Original Article
https://doi.org/10.21823/2311-2905-2020-26-4-80-92

Gender Differences of the ACL Insertion Sites

Dmitry A. Malanin[1,2], Ilya V. Volodin[1,2], Ilya A. Suchilin[1,2], Maxim V. Demeshchenko[1,2]

[1]*Volgograd State Medical University, Volgograd, Russia*
[2]*Volgograd Science Medical Center, Volgograd, Russia*

Abstract

Background. The modern principles of reconstruction of the anterior cruciate ligament (ACL) and well-known surgical techniques do not take into account the peculiarities of the anatomical structure of the female knee. This happens due to insufficient substantiation that these peculiarities could influence the results of the treatment. ***The purpose of this study*** was to obtain new data on the structure of the areas of the ACL attachment, taking into consideration patient's gender and the surgical anatomy. ***Materials and Methods.*** 40 unpaired "fresh" anatomical preparations of the human female and male knees were studied. After preparation of the knee joints, the morphometry of the distal femoral epiphysis and the proximal tibial epiphysis was carried out by a digital sliding caliper according to 16 parameters. The shape, size, area, and the distance of the ACL attachment center from individual bone structures were assessed. The obtained data were correlated with the gender type of the knee structure. ***Results.*** The distal femoral epiphysis of the "female" type knee joint compared with the "male" type revealed the significant differences ($p<0.05$) in the following parameters: the width of the condyles at the level of the transepicondylar line, the width of the intercondylar fossa, the length and height of the lateral condyle, and the ratio of the condyles width at the level of the transepicondylar line to the height of the lateral condyle. The tibial proximal epiphysis showed the gender differences in the articular surface frontal and sagittal dimensions, the width of the intercondylar eminence and the posterior slope of the tibial epiphysis articular surface. These features determined the different proportions of the female knee structure. The area of the anterior cruciate ligament femoral attachment and its center in the "female" type of structure were located 3 mm distal and 1.5 mm posteriorly (anteriorly and downwardly in arthroscopic imaging). The area of the tibial attachment of the same ligament and its center were localized 2 mm anteriorly in comparison with the "male" type structure. ***Conclusion.*** The discovered anatomical differences made it possible to distinguish the "female" and "male" types of the knee structure. The topography of the anterior cruciate ligament attachment areas is gender specific. This should be taken into account in the anatomical reconstruction of the ligament.

Keywords: gender anatomy, ACL, knee morphometry, anatomical reconstruction.

Funding: state budgetary funding.

Cite as: Malanin D.A., Volodin I.V., Suchilin I.A., Demeshchenko M.V. [Gender Differences of the ACL Insertion Sites]. *Travmatologiya i ortopediya Rossii* [Traumatology and Orthopedics of Russia]. 2020;26(4): 80-92. (In Russian). doi: 10.21823/2311-2905-2020-26-4-80-92.

Ilya V. Volodin, e-mail: volodin_ili@mail.ru

Received: 21.05.2020. Accepted for publication: 28.08.2020.

Introduction

According to the literature, in cases of traumatic knee joint injuries, women are more predisposed to anterior cruciate ligament (ACL) ruptures than men [1, 2, 3, 4, 5]. The risk ratio of such injuries in some studies is estimated as 1:1.4–9.5, respectively, in men and women [6, 7, 8].

Predisposition to ACL injuries in women has multifactorial causes, among which some knee joint anatomical features [2, 9, 10, 11, 12, 13]. Particularly, in case of ACL injuries high risk of developing anteroposterior and rotational instability is associated with a more pronounced posterior tibial slope compared to the same indicator in men and lower tibiofemoral joint congruence [8, 9, 14, 15, 16, 17]. There are also number of other differences in the distal femur anatomical structure, which allow us to distinguish the so-called "female" type of knee joint, particularly in gender-specific endoprostheses design developing 18, 19, 20, 21].

Modern principles of ACL reconstruction and well-known surgical techniques do not account knee joint anatomical features in women due to the insufficient validity of their influence on the treatment results [22, 23, 24, 25, 26].

Our study hypothesis was the assumption about "female" type of femur and tibia condyles size influence on topography of ACL attachment and bone tunnels for ACL reconstruction.

The aim of the study was to obtain new data on the structure of ACL attachment areas, based on the gender and surgical anatomy.

Materials and Methods

The material for the study was 40 unpaired human knee joint cadaver specimens, of which 20 were from female individuals, and 20 – from men. The average age of the studied women and men was 54±3.4 and 57±5.0 years ($p>0.05$). The height of women during life reached 165±3.9 cm, men-168±4.4 cm ($p>0.05$).

The criteria for exclusion from the study were the presence of pronounced degenerative changes in the joint, dysplasia, signs of previous intra-articular fractures, ACL injuries.

To obtain anatomical specimens was performed anterior approach to the knee joint, soft tissue was removed, a digital sliding caliper with an accuracy of 50 microns (Topex, Poland) performed distal femur morphometry in 10 parameters (Fig. 1): the femoral condyles width at the level of transepicondylar line (A-B), the shape of the femoral intercondylar notch, the width of the femoral intercondylar notch by the M. Wada c coauthors method (H-I) [27], the lateral femoral condyle width (G-H), the lateral femoral condyle height (C-D), the lateral femoral condyle length (K-L), the medial femoral condyle width (I-J), the medial femoral condyle height (E-F), the medial femoral condyle length (K-L), the ratio of condyles width at the transepicondylar line level to the lateral femoral condyle height (A-B/C-D).

The femoral intercondylar notch with its anatomical structures was U-shaped cut out with oscillating saw (Fig. 2).

Then the ACL femoral attachment was dissected, determined its location on the lateral femoral condyle inner surface, marked a common border, defined shape and set the anatomical center (see Fig. 1 b).

Likewise, after patella and soft tissues removal was carried out proximal tibia morphometry for 6 parameters (see Fig. 1): the frontal tibial plateau size (M-N), the sagittal tibial plateau size (P-O), the posterior tibial slope angle, the tibial intercondylar eminence length, the tibial intercondylar eminence width (Q-R), the distance between the medial and lateral intercondylar tubercles tops, after that tibial articular surface was completely removed with the oscillating saw.

The study of ACL tibial attachment area began with removal of the remaining ACL remnant, delineating the ACL general border using a marker. The form of ACL attachment area was determined and established its anatomical

center (Fig. 3). Then were marked ACL and its attachment area zones of contact with the surrounding bone structures of the articular surface — the lateral, medial tubercles and posterior edge of the intercondylar eminence, which occur with a frequency almost equal to 100%.

Based on a comparison of morphometric parameters that characterize the anatomical proportions of the distal femur and the proximal tibia in men and women, only those that had statistically significant differences and described the so-called "female" type of knee joint were selected. The assessment of the ACL attachment area (shape, size, area, topography) was correlated with the "female" or "male" types of knee joint.

