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RELATION OF STRESS-STRAIN STATE IN THE KINEMATIC CHAIN "HIP-AND-KNEE JOINT" WITH THE CERVICAL DIAPHYSEAL ANGLE CHANGING UNDER THE CONDITIONS OF DYSPLASIA

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The article presents the study of biomechanical disorders in the dysplastic process in the hip and knee joints using the finite elements model with different cervical-diaphyseal angles (CDA) of the proximal femoral bone. With the CDA equal to 90°, the femoral neck stress was 42.4 MPa (27.6 in the norm). In the proximal tibia, the level of the stress condition has increased on the medial side up to 17.9 MPa (11.1 normal), and on the lateral side 9.1 MPa (3.5 normal). Thus, on the medial side the stress magnitude is 21.6 MPa (11.2 normal), on the lateral side - 1.7 MPa (2 in the norm). For the CDA equal to 160° the stress in the hip joint reaches 26.5 MPa (27.6 normal). In the proximal tibia on the medial side the tension is 9 MPa (11.1 normal), and on the lateral side it is 3.5 MPa (3.5 normal). Distribution of the stress condition in the knee joint showed that on the medial side the stress magnitude is 13.1 MPa (11.2 normal), and on the lateral side - 3.8 MPa (2 normal). Comparative analysis of the calculations performed for models with different CDA showed that the CDA reduction leads to a significant increase in the stress condition not only in the neck of the femoral bone, but also in the knee joint. Whereas, with increasing CDA the growth of stress-strain state is slight, mainly in the lateral part of the knee joint.

Key words: CDA change, stress-strain state of the hip joint, proximal tibia.

The work is a fragment of the research project "To study biomechanical features of standing and gait of patients with a long course of hip osteoarthritis", state registration No. 0118U006950.

The past decade is characterized by an increase in syndromic pathology, which is based on connective tissue dysplasia. Scientific advances in this field have permitted to consider the problem of dysplastic diseases in a different way. It is believed that these diseases formation causes a hereditary susceptibility factor that adversely affects the connective tissue development, including that in the musculoskeletal system, which further leads to anatomic and functional unconformity of the joint's surfaces (discongruence), and further to biomechanical imbalance and arthrosis [4].

A sufficiently detailed review of modern biomechanical studies in the hip joint was made in B. Vafaeian's et al. study [13]. The stress state of the femur for different CDA values was analyzed in the studies of I.B. Zelenetsky [1], Diplesh Gautam [8]. The researchers [2, 3, 7, 11] studied the stress condition of the knee joint both normal and with dysplastic changes.

Since the dysplastic process relates to all systems of the human body, it is natural that changes in the biomechanical parameters of the joints, to varying degrees, will mutually affect each other [5]. Together, multiple pathological, especially biomechanical, changes form a multilevel spatial system of the musculoskeletal system with impaired function.

However, mutual compensatory processes (concordance) that mask anomalies of joint development are possible, often temporarily.

Insufficient supply of the necessary equipment (CT, MRI) in domestic medicine complicates the construction of the entire human musculo-skeletal system (MSS) model. Geometric constructions of pathological abnormalities in the joints were applied in the individual approach for the purpose of diagnosis, treatment and prevention. Therefore the preferred local approach to the joints, complicates early diagnosis and treatment.

Increased load on particular areas of the articular surfaces leads to an increase of the stress-strain state (SSS). Chronic stress of their cartilaginous tissue creates conditions for the development of arthrosis, the start for which in the prenatal period is dysplasia [4, 13].

In this regard, numerous tasks stand out clarifying the impact of each dysplastic component in the overall disease process.

In the process of studying this problem by means of the finite elements method (FEM), isolated models of the hip and knee joints were built to solve various problems. However, in order to bring the model closer to real conditions, as well as to establish the correlation and mutual influence of the lower extremity joints, it is necessary to build a model adapted to the set tasks.

When studying the stresses in the hip and knee joints (both in normal and with different pathology) by FEM, data were obtained on their uneven distribution, localization in particular areas of the joint elements. However, the main factor of the joint load was considered insufficiently due to disorganized location of the limb's mechanical axis.

