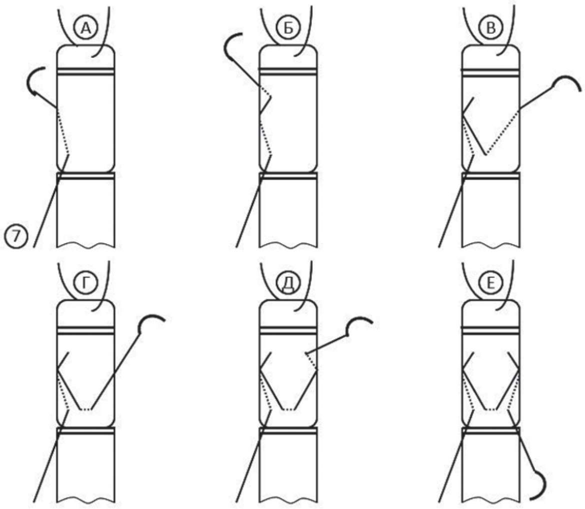

Fig. 3. Corrugated suture formation: the letters indicate the sequence of stages.

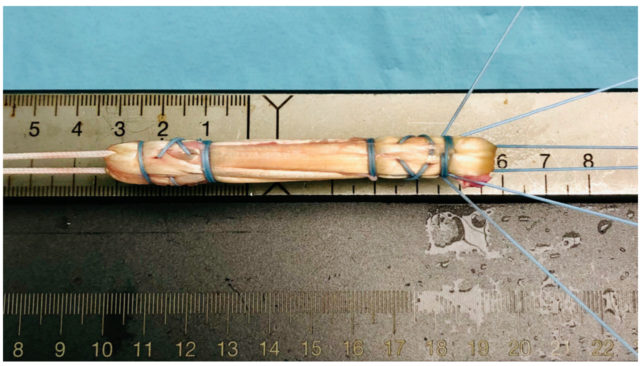

Fig. 4. View of the graft prepared by our method.

The graft was inserted retrograde through the tibial tunnel into the knee cavity, and then into the femoral tunnel according to the standard technique. The traction for the graft conduction was carried out by the ends of suture 1 (TightRope RT) through the femoral canal in the proximal direction. The immersion of the tendon into the femoral tunnel was carried out in accordance with the manufacturer's recommendations with alternating pulling of the white threads. The canal length at this stage was calculated in such a way that there was a reserve of the wide part of the canal of about 5 mm for the possibility of additional tendon tightening with the help of a tightening loop after fixation on the tibia. After placing the graft, its central part was in the knee cavity, the proximal (sutured with thread 7) was immersed in the femoral bone tunnel, while the distal (sutured with thread 8) occupied the proximal part of the tibial canal. Then, constantly pulling thread 2, several cycles of passive flexion and extension in the knee were performed. The ends of sutures 2, 7 and 8 were threaded in pairs into the ABS ButtonRound tibial cortical fixator (Arthrex Inc., USA), on which the ends of suture 2 were tied. Then, for additional tightening on the graft, the loop of the femoral fixator was pulled, for which a 5 mm margin of the femoral tunnel was used. Finally, after preliminary pulling, the ends of the CS were tied in pairs. First proximal end was tied, then — distal. This ensured an increase in the diameter of the graft in the femur and tibia. The ends of the threads were cut off. After the drain placement through the anteromedial arthroscopic port, the wound was sutured. The CS mode of functioning is shown in Figure 5.

The arthroscopic picture before and after ACL grafting shown in Figure 6.

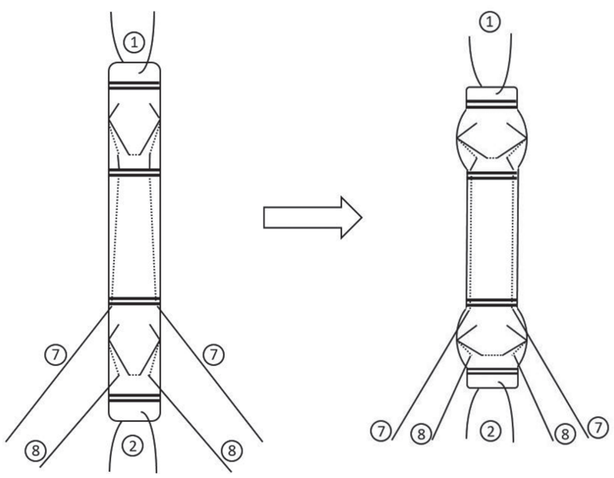

Fig. 5. Operating principle of the corrugated suture:
a — before threads tension;
b — after threads tension
The digital designations are similar to Fig. 2.