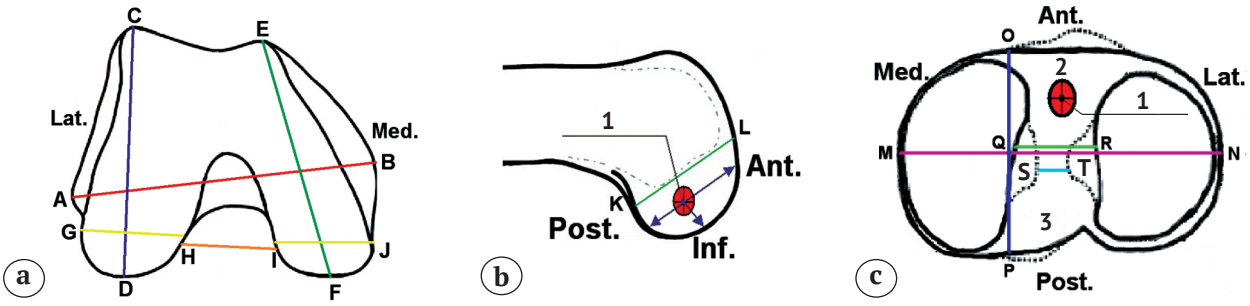

Figure 1. The scheme of measurements of the studied parameters of the distal femoral epiphysis and proximal tibial epiphysis: a — the distal femoral epiphysis in the axial plane at the level of the femoral epicondyles: A–B — width of the femoral condyles at the level of transepicondylary line; H–I — width of the femoral intercondylar fossa; G–H — width of the femoral lateral condyle; C–D — height of the femoral lateral condyle; I–J — width of the femoral medial condyle; E–F — height of the femoral medial condyle; b — the distal femoral epiphysis in the sagittal plane at the level of the inner surface of the femoral lateral condyle: 1 — center of the anterior cruciate ligament; K–L — length of the femoral lateral condyle; the arrows indicate the distance from the center of the ACL to the lower, anterior and posterior edges of the articular cartilage of the femoral lateral condyle; c — the tibial proximal epiphysis plateau in the axial plane: 2 — the anterior edge of the intercondylar eminence; 3 — the posterior edge of the intercondylar eminence; M–N — frontal size of the tibial plateau; P–O — sagittal size of the tibial plateau; 2–3 — the length of the tibial intercondylar eminence measured from the anterior to posterior edges of the intercondylar eminence; Q–R — width of the tibial intercondylar eminence; S–T — the distance between the tops of the medial and lateral intercondylar tubercles

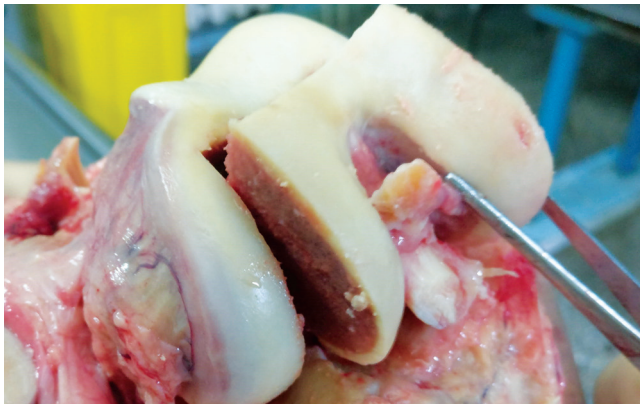

Figure 2. Extraction of a part of the distal femoral epiphysis with anatomical structures of the intercondylar fossa

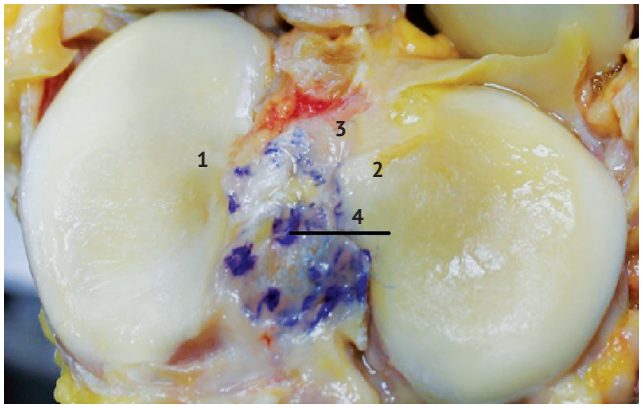

Figure 3. The relationship of the ACL attachment area center with the surrounding bone structures of the tibial proximal epiphysis articular surface: 1 — medial tubercle; 2 — lateral tubercle; 3 — the posterior edge of the intercondylar eminence; 4 — the center of the ACL attachment area

Statistical analysis

Variational and statistical processing of the results was carried out in the SPSS 17.0 program (Microsoft ®, USA), using the methods of descriptive statistics and the comparative nonparametric Mann-Whitney U-test. The result was considered statistically significant at $p<0.05$.

Results

The most significant "female" type distal femur parameters were the femoral condyles width at the level of transepicondylar line, the width of the femoral intercondylar notch, the lateral femoral condyle length and height, the ratio of condyles width at the transepicondylar line level to the lateral femoral condyle height (Table 1). The average values of these parameters were statistically significantly different from "male" type of knee joints and created the characteristic proportions of the distal femur in women — a smaller width of the condyles and the intercondylar notch, as well as a shorter length of the lateral femoral condyle.

The ratio of condyles width at the transepicondylar line level to the lateral femoral condyle height was slightly smaller in women than in men.

In the end, the distal femur shape in women looked more narrow, but greater in height, which causes V-shaped intercondylar notch, which differs from a U-shape in men (Fig. 4).

The distal femur of 20 female specimens had significant differences in these 6 parameters in 19 (95%) cases.

A comparative study of 6 morphometric parameters of the proximal tibia in female and male knee joints revealed significant differences in 4 of them (Table 2).

The frontal and sagittal sizes of the proximal tibia, the tibial intercondylar eminence length in men were larger than in women ($p<0.05$). Its front size provided some visual differences and formed the "female" type of proximal tibia (Fig. 5). On the contrary, posterior tibial slope angle in women were average on 2° larger than in men ($p<0.05$). The proximal tibia of 20 female specimens had significant differences in these 6 parameters in 19 (95%) cases.

