Genij Ortopedii. 2023;29(2):159-166.

Original article

https://doi.org/10.18019/1028-4427-2023-29-2-159-166

The influence of extension-flexion gap imbalance on the joint function in primary total knee arthroplasty

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Abstract

Introduction A poorly balanced, unstable, or stiff joint is a major cause of residual pain, dissatisfaction, and revision after total knee replacement (TKA), but the definition of a well-balanced joint remains debatable. **The aim** of the study was to explore the influence of the knee space and the extension-flexion gap being accurately restored in primary TKA on the knee function and the quality of life of the patient. **Material and methods** A prospective, single-center, randomized, controlled study was performed for 41 patients with grade 3-4 knee osteoarthritis. (K-L): the first group (n = 21) underwent primary TKA with the method proposed for precise realignment of the extension-flexion gap, the second group (n = 20) underwent standard arthroplasty. The patients had CT scans of the knee performed preoperatively and postoperatively, and VAS scale pain, knee joint scales: OKS, FJS-12, KSS (pain and function), SF-36 (parameters: PF, RP, BP, GH, VI, SF, RE, MH) were used at 3, 6 and 12 months. **Results** Comparison of the standing height of the joint space preoperatively and postoperatively showed a high statistical significance measuring about 20.7 % in frontal plane (group 1: 2.06 ± 2.368, group 2: 2.629 ± 2.455, p < 0.001), 28.2 % in the sagittal projection (group 1: 2.657 ± 2.143, group 2: 3.7 ± 1.717, p < 0.001), i.e., the method proposed allowed for more accurate positioning of the extension gap by 20.7 %, the flexion gap by 28.2 % and more accurate positioning of the knee space level. Preoperative and postoperative VAS, OKS, FJS-12 and SF-36 scores showed significant positive dynamics in both groups with no statistically significant difference between the groups. A statistically significant difference was seen in the functional KSS score in the groups measuring 90.6 ± 3.5 in group $1_{\text{12 months after surgery}}$ and 85.6 ± 4.2 (p < 0.001) in group $2_{\text{12 months after surgery}}$. **Conclusion** The study demonstrated the simple and effective technique proposed for positioning the flexion and extension gap of the knee joint in primary TKA and facilitated more accurate positioning of the implant and improved knee function at standard testing 12 months after surgery.

Keywords: extension-flexion gap, primary total knee arthroplasty

For citation: Lychagin A.V., Rukin Ya.A., Gritsyuk A.A., Pang Zhengyu. The influence of extension-flexion gap imbalance on the joint function in primary total knee arthroplasty. *Genij Ortopedii*. 2023;29(2):159-166. doi: 10.18019/1028-4427-2023-29-2-159-166

INTRODUCTION

A poorly balanced, unstable or stiff joint is a major cause of residual pain [1], dissatisfaction [2], and revision after total knee replacement (TKA) [3-7]. However, the quantification of a well-balanced joint remains a matter of controversy [8].

Many authors consider this clinical problem and advocate creation of a balance between the flexion and extension spaces of the knee joint during surgery [9, 10]. The standard solution for flexion contracture of the knee joint is to increase (+2 mm) the distal resection of the femur to increase the extension gap and facilitate full extension of the knee joint, however, this does not always remain in balance with the flexion gap, which may also need to be adjusted. An increase in distal resection of the femur elevates the articular line, which can affect the patellofemoral joint and cause anterior pain in the knee after arthroplasty [11]. The level of the knee space is a constant value, but the balance of the flexion-extension gap depends on the position of the knee joint. Many researchers [12] have shown that if the size of the flexion gap exceeds the size of the extensor, then, on the one hand, this gives a good range of motion in the postoperative period. However, the imbalance of the joint space with the limb flexed between 0° and 90° leads to the formation of a gap between the femoral component and the liner after surgery [13], which accelerates the wear of polyethylene by 2-3 times [14]. Studies have shown that increased freedom of flexion during implantation will lead to instability and imbalance of the ligaments in the mid-flexion after implantation [15]. The main concept in primary total knee arthroplasty is to maintain the level of the joint space and equalize the flexion-extension gap. Total joint replacement with a deliberately increased distal resection or the predominance of one of the gaps leads to patient dissatisfaction.

The aim of the study was to explore the influence of the knee space and the extension-flexion gap being accurately restored in primary TKA on the knee function and the quality of life of the patient.

