DOI 10.26724/2079-8334-2020-4-74-116-121
UDC 616.728.2-007-053.2-085

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STUDY OF THE STRESS-DEFORMED STATE OF THE HIP JOINT MODEL IN CHILDREN IN THE CONDITIONS OF NORMAL AND DYSPLASION

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The work presents a comparative study of the stress-deformed state of the normal hip joint elements in children and in the case of its dysplastic changes. To achieve this purpose, several mathematical models of the child's hip joint were built using the finite elements method. In the process of constructing the calculation model, the geometric model of the pelvis-thigh was taken as a basis, which is based on the method of creating a model of geometric sections obtained from tomographic images. As a result of the performed mathematical study, significant changes in the nature of the stress-deformed state in the dysplastic hip joint compared to the norm, which, in our opinion, may be one of the significant factors delaying the formation of the acetabulum and progression of the thigh subluxation, as well as initiate occurrence of femoral head cartilage and acetabulum degeneration areas. The obtained data should contribute to the definition and optimization of methods for additional mechanical stimulation of the hip joint components for its normal development during treatment.

Key words: hip joint, dysplasia, child, biomechanics, acetabulum.

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ДОСЛІДЖЕННЯ НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ МОДЕЛІ КУЛЬШОВОГО СУГЛОБА У ДІТЕЙ В УМОВАХ НОРМИ ТА ДИСПЛАЗІЇ

В даній роботі проведено порівняльне дослідження напружено-деформованого стану елементів кульшового суглоба у дітей в нормі та у випадку його диспластичних змін. Для вирішення поставленої мети були побудовані декілька математичних моделей дитячого кульшового суглобу за допомогою методу скінчених елементів. У процесі побудови розрахункової моделі за основу була взята геометрична модель таз-стегно, в основу якої покладено методику створення моделі по геометричних перетинах, отриманих з томографічних знімків. В результаті проведеного математичного дослідження встановлено значні зміни характеру напружено-деформованого стану в диспластичному кульшовому суглобі в порівнянні з нормою, що, на нашу думку, може бути одним із суттєвих факторів затримки формування кульшової западини та прогресування підвивиху стегна, а також ініціювати виникнення ділянок початкової дегенерації хряща голівки стегнової кістки і кульшової западини. Отримані дані мають сприяти визначенню та оптимізації методів додаткової механічної стимуляції компонентів кульшового суглоба для його нормального дорозвитку в процесі лікування.

Ключові слова: кульшовий суглоб, дисплазія, дитина, біомеханіка, кульшова западина.

The work is a fragment of the research project "Functional treatment of humerus fractures", state registration No. 0117U4682.

One of the most important manifestations of hip joint dysplasia (HJD) is the acetabulum deficiency (Acd) of varying severity, which usually develops gradually and is not accompanied by pronounced clinical changes at the early stages of the child's body development. The pronounced deformations of both, Acd and the whole of the hip joint (HJ) in cases of its dysplasia, is accompanied not only by pain and restriction of movements in the HJ, but also by loss of congruence of the joint's components, decentration and subluxations of the hip develop, there is an overload of certain Acd zones and proximal femur (PF) and, as a consequence, early coxarthrosis develops.

Currently, there are numerous methods of conservative HJD treatment in children, but according to various authors, in 15-45% of cases, they do not lead to the restoration of the correct anatomical ratio in the HJ [2,5]. The best results of conservative treatment of HJD are observed in cases of its early onset (the first 3 months after birth) using the functional method – when the extremities are given the necessary position while maintaining active movements in the joints, leading to the centering of the femoral head (FH),and stimulating active complete development of HJ [2]. However, these techniques are effective until the age of 6 months, and at an older age the percentage of reluxations and secondary deformations increases significantly [5,7].

For the treatment of HJD at the age of 6 to 18 months, methods are used that center and retain femoral head (FH) in the Acd, but rigid fixation, which cannot be avoided at this stage, eliminates physiological loads and normal joint function, which at such an early age significantly delays the dynamics of HJdevelopmentand leads to the loss of valuable time, because with each month of the child's life, the dynamics of its growth decreases and the opportunities for further development of the HJ components are reduced [2,5].

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A means to improve the existing methods of conservative treatment can be additional stimulation of the HJ components complete development is performing physiological loads on the joint, particularly, the use of the “trampling” method. This method is that under the conditions of maintaining stable fixation of the limbs in orthopedic devices, the hip abduction at 50 ° -55 ° and internal rotation at 15 ° -20 °, a series of periodic loads of "trampling" on the limb is performed, directed along its longitudinal axis. These sessions are regular and are performed several times a day with a total of 1000 to 1500 exercises per day [3].