Surgical fixation technique without a CS

In the patients of the 2nd group, the sampling of the tendon, preparation of the graft and the formation of the tunnels were carried out similarly to the preparation in the 1st group, but during fixation, no CS were used.

Rehabilitation

Activation of the patients began on the day of the surgery, isometric tension of the quadriceps femoris was allowed the next day. Immobilization of the knee in the extension position was carried out for 2 weeks, after which exercises began with flexion in the knee up to 90° with a closed kinematic chain. The full support on the operated limb was allowed in 3 weeks after the surgery and the full flexion in the knee — after 5 weeks. Running in a straight line was allowed in 3 months after ACL recovery.

Clinical outcomes evaluation

The clinical outcomes of the study were evaluated in 6 months after the surgery using the *International Knee Documentation Committee* (IKDC) scales by the following indicators: pain, edema, episodes of instability and stiffness in the knee, the level of physical activity of the patients and Lysholm score by the following indicators: lameness, subjective feeling of blockage and instability in the knee, pain, edema, the ability to squat and walk on steps [16, 17, 18].

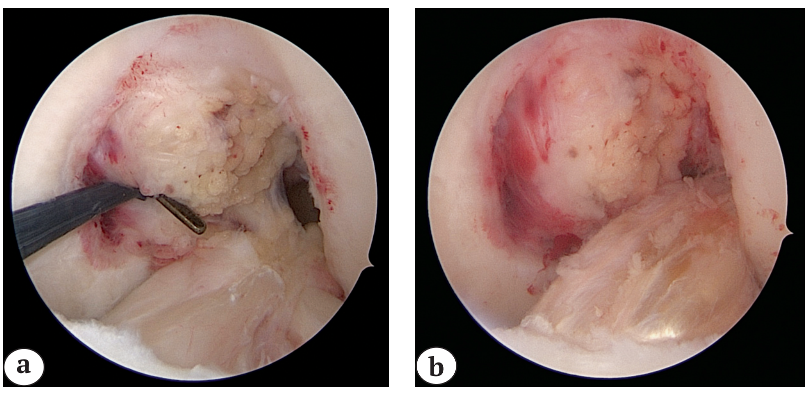

Fig. 6. Arthroscopic picture of fixation with only cortical fixators:
a — before the anterior cruciate ligament grafting;
b — after the grafting.

Radiological evaluation

The multispiral CT was performed on an outpatient basis in 6 months after the surgery to assess the diameter of the femoral and tibial tunnels. For this purpose, the sagittal and coronal planes were constructed with a step of 1 mm along the axis of the femoral and tibial tunnels and the diameter of the tunnels was measured in the area of their maximum widening. The data obtained were compared with the diameter of the drill used to form the bone tunnel. The diameter of the drill used during the surgery corresponded to the diameter of the graft. The CT scans of the patient in 6 months after the surgery are presented in Figure 7. The maximal diameter of the femoral tunnel was 8.19 mm and that of the tibial tunnel — 8.00 mm. This is comparable to the diameter of the drill (8.00 mm) used to form the tunnels.

Statistical analysis

The statistical analysis was performed using the Statistica 10.0 software (Statsoft Inc., USA). The type of the distribution was taken into account, the assessment was carried out for both groups using the corresponding paired criteria Mann-Whitney. The null hypothesis was rejected at $p<0.05$. The non-parametric Mann-Whitney method for small samples was employed. The value of the critical level of significance was taken equal to 0.05. The differences were recognized as statistically significant at $p<0.05$.

Results

The study groups were comparable by sex (in the 1st group there were 9 women and 18 men, in the 2nd group — 10 women and 20 men) and by age (mainly from 20 to 40 years old in both groups), as well as by the Tegner Activity Scale (Table 1).