MATERIAL AND METHODS

The study was conducted at the Clinic of Traumatology, Orthopedics and Joint Pathology of the First Moscow State Sechenov Medical University, the Ministry of Health of Russia (Sechenov University) between January 2019 and July 2021. Inclusion criteria were primary idiopathic osteoarthritis of the knee Kellgren-Lawrence grade 3-4, BMI < 35 kg/m^2. Exclusion criteria were specific osteoarthritis, and severe valgus-varus deformities (more than 10 degrees), defects in the bones of the knee joint, fractures of the femur or tibia and their consequences, instability of the ligaments and extension apparatus of the knee. The study included 50 patients with 9 patients excluded during the study for various reasons (refusal, no communication, etc.) (Fig. 1), the rest were randomized into two groups (according to the method of random numbers). The first group underwent primary TKA with precise alignment of the flexion-extension gap, the second (control) group underwent standard TKA.

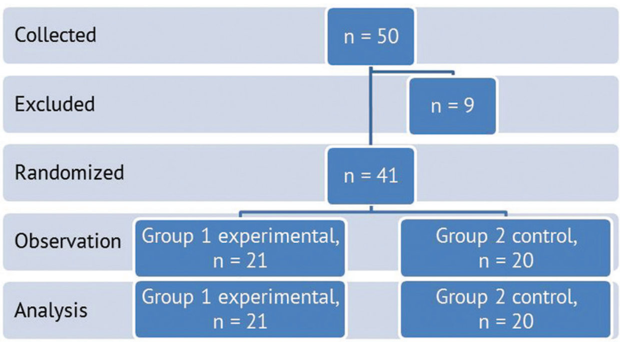

Fig. 1 Scheme of the dynamics in the distribution of participants at all stages of a randomized controlled trial

The final analysis was performed on a total cohort of 41 patients: 18 males and 23 females, mean age 66.5 ± 7.2 years (males: 67.2 ± 7.5, females: 65.9 ± 7.1, min. 43 years, max. 75 years, p = 0.587), average BMI measuring 32.0 ± 2.6 kg/m^2 (males: 31.9 ± 2.7 kg/m^2, females: 32.1 ± 2.6 kg/m^2, p = 0.857), gender of patients are presented in Table 1.

The patients underwent standard computed tomography (Toshiba Aquilion One 640-slice multispiral computed tomography) preoperatively and postoperatively. Images were obtained using the PACS system and measured by radiologists not participating in the study using the RadiAnt DICOM Viewer 2020.2 software.

The technique included preoperative planning: the first step was to determine the level of the knee space, which was measured by CT in the frontal projection from the line of the femoral condyles to the line of the articular space (Fig. 2a), choosing the scan from the tomogram with the distance between the condyles being the greatest. In the postoperative period, the level of the joint space was measured from the condyles of the femur (focusing on the size between the condyles of the femur) and the line of the femoral component. Then the thickness of the femoral component was measured (Fig. 2c), the level of resection of the largest of the condyles (usually medial) determined by subtracting the thickness of the femoral component from the articular line. A line of the knee was drawn along the most protruding points of the femoral condyles, and the distance to the head of the fibula measured from this line using another scan in the frontal plane, with the apex of the fibula head being maximally projected (Fig. 2b). The thickness of the tibial component and the liner was subtracted from this distance and a line of proximal resection of the tibia obtained; the size of the extension gap corresponded to the thickness of the femoral and tibial components plus the thickness of the polyethylene liner (Fig. 4d). Landmarks of the intercondylar line of the femur and the fibular head were used for postoperative measurement of the parameters of the extension joint space.

Table 1

Gender of patients by study groups

Description	Overall (n = 41)	Group 1 (n = 21)	Group 2 (n = 20)	p*
Age (years)	66.463 ± 7.211	63.762 ± 8.173	69.3 ± 4.758	0.012
Gender (M/F)	18/23	8/13	10/10	0.689
Right/left	20/21	9/12	11/9	0.726
Height (cm)	167.707 ± 9.696	167.238 ± 9.322	168.2 ± 10.294	0.755
Weight (kg)	90.244 ± 12.304	89.143 ± 10.603	91.4 ± 14.058	0.564
BMI (kg/m^2)	32.01 ± 2.603	31.826 ± 2.246	32.203 ± 2.979	0.649