Studies of the loading features and the impact of dosed physiological loads on the development of HJ in children in normal and HJD in the domestic and foreign literature are insufficiently covered and leave this question open [9]. One of the promising fields for obtaining new knowledge on determination of force stresses in the HJ components, both in normal and in the case of its dysplastic changes, is application of the finite elements method (FEM) to study the stress-deformed state (SDS) in the joint elements [8].

The purpose of the study was to compare the stress-deformed state of the of the hip joint elements in children in normal and in the case of dysplastic changes in the acetabulum and proximal femur.

Materials and methods. To achieve this purpose, several mathematical models of child's HJ were built usingfiniteelementmethod(FEM). The construction of these models and calculations were performed in the SolidWorkssoftware [8].

In the process of building, the calculation model was based on a geometric pelvis-thigh model, developed at the laboratory of biomechanics SI “Sytenko Institute of Spine and Joint Pathology NAMS”, which is based on the method for creating a model of geometric sections obtained from tomographic images [5]. The following changes were included into the constructed model, according to previous research [4]:

- zones of pelvic bones and femur growth are taken into account (presence of Y-shaped cartilage of the acetabulum, apophysis of the great acetabulum and clavus zone of the femoral headepiphysis);
- reduced anatomical size of bone structures in children compared to adults;
- altered anatomical parameters of the hip joint elements’ structure in accordance with the features characteristic of these joints’ dysplastic damage – increased antetorsion from 15 ° to 35 ° and valgus deformity of the proximal femur – cervical-diaphyseal angle (CDA) was 130 ° and 140 °, which is the norm in childhood.

Taking into account the above changes, several variants of the HJ calculation models were constructed (fig. 1):

1. Model of normal HJ with CDA, which was 130 °, antetortion angle - 20 ° and normal acetabulum (acetabular index - 25⁰) - determination of stress-deformed state of HJ elements under conditions of single-support standing;
2. Model of dysplastic HJ with CDA, which was 130 °, antetortion angle - 20 ° and acetabular index 60 ° ("beveled" dysplastic Acd) - determination of stress-deformed state of HJ elements under conditions of single-support standing;
3. Model of dysplastic HJ with CDA, which was 140 °, antetor torsion angle 40 ° and acetabular index 60 ° - (dysplastic changes in both proximal femur and Acd) - determination of stress-deformed state of HJ elements under conditions of single-support standing.

Properties of materials. In this study, the material was considered homogeneous and isotropic. In the process of choosing the properties of bone structures, we based on the data that are most common in the literature [10]. The following characteristics of the materials were used: E - modulus of elasticity (Young's modulus) and ν - Poisson's ratio, which are presented in table 1.

Load scheme. In this paper, we considered a single variant of the load - single-support standing (other variants of the load in cases of dysplastic changes in the elements of the HJ will be considered in our next publication). The main load is the weight of the body, which in our study was assumed to be equal to P = 100H. The muscle strength values in a single support position are taken in accordance with the data presented in the work. The lower plane of the left knee joint is fixed. As the stress state assessment, Mises stresses are selected as the most informative type of the general stress state. In the course of our study, all numbers in the text are rounded to one decimal place.

Table 1

Mechanical characteristics of the materials used

Tissue	E (MPa)	ν
Corticalis bone	12240	0.3
Cancellous bone	380	0.3
Cartilage	10.5	0.49
Bone growth plate	5	0.45

Results of the study and their discussion. Initially, the analysis of stress-deformed state elements of the HJ during single-support standing was carried out. These data are necessary for further comparative analysis in the case of different variants in the model of dysplastic HJ in children.