Taking into consideration the significant priority of biomechanical disturbances in this process, it is of interest to study their interaction in the "hip-knee joint" system. It is known that change of the limb's anatomical-mechanical axis and, accordingly, the angles of muscles insertion affects their muscle strength and muscle imbalance [1]. In their turn, different conditions arise for the local loading on the articular surfaces. It can be assumed that the axial parameters disturbance also affects the stress-strain state (SSS) in all elements of the joints. However, to date, we believe that for the sake of the study completeness, it is more appropriate to consider joints not isolated, but within the kinematic chain of the musculoskeletal system, which brings them closer to the real object.

Since dysplasia in the lower extremity is frequently a combination of anatomical and parametric abnormalities, it can be considered that their total impact will increase the negative effect on the joints function. We have not found any similar studies in the available literature.

The purpose of the work was to study the correlation of stress-strain state of the "hip-knee joint" system in the norm and with the increased cervical-diaphyseal angle (CDA) in dysplasia.

Materials and methods. In this work, we studied the "hip-knee joint" system SSS with the changed cervical-diaphyseal angle of the femur and the normal knee joint. The studies were performed on a volumetric model of the lower extremity, developed in the Biomechanics Laboratory of State Institution «Sytenko Institute of Spine and Joint Pathology NAMS of Ukraine». Three models have been constructed with the CDA 127°, 90° and 160°.

The model has restrictions on movement, the heel bone and the foot bones are fixed. The single-support standing was considered. The main load is the body weight: the mean value for an adult is 700 N, excluding of the weight of the support foot from the load: 700-126 = 574 N. The musculoskeletal apparatus action was replaced by the equivalent load action (1580 N), which is added to the trochanter major. Angles, applications and load values were taken according to the studies [6, 14]. The finite element model consists of 902647 10-node tetraidal finite elements with quadratic approximation [9, 15]. The calculations were performed in the Solid Works software [10].

The calculations took into account different types of biological tissues: cortical and spongy bone, cartilage tissue, the material was considered homogeneous and isotropic. The data that are most commonly found in the literature are used in the work [12].

Results of the study and their discussion. The model's calculations with the CDA of 127° (fig. 1) showed that in the hip joint, the femoral neck is the most stressed, where the stress level reaches 27.6 MPa.

The stress values by Mises in the central part of the femur both on the medial and on the lateral sides reach values of 15-18 MPa. In the proximal tibia on the medial side, the stress magnitude by Mises is 11.1 MPa, and on the lateral side - 3.5 MPa.

The stress distribution in the knee joint according to Mises is equal to 11.2 MPa on the medial side, and to 2 MPa on the lateral side.

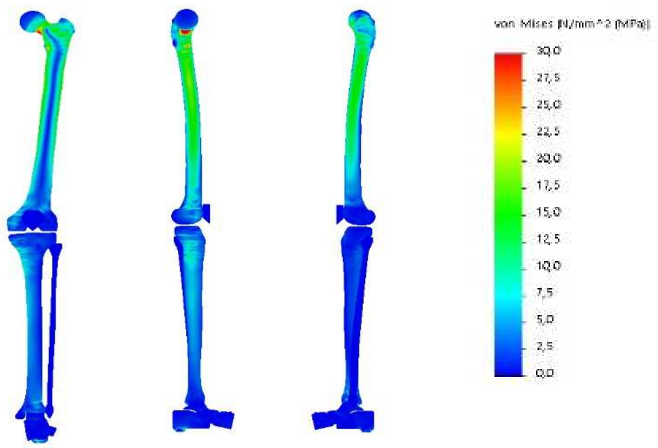

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Fig. 1. The stress distribution according to Mises in the proximal tibia at CDA 127°: a) frontal view; b) medial view; c) lateral view.

Comparison of the study results with the work of the author [8] showed that the maximum stress value according to Mises in the work [8] is 21.3 MPa (27.6 MPa in our study). The difference in values is explained by the difference in the load on the femur head 627 N (574 N in our study), as well as by the action of muscles - 1580 N, applied to the large femoral head, which is not taken into account in the work [8]. The difference in the materials properties should also be noted; for example, the modulus of the tubular bone elasticity in the work of the author [8] is 15500 MPa (18350 MPa in our study).

Comparative analysis of the stress condition in the knee joint to the work of the authors [10] shows that the nature of the stress state distribution coincides, the medial side of the knee joint is more stressed, and the lateral side is less stressed.