*, $p < 0.05$

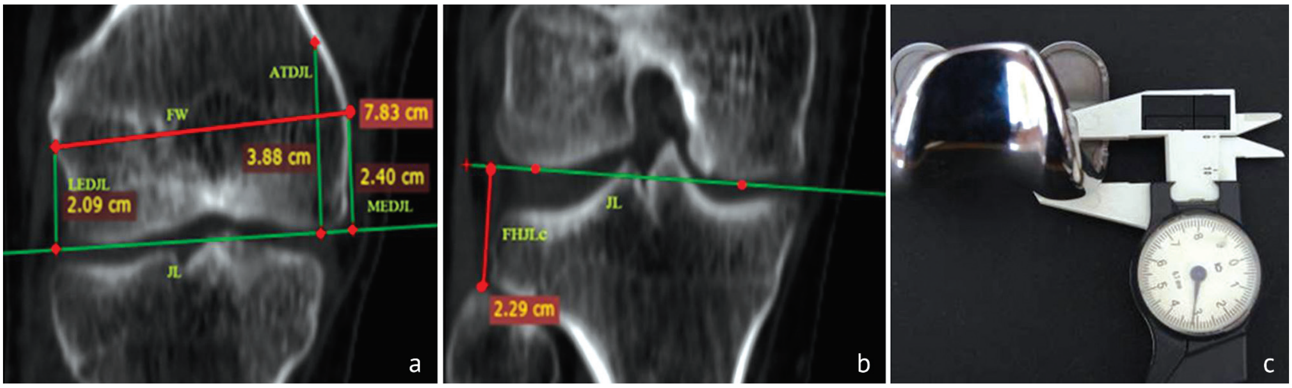

Fig. 2 CT scan of the knee joint, frontal projection, presurgical planning: (a) determination of the level of the knee space using the anatomical landmarks of the femur; (b) along the top of the fibular head; (c) the thickness of the femoral component measured

Planning of the flexion gap in the axial projection is the second step. A line was drawn through the most protruding parts of the posterior sections of the femoral condyles with perpendiculars descended from the lateral and medial epicondyles of the femur (Fig. 3a). The thickness of the posterior portions of the femoral component was subtracted from the largest perpendicular (usually 9 mm) with the difference reflecting the level of posterior resection required in relation to the femoral epicondyles (Fig. 3b). The third step included measurement of the level of the articular space in the sagittal projection along the reference point of the apex of the fibular head (Fig. 3c) and protraction of the required level of posterior resection of the femoral condyle in the sagittal projection from the mechanical axis of the femur (Fig. 3d).

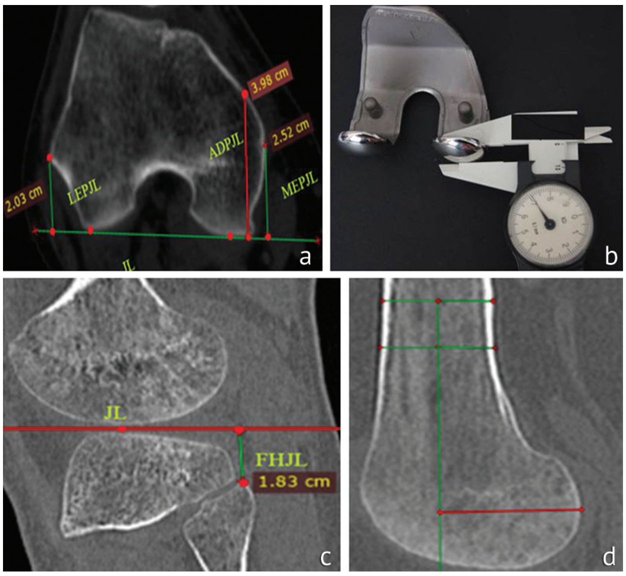

Fig. 3 CT scan of the knee joint, presurgical planning: (a) measurement of the distance from the condyles of the femur to the flexion line using an axial image; (b) measurement of the thickness of the posterior flange of the implant; (c) measurement of the level of the knee space relative to the fibula using a sagittal view; (d) measurement of the level of posterior resection of the femur

The surgical technique (clinical example) was aimed at accurate restoration of the level of the knee space and a uniform extension-flexion gap during primary TKA.