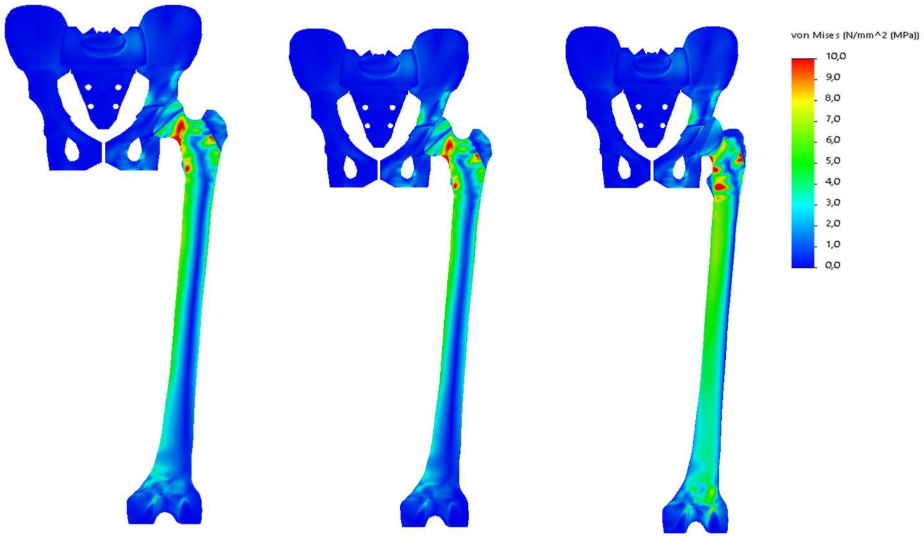
Analysis of the stress-deformed state in the hip joint in children is normal. The analysis of the proximal femur model of normal HJ in the case of single-support standing showed that the most intense is the lower part of the femoral neck and the medial side of the proximal femur (fig. 1a).

In Acd, areas of increased stress are observed along the edge of the anterior-upper and posterior areas of the acetabulum. Thus, in the anterior region of the Acd, the Mises stresses reach 3 MPa, in the upper part – 5.1 MPa, in the rear part – 5.2 MPa. In the center of the acetabulum, the level of stress is lower and equals to 1.5 MPa (fig. 2a).

Also, a higher level of stress-deformed state is observed in the Corticalis zone of the Acd (fig. 3a), in other parts of the Acd the amount of stress varies from 0.6 to 1.9 MPa. Due to its concavity, compressive stresses are mainly observed. The unloaded surface of the femoral head“protrudes” outwards under the action of tensile stresses. Based on our calculations, we found that normally the high-stress area corresponds to the zone of femoral head’s maximum contact with Acd (loaded sector), which is accompanied by increased compression of the subchondral plate. In the case of maximum contact between the femoral head and Acd, the central part of the latter (fossa) and the peripheral parts of the femoral head remained little in contact.

Based on the calculations, the following conclusions can be drawn:

1. In the calculation model of theHJ, the most stressed areas are the area of the femoral neck and the medial side of the proximal femur;
2. In the acetabulum, the upper and posterior edges are more stressed;
3. In the central part of the Acd, the level of stress is lower by more than 3 times, compared to its upper and posterior edges;
4. The cortical layer of the acetabulum is more stressed.



a b c

Fig.1 Stress according to Mises– a complete model of HJ: a) norm; b) acetabular index 60°; c) acetabular index 60 ° + antetorsion of the femur 40°.

*Analysis of the stress-deformed state of the hip joint components in the case of a model with an antetorsion angle of 20 ° and dysplastic Acd with an acetabular index of 60 °.*Analysis of stress-deformed state in this HJ model in the case of single-support standing showed that the most stressed, as for the normal model, is the lower femoral neck and the medial side of the proximal femur (Fig. 1b). In the Acd, the nature of the stress-deformed state distribution in comparison with the norm has changed– the front and rear edges of the acetabulum were more stressed, and in the upper edge the level of stress-deformed state became lower. Thus, in the front and rear areas of the Acd, the Mises’ stresses reach 5.3 MPa and 5.6 MPa, respectively, and in the upper part – 4.1 MPa. In the center of the Acd, the level of stress state, as for the normal model, was lower and equalled to 2.4 MPa (fig. 2b). A higher level of stress is observed in the Corticalis bone of the acetabulum (fig. 3b).