Table 1

Forty specimens of the distal femur parameters

Parameters	Female*	Male*	p
The femoral condyles width at the level of transepicondylar line (A-B), mm	75,8 ± 2,7 (69,3–79,6)	87,2 ± 2,0 (82,1–93,4)	<0,05
The shape of the femoral intercondylar notch	V-shape (85% of cases)	U-shape (95% of cases)	<0,05
The width of the femoral intercondylar notch (H-I) , mm	21,5±1,2 (18,7–24,7)	25,2±1,7 (21,4–28,3)	<0,05
The lateral femoral condyle width (G-H) , mm	22,1±1,1 (19,4–24,4)	25,9±1,9 (21,6–31,4)	<0,05
The lateral femoral condyle height (C-D) , mm	60,1±3,0 (52,9–65,8)	64,7±2,5 (58,2–69,4)	<0,05
The lateral femoral condyle length (K-L) , mm	35,9 ± 1,8 (32,2–42,0)	38,4±2,2 (32,7–42,6)	<0,05
The medial femoral condyle width (I-J) , mm	25,5±1,9 (22,4–29,9)	26,6±1,3 (23,8–28,7)	>0,05
The medial femoral condyle height (E-F) , mm	61,8±2,4 (56,5–65,4)	62,9±3,2 (67,3–54,2)	>0,05
The medial femoral condyle length (K-L) , mm	35,3±2,9 (29,8–40,4)	37,6±3,0 (30,6–45,1)	>0,05
The ratio of condyles width at the transepicondylar line level to the lateral femoral condyle height (A-B/C-D)	1,26±0,04 (1,17–1,36)	1,35±0,05 (1,25–1,51)	<0,05

* The data is presented as the mean value ± the mean square deviation (the range of minimum and maximum values).

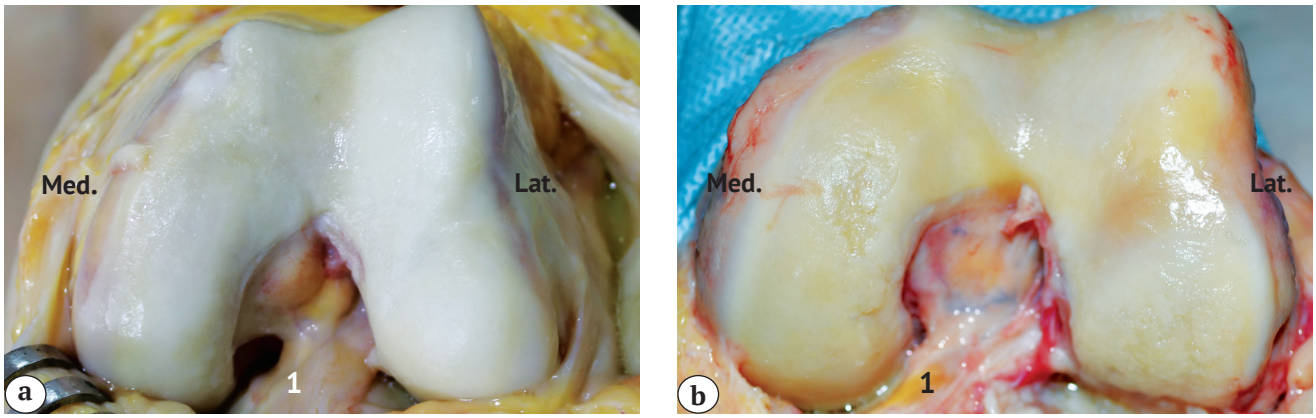

Figure 4. The gender differences in the shape of the distal part and intercondylar fossa of the femur:
a — "female" type of structure with a V-shaped intercondylar fossa;
b — "male" type of structure with a U-shaped intercondylar fossa; 1 — ACL

Table 2

40 specimens of the proximal tibia parameters

Parameters	Female*	Male*	p
The frontal tibial plateau size (M-N), mm	69,1±1,7 (64,7–71,9)	80,1±2,5 (73,3–83,1)	<0,05
The sagittal tibial plateau size (O-P), mm	46,8±2,8 (40,4–51,3)	51,9±2,6 (42,1–56,3)	<0,05
The posterior tibial slope angle, o.	5,9±1,6 (3,2–9,8)	3,8±1,2 (1,3–7,4)	<0,05
The tibial intercondylar eminence length, mm	26,0±1,5 (24,2–29,4)	27,8±1,6 (24,1–31,0)	>0,05
The tibial intercondylar eminence width (Q-R), mm	22,6±2,2 (15,9–27,3)	25,2±1,2 (23,4–29,7)	<0,05
The distance between the medial and lateral intercondylar tubercles tops, mm	10,4±1,0 (7,2–12,1)	11,3±0,6 (9,3–12,8)	>0,05

* The data is presented as the mean value ± the mean square deviation (the range of minimum and maximum values).

Subsequent measurements of the ACL attachment to the inner surface of the lateral femoral condyle showed smaller values of long and wide dimensions in women compared to men — 11.1±1.0 mm (range 10.0-12.2 mm (♀)) and 15.1±2.4 mm (range 11.1–18.6 mm (♂)), 9.0±2.9 mm (range 6.9–10.8 mm (♀)) and 12.7±3.9 mm (range 9.9–16.6 mm (♂)), respectively. The area of the femoral ACL attachment in the female joints, which had an oval shape, was 67.9±10.4 mm^2 (range from 49.4 to 82.1 mm^2). In male joints, the attachment area had more elongated oval shape, its area reached 135.7±39.1 mm^2 (range from 99.3 to 180.6 mm^2). The center of the ACL attachment area was located at a distance of 9.2±1.4 mm (range 6.5-11.9 mm) from the anterior edge of the articular cartilage in women and 12.2±1.9 mm (range 9.1–16.8 mm) in men. The distance to the lower edge of the lateral femoral condyle articular cartilage was 6.4±1.0 mm (range 4.3-8.7 mm) and 7.9±0.9 mm (range 6.1–9.2 mm), respectively. The posterior edge of the articular cartilage was distanced from the ACL attachment area center in women by greater distance of 7.8±0.9 mm (range 5.7–10.3 mm) than in men by 6.6±1.1 mm (range 4.2–9.1 mm).

Thus, the smaller area of the femoral ACL attachment and its center in the "female" type of knee joints was located more distal (3 mm) and posteriorly (1.5 mm) (front and down under arthroscopic visualization) compared to the ACL attachment area and its center in the "male" type of knee joints (Fig. 6).

