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Evaluation of the efficacy of kinematic and mechanical alignment in primary total knee arthroplasty during the early postoperative period

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Mechanical alignment is widely accepted as a standard technique for total knee arthroplasty (TKA). However, approximately 20 % of patients remain dissatisfied with the outcomes. Recent studies suggest that an alternative method, known as kinematic alignment, could potentially improve functional outcomes and provide more rapid pain relief during the early postoperative period. Objective. To compare early postoperative clinical and functional outcomes of primary total knee arthroplasty performed using either kinematic or mechanical alignment. Methods. We prospectively analyzed the outcomes of 100 patients undergoing primary TKA, with 50 patients receiving mechanical alignment and 50 receiving kinematic alignment. Clinical assessments included pain measurement using the VAS, functional evaluation using the WOMAC, and knee range of motion (ROM). Assessments were conducted preoperatively, at 14 days, and 1.5 months postoperatively. Results. Analysis of key surgical parameters — including operation duration, intraoperative blood loss, and length of hospital stay — revealed no significant differences between the two groups. However, the requirement for additional ligament releases was significantly higher in the mechanical alignment group. According to WOMAC scores, the kinematic alignment group showed consistently better outcomes at all follow-up stages. At postoperative day 14, the kinematic alignment group had significantly better VAS pain scores and greater knee ROM compared to the mechanical alignment group ($p < 0.05$). However, by 1.5 months after surgery, the differences between the two groups were no longer statistically significant ($p > 0.05$). Conclusions. Kinematic alignment leads to superior early pain relief and faster functional recovery in the initial postoperative period compared to mechanical alignment. Nevertheless, differences in pain and function between both groups diminish by 1.5 months after surgery. These findings suggest the need for further studies with a longer follow-up (at least one year) to evaluate long-term outcomes and potential complications.

Ендопротезування колінного суглоба з використанням механічного вирівнювання є загальноприйнятим стандартом, проте близько 20 % пацієнтів залишаються незадоволеними отриманими результатами. Мета. Порівняти ранні післяопераційні клінічні та функціональні результати первинного ендопротезування колінного суглоба, виконаного кінематичним і механічним способами вирівнювання. Методи. Проспективно проаналізовано результати лікування 100 пацієнтів, яким здійснене ендопротезування за механічним (n = 50) та кінематичним (n = 50) вирівнюванням. Аналізували біль (VAS), суб'єктивне оцінювання функції (WOMAC) і амплітуду рухів (ROM) у колінному суглобі перед операцією, на 14-й день та через 1,5 місяці після оперативного втручання. Результати. Аналіз основних хірургічних параметрів, таких як час операції, обсяг інтраопераційної крововтрати й тривалість госпіталізації, не показав суттєвої різниці між групами. Водночас потреба у виконанні додаткових релізів зв'язкового апарата була істотно вищою в групі механічного вирівнювання. За опитувальником WOMAC, кінематичне вирівнювання мало перевагу на всіх етапах спостереження. На 14-ту добу після втручання група кінематичного вирівнювання продемонструвала кращі показники за VAS, інтенсивності амплітуди рухів у колінному суглобі, ніж група механічного ($p < 0,05$). Проте через 1,5 місяці після операції відмінності між групами за цими параметрами вже не були статистично значущими ($p > 0,05$). Висновки. Кінематичне вирівнювання сприяє більш вираженому зниженню болю та швидшому відновленню функції колінного суглоба в ранньому післяопераційному періоді. Проте через 1,5 місяці після операції показники функціонального стану та інтенсивності болю в обох групах вирівнюються. Це вказує на доцільність проведення додаткових досліджень із тривалішим спостереженням для визначення довгострокових результатів і потенційних ускладнень. Ключові слова. Кінематичне вирівнювання, механічне вирівнювання, ендопротезування колінного суглоба, колінний суглоб.

Keywords. Kinematic alignment, mechanical alignment, total knee arthroplasty, knee joint

Introduction

Osteoarthritis is one of the most common conditions of the knee joint, resulting in degeneration of articular cartilage and significantly reducing the quality of life. According to WHO estimates, this disorder is among the ten most disabling diseases in developed countries, affecting approximately 528 million people worldwide. More than a million knee replacement surgeries are performed annually, making it one of the most effective surgical procedures, significantly reducing pain and improving joint functionality in patients with severe forms of arthritis. In Europe, the leaders in the frequency of such interventions are Switzerland, Germany and Finland (287, 284 and 255 surgeries per 100,000 population, respectively) [1].