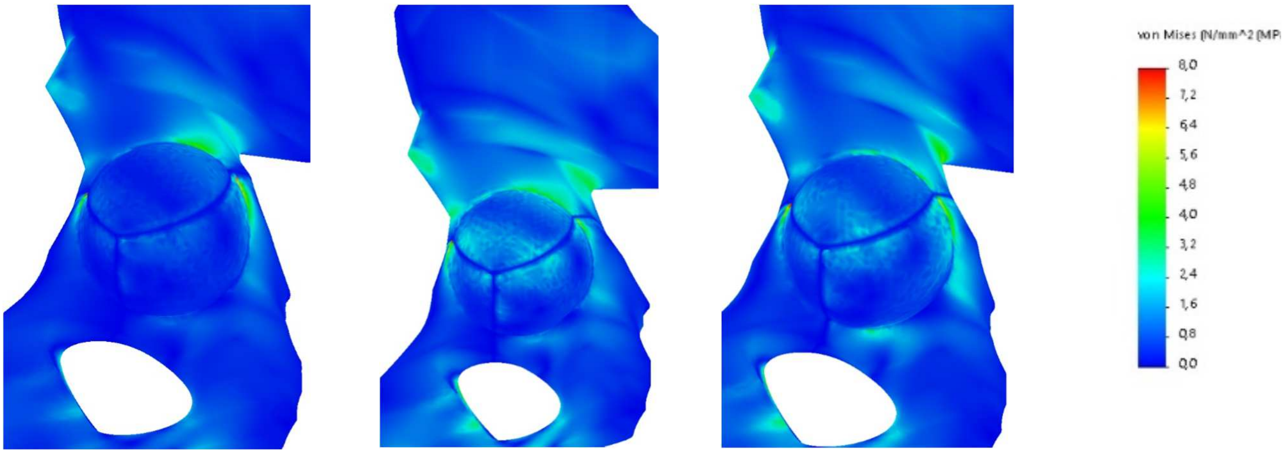


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Fig.2 Stress according to Mises - acetabulum: a) norm; b) acetabular index 60 °; c) acetabular index 60° + antetorsion of the femur 40°.

Based on the calculations of this HJ model, the following conclusions can be drawn:

1. In general, for theHJ model with an acetabular index of 60°, but normal indices of proximal femur, the most stressed areas, as for the normal model, are the femoral neck and the medial side of the proximal femur;

2. In the acetabulum, the nature of the stress-deformed state distribution has changed – the front and rear edges are more stressed;

3. In the central part of the Acd, the level of stress is lower than by 2 times, compared to its front and rear edges;

4. The most stressed is the cortical layer of the acetabulum.

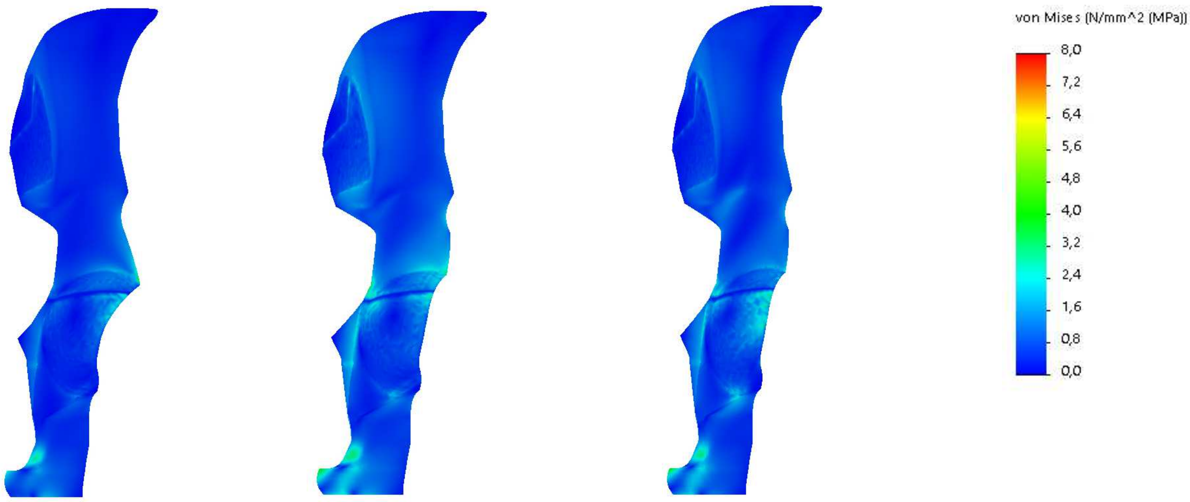

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Fig.3. Stress according to Mises– frontal section in the center of the Acd: a) norm; b) acetabular index 60°; c) acetabular index 60° + antetorsion of the femur 40°.

Analysis of the stress-deformed state of the dysplastic HJ components in the case of a model with an antetortion angle of 40° and an acetabular index of 60°. Analysis of stress-deformed state in this HJ model in the case of single-support standing showed that the most stressed in the proximal femur, as in the normal model, is the femoral neck, but the zone of stress concentration has shifted to its posterior side (fig. 1c).