The results of statistical processing of the data obtained in both groups are shown in Table 2. The level of threshold statistical significance in the studied groups was taken equal to 0.05. The critical value of the Mann-Whitney U-test for the specified sample size was 44 at $U \leq 44$, $p<0.05$.

Table 1

The comparative characteristics of the patient groups by age

Indicator	1st group (n = 27)	2nd group (n = 30)
Mean	32.2 (18;51)	33.9 (18;53)
Median	31	33.5

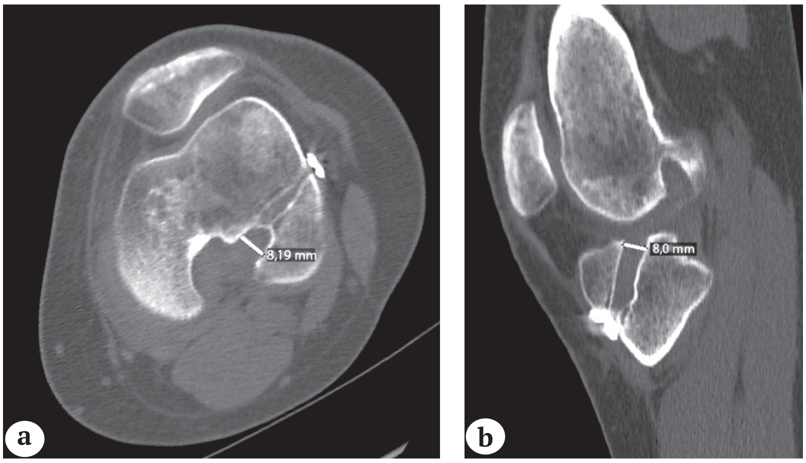

Fig. 7. CT data: images of the bone tunnels: femoral (a) and tibial (b) in 6 months after surgery.

Table 2

The comparative characteristics of the patient groups

Indicator	1st group (n = 27)	2nd group (n = 30)	Mann-Whitney U-criterion	p
Time from the moment of injury to surgery, months	6.40±2.75	5.6±2.4	48.8	0.38
Graft preparation time, min.	30.5±2.3	24.7±2.0	62.3	0.49
Femoral tunnel diameter after the surgery, mm	8.2±0.5	8.2±0.7	42	0.38
Tibial tunnel diameter after the surgery, mm	8.2±0.4	8.2±0.7	43.0	0.24
Increase of the femoral tunnel diameter in 6 months, %	18.2±3,7	29.8±6,8	64.4	0.04
Increase of the tibial tunnel diameter in 6 months, %	17.0±5.6	31±6	56.6	0.05
IKDC 2000, points	89.0±4.7	85.6±4.8	48.0	0.05
Lysholm score, points	93.50±4.0	90.8±3.5	49.0	0.03

The localization of the femoral and tibial bone tunnels in both groups was comparable, since the intraoperative electron-optical converter was used to confirm the location of the intra-articular tunnels aperture. The location of the femoral tunnel by the quadrant method in the patients of the 1st group was at 37.5±0.7% from the posterior edge of the LCF along the t axis and at 24.8±0.8% from the upper edge of the LCF medial surface along the h axis. In the 2nd group, the center of the femoral tunnel was at 38.0±0.6% from the LCF posterior edge along the t axis and at 25.3±0.6% from the upper edge of the LCF medial surface along the h axis. The tibial tunnel in the sagittal plane in the patients of the 1st group was located at 44.0±0.5% posterior to the anterior edge of the lateral condyle of the tibia, in the 2nd group — at 45.0±0.7%. The statistical processing of the study data did not reveal any significant differences in the location of the tunnels between the 1st and the 2nd groups (p>0.05).