Although knee arthroplasty using mechanical alignment is effective and widely used as a standard approach for the treatment of patients with osteoarthritis, about 20 % of patients remain dissatisfied with the results of the intervention. In the postoperative period, patients most often present with persistent pain, limited range of motion of the operated joint, and inconsistency of the actual results with previous expectations [2, 3]. According to the literature, the main reason for dissatisfaction is the significant individual variability of the anatomical structure, which complicates the accurate positioning of the endoprosthesis components. Failure to take into account these anatomical parameters leads to uneven load distribution and disruption of the natural biomechanics of movement in the knee joint, which ultimately causes the above-mentioned symptoms [4, 5]. Mechanical alignment remains the generally accepted method in total knee arthroplasty. At the same time, the results of recent studies indicate a number of advantages of the kinematic approach [8]. According to modern meta-analyses, kinematic alignment provides a more physiological distribution of the load on the medial and lateral parts of the joint, which is accompanied by less pain intensity and better restoration of the amplitude of movements in the early postoperative period [6, 7, 9].

Despite the presence of numerous studies with convincing results in favor of kinematic alignment, the final decision on the optimal technique for positioning the endoprosthesis components remains a subject of debate.

Objective: to conduct a comparative analysis of the results of primary knee arthroplasty in patients with osteoarthritis of the III–IV degrees using kinematic and mechanical alignment methods, with a special emphasis on reducing the intensity of the pain syndrome, improving joint function and recovery rates in the early postoperative period.

Material and methods

The study was conducted at the Department of Traumatology and Orthopedics of the State Institution "Institute of Traumatology and Orthopedics of the National Academy of Medical Sciences of Ukraine" from January 2022 to October 2024.

The study included 100 patients aged 40 to 65 years who underwent knee arthroplasty for deforming arthrosis of stages III–IV according to the Kellgren & Lawrence classification. All patients underwent a comprehensive preoperative examination and postoperative control within 2 months from the moment of surgery.

The study did not include patients with post-traumatic arthrosis, septic arthritis, and knee instability resulting from damage to the capsular ligament apparatus. Patients with arthrosis accompanied by significant defects in the bone tissue of the femoral condyles and/or tibial plateau were excluded, as well as individuals with varus or valgus deformities of the knee joint greater than 15° or those with pronounced contractures of the operated joint exceeding 30°.

The criteria for intergroup distribution were the methods of alignment of the knee joint endoprosthesis components used during primary endoprosthetic repair. The first group (n = 50) underwent surgery using the mechanical alignment technique, while patients in the second group (n = 50) used non-restrictive kinematic alignment. The mean age of the patients in the first group was (51.52 ± 4.92) years (range: 42–63), in the second group — (51.78 ± 4.99) years (range: 41–62). In both groups, a uniform distribution by gender was ensured (25 women and 25 men).

The preoperative planning protocol included performing axial images of the lower extremities with subsequent determination of key reference lines and angles, mechanical lateral distal femoral (mLDFA) and mechanical medial proximal tibial (mMPTA), as well as the Hip–Knee–Ankle (HKA) angle [15, 16]. In the mechanical alignment group, the mean mLDFA value was 88.78° ± 1.49°, in the kinematic group — 88.47° ± 1.53°. The corresponding mMPTA values were 88.03° ± 1.86° and 87.70° ± 1.89°. The mean HKA values were 180.75° ± 2.51° for mechanical and 180.77° ± 2.55° for kinematic alignment. No statistically significant differences were found between the groups ($p > 0.5$).

Determination of the maximum amplitude of movements in the knee joint was assessed using a goniometer, a comprehensive assessment of the subjective sensations of patients using a visual analogue scale of pain (VAS) and the Western Ontario and McMaster University Osteoarthritis Index (WOMAC) questionnaire. The maximum amplitude of movements in patients of the first and second groups was 71.02° ± 7.02° and 69.14° ± 13.87°, respectively. The mean VAS score was 7.5 ± 0.71 in the first group and 7.6 ± 0.7 in the second group. The mean WOMAC score was 54.9 ± 3 and 56.6 ± 3.75 in the first and second groups, respectively. The intergroup differences were statistically significant for WOMAC and maximum range of motion ($p < 0.05$), while demographic parameters and VAS were similar in both groups ($p > 0.05$) (Table 1).