A 66-year-old patient N.G.I. diagnosed with right-sided gonarthrosis stage III. There were indications for total arthroplasty of the right knee joint. Preoperative computed tomography of the right knee joint was performed to measure the distance from the epicondyles of the right femur to the line drawn through the most protruding points of the posterior portions of the femoral condyles. The distance from the lateral epicondyle was 24 mm and 23 mm from the medial epicondyle. The size of the femoral component was determined as Zimmer Nex Gen LPS Right – F – thickness measuring 9 mm in the distal part. The thickness of the posterior portions of the femoral component was known to be 9 mm. The distance from the supracondylar line to the level of the posterior resection of the femoral condyles was 24 - 9 = 15 mm. Operation included medial arthrotomy with the patella retracted outward using a 15 cm median skin incision along the anterior surface of the right knee. Distal resection of the femoral condyles was performed according to the preoperative plan using the standard technique and an intramedullary guide (see the first step).

A proximal resection of the tibia was performed using the standard technique, an extramedullary guide according to the preoperative plan considering the thickness of the components and the extension gap was measured with expanding plates at the extension of 180°, and the compliance of the extension gap with the preoperative plan was determined. The size of the liner could be changed if needed. A 4-in-1 resection plate was placed on the distal sawdust of the femur with the knee flexed at an angle of 90 degrees, setting the posterior resection line and focusing on the medial and lateral epicondyles, the posterior incision was positioned according to preoperative planning and fixed (Fig. 4a). The resection line was laid off (by 15 mm, according to previous calculations) from the posterior cortical bone of the medial femoral condyle for measurements and the hyaline cartilage was exfoliated with a scalpel at the measurement site. The posterior portions of the femoral condyles was resected parallel to the line of the condyles (Fig. 4a). Then the remaining resections of the femur were performed (Fig. 4b). The corresponding fitting components of the implant were placed and the balance of the ligaments checked at the extension and flexion (Fig. 4c). The figure shows measurements of the extension-flexion gap (Fig. 4d). Soft tissue releases could be performed after provisional reduction and assessment of the knee function to obtain the range of motion as required to be followed by endoprosthetic components to be placed using bone cement (Fig. 4e).

Full extension of the knee was achieved intraoperatively with passive flexion of 135 degrees. The wound was sutured tightly in layers leaving drainage. Similar angles were achieved with active movements at 7 days of the rehabilitation. The patient reported no pain and was discharged for outpatient observation. The postoperative level of posterior resection of the femoral condyles could not be measured accurately with axial CT scan due to image artifacts and frontal and sagittal planes used to measure the articular space to characterize the extension gap focusing on the top of the fibular head (Fig. 5a) and the sagittal projection was used to measure the distance from the femoral axis to the edge of the implant which corresponded to the level of the flexion gap (Fig. 5b).

VAS, OKS, FJS-12, KSS (pain and function), SF-36 (parameters: PF, RP, BP, GH, VI, SF, RE, MH) questionnaires were used to evaluate the knee preoperatively and postoperatively.