Gender-specific differences with the anatomical proportions of the proximal tibia and the relief of its articular surface, ACL attachment area location was also revealed. The latter, in contrast to that in the knee joints in men, had a more pronounced oval shape, which correlated with the predominance of the long (anteroposterior) size of the tibial intercondylar eminence over the latitudinal (transverse) one. Thus, the length of the tibial intercondylar eminence in women was 26.0±1.4 mm (range 24.2-29.4 mm), in men-27.8±1.6 mm (range 24.1–31.1 mm); width — 22.5±2.2 mm (range 15.9-27.3 mm) and 25.2±1.2 mm (range 23.4–29.7 mm), respectively. At the same time, the distance between the medial and lateral intercondylar tubercles tops of the intercondylar eminence in female joints did not exceed 10.4±1.0 mm (range 7.2–12.1 mm), and in male joints — 11.3±0.6 mm (range 9.3–12.8 mm). The length of the ACL attachment area showed slight differences — 12.2±2.2 mm in women (range 8.0-15.9 mm) and 13.3±1.8 mm in men (range 10.3–16.3 mm). In contrast, the width differed by more than 3 mm — 8.0±1.0 mm (range 6.5-11.7 mm) in women and 11.5±1.8 mm

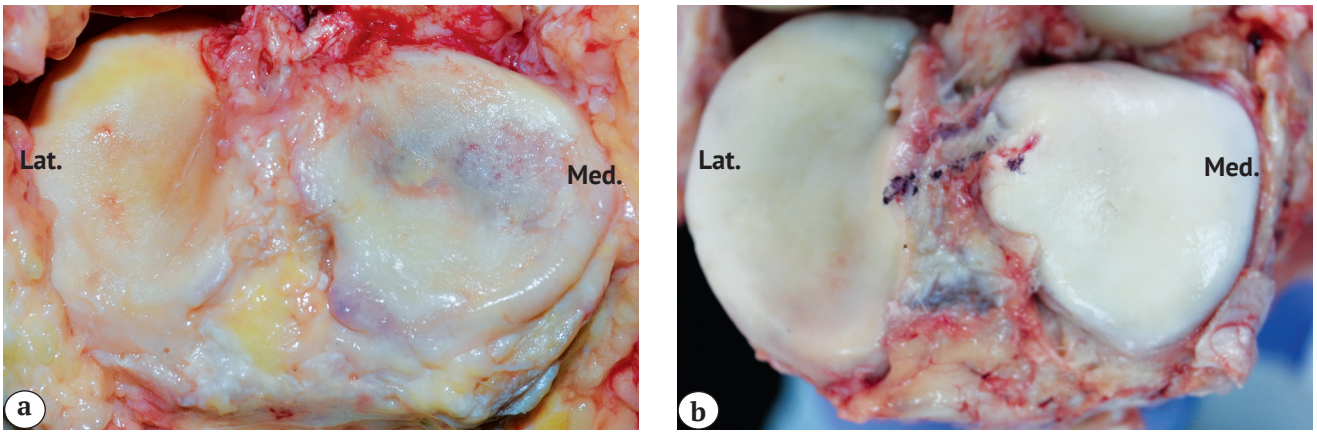

Figure 5. The gender differences of tibial plateau structure: a — "female" type; b — "male" type

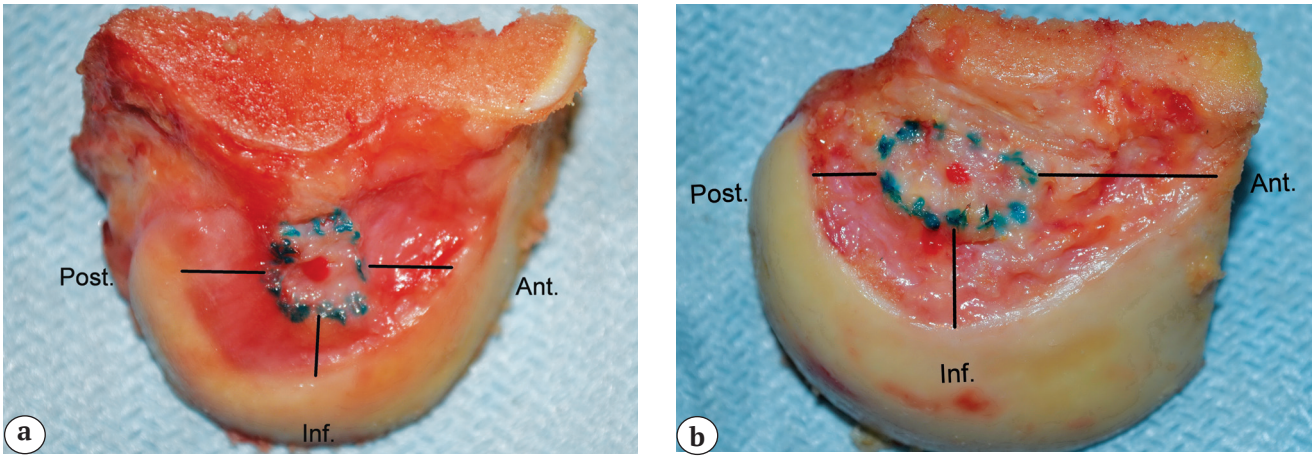

Figure 6. The topography of the ACL femoral attachment: a — "female" type, b — "male" type (the position of the knee joint during arthroscopy)

(range 8.4–16.5 mm) in men. As a result, the area of the tibial ACL attachment area in the "female" type of joints had a smaller value — 76.6±16.4 mm^2 (range 53.2–115.6 mm^2) than in the "male" type of joints — 120.1±24.2 mm^2 (range 71.4–192.4 mm^2).

A comparative change in the topographic relationships between the individual formations of the femoral articular surface in the female and male knee joints resulted in a slight increase in the distance from the ACL attachment center to the posterior edge of the intercondylar eminence. In the first case, this value was 14.9±1.2 mm (range 12.7-17.2 mm), in the second — 12.9±1.5 mm (range 10.2–15.3 mm).

Thus, the smaller area of the tibial ACL attachment and its center in the "female" type of knee joints were located slightly anteriorly (by 2 mm) compared to the ACL attachment and its center in the "male" type of knee joints (Fig. 7).

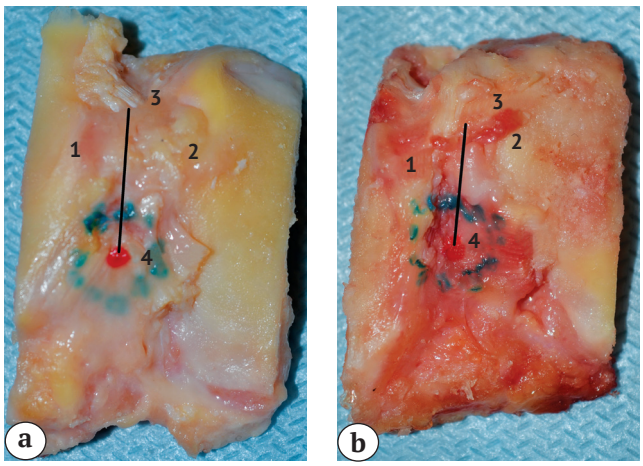

Figure 7. The topography of the ACL tibial attachment:
a — "female" type; b — "male" type;
1 — medial tubercle;
2 — lateral tubercle;
3 — the posterior edge of the intercondylar eminence; 4 — the center of the ACL attachment area

Discussion

A significantly higher risk of ACL injuries in women compared to men is confirmed by statistical data obtained assessing different types of injuries and physical activity. Thus, the frequency of non-contact injuries of the ACL, according to studies by D. E. Gwinn et al. and L. J. Huston et al., was 3-9 times higher in women than in men [7, 28]. In women's football, this parameter is 2-6 times higher, in women's rugby-2 times, in women's freestyle wrestling-4 times, in women's basketball — 4 times, when women pass military training — 10 times higher compared to men [7, 29, 30]. At the same time, women have a 33.7% higher risk of ACL reconstruction in the opposite knee joint that has already undergone surgical treatment [10]. It is no coincidence that in some countries from the beginning of the 2000s, the number of ACL reconstructions, even in younger athletes 18 years, increased by more than 30% [31].