The reason for the surgical intervention was chronic knee pain syndrome, resistant to therapy with nonsteroidal anti-inflammatory drugs (NSAIDs) for at least 6 months, with confirmation of the severity of pain using the VAS scale of more than 6 points. Additionally, high WOMAC scores > 40.

The surgical intervention was performed by a single surgical team with all technical aspects of mechanical [10, 11] and non-restrictive kinematic alignment [12, 13]. For surgical access to the knee joint, a medial subvastus approach was performed with mobilization of the *vastus medialis muscle* without its dissection. For all patients, the same model of implant with cement fixation was used, the design and surgical instruments of which allowed implantation of endoprosthesis components using both mechanical and kinematic alignment methods. In addition, in all cases, a medially stabilized tibial insert was used, developed according to the medial pivot concept in accordance with the principles of multimodal analgesia. Analgesia included pre- and intraoperative perifocal blocks, the use of opioids and NSAIDs during surgery, and postoperative analgesia using paracetamol and nonsteroidal drugs [14].

Physical rehabilitation after surgery was carried out under the supervision of a rehabilitation physician in accordance with a unified rehabilitation program. Passive mobilization of the knee joint began on the first postoperative day. Starting from the second day and until discharge, patients underwent daily physiotherapy sessions lasting about one hour, which included a combination of active and passive exercises aimed at gradually restoring the range of motion in the joint, strengthening the muscular system and improving coordination skills.

To study the correct positioning of the endoprosthesis components in patients of both groups on the 14th day after surgery, axial radiography of the lower extremities was performed with subsequent measurement of the main reference lines and angles (Fig. 1).

The clinical results of knee joint prosthetics were assessed by measuring the maximum amplitude of movements using a goniometer before surgery, 2 weeks and 1.5 months after surgery. The time course of improvement in the functional state of patients was analyzed by comparing the indicators obtained on the 14th day and 1.5 months after surgery. The effectiveness of endoprosthetic repair was determined by comparing preoperative values with the results recorded 1.5 months after the intervention.

Table 1

Demographic and clinical data in groups before surgery

Characteristic	Group 1 (n = 50)	Group 2 (n = 50)	p*
Number of patients	50	50	p > 0.05
Male	25	25	p > 0.05
Female	25	25	p > 0.05
Age (M + SD), years	51.52 ± 4.92	51.78 ± 4.99	p > 0.05
Age range, years	42–63	41–62	p > 0.05
mLDFA, degrees	88.78 ± 1.49	88.47 ± 1.53	p > 0.05
mMPTA, degrees	88.03 ± 1.86	87.70 ± 1.89	p > 0.05
HKA, degrees	180.75 ± 2.51	180.77 ± 2.55	p > 0.05
VAS (M + SD), points	7.50 ± 0.71	7.60 ± 0.70	p > 0.05
WOMAC (M + SD), points	54.90 ± 3.00	56.60 ± 3.75	p > 0.05
Maximum range of motion (M + SD), degrees	71.02 ± 7.02	69.14 ± 13.87	p < 0.05

Note. * — The reliability of the differences in results between groups is, accordingly, statistically significant at the $p < 0.05$ level.

To assess the subjective sensations of patients, the intensity of pain was measured using the VAS scale. Determination of the subjective state of the knee joint using the WOMAC questionnaire was carried out before surgery, on the 14th day and 1.5 months after surgery. The time course of improvement in the subjective state was analyzed by comparing the indicators obtained on the 14th day and 1.5 months after surgery, and the effectiveness of endoprosthetic repair was determined by comparing preoperative data with the results recorded 1.5 months after the intervention.

The study was conducted in strict accordance with the principles of bioethics, legislative requirements, and established standards for conducting biomedical research, as set forth in the Declaration of Helsinki of the World Medical Association (2000), the Constitution of Ukraine (1996), the Civil Code of Ukraine (2006), the Fundamentals of Ukrainian Legislation on Health Care (1992), and the Law of Ukraine "On Information" (1992) with amendments and supplements as of 01 December 2021. Before the start of the study, written voluntary consent was obtained from all participants, and data from medical records were analyzed in accordance with the requirements of the Bioethics Committee of the State Institution "ITO of the NAMS of Ukraine" (Protocol No. 3 of the meeting of the Bioethics Commission dated 29 April 2025).

Statistical data processing was performed using Microsoft Excel and Statistica 8.0 (StatSoft Inc.). The Mann–Whitney test was used to compare independent samples, and the Wilcoxon test was used to analyze repeated measures. The results were analyzed using standard methods of mathematical statistics, including the calculation of the number of samples (n), the arithmetic mean (M), and the standard deviation (SD). The statistical relationship between the studied variables was assessed using the Fisher test. The confidence level was set at 95 %, and the statistical significance was 0.05 ($p = 0.05$).