The model calculations at CDA 90° (fig. 2) show that in the area of the hip joint, as in the previous calculation, the most stressed is the femoral neck, but the level of the stress state is much higher - 42.4 MPa (27, 6 MPa for the model is normal).

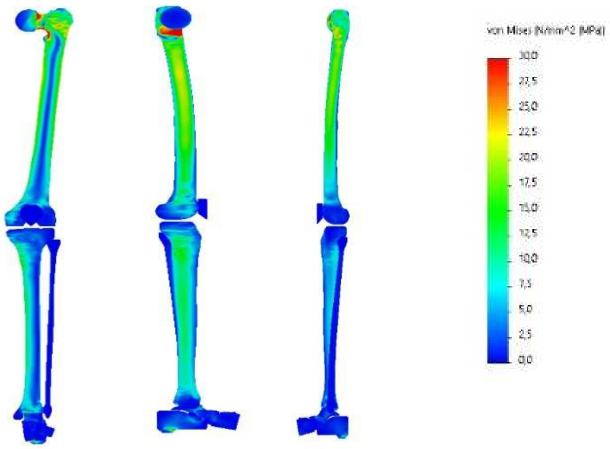

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Fig. 2. Stress distribution by Mises in the design model at CDA 90^{o}: a) frontal view; b) medial view; c) lateral view.

The stress values by Mises in the central part of the femur on both the medial and lateral sides reach values of 18-21 MPa (15-18 MPa for the model is normal). In the proximal tibia, the level of stress also increased and was 17.9 MPa on the medial side (11.1 MPa for the normal model) and 9.1 MPa on the lateral side (3.5 MPa for the normal model).

Also, in the tibia as a whole, there was the SSS increase in the knee joint. Thus, on the medial side, the stress magnitude according to Mises is 21.6 MPa (11.2 MPa for the model is normal), on the lateral side - 1.7 MPa (2 MPa for the model is normal).

Comparison of the study results with the work of the author [8] shows that the maximum stress value by Mises in the work [8] is 66.3 MPa (42.4 MPa in our study).

The difference in values is explained by both the factors mentioned above and the difference in the CDA value. In the work [8], the angle of 106^{o} (90^{o} in our research) was studied.

The model calculations at the CDA equal to 160° (fig. 3), show that in the area of the hip joint, as well as in the previous calculations, the most stressed is the femoral neck, where the level of the stress state reaches the value of 26.5 MPa (27.6 MPa for the model is normal).

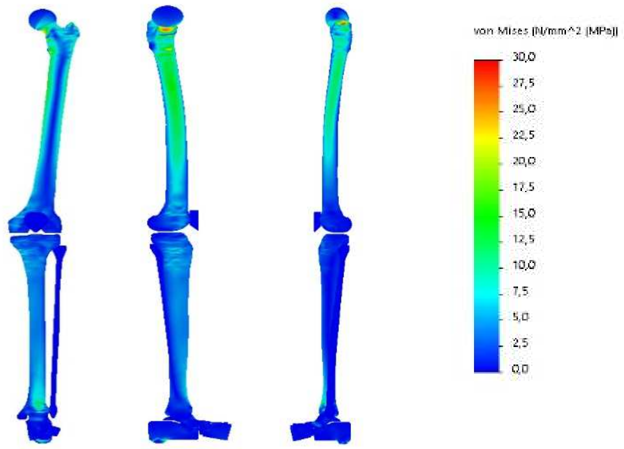

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Fig. 3. Mises stress distribution in the design model at CDA of 160°: a) frontal view; b) medial view; c) lateral view.

The stress values by Mises in the central part of the femur from on the medial and the lateral sides reach values of 12-23 MPa (15-18 MPa for the model is normal). In the proximal tibia on the medial side, the stress value by Mises is 9 MPa (11.1 MPa for the model is normal), and on the lateral side - 3.5 MPa (3.5 MPa for the model is normal). The stress distribution in the knee joint shows that on the medial side, the stress values by Mises is 13.1 MPa (11.2 MPa for the model is normal), and on the lateral side - 3.8 MPa (2 MPa for the model is normal).