Predisposition to ACL injury in women explained by a combination of individual factors, among which the most important are anatomical features of the knee joint. A relatively smaller resistance to anterior and rotational tibia displacements with the typical for ACL injuries mechanisms, the injury occurs in women due to increase of posterior tibial slope angle [16]. Significant vulnerability to ACL injury is explained by the relatively more pronounced discongruence of the knee joint medial and lateral compartments due to the smaller radius of curvature of the femoral condyles, the smaller concavity of the medial surface and, on the contrary, greater convexity of the lateral surface of the tibial plateau [8, 9, 32]. The relatively smaller width of the lateral femoral condyle also contributes to decrease in the stability of the knee joint in women [14].

Increased Q angle (17°), according to the research, increases the risk of noncontact ACL rupture, especially when there are narrow and low femoral intercondylar notch — quite typical structure features of the knee joint in women [33, 34, 35], which was observed in our study. On the contrary, the relatively shorter length of the ACL in women found by R. F. LaPrade and co-authors is still a subject of discussion, and the consideration of this factor as a predictor of ligament ruptures remains insufficiently justified [34].

In this regard, it is impossible to ignore the higher frequency of joint hypermobility in comparison with men, which demonstrates dependence on the hormonal background of the female body and tends to increase in the menstrual cycle first 10-14 days [2, 9, 33, 36].

The increased risk of ACL injury in women is also explained by neuromuscular and kinematic factors that lead to the coordination relationships violations between individual groups of thigh muscles, which, in turn, increases more than twice peak loads in the knee joint at the time of abduction, axial pressure and internal rotation of the tibia [2, 9, 11, 13].

The influence of ACL injury predictors, the number of which is greater in women than in men, seems to persist in connection with subsequent surgical treatment, rehabilitation, as well as a return to the previous level of physical activity or sports. Nevertheless, the claim of a higher risk of the reconstructed ACL injury in women compared to men does not have significant evidence to date and remains controversial [10, 37, 38].

Following the anatomical principles of the ACL reconstruction, such as restoring of the individual shape, size, spatial location of the graft, close to the native ACL of a particular patient, becomes crucial in achieving positive treatment results [39, 40, 41, 42]. On the contrary, the anatomically incorrect tunnel location for conducting and fixing the graft is recognized among the leading causes of unsuccessful outcomes of primary and revision ACL reconstructions, regardless of the patient gender. According to separate studies, their frequency is 22-79% of cases among other causes that lead to negative treatment results. Moreover, the wrong location of the femoral tunnel occurs in more than 35% of patients, while the wrong choice of the femoral and tibial tunnels topography becomes the main cause of such outcomes in more than 70% of patients [41, 42, 43].

At the beginning of the study, we assumed the influence of the distal femur and proximal tibia condyles size, typical for the "female" type of knee joint, on the topography and structure of the ACL attachment areas and the location of their centers, and in cases of ligament reconstruction — on the topography of the femoral and tibial tunnels intended for the graft conduction.

Confirmation or confutation of this hypothesis required a comparative study of the knee joint anatomical structure features in women. The study revealed several parameters that determine the typical distal femur and proximal tibia proportions, which differ from the knee joints in men. The average values of the femoral condyles width at the level of transepicondylar line, the width of the femoral intercondylar notch, length and height of the lateral femoral condyle, and the ratio of condyles width at the transepicondylar line level to the lateral femoral condyle height, as well as tibial plateau frontal and sagittal sizes, intercondylar eminence width and the posterior tibial slope had significant differences related to gender.

The results obtained are consistent with previous studies, in which the authors found differences in the anatomical structure of the knee joint and identified several of its morphological types related not only to gender, but also to race [18, 20]. The most characteristic feature of the "female" type was the "narrow and deep joint", which formed the basis for the design of the so-called gender-specific endoprostheses [21, 44, 45].

The anatomical structure of the ACL attachment areas has been studied quite well, and current research is mainly aimed at identifying the relationships between their metric parameters and individual simpler and more measurable parameters for the purpose of preoperative planning. In general, the size of the ACL attachment areas in the knee joint in women was significantly smaller (by 36-49%) than in men. At the same time, in some clinical studies, there was a significant variability in the size of the ACL attachment areas, often not related to gender [46, 47]. Thus, S. Kopf and co-authors revealed significant, but weak correlations of the ACL attachment area size with the height, weight, and body mass index of each patient [48]. In the studies of Gali J. S. et al. and Y. B. Park et al., we can find the conclusion that there is a stable relationship between the anthropometric data and the size of the ligament attachment areas [49, 50]. The correlation between the latter and the area of the medial surface of the lateral femoral condyle or the tibial articular surface was established by the results of the study of T. Iriuchishima and co-authors [46].

The difference in our study was the consideration of the structure and topography of the ACL attachment areas according the identified "female" type features of the knee joint. The proportions of the distal femur and the proximal tibia typical for the "female" type correlated with a smaller area (by 36-49%) and a more oval shape of the ACL attachment area, mainly due to a decrease in latitudinal dimensions. Topographically, the femoral ACL attachment area and its center were located at

3 mm distal and 1.5 mm posterior (anteriorly and downwards in arthroscopic imaging) than in men. The tibial ACL attachment area and its center were displaced 2 mm anteriorly.

The analysis of modern literature data in an attempt to get an answer to the question:" Does the female gender, along with a higher risk of ACL ruptures, determine the comparatively worse results of its reconstruction? " — does not yet allow us to speak unequivocally about this. In a number of comparative clinical studies and systematic reviews, there were no significant differences in the functional results of ACL reconstruction, as well as in the values of the tibia anterior displacement, regardless of the used graft [24, 51, 52, 53].