Results

In the mechanical alignment group, the mean mLDFA value was 89.45° ± 1.10°, in the kinematic group — 88.37° ± 1.47°. The corresponding mMPTA values were 89.46° ± 1.55° and 87.64° ± 1.92°. The mean HKA angles were 179.98° ± 1.55° in the mechanical and 180.73° ± 2.56° in the kinematic alignment groups. No statistically significant differences were found between the groups ($p > 0.5$). Analysis of key radiographic angles before and after surgery confirmed the fulfillment of the preoperative technical tasks: the mean deviation of HKA from the planned was –0.77° ± 0.52° in the mechanical and -0.04° ± 0.31° in the kinematic alignment groups ($p > 0.05$) (Table 2).

In the preoperative period, the intensity of knee pain, measured by the VAS scale, ranged from 7 to 9 points, with a mean value of 7.50 ± 0.71 in group 1 and 7.60 ± 0.70 in group 2. On the 14th day after surgery, the pain score in group 1 decreased from 7.50 ± 0.71 to 4.40 ± 0.70, and during 1.5 months of observation to (3.00 ± 0.45) points. Similarly, in group 2, on the 14th day after surgery, the VAS value decreased from 7.60 ± 0.70 to 4.18 ± 0.52, and after 1.5 months to (2.90 ± 0.95) points.

Subjective assessment of the knee joint using the WOMAC questionnaire, conducted before the intervention and in the postoperative period, showed a significant improvement in the functional state of patients in both groups. At the preoperative examination stage, the WOMAC score was (54.90 ± 3.00) and (56.60 ± 3.75) points in groups 1 and 2, respectively. As early as 14 days after the operation, a decrease in the average score was observed in group 1 to (32.50 ± 4.77), and after 1.5 months to (20.80 ± 4.32). Similarly, in group 2, the WOMAC scores decreased to (24.86 ± 4.50) points on the 14th day and to (19.10 ± 3.12) 1.5 months after the operation.

In the postoperative period, a statistically significant improvement in the subjective assessment of the condition of the operated joint was recorded in both groups ($p < 0.05$). On the 14th day, the intensity of pain on the VAS scale significantly decreased ($p < 0.05$). However, 1.5 months after the start of observation, the difference between the groups no longer reached the level of statistical significance ($p > 0.05$).

Table 2

Main radiological angles before and after surgery in the study groups

Indicator / Group	Mechanical alignment (before → after surgery)	Kinematic alignment (before → after surgery)	p
mLDFA	(88.78° ± 1.49°) → (89.45° ± 1.10°)	(88.47° ± 1.53°) → (88.37° ± 1.47°)	p > 0.05
mMPTA	(88.03° ± 1.86°) → (89.46° ± 1.55°)	(87.70° ± 1.89°) → (87.64° ± 1.92°)	p > 0.05
HKA	(180.75° ± 2.51°) → (179.98° ± 1.55°)	(180.77° ± 2.55°) → (180.73° ± 2.56°)	p > 0.05

The changes of indicators on the VAS and WOMAC scales before and after the performed surgical intervention in patients of the two groups is presented in Fig. 2, 3.

Analysis of the clinical data showed the following changes in improvement in the amplitude of movements in the knee joint. In group 1, the average ROM increased from 71.02° ± 7.02° (preoperative measurement) to 82.30° ± 5.18° on the 14th day after surgery, and 1.5 months after the intervention it reached 95.34° ± 5.44°. Similarly, in group 2, the average ROM before surgery was 69.14° ± 13.87°, with further improvement to 91.14° ± 5.46° on the 14th day and to 99.20° ± 13.19° 1.5 months after surgery.

On the 14th day after surgery, both groups showed a significant increase in the maximum amplitude of movements in the operated joint ($p < 0.05$). At the same time, after 1.5 months, the difference between the ROM indicators was statistically insignificant ($p > 0.05$).

The time course of the increase in the amplitude of movements in the knee joint before and after the surgery in patients of the two groups is shown in Fig. 4.