Discussion

In comparative evaluation of paired samples, the statistically significant differences between both groups were found in the degree of bone tunnels widening and in some the evaluating scales indicators in 6 months after surgery. In the group with CS, the degree of postoperative bone tunnels widening was significantly lower compared with the group where isolated cortical fixation was used. In the 1st group the femoral widening was by 18% of the initial, the tibial — by 17%, in the 2nd group femoral widening was by 30% of the initial, tibial — by 31%. These differences play a significant role in determination of the tactics in case of need for ACL revision grafting. The scores on the IKDC 2000 and Lysholm scales were higher in the group where with CS was used, although in both groups the medium-term outcomes were equally interpreted as good. This was confirmed by studies that indicate the absence of a significant effect of the bone tunnels widening on the treatment outcome [16, 17, 18]. The time for the graft preparation was on average 6 minutes more in the group with a CS, which insignificantly increased the total operative time. R. Mayr and co-authors, assessing the degree of bone tunnels widening by CT in 6 months after ACL repair with the all-inside technique, found the tibial bone tunnel widening by 17.7±2.4%, and the femoral — by 43.2±3.4% [19]. In our study, the degree both bone tunnels widening in the 1st group in 6 months after the surgery did not exceed 18%. This suggests a more significant effect of the CS employment on the prevention of the femoral tunnel widening. The the bone canals widening occurs as a result of the combination of several biological and biomechanical factors. One of the main factors is the micro-mobility of the graft [20]. The factors that influence the degree of widening also include the type of graft (auto- or allograft, from the patellar ligament with bone blocks or from the popliteal muscles tendon), the method of fixation, the degree of its strain and the location of the tunnels themselves [21]. Also, the potential risk factors for widening are young age (less than 30 years), male gender, and the time (more than 1 year) from the ACL injury to its repair [22].

Various intracanal fixators (screws), cortical implants, and transverse pins are used to fix the graft. Bioresorbable IS have a number of advantages over metal ones, for example, the absence of artifacts during MRI and theoretically their subsequent gradual resorption, although in practice this does not always happen. The formation of bone cysts is a common complication in such fixators employment [23]. This has prompted some surgeons to choose the interferential but non-resorbable screws made from polyetheretherketone (PEEK) [24]. Reducing the distance between the graft fixation area and the bone tunnel aperture reduces the degree of its widening. The IS brings the fixation point as close as possible to the canal aperture. And this is its important advantage. Biomechanical studies show that the graft fixed with two cortical buttons is less rigid and elongates more than the one fixed with a button on the femur and a screw on the tibia [25]. The growth of collagen fibers between the graft and the walls of the bone tunnel directly depends on the contact zone between them. At the same time, the interferential resorbable screws limit the contact area, since most of the tunnel is filled by the screw itself, while cortical fixation does not have this drawback [26].

The use of only cortical fixators leads to the mobility of the graft in the bone canal. On the other hand, the use of IS results in tunnels widening. In one of the studies in which these methods of fixation were compared, it was found that widening occurs in both cases. Although, when screws were used, the widening revealed immediately due to the destruction of the border bone by the screw. And with cortical fixation, the widening appeared during the first 6 months and then decreased [27].

The "suspenders effect" and "wiper effect" associated with the use of cortical fixators are widely known. The first phenomenon refers to the movement of the graft in the canal in the longitudinal direction due to the relatively large distance between the fixation area and the joint line. The second is associated with its movements in the transverse direction. The greater the distance between the fixation area and the articular surface, the greater the degree of graft mobility in the tunnel. Both effects impede the integration of the tendon and the bone [28].

In ACL grafting with the all-inside technique (cortical fixation on the femur and tibia), the expansion of the femoral tunnel is observed to a greater extent than with IS [29].

The use of transverse pins as fixators is also not without complications, such as breakage and migration, iliotibial tract syndrome, and stress fracture of the femur [30, 31]. Moreover, for biodegradable pins, the cases of the bone cysts formation have been described [32].

The idea of tight intracanal fixation and the maximum contact area between the graft and of the bone tunnel wall created the basis of our method of graft fixation using a combination of cortical fixation and CS.

Many attempts have been made to reduce the degree of expansion of the bone tunnels from increasing the duration of the knee immobilization, employment of special drilling techniques, intracanal placement of cancellous bone cylinders to the use of alpha-2-macroglobulin and poorly differentiated periosteal cells. Nevertheless, the problem of preventing the bone tunnels widening after ACL grafting remains open [33].