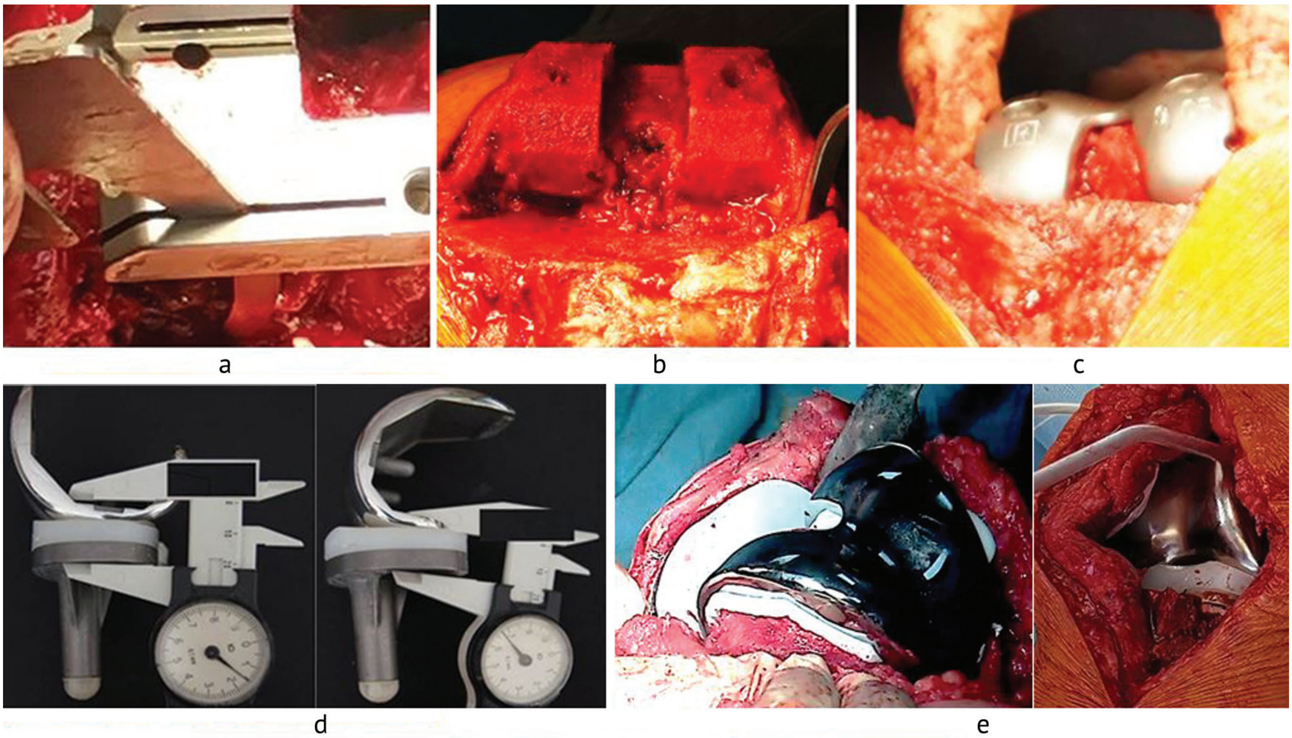

Fig. 4 Intraoperatively: (a) positioning and fixation of the instrument; (b) femoral condyles resected; (c) provisional implant and ligament balance; (d) measurement of the uniformity of the extension-flexion gap; (e) cement fixation of the implant

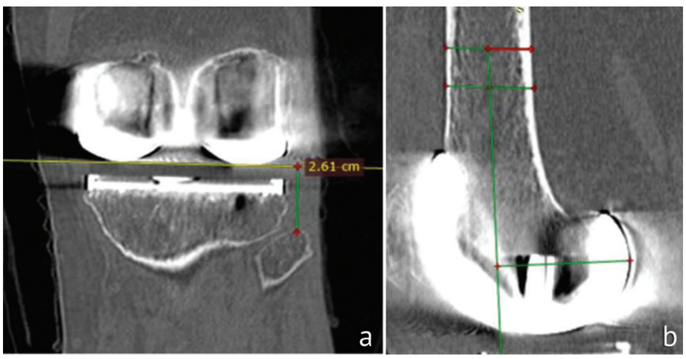

Fig. 5 Postoperative CT scan of the knee: (a) frontal view; (b) sagittal projection

The measurements entered an electronic database created in the Excel program with no changes made during the investigation. Statistical processing was produced with the IBM SPSS Statistics 22 software. We calculated the mean and standard error, compared variables in the group before surgery and at 1 year and between groups using Student's coefficients and χ^2. A p value < 0.05 was considered statistically significant in this study.

RESULTS

The patients underwent similar rehabilitation postoperatively to arrest acute pain was stopped, early active rehabilitation was initiated, flexion-extension gaps were measured using computed tomography of the knee (Table 2). Comparison of the error of the postoperative articular space in both planes showed high statistical significance: about 20.7 % (2.06 ± 2.368, group 1; 2.629 ± 2.455, group 2; p < 0.001) in the frontal plane, and 28.2 % (2.657 ± 2.143, group 1; 3.7 ± 1.717, group 2; p < 0.001) in the sagittal images. Based on the CT measurements, it can be concluded that the method offered allowed more accurate positioning of the extension gap by 20.7 % and the flexion gap of the knee by 28.2 %.

Significant positive dynamics in VAS score was noted in the groups preoperatively and postoperatively as compared to baseline values measuring 6.8 ± 1.7 before surgery; 0.8 ± 0.6 at 12 months after surgery in group 1; p < 0.001; 6.7 ± 1.7 before surgery and 1.1 ± 0.5 after surgery at 12 months in group 2; p < 0.001), however, there was no statistically significant difference between the groups (Fig. 6).