Stress distribution in the knee joint according to Mises is equal: on the medial side, the stress value is 13.1 MPa (11.2 MPa for the model is normal), and on the lateral side - 3.8 MPa (2 MPa for the model is normal).

Comparison of the study results with the work of the author [8] shows that the maximum stress value by Mises in the work [8] is 73.2 MPa (26.5 MPa in our study). In contrast to the previous calculations, the difference in the stress state is sufficient and it is not explained by the factors mentioned above. The difficulty of comparison is caused by the lack of modern works to study the CDA effect on the stress state of the femur. In the work of the authors [10], who carried out studies by another method (analytical estimates of the stress state with the changed CDA), the CDA ratio with the maximum stress value is close to that in our studies. The minimal stress values at CDA are 138^{o} and 1500^{o} [10] (in our study - 1270 and 1600 respectively).

The comparative analysis of the calculations performed for models with different CDA is presented in table 1.

Thus, the study showed that the CDA reduction leads to a significant increase in the stress state not only in the neck of the femur, but also in the knee joint, with an increase in CDA, the growth of SSS occurs slightly, mainly in the lateral part of the knee joint.

In the available literature, we have practically failed to find works in this formulation of tasks. Somewhat close to our study are the works by R.O. Solodilov and S.I. Loginov [5] in the clinical field confirming our calculations and hypotheses [2].

Table 1

Comparison of the stress values by Mises at different CDA in the femur and the knee joint

Segment	Normal	CDA 90°	CDA 160°
Neck of the femur	27.6	42.4	26.5
Medial side of the femur	18.9	22.7	22.6
Lateral side of the femur	15.3	18.3	12
Medial side of the knee joint	11.2	21.6	13.1
Lateral side of the knee joint	2	1.7	3.8
Medial side of the tibia	11.1	17.9	9
Lateral side of the tibia	3.5	9.1	3.5

We believe that expanding medical knowledge about the correlation and mutual influence of pathological changes in the dysplastic joints will help to change the tactics of conservative and surgical treatment, especially at the early stages, which significantly inhibits development of arthrosis.

Because the technologies for radical elimination of dysplasia at the cellular level are at their initial stages, such a complex and multidisciplinary problem requires further study, which will influence the inhibition of dystrophic processes.

Conclusions

1. The CDA change leads to an increase in SSS in the “hip and knee joint” design models.

2. CDA reduction leads to an increase in SSS both in the femur and the tibia, to a greater extent on the medial side. At CDA equal to 90°, stress in the neck of the femur and in the knee joint grows practically twice.

3. At CDA of 160°, the stress state in the bones varies within 20%. In the knee joint from the lateral side there is stress increase by 47%.

4. A direct correlation between the stresses in the model of the lower extremity with CDA changing is established.

5. An increase in the SSS in the model of a normal knee at 160° CDA may be a “risk zone” especially for its lateral surface under the dysplasia conditions.

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Реферати

ВЗАЄМОЗВ'ЯЗОК НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ В КІНЕМАТИЧНОМУ ЛАНЦЮЗІ «КУЛЬШОВО-КОЛІННОГО СУГЛОБУ» ПРИ ЗМІНІ ШИЙКОВО-ДІАФІЗАРНОГО КУТА В УМОВАХ ДИСПЛАЗІЇ

Зеленецький І.Б., Мітелева З.М., Снісаренко П.І., Яресько А.В.

Статтю присвячено дослідженню біомеханічних порушень при диспластичному процесі у кульшовому та колінному суглобах з використанням моделі кінцевих елементів при різних шийково-діафізарних кутах (ШДК) проксимального відділу стегнової кістки. При ШДК рівним 90°, напруження шийки стегнової кістки склала - 42,4 МПа (27,6 в нормі). У проксимальному відділі великогомілкової кістки рівень напруженого стану зріс на медіальній стороні до 17,9 МПа (11,1 в нормі), а на латеральній стороні 9,1 МПа (3,5 в нормі). Так на медіальній стороні величина напружень дорівнює 21,6 МПа (11,2 в нормі), на латеральній стороні - 1,7 МПа (2 в нормі). Для ШДК рівного 160° напруження в області кульшового суглоба досягає 26,5 МПа (27,6 в нормі). У проксимальному відділі великогомілкової кістки на медіальній стороні напруження становить 9 МПа (11,1 в нормі), а на латеральній стороні 3,5 МПа (3,5 в нормі). Розподіл напруженого стану в колінному суглобі показав, що на медіальній стороні величина напружень дорівнює 13,1 МПа (11,2 в нормі), а на латеральній стороні - 3,8 МПа (2 в нормі). Порівняльний аналіз проведених розрахунків для моделей з різним ШДК показав, що зменшення ШДК призводить до значного збільшення напруженого стану не тільки в шийці стегнової кістки, але і в колінному суглобі. При збільшенні ШДК зростання напружено-деформованого стану відбувається незначно, в основному, в латеральній частині колінного суглобу.