Our technique combines biomechanical advantages of intracanal graft fixation, such as tight close contact with the bone walls and the maximal bringing closer the fixation point to the intra-articular aperture of the tunnels, with the natural cortical fixation due to the absence of foreign materials in the tunnels and the maximum contact area of the tendon with the canal walls.

The technique of fixation of an autograft from ST with CS employment in ACL grafting makes it possible to ensure tight contact of the tendon inside the bone tunnels without the use of additional implants and to reduce the degree of their widening. This plays an important role in case of need for revision ACL grafting.

Publication Ethics

The study was approved by the Committee on Biomedical Ethics of the N.V. Sklifosovskiy Scientific Research Institute of Emergency Care of Moscow Healthcare Department" (Protocol No. 4-17 of May 29, 2017)

The patients gave an informed consent for the participation in this clinical study.

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

Funding: The state budget.

Authors' contributions

V.V. Slastinin — research conception and design, research and surgery conduction, collection and processing of material, data interpretation and analysis, text preparation.

N.V. Yarygin — coordination of the study participants, editing.

M.V. Parshikov — coordination of the study participants, editing.

A.M. Fain — coordination of the study participants, editing.

M.V. Sychevskiy — collection and processing of material, research conduction.

M.V. Govorov — data interpretation and analysis, data statistical processing, text preparation.

References

1. Chen C.H. Strategies to enhance tendon graft-bone healing in anterior cruciate ligament reconstruction. *Chang Gung Med J.* 2009;32(5):483-493.
2. Celik H., Lee D.H. Comparison of the aperture and midportion femoral tunnel widening after anterior cruciate ligament reconstruction: A systematic review and meta-analyses. *Medicine (Baltimore).* 2019;98(26):e16121. doi: 10.1097/MD.0000000000016121.
3. Zhang Q., Zhang S., Cao X., Liu L., Liu Y., Li R. The effect of remnant preservation on tibial tunnel enlargement in ACL reconstruction with hamstring autograft: a prospective randomized controlled trial. *Knee Surg. Sports Traumatol Arthrosc.* 2014;22(1):166-173. doi: 10.1007/s00167-012-2341-7.
4. Rodeo S.A., Kawamura S., Kim H.J., Dynybil C., Ying L. Tendon healing in a bone tunnel differs at the tunnel entrance versus the tunnel exit: an effect of graft-tunnel motion? *Am J Sports Med.* 2006;34(11):1790-800. doi: 10.1177/0363546506290059.
5. Chen B.C., Sun R., Wang X.F., Shao D.C., Lu B., Chen J.Q. [The incidence and variation of tunnel enlargement after anterior cruciate ligament reconstruction]. *Zhonghua Wai Ke Za Zhi*. 2007;45(2):78-81. (In Chinese).
6. Pereira H., Correlo V.M., Silva-Correia J., Oliveira J.M., Reis R.L., Espregueira-Mendes J. Migration of «bioabsorbable» screws in ACL repair. How much do we know? A systematic review. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(4):986-994. doi: 10.1007/s00167-013-2414-2.
7. Lubowitz J.H. All-inside anterior cruciate ligament graft link: graft preparation technique. *Arthrosc Tech.* 2012;1(2):e165-168. doi: 10.1016/j.eats.2012.06.002.
8. Smith P.A., Stannard J.P., Pfeiffer F.M., Kuroki K., Bozynski C.C., Cook J.L. Suspensory Versus Interference Screw Fixation for Arthroscopic Anterior Cruciate Ligament Reconstruction in a Translational Large-Animal Model. *Arthroscopy*. 2016;32(6):1086-1097. doi: 10.1016/j.arthro.2015.11.026.
9. Tegner Y., Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res.* 1985;(198):43-49.
10. Slastinin V.V., Yarygin N.V., Parshikov M.V., Sychevsky M.V., Fain A.M. [Modified technique for preparation and placement of quadrupled semitendinosus autograft in anterior cruciate ligament reconstruction]. *Genij Ortopedii.* 2019;25(3):277-284. (In Russian). doi: 10.18019/1028-4427-2019-25-3-277-284.
11. Badran M.A., Moemen D.M. Hamstring graft bacterial contamination during anterior cruciate ligament reconstruction: clinical and microbiological study. *Int Orthop.* 2016;40(9):1899-1903. doi: 10.1007/s00264-016-3168-5.
12. Bernard M., Hertel P., Hornung H., Cierpinski T. Femoral insertion of the ACL. Radiographic quadrant method. *Am J Knee Surg.* 1997;10(1):14-21.
13. Mochizuki Y., Kaneko T., Kawahara K., Toyoda S., Kono N., Hada M. et al. The quadrant method measuring four points is as a reliable and accurate as the quadrant method in the evaluation after anatomical double-bundle ACL reconstruction. *Knee Surg*