The OKS knee joint scale is used to assess the knee function before and after surgery. The dynamics in the OKS score showed a significant improvement in limb function after surgery compared to preoperative level with high statistical significance. There was no statistical significance between groups, despite slightly better dynamics in the experimental group (Fig. 7).

Pain and function of the knee are evaluated on the KSS scale. The analysis revealed a statistically significant dynamics in the KSS score in both groups before and after surgery. There was no difference in pain between the groups. The function KSS score was 90.6 ± 3.5 in group 1 and 85.6 ± 4.2 (p < 0.001) in group 2 at 12 months with a statistically significant difference noted between the groups (Fig. 8). The FJS-12, a validated patient-reported outcome measure demonstrated the same dynamics in assessment of artificial prosthesis awareness during daily activities at 12 months after surgery and 90 % of patients "forgot" about TKA, however, there was no statistically significant difference between the groups (Fig. 9).

Table 2

CT findings

Description		Patients: Group 1 (n = 21)	Patients: Group 2 (n = 20)	p
The height of the knee space in the frontal view, mm	pre-op	26.3 ± 2.6	26.4 ± 2.1	0.946*
	post-op	24.3 ± 2.9	23.8 ± 3.0	0.584*
Distance from the axis of the femur to the posterior surface of the medial condyle in the sagittal plane, mm	pre-op	38.3 ± 2.8	39.2 ± 2.8	0.323*
	post-op	41.9 ± 3.7	42.1 ± 3.0	0.874*
Difference in the articular space height in frontal view before and after surgery, mm		2.1 ± 2.4	2.6 ± 2.5	< 0.001**
Difference in the articular space height in sagittal projection before and after surgery, mm		-2.7 ± 2.1	-3.7 ± 1.7	< 0.001**

P < 0.05; * – p when comparing groups; ** – p when comparing groups before and after surgery.

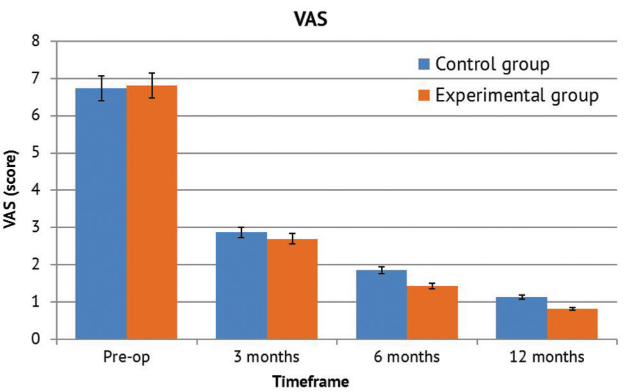

Fig. 6 Dynamics in VAS score

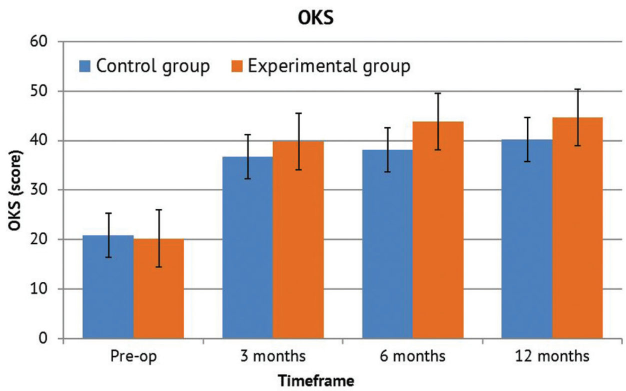

Fig. 7 Dynamics in OKS score

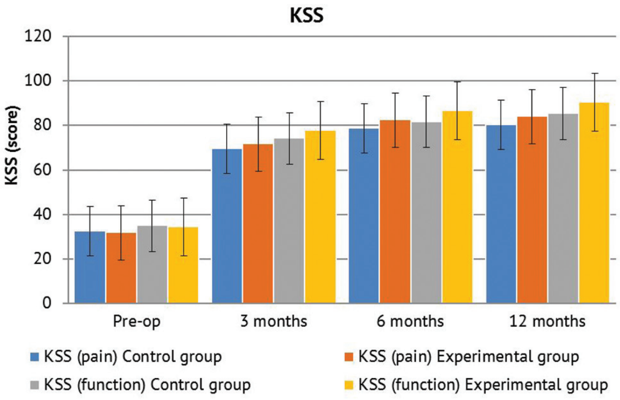

Fig. 8 Dynamics in KSS scores (pain and function)