The analysis of the main surgical parameters, such as the duration of the operation and hospitalization, the volume of intraoperative blood loss, did not reveal a significant difference between the groups. At the same time, the need for additional releases of the ligamentous apparatus to align the flexion-extension gap was significantly higher in the mechanical alignment group. The mean duration of surgery was (55.7 ± 12.5) minutes in the kinematic alignment group and (57.4 ± 11.8) in the mechanical group ($p > 0.05$). The amount of blood loss was similar: (119.6 ± 18.9) ml for mechanical and

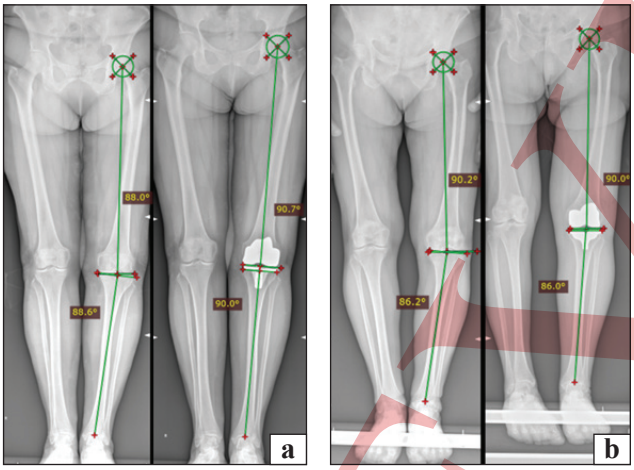

Fig. 1. Radiography findings before and after the installation of the endoprosthesis components according to the preoperative planning (a — mechanical alignment, b — kinematic)

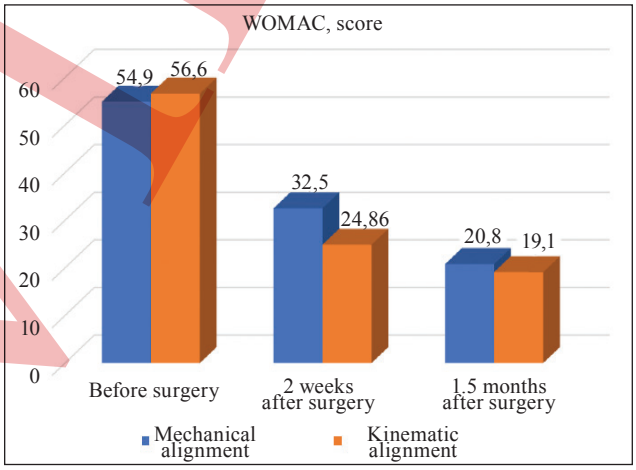

Fig. 3. Indicators of the patient's subjective assessment of the condition of the knee joint on the Western Ontario and McMaster University Osteoarthritis Index (WOMAC) scale in both groups before and after surgical treatment

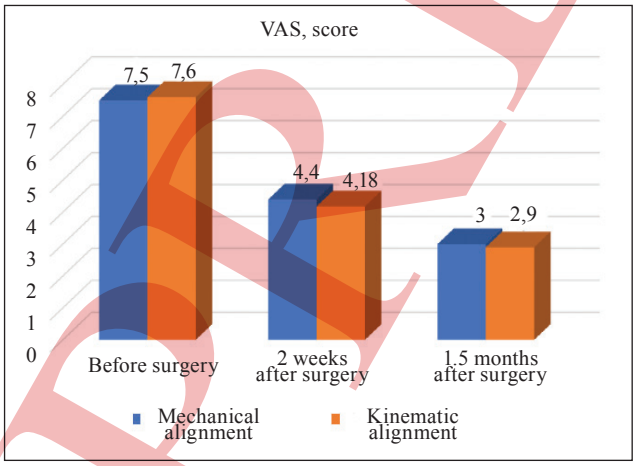

Fig. 2. Indicators of the level of pain syndrome on the VAS scale in both groups before and after surgical treatment

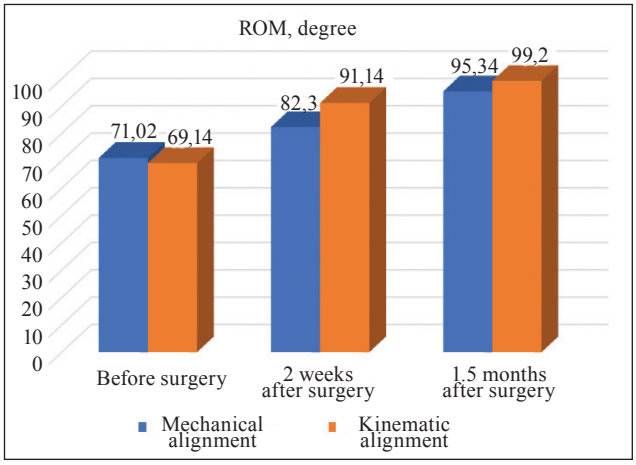

Fig. 4. Amplitude of movements in the knee joint in both groups before and after surgical treatment