Sports Traumatol Arthrosc. 2018;26(8):2389-2394. doi: 10.1007/s00167-017-4797-y.

14. Amis A.A., Jakob R.P. Anterior cruciate ligament graft positioning, tensioning and twisting. *Knee Surg Sports Traumatol Arthrosc.* 1998;6 Suppl 1:S2-12. doi: 10.1007/s001670050215.
15. Kumar S., Kumar A., Kumar R. Accurate Positioning of Femoral and Tibial Tunnels in Single Bundle Anterior Cruciate Ligament Reconstruction Using the Indigenously Made Bernard and Hurtle Grid on a Transparency Sheet and C-arm. *Arthrosc Tech.* 2017;6(3):e757-e761. doi:10.1016/j.eats.2017.02.005.
16. Lysholm J., Gillquist J. Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. *Am J Sports Med.* 1982;10(3):150-154.
17. Magnitskaya N.E., Ryazantsev M.S., Maisigov M.N., Logvinov A.N., Zaripov A.R., Korolev A.V. [Translation, validation and cultural adaptation of orthopaedic questionnaire IKDC 2000 subjective knee form to measure knee function]. *Genij Ortopedii.* 2019;25(3);348-354. (In Russian). doi: 10.18019/1028-4427-2019-25-3-348-354.
18. Collins N.J., Misra D., Felson D.T., Crossley K.M., Roos E.M. 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 11:208-228. doi: 10.1002/acr.20632.
19. Mayr R., Smekal V., Koidl C., Coppola C., Fritz J., Rudisch A. et al. Tunnel widening after ACL reconstruction with aperture screw fixation or all-inside reconstruction with suspensory cortical button fixation: Volumetric measurements on CT and MRI scans. *Knee.* 2017;24(5):1047-1054. doi: 10.1016/j.knee.2017.06.007.
20. Sabzevari S., Rahnemai-Azar A.A., Shaikh H.S., Arner J.W., Irrgang J.J., Fu F.H. Increased lateral tibial posterior slope is related to tibial tunnel widening after primary ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2017;25(12):3906-3913. doi: 10.1007/s00167-017-4435-8.
21. DeFroda S.F., Karamchedu N.P., Owens B.D., Bokshan S.L., Sullivan K., Fadale P.D. et al. Tibial tunnel widening following anterior cruciate ligament reconstruction: A retrospective seven-year study evaluating the effects of initial graft tensioning and graft selection. *Knee.* 2018;25(6):1107-1114. doi: 10.1016/j.knee.2018.08.003.
22. Weber A.E., Delos D., Oltean H.N., Vadasdi K., Cavanaugh J., Potter H.G., Rodeo S.A. Tibial and Femoral Tunnel Changes After ACL Reconstruction: A Prospective 2-Year Longitudinal MRI Study. *Am J Sports Med.* 2015;43(5):1147-1156. doi: 10.1177/0363546515570461.
23. Chevallier R., Klouche S., Gerometta A., Bohu Y., Herman S., Lefevre N. Bioabsorbable screws, whatever the composition, can result in symptomatic intraosseous tibial tunnel cysts after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(1):76-85. doi: 10.1007/s00167-018-5037-9.
24. Shumborski S., Heath E., Salmon L.J., Roe J.P., Linklater J.P., Facek M., Pinczewski L.A. A Randomized Controlled Trial of PEEK Versus Titanium Interference Screws for Anterior Cruciate Ligament Reconstruction With 2-Year Follow-up. *Am J Sports Med.* 2019;47(10): 2386-2393. doi: 10.1177/0363546519861530.
25. Mayr R., Heinrichs C.H., Eichinger M., Coppola C., Schmoelz W., Attal R. Biomechanical comparison of 2 anterior cruciate ligament graft preparation techniques for tibial fixation: adjustable-length loop cortical button or interference screw. *Am J Sports Med.* 2015;43(6): 1380-1385. doi: 10.1177/0363546515574062.
26. Colombet P., Graveleau N., Jambou S. Incorporation of Hamstring Grafts Within the Tibial Tunnel After Anterior Cruciate Ligament Reconstruction: Magnetic Resonance Imaging of Suspensory Fixation Versus Interference Screws. *Am J Sports Med.* 2016;44(11):2838-2845. doi: 10.1177/0363546516656181.
27. Buelow J.U., Siebold R., Ellermann A. A prospective evaluation of tunnel enlargement in anterior cruciate ligament reconstruction with hamstrings: extracortical versus anatomical fixation. *Knee Surg Sports Traumatol Arthrosc.* 2002;10(2):80-85. doi: 10.1007/s00167-001-0267-6.
28. Stolarz M., Ficek K., Binkowski M., Wróbel Z. Bone tunnel enlargement following hamstring anterior cruciate ligament reconstruction: a comprehensive review. *Phys Sportsmed.* 2016;45(1):31-40. doi: 10.1080/00913847.2017.1253429.
29. Mayr R., Smekal V., Koidl C., Coppola C., Fritz J., Rudisch A. et al. Tunnel widening after ACL reconstruction with aperture screw fixation or all-inside reconstruction with suspensory cortical button fixation: Volumetric measurements on CT and MRI scans. *Knee.* 2017;24(5):1047-1054. doi: 10.1016/j.knee.2017.06.007.
30. Choi N.H., Son K.M., Victoroff B.N. A pitfall of transfix fixation during anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2008;16(5):479-481. doi: 10.1007/s00167-008-0489-y.
31. Vecchini E., Micheloni G.M., Corbo V.R., Perusi F., Dib G., Magnan B. A complication following ACL reconstruction using bioabsorbable cross-pins. *Acta Biomed.* 2016;87 Suppl 1:122-126.
32. Ahn J.H., Lee Y.S., Choi S.H., Chang M.J., Lee D.K. Single-bundle transtibial posterior cruciate ligament reconstruction using a bioabsorbable cross-pin tibial back side fixation. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(5):1023-1028. doi: 10.1007/s00167-011-1769-5.
33. Slastinin V.V., Fain A.M., Vaza A.Y. [Bone tunnel widening after anterior cruciate ligament autoplasty with hamstrings (literature review)]. [Russian Sklifosovsky Journal «Emergency Medical Care»]. 2017;6(3):233-237. (In Russian). doi: 10.23934/2223-9022-2017-6-3-233-237.