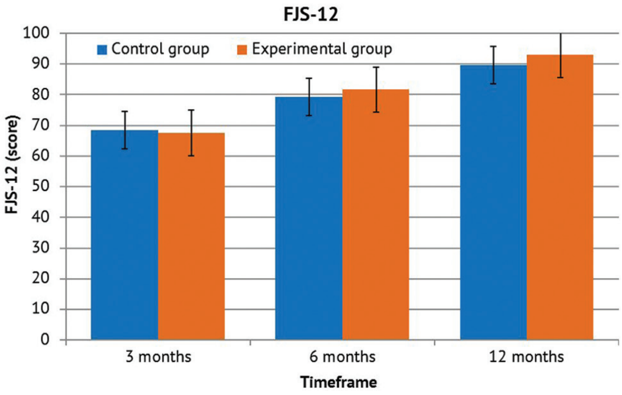

Fig. 9 Dynamics in FJS-12 scores

The dynamics in the patient's quality of life is the most informative parameter of the effective surgical treatment. Data on the SF-36 scale before and after surgery are presented in both groups in Figure 10. The variables showing the physical and mental parameters of the quality of life after surgery indicated a significant improvement in both groups, but no statistical difference was detected. Overall results of tests in both groups before and after surgery are presented in Table 3.

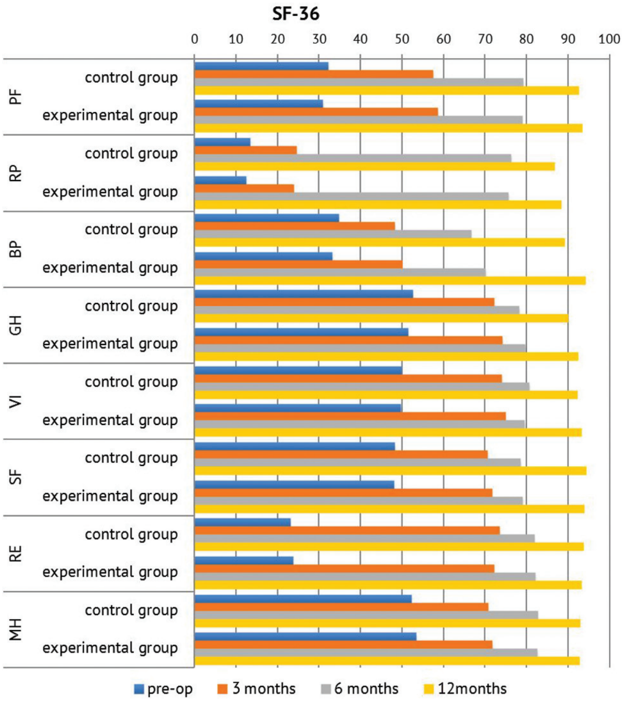

Fig. 10 Dynamics in changes in the parameters on the SF-36 scale

Table 3

The results of knee joint assessment scales

Description		Patients					
		Group 1 (n = 21)		p*	Group 2 (n = 20)		p**
		pre-op	At 12 months		pre-op	At 12 months	
VAS		6.8 ± 1.7	0.8 ± 0.6	< 0.001	6.7 ± 1.7	1.1 ± 0.5	< 0.001
OKS		20.2 ± 6.9	44.7 ± 1.0	< 0.001	20.9 ± 6.1	40.2 ± 0.8	< 0.001
FJS-12		–	93 ± 2.2	< 0.001	–	89.6 ± 2.3	< 0.001
KSS	(pain)	32.0 ± 5.4	84.2 ± 3.9	< 0.001	32.7 ± 6.2	80.4 ± 4.2	< 0.001
	(function)	34.5 ± 5.9	90.6 ± 3.5	< 0.001	35.2 ± 5.7	85.6 ± 4.2	< 0.001
SF-36	PF	30.9 ± 11.3	93.4 ± 4.2	< 0.001	32.2 ± 12.5	92.7 ± 4.5	< 0.001
	RP	12.3 ± 22.3	88.3 ± 8.8	< 0.001	13.3 ± 21.8	86.6 ± 9.3	< 0.001
	BP	33.1 ± 17.6	94.1 ± 3.0	< 0.001	34.6 ± 18.6	89.1 ± 4.5	< 0.001
	GH	51.4 ± 15.9	92.4 ± 3.5	< 0.001	52.6 ± 16.8	89.9 ± 3.7	< 0.001
	VI	49.6 ± 16.6	93.1 ± 3.4	< 0.001	49.7 ± 15.6	92.1 ± 4.4	< 0.001
	SF	47.9 ± 24.7	93.8 ± 3.3	< 0.001	48.2 ± 25.5	94.2 ± 4.2	< 0.001
	RE	23.7 ± 34.9	93.2 ± 3.1	< 0.001	22.9 ± 33.3	93.5 ± 3.2	< 0.001
	MH	53.3 ± 20.1	92.6 ± 4.4	< 0.001	52.2 ± 21.6	92.7 ± 5.1	< 0.001