In a number of similar studies, the results of surgical treatment in women were significantly worse than in men, including in terms of anterior tibia displacement, quality of life and recovery of the physical activity level [54, 55, 56]. In relation to the plastic material used, A. Gobbi and co-authors and M. V. Paterno co-authors justified the preference for an autograft from the patellar ligament "bone-tendon-bone" with two bone blocks, which in women is less stretching in the postoperative period compared to the tendons of the popliteal muscles [57, 58]. On the contrary, other authors have concluded that gender differences are not decisive for graft choice for ACL reconstruction [51, 59, 60].

Thus, according to the literature, we are currently entitled to say the higher risk of ACL injury in women and the anatomical structure features of their knee joint as one of the main factors predisposing to such injuries. It should also be noted that there is still no convincing clinical evidence about the influence of the gender factor on the results of primary ACL reconstruction. The latter circumstance, however, does not negate the fundamental approaches to improving the technique of anatomical ACL reconstruction, taking into account the existing gender-specific knee joint structure features and the ACL attachment areas.

Conclusion

The anatomical proportions that characterize the distal femur and proximal tibia structure in women and men allow us to distinguish the "female" and "male" types of the knee joint, and also underlie some morphometric and topographic differences in the ACL attachment areas.

The smaller area of the femoral ACL attachment and its center in the "female" type of knee joints are located 3 mm distal and 1.5 mm posteriorly (anteriorly and downwards in arthroscopic imaging) compared to the ACL attachment area and its center in the "male" type of knee joints. Similarly, the area of the tibial ACL attachment and its center in the comparative aspect are shifted 2 mm anteriorly.

Gender-specific differences in the ACL attachment area structure make it necessary to take them into account in existing surgical approaches to performing anatomical ACL reconstruction.

References

1. Schilaty N.D., Bates N.A., Nagelli C., Krych A.J., Hewett T.E. Sex-based differences in knee kinetics with anterior cruciate ligament strain on cadaveric impact simulations. *Orthop J Sports Med.* 2018;6(3):23-25. doi: 10.1177/2325967118761037.
2. Griffin L.Y., Agel J., Albohm M.J., Arendt E.A., Dick R.W., Garrett W.E. et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg.* 2000;8(3):141-150. doi: 10.5435/00124635-200005000-00001.
3. Hutchinson M.R., Ireland M.L. Knee injuries in female athletes. *Sports Med.* 1995;19:288-302. doi: 10.2165/00007256-199519040-00006.
4. Arendt E., Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. *Am J Sports Med.* 1995;23:694-701. doi: 10.1177/036354659502300611.
5. Nicholls M., Aspelund T., Ingvarsson T., Briem, K. Nationwide study highlights a second peak in ACL tears for women in their early forties. *Knee Surg Sports Traumatol Arthrosc.* 2017;26:648-654. doi: 10.1007/s00167-017-4807-0.
6. Stevenson H., Webster J., Johnson R., Beynnon B. Gender differences in knee injury epidemiology among competitive alpine ski racers. *Iowa Orthop J.* 1998;18:64-66.
7. Gwinn D.E., Wilckens J.H., McDevitt E.R., Ross G., Kao T.C. The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. *Am J Sports Med.* 2000;28(1):98-102. doi: 10.1177/03635465000280012901.
8. Schneider A., Si-Mohamed S., Magnussen R.A., Lustig S., Neyret P., Servien E. Tibiofemoral joint congruence is lower in females with ACL injuries than males with ACL injuries. *Knee Surg Sports Traumatol Arthrosc.* 2018;26:1375-1383. doi: 10.1007/s00167-017-4756-7.
9. Hewett T.E., Myer G.D., Ford K.R., Heidt R.S., Colosimo A.J., McLean S.G. et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005;33(4):492-501. doi: 10.1177/0363546504269591.
10. Snaebjörnsson T., Svantesson E., Sundemo D., Westin O., Sansone M., Engebretsen L. et al. Young age and high BMI are predictors of early revision surgery after primary anterior cruciate ligament reconstruction: a cohort study from the Swedish and Norwegian knee ligament registries based on 30,747 patients. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(11):3583-3591. doi: 10.1007/s00167-019-05487-2.
11. Iguchi J., Tateuchi H., Taniguchi M., Ichihashi N. The effect of sex and fatigue on lower limb kinematics, kinetics, and muscle activity during unanticipated sidestep cutting. Knee Surg Sports Traumatol Arthrosc. 2014;22(1):41-48. doi: 10.1007/s00167-013-2526-8.
12. Trigsted S.M., Cook D.B., Pickett K.A., Cadmus-Bertram L., Dunn W.R, Bell D.R. Greater fear of reinjury is related to stiffened jump-landing biomechanics and muscle activation in women after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2018;26:3682-3689. doi: 10.1007/s00167-018-4950-2.
13. Sigurethsson H.B., Briem K. Cluster analysis successfully identifies clinically meaningful knee valgus moment patterns: frequency of early peaks reflects sex-specific ACL injury incidence. *J Exp Orthop.* 2019;6(1):37. doi: 10.1186/s40634-019-0205-5.
14. Hashemi J., Chandrashekar N., Mansouri H., Gill B., Slauterbeck J. R., Schutt R.C. et al. Shallow medial tibial plateau and steep medial and lateral tibial slopes: new risk factors for anterior cruciate ligament injuries. *Am J Sports Med.* 2010;38(1):54-62. doi: 10.1177/0363546509349055.
15. Wahl C.J., Westermann R.W., Blaisdell G.Y., Cizik A.M. An association of lateral knee sagittal anatomic factors with noncontact ACL injury: sex or geometry? *J Bone Joint Surg Am.* 2012;94(3):217-226. doi: 10.2106/JBJS.K.00099.
16. Hohmann E., Bryant A., Reaburn P., Tetsworth K. Is there a correlation between posterior tibial slope and non-contact anterior cruciate ligament injuries? *Knee Surg Sports Traumatol Arthrosc.* 2011;19(1):109-114. doi: 10.1007/s00167-011-1547-4.
17. Brandon M.L., Haynes P.T., Bonamo J.R., Flynn M.I., Barrett G.R., Sherman M.F. The association between posterior–inferior tibial slope and anterior cruciate ligament insufficiency. *Arthroscopy.* 2006;22(8):894-899. doi: 10.1016/j.arthro.2006.04.098.
18. Everhart J.S., Chaudhari A.M.W., Flanigan D.C. Creation of a simple distal femur morphology classfication system. *J Ortopedic Research.* 2016;34(6):924-931. doi: 10.1002/jor.23102.
19. Hohe J., Ateshian G.A., Reiser M., Englmeier K., Eckstein F. Surface size, curvature analysis, and assessment of knee joint incongruity with MRI in vivo. *Magn Reson Med.* 2002;47(3):554-561. doi: 10.1002/mrm.10097.
20. Mahfouz M., Abdel Fatah E.E., Bowers L.S., Scuderi G. Three-dimensional morphology of the knee reveals ethnic differences. *Clin Orthop Relat Res.* 2012;470(1):172–185. doi: 10.1007/s11999-011-2089-2.
21. Gillespie R.J., Levine A., Fitzgerald S.J., Kolaczko J., DeMaio M., Marcus R.E. et al. Gender differences in