In the Acd, the nature of the stress-deformed state distribution has also changed in comparison with the norm and a variant of the HJ model, which only considered the dysplasia of the acetabulum (acetabular index 60°). The most stressed was the anterior edge of the Acd, where the level of stress according to Mises reaches 8.8 MPa, at the rear edge of the acetabulum the maximum value of stress according to Mises was 6.1 MPa, and at the top edge – 3.3 MPa. In the center of the Acd, the level of stress, as for previous calculation models was lower and equalled to 2.6 MPa (fig. 2c). It should be noted that a higher level of stress is observed in the Corticalis bone of the acetabulum (fig. 3c).

Based on the calculations of this HJ model, the following conclusions can be drawn:

In general, for the HJ model with an acetabular index of 60° and antetorsion of 40°, the most stressed area, as well as for the previous calculation models, is the medial section of the proximal femur;

1. In the femoral neck, the zone of stress concentration has shifted backward;

2. The nature of the stress-deformed statedistribution has changed in the Acd– the anterior edge is the most stressed.

3. At the rear edge of the Acd, the level of stress also increased, and at the upper edge – decreased;

4. In the central part of the Acd, the level of stress is lower than by 2 times, compared to its front and rear edges;

5. The most stressed also was the cortical layer of the acetabulum.

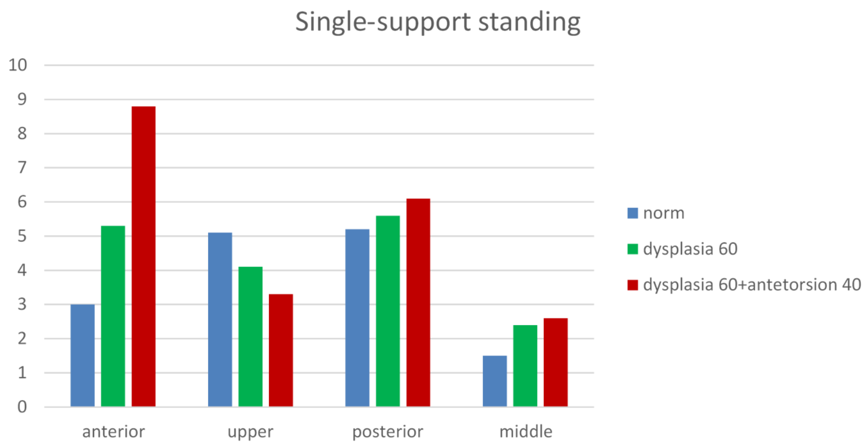

Fig.4 Comparison diagram of Mises stress values in the acetabulum in three HJ models: 1. under normal conditions; 2. Acd dysplasia (acetabular index 60°); 3. dysplastic changes both in proximal femur (antetorsion 40°) and in Acd (acetabular index 60°).

Comparative analysis of stress-deformed state in the above calculated HJ models showed (fig. 4) that in the case of acetabulum dysplasia the level of stress state decreases in the Acd upper edge, and increases –in its anterior and posterior parts. In the presence of additional changes in proximal femur, namely –antetorsion of the femur (in our case – 40°), there is a sharp increase (up to 50%) of the stress state at the anterior edge of the Acd, and there is an increase in the stress state at the posterior edge of the Acd(by 10%) and a reduction in stress-deformed state on the upper edge of the Acd (by 20%).

Thus, based on the data of a number of authors proving the influence of the stress-deformed state distribution on the development and shape of the bone [7,13] and the influence of pathological stress-deformed state deviations on articular cartilage [1,10], revealed in this study high, in absolute terms, stresses, as well as the nature of their distribution in the femoral head and acetabulum in the case of HJ dysplastic changes, in our opinion, may be one of the significant factors in the progression of the femur subluxation, and they also can initiate the occurrence of cartilage degeneration areas in the femoral head andAcd.

Conclusions

1. In the case of determining the stress-deformed state in the model of a child's hip joint that corresponds to the norm, in the case of single-support standing, the most stressed is the lower part of the femoral neck and the medial side of the proximal femur. In the anterior part of the Acd, the Mises stresses reach 3 MPa, in the upper part – 5.1 MPa, in the rear part – 5.2 MPa, in the center of the acetabulum– 1.5 MPa, in other parts of the Acd the stress varies from 0.6 to 1.9 MPa.