p* – in the experimental (first) group preoperatively and postoperatively; p** – in the control (second) group preoperatively and postoperatively.

DISCUSSION

Preservation of the articular space level and the balance of the flexion-extension gap of the native knee joint is important in primary TKA. A reliable method has not yet been found. What is the correct guideline to determine the line of the knee joint on radiographs, CT or MRI and how to position it correctly during surgery

– these were the questions that researchers asked [16], which was the goal of our work.

The surgeon can adjust the position of the articular space during the primary TKA based on the thickness of the distal femoral osteotomy, which is equal to the thickness of the femoral component of the implant with the balance of the ligaments and the full range of motion being maintained. The surgeons are forced to increase the level of distal resection to achieve full extension with flexion contracture and ineffective posterior soft tissue release. But how to maintain the balance of the flexion and extension gaps if the joints are significantly deformed? Which of them is the most important, when the normal anatomy of the knee joint is changed, the joint gap is deformed, how to determine the location of the medial and lateral condyles of the femur, what anatomical landmark should and can be used? [17]

The use of anatomical landmarks to determine the position of the articular space and the definition of the resection line is widely used in clinical practice to recreate the flexion-extension gap. Soft tissue landmarks, such as the meniscus, can be used but they are not always informative during surgery [18], while bony landmarks are more reliable. The adductor tubercle, the medial and lateral epicondyles, the tibial tubercle, the fibular head, and the inferior pole of the patella are the most commonly used bony landmarks [19, 20, 21].

Surgeons can evaluate the landmarks on radiographs, CT scans, or MRI scans before surgery, or by palpation during surgery. This is effective if the contralateral knee is intact, but the use is limited. However, given the importance of positioning the level of the knee gap, with small changes or errors in the balance between the flexion and extension gap leading to pain or limitation of movement, worsening the results of TKA, it is important and necessary to identify landmarks for widespread use [22, 23, 24].

We offered a method for determining the level of the joint line, measuring the extension and flexion gaps, determining the resection line of the posterior surface of the femoral condyles, which allow precise restoration of the above parameters of the knee joint during primary TKA. You can focus on both preoperative planning and direct measurement of the extension gap during surgery, and adjust the level of resection of the posterior portions of the femoral condyle. The authors understand that the work has a number of disadvantages: the technique requires more time for measurements, the sample of patients is small, and it is necessary to perform an expensive CT scan of the knee joint before and after surgery. The absence of statistically significant differences with scales assessing the knee joint at 12 months after surgery requires longer follow-up periods. The authors understand the problem and continue to work towards understanding and improving the outcome of TKA. The authors are developing a measuring guide of a simple design, which will help to correctly and quickly navigate in the surgical wound to the level of the medial and external condyle that can be used in conjunction with traditional instruments and will allow achieving the results shown by the authors.

CONCLUSION

The study showed the simplicity and effectiveness of the technique proposed for positioning the flexion and extension spaces of the knee joint in primary TKA to allow more accurate location of the implant and improved knee function (KSS at 12 months after surgery).

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The article was submitted 22.06.2022; approved after reviewing 22.09.2022; accepted for publication 20.02.2023.

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*There is no **conflict of interest.***

***Funding** none.*

***Ethical expertise** Approved by the local ethics committee of Sechenov University, Protocol No. 2341 dtd 10/16/2018.*

***Informed consent** Patients consented to participate prior to enrollment in the study.*