the anatomy of the distal femur. *J Bone Joint Surg Br*. 2011;93(3):357-363. doi: 10.1302/0301-620X.93B3.24708.
22. Aldrian S., Valentin P., Wondrasch B., Krusche-Mandl I., Ostermann R.C., Platzer P. et al. Gender differences following computer-navigated single- and double-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2014;22:2145-2152. doi: 10.1007/s00167-013-2649-y.
23. Siebold R., Webster K.E., Feller J.A., Sutherland A.G., Elliott J. Anterior cruciate ligament reconstruction in females: a comparison of hamstring tendon and patellar tendon autografts. *Knee Surg Sports Traumatol Arthrosc.* 2006;14(11):1070-1076. doi: 10.1007/s00167-006-0100-3.
24. Ryan J., Magnussen R., Cox C., Hurbanek J., Flanigan D., Kaeding C. ACL reconstruction: Do outcomes differ by sex? A systematic review. *J Bone Joint Surg Am*. 2014;96(6):507-512. doi: 10.2106/JBJS.M.00299.
25. Tan S.H., Lau B.P., Khin L.W., Lingaraj K. The importance of patient sex in the outcomes of anterior cruciate ligament reconstructions: a systematic review and meta-analysis. *Am J Sports Med*. 2016;44(1):242-254. doi: 10.1177/0363546515573008.
26. Paterno M.V., Weed A.M., Hewett T.E. A between sex comparison of anterior-posterior knee laxity after anterior cruciate ligament reconstruction with patellar tendon or hamstrings autograft: a systematic review. *Sports Med*. 2012;42(2):135-152. doi: 10.2165/11596940-000000000-00000.
27. Wada M., Tatsuo H., Baba H., Asamoto K., Nojyo Y. Femoral intercondylar notch measurements in osteoarthritic knees. *Rheumatology*. 1999;38(6),554-558. doi: 10.1093/rheumatology/38.6.554.
28. Huston L.J., Greenfield M.L., Wojtys E.M. Anterior cruciate ligament injuries in the female athlete. Potential risk factors. *Clin Orthop Relat Res*. 2000;(372):50-63. doi: 10.1097/00003086-200003000-00007.
29. Caplan N., Kader D.F. Knee injury patterns among men and women in collegiate basketball and soccer: NCAA data and review of literature. In: Classic Papers in Orthopaedics. London: Springer; 2014. p. 153-155. doi: 10.1007/978-1-4471-5451-8_37.
30. Sutton K.M., Bullock J.M. Anterior cruciate ligament rupture: differences between males and females. *J Am Acad Orthop Surg*. 2013;21:41-50. doi: 10.5435/JAAOS-21-01-41.
31. Herzog M.M., Marshall S.W., Lund J.L., Pate V., Mack C.D., Spang J.T. Incidence of anterior cruciate ligament reconstruction among adolescent females in the United States, 2002 Through 2014. *JAMA Pediatr*. 2017;171(8):808-810. doi: 10.1001/jamapediatrics.2017.0740.
32. McNair P.J., Wood G.A., Marshall R.N. Stiffness of the hamstring muscles and its relationship to function in anterior cruciate ligament deficient individuals. *Clin Biomech (Bristol, Avon)*. 1992;7(3):131-137. doi: 10.1016/0268-0033(92)90027-2.
33. Alenton-Geli E., Myer G.D., Silvers H.J. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: Mechanisms of injury and underlying risk factors. *Knee Surg. Sports Traumatol. Arthrosc*. 2009;17(7):705-729. doi: 10.1007/s00167-009-0813-1.
34. LaPrade R.F., Burnett Q.M. Femoral intercondylar notch stenosis and correlation to anterior cruciate ligament injuries. A prospective study. *Am J Sports Med*. 1994;22(2):198-202. doi: 10.1177/036354659402200208.
35. Bouras T., Fennema P., Burke S., Bosman H. Stenotic intercondylar notch type is correlated with anterior cruciate ligament injury in female patients using magnetic resonance imaging. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(4):1252-1257. doi: 10.1007/s00167-017-4625-4.
36. Kumar B., Lenert P. Joint hypermobility syndrome: recognizing a commonly overlooked cause of chronic pain. *Am J Med*. 2017;130(6):640-647. doi: 10.1016/j.amjmed.2017.02.013.
37. Lind M., Menhert F., Pedersen A.B. The first results from the Danish ACL reconstruction registry: epidemiologic and 2 year follow-up results from 5,818 knee ligament reconstructions. *Knee Surg Sports Traumatol Arthrosc*. 2009;17:117-124. doi: 10.1007/s00167-008-0654-3.
38. Capogna B.M., Mahure S.A., Mollon B., Duenes M.L., Rokito A.S. Young age, female gender, Caucasian race, and workers' compensation claim are risk factors for reoperation following arthroscopic ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2019;(28):2213-2223. doi: 10.1007/s00167-019-05798-4.
39. Ouanezar H., Blakeney W.G., Fernandes L.R., Borade A., Latrobe C., Temponi E.F. et al. Clinical outcomes of single anteromedial bundle biologic augmentation technique for anterior cruciate ligament reconstruction with consideration of tibial remnant size. *Arthroscopy*. 2018;34(3):714-722. doi: 10.1016/j.arthro.2017.08.309.
40. Yasen S.K., Borton Z.M., Eyre-Brook A.I., Palmer H.C., Cotterill S.T., Risebury M.J. et al. Clinical outcomes of anatomic, all-inside, anterior cruciate ligament (ACL) reconstruction. *Knee*. 2017;24(1):55-62. doi: 10.1016/j.knee.2016.09.007.
41. Tachibana Y., Shino K., Mae T., Iuchi R., Take Y., Nakagawa S. Anatomical rectangular tunnels identified with the arthroscopic landmarks result in excellent outcomes in ACL reconstruction with a BTB graft. *Knee Surg Sports Traumatol Arthrosc*. 2019;27:2680-2690. doi: 10.1007/s00167-018-5300-0.
42. Rothrauff B.B., Jorge A., de Sa D., Kay J., Fu F.H., Musahl V. Anatomic ACL reconstruction reduces risk of post-traumatic osteoarthritis: a systematic review with minimum 10-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2019;28:1072-1084. doi: 10.1007/s00167-019-05665-2.
43. Achtnich A., Ranuccio F., Willinger L., Pogorzelski J., Imhoff A.B., Braun S. et al. High incidence of partially anatomic tunnel placement in primary single-bundle ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2018;26:462-467. doi: 10.1007/s00167-017-4555-1.
44. Greene K.A. Gender-specfic design in total knee arthroplasty. *J Arthroplasty*. 2007;22:27-31. doi: 10.1016/j.arth.2007.05.019.
45. Yoshioka Y., Siu D., Cooke T.D. The anatomy and functional axes of the femur. *J Bone Joint Surg Am*. 1987;69(6):873-880.
46. Iriuchishima T., Ryu K., Aizawa S., Fu F.H. Proportional evaluation of anterior cruciate ligament foot-