AUTHORS' INFORMATION:

Vladimir V. Slastinin — Orthopaedic Surgeon, Kuskovo University Clinic; Assistant, Department of Traumatology, Orthopedics and Disaster Medicine, A.I. Yevdokimov Moscow State University of Medicine and Dentistry, Moscow, Russian Federation

Nikolai V. Yarygin — Dr. Sci. (Med.), Corresponding Member of RAS, Professor, Head of the Traumatology, Orthopedics and Disaster Medicine Chair, A.I. Yevdokimov Moscow State University of Medicine and Dentistry, Moscow, Russian Federation

Mikhail V. Parshikov — Dr. Sci. (Med.), Professor, Department of Traumatology, Orthopedics and Disaster Medicine, A.I. Yevdokimov Moscow State University of Medicine and Dentistry, Moscow, Russian Federation

Aleksei M. Fain — Dr. Sci. (Med.), Head of the Orthopaedic Department, N.V. Sklifosovskiy Scientific Research Institute, Moscow, Russian Federation

Mikhail V. Sychevsky — Cand. Sci. (Med.), Head of the Orthopaedic Department, Kuskovo University Clinic, A.I. Yevdokimov Moscow State University of Medicine and Dentistry, Moscow, Russian Federation

Mikhail V. Govorov — Assistant, Department of Traumatology, Orthopedics and Disaster Medicine, A.I. Yevdokimov Moscow State University of Medicine and Dentistry, Moscow, Russian Federation