Ключові слова: зміна ШДК, напружено-деформований стан стегнової кістки, проксимального відділу великогомілкової кістки.

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ВЗАИМОСВЯЗЬ НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ В КИНЕМАТИЧЕСКОЙ ЦЕПИ «ТАЗОБЕДРЕННЫЙ-КОЛЕННЫЙ СУСТАВ» ПРИ ИЗМЕНЕНИИ ШЕЕЧНО-ДИАФИЗАРНОГО УГЛА В УСЛОВИЯХ ДИСПЛАЗИИ

Зеленецкий И.Б., Мителева З.М. , Снисаренко П.И., Яресько А.В.

Статья посвящена исследованию биомеханических нарушений при диспластическом процессе в тазобедренном и коленном суставах с использованием модели конечных элементов при различных шеечно – диафизарных углах (ШДУ) проксимального отдела бедренной кости. При ШДУ равным 90°, напряжение шейки бедренной кости составила - 42,4 МПа (27,6 в норме). В проксимальном отделе большеберцовой кости уровень напряженного состояния вырос на медиальной стороне до 17,9 МПа (11,1 в норме), а на латеральной стороне 9,1 МПа (3,5 в норме). Так на медиальной стороне величина напряжений равна 21,6 МПа (11,2 в норме), на латеральной стороне - 1,7 МПа (2 в норме). Для ШДУ равного 160° напряжение в области тазобедренного сустава достигает 26,5 МПа (27,6 в норме). В проксимальном отделе большеберцовой кости на медиальной стороне напряжение составляет 9 МПа (11,1 в норме), а на латеральной стороне 3,5 МПа (3,5 в норме). Распределение напряженного состояния в коленном суставе показало, что на медиальной стороне величина напряжений равна 13,1 МПа (11,2 в норме), а на латеральной стороне - 3,8 МПа (2 в норме). Сравнительный анализ проведенных расчетов для моделей с различным ШДУ показал, что уменьшение ШДУ приводит к значительному увеличению напряженного состояния не только в шейке бедренной кости, но и в коленном суставе. При увеличении ШДУ рост напряженно-деформированного состояния происходит незначительно, в основном, в латеральной части коленного сустава.

Ключевые слова: изменение ШДУ, напряженно-деформированное состояние бедренной кости, проксимального отдела большеберцовой кости.

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ANALYSIS OF DENTURE BASE IMPACT ON THE DENTURE FOUNDATION AREA TISSUES

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The article presents the results of the study of the dental base impact on the denture foundation area tissues. The study was conducted in 149 patients aged 41 to 74 years. Removable partial laminar dentures for the upper and lower jaws were made of plastics "Ftorax" and "Etacryl-02" by three technologies: in a "water bath", in a dry polymerizer under the pressure and in an advanced injection molding machine. The results obtained allow us to recommend the technology of manufacturing removable partial laminar dentures in the advanced injection molding machine for using in dental orthopedics clinic.

Key words: removable partial laminar dentures, polymerization technologies, base plastics, denture foundation area.

The study is a fragment of the research project "New approaches to the diagnosis and treatment of secondary adentia, periodontal and TMJ tissue lesions in adults", state registration No. 0117U000302.

Modern orthopedic dentistry offers a large number of structures that are used in the restoration of partial defects of the dental arches [6].

Rehabilitation of patients with partial teeth loss is a difficult problem in the manufacturing dentures, which must be high-grade as to functional, aesthetic and psycho-emotional. Despite the emergence of new base materials, acrylic plastics are usually essential for the manufacturing removable partial laminar dentures [2].