print size and knee bony morphology. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(11):3157-3162. doi: 10.1007/s00167-014-3139-6.
47. Gali J.C., Camargo D.B., Oliveira F.A.M., Pereira R.H.N., Silva P.A.C.D. Descriptive anatomy of the anterior cruciate ligament femoral insertion. *Rev Bras Ortop.* 2018;53(4):421-426. doi: 10.1016/j.rboe.2018.05.004.
48. Kopf S., Pombo M.W., Szczodry M., Irrgang J., Fu F.H. Size variability of the human anterior cruciate ligament insertion sites. *Am J Sports Med.* 2011;39(1):108-113. doi: 10.1177/0363546510377399.
49. Gali J.C., Del Giglio D.B., Patriarcha L.F., Cruz B.A.P., Gali Filho J.C. Correlation bettween Individual Anthropometric Characteristics and Anterior Cruciate Ligament Tibial Fovea Measurements. *Rev Bras Ortop (Sao Paulo).* 2020;55(1):88-94. doi: 10.1055/s-0039-1700816.
50. Park Y.B., Song Y.S., Kim S.C., Park Y.G., Ha C.W. The size of tibial footprint of anterior cruciate ligament and association with physical characteristics in Asian females. *Arch Orthop Trauma Surg.* 2015;135(7):985-992. doi: 10.1007/s00402-015-2229-3.
51. Siebold R., Webster K.E., Feller J.A., Sutherland A.G., Elliott J. Anterior cruciate ligament reconstruction in females: a comparison of hamstring tendon and patellar tendon autografts. *Knee Surg Sports Traumatol Arthrosc.* 2006;14:1070-1076. doi: 10.1007/s00167-006-0100-3.
52. Tan S.H.S., Lau B.P.H., Krishna L. Outcomes of Anterior Cruciate Ligament Reconstruction in Females Using Patellar-Tendon-Bone versus Hamstring Autografts: A Systematic Review and Meta-Analysis. *J Knee Surg.* 2019;32(8):770-787. doi: 10.1055/s-0038-1669916.
53. Kautzner J., Kos P., Hanus M., Trc T., Havlas V. A comparison of ACL reconstruction using patellar tendon versus hamstring autograft in female patients: a prospective randomised study. *Int Orthop.* 2015;39(1):125-130. doi: 10.1007/s00264-014-2495-7.
54. Noojin F.K., Barrett G.R., Hartzog C.W., Nash C.R. Clinical comparison of intraarticular anterior cruciate ligament reconstruction using autogenous semitendinosus and gracilis tendons in men versus women. *Am J Sports Med.* 2000;28(6):783-789. doi: 10.1177/03635465000280060301.
55. Ageberg E., Forssblad M., Herbertsson P., Roos E.M. Sex differences in patient-reported outcomes after anterior cruciate ligament reconstruction: data from the Swedish knee ligament register. *Am J Sports Med.* 2010;38(7):1334-1342. doi: 10.1177/0363546510361218.
56. Aldrian S., Valentin P., Wondrasch B., Krusche-Mandl I., Ostermann R.C., Platzer P. et al. Gender differences following computer-navigated single- and double-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2014;22:2145-2152. doi: 10.1007/s00167-013-2649-y.
57. Gobbi A., Domzalski M., Pascual J. Comparison of anterior cruciate ligament reconstruction in male and female athletes using the patellar tendon and hamstring autografts. *Knee Surg Sports Traumatol Arthrosc.* 2004;12:534-539. doi: 10.1007/s00167-003-0486-0.
58. Paterno M.V., Huang B., Thomas S., Hewett T.E., Schmitt L.C. Clinical factors that predict a second ACL injury after ACL reconstruction and return to sport: preliminary development of a clinical decision algorithm. *Orthop J Sports Med.* 2017;5(12):1-7. doi: 10.1177/2325967117745279.
59. Ferrari J.D., Bach B.R., Bush-Joseph C.A., Wang T., Bojchuk J. Anterior cruciate ligament reconstruction in men and women: An outcome analysis comparing gender. *Arthroscopy.* 2001;17(6):588-596. doi: 10.1053/jars.2001.24686.
60. Magnussen R.A., Trojani C., Granan L.P., Neyret P., Colombet P., Engebretsen L. et al. Patient demographics and surgical characteristics in ACL revision: a comparison of French, Norwegian, and North American cohorts. *Knee Surg Sports Traumatol Arthrosc.* 2015;23:2339-2348. doi: 10.1007/s00167-015-3835-x.

AUTHORS' INFORMATION:

Dmitry A. Malanin — Dr. Sci. (Med.), Professor, Head of Department for Traumatology, Orthopaedics and Field Surgery, Volgograd State Medical University; Head of Laboratory for Clinical and Experimental Orthopaedics, Volgograd Medical Research Center, Volgograd, Russia. malanin67@mail.ru; http://orcid.org/0000-0001-7507-0570

Ilya V. Volodin — PhD Student, Volgograd State Medical University; Researcher, Volgograd Medical Research Center, Volgograd, Russia. volodin_ili@mail.ru;
https://orcid.org/0000-0002-8037-1674

Ilya A. Suchilin — Cand. Sci. (Med.), Associated Professor, Department of Traumatology, Orthopaedics and Field Surgery, Volgograd State Medical University; Researcher, Volgograd Medical Research Center, Volgograd, Russia. omnio@mail.ru;
https://orcid.org/0000-0001-7375-5365

Maxim V. Demeshchenko — Cand. Sci. (Med.), Assistant Professor, Department of Traumatology, Orthopaedics and Field Surgery, Volgograd State Medical University; Researcher, Volgograd Medical Research Center, Volgograd, Russia. maximus275@yandex.ru; https://orcid.org/0000-0003-1797-2431

Authors' contributions:

Malanin D.A. —literatute review, hypothesis development, study design, text preparation.

Volodin I.V. — collection and processing of the material, text preparation, data statistical processing.

Suchilin I.A. — study design, collection and processing of the material.

Demeshchenko M.V. — collection and processing of the material, database preparation, data statistical processing.

All authors made a significant contribution to the research and preparation of the article and read and approved the final version before its publication. They agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests: the authors declare that there are no competing interests.