Table 3

Differences in the average values of surgical indicators of mechanical and kinematic alignment methods

Parameter	Mechanical alignment	Kinematic alignment	p
Duration of surgery, min	57.4 ± 11.8	55.7 ± 12.5	p > 0.05
Intraoperative blood loss, ml	119.6 ± 18.9	122.2 ± 15.9	p > 0.05
Hospital stay, days	7.0 ± 1.9	6.0 ± 1.7	p > 0.05
Frequency of soft tissue releases, %	44	8	p < 0.05

(122.2 ± 15.9) for kinematic alignment (p > 0.05). The mean hospital stay was slightly shorter in the kinematic alignment group (6.0 ± 1.7) days compared to the mechanical group (7.0 ± 1.9) (p > 0.05), which is probably due to better functional recovery and reduced pain. Additional soft tissue releases were performed in 8 % of surgical interventions in the kinematic alignment group and in 44 % of cases in the mechanical group (p < 0.05) (Table 3).

Discussion

Throughout the study, both techniques for positioning the endoprosthesis components, kinematic and mechanical, demonstrated comparable accuracy in component placement and similar effectiveness in terms of key surgical outcomes. In particular, the average operation time, intraoperative blood loss, and length of hospitalization did not have statistically significant differences between the groups: (57.4 ± 11.8) min vs. (55.7 ± 12.5); (119.6 ± 18.9) ml vs. (122.2 ± 15.9); (7.0 ± 1.9) vs. (6.0 ± 1.7) days, respectively (p > 0.05) (Table 2). The results obtained are consistent with the data of international studies, which also show no significant differences between these techniques in terms of the specified parameters [7, 17, 18].

At the same time, we found that kinematic alignment required significantly fewer additional soft tissue releases, 8 % compared to 44 % in the mechanical alignment group (p < 0.05). This result is consistent with the theoretical premises of the kinematic alignment concept, according to which the restoration of the individual anatomical axis of the joint minimizes the need for intervention in the ligamentous apparatus. The obtained data also align with the results of individual randomized studies and meta-analyses that report a decrease in the frequency of releases when using the kinematic technique [19–21]. Early functional dynamics demonstrated the superiority of the kinematic method: on the 14th day after surgery, the increase in the flexion amplitude in this group was 43 %, which exceeded the similar indicator in the mechanical alignment group (34 %; p < 0.05). However, 1.5 months after the intervention, a statistically significant difference between the groups was no longer detected. A similar trend was observed for pain syndrome on the VAS scale: on the 14th day, the intensity of pain in the kinematic alignment group was significantly lower (p < 0.05), but at the end of the observation period, the indicators in both groups were equalized (p > 0.05).

The assessment according to the WOMAC questionnaire showed the superiority of kinematic alignment at all stages of observation. The overall improvement was 37.5 points in the kinematic alignment group compared to 34.1 in the mechanical alignment group, while the "pain/discomfort" component showed an improvement of 4.7 versus 4.5 points, respectively (p < 0.05).

Conclusions

The use of kinematic alignment technologically reduces the need for additional soft tissue releases, helping to preserve the individual kinematics of the joint, which contributes to the reduction of pain syndrome and faster functional recovery in the first two weeks after surgery. At the same time, 1.5 months after the intervention, the differences between the groups become statistically insignificant, emphasizing the feasibility of further studies with a longer observation period to determine long-term results and potential complications.

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. Study of the effectiveness of kinematic and mechanical alignment with the analysis of clinical results and possible complications within a year after primary knee arthroplasty.

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Contribution of the authors. Moroz M. D. — drafting the article, collecting, analyzing and statistical processing of clinical material; Kozak R. A. — participation in drafting the article, analyzing the results of the study, drafting the conclusions; Kostogryz O. A. — research management, critical review and approval of the final version of the article; Bondar V. I. — performing radiography, comparing and contrasting clinical and radiological indicators.

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EVALUATION OF THE EFFICACY OF KINEMATIC AND MECHANICAL ALIGNMENT IN PRIMARY TOTAL KNEE ARTHROPLASTY DURING THE EARLY POSTOPERATIVE PERIOD

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