2. The stress-deformed state of the HJ components in children in the case of dysplastic changes in the Acd (acetabular index 60°) under conditions of single-support standing was characterized by an increase in stresses primarily in the acetabulum. Thus, in the front and rear parts of the Acd, the stress value is 5.3 MPa and 5.6 MPa, respectively, and in the upper part – 4.1 MPa. In the center of the Acd, the level of stress, as for the normal model, was lower and equalled to 2.4 MPa;

3. In the case of determining the stress-deformed state in elements of dysplastic HJ with cervical diaphyseal angle – 140°, antetorsion angle – 40° and acetabular index – 60° under conditions of single support, it is found that in the femoral neck the stress concentration zone shifted backward, the most stressed is the anterior edge – 8.8 MPa, at the rear edge of the Acd – 6.1 MPa, and at the upper edge – 3.3 MPa.

Thus, the high stresses determined in this study, in absolute values, as well as the nature of their distribution in femoral head and Acd in the case of dysplastic changes in the HJ, in our opinion, may be one of the significant factors of delaying the acetabulum formation and progression of hip subluxation, and it also can initiate occurrence of initial cartilage degeneration sites in femoral head and Acd that can be result of stresses distribution change in sites of the joint.

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Стаття надійшла: 17.11.2019 р.

DOI 10.26724/2079-8334-2020-4-74-121-125
UDC 616.314.17:615.3

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THERAPEUTIC POTENTIAL OF LACTOBACILLI-BASED DRUG IN THE TREATMENT OF GENERALIZED PERIODONTITIS

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The article presented the study results on the method of generalized periodontitis treatment with lactobacilli-based probiotic drug. Its efficacy was accessed according to generally accepted clinical and microbiological studies in the treatment dynamics in patients with stages I and II of generalized, chronic periodontitis on the 1st, 5th and 10th day of follow-up. Treatment of periodontitis included professional oral hygiene, topical and common application of probiotics. Probiotic application for the treatment of generalized periodontitis contributed to the improvement of oral health (p<0.001), as well as a significant reduction in symptomatic manifestation of gingivitis (p <0.001). The results of microbiological studies showed a decrease in the total count of colony-forming units in gingival pockets on Day 10 of treatment (p<0.05), as well as an increase in stabilizing bacterial species.

Key words: generalized periodontitis, probiotic, lactobacilli, microflora of gingival pockets.

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МОЖЛИВОСТІ ЗАСТОСУВАННЯ ПРЕПАРАТУ НА ОСНОВІ ЛАКТОБАЦИЛ У ЛІКУВАННІ ГЕНЕРАЛІЗОВАНОГО ПАРОДОНТИТУ

В статті наведені результати вивчення способу лікування генералізованого пародонтиту із використанням пробіотика, виготовленого на основі лактобацил. Ефективність оцінювали за даними загальноприйнятих клінічних та мікробіологічних досліджень в динаміці лікування пацієнтів із хронічним генералізованим пародонтитом I та II ступеню тяжкості на 1, 5 та 10 добу спостережень. Лікування пародонтиту включало професійну гігієну ротової порожнини, місцеве та загальне застосування пробіотика. Застосування пробіотика для лікування генералізованого пародонтиту сприяло покращенню стану гігієни порожнини рота (p<0,001), а також значному зменшенню явищ симптоматичного гінгівіту (p<0,001). Результати мікробіологічних досліджень показали зменшення загальної кількості колонієутворюючих одиниць у пародонтальних кишенях на 10 добу лікування (p<0,05), а також збільшення стабілізуючих видів мікроорганізмів.

Ключові слова: генералізований пародонтит, пробіотик, лактобацили, мікрофлора пародонтальних кишень.

The work is a fragment of the research project "Study of the role of opportunistic and pathogenic infectious agents with different sensitivity to antimicrobial and antiviral drugs in human pathology", state registration No. 0118U004456.

The importance of finding new ways to treat periodontal disease is determined by the fact that the number of people suffering from generalized periodontitis is growing steadily and this pathology is losing its age restrictions. The reason for this situation is the deterioration of environmental, demographic, and social factors, which leads to the immune system disorders and causes a depression of the protective barriers of the oral mucosa (OM). Decreased colony-forming resistance of OM, imbalance of the resident microflora in the oral ecosystem contributes to the development of generalized, chronic periodontitis [1].

To date, probiotic drugs are considered the most promising drugs against antibiotic-resistant subpopulations of pathogenic bacteria [3]. According to the WHO (2002), probiotics are living microorganisms, the use of which in the required amount provides therapeutic and preventive care for the

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