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**Original article**

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# *Osteoarthritis of the knee joint associated with a walking pattern classified as crouch gait in adolescents and adults with cerebral palsy*

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***Abstract***

**The aim** of this prospective study of a continuous cohort was to investigate anatomical and functional disorders, as well as their combination with manifestations of pathological changes in the articular cartilage of the knee joint in patients with cerebral palsy and a gait pattern classified as crouch gait. **Materials and methods** The study cohort consisted of 24 patients (20 men and 4 women) with cerebral palsy who had completed natural long bone growth (ages 16 to 42 years). Clinical, X-ray data, results of magnetic resonance imaging, computer analysis of gait, as well as visual assessment of articular cartilage according to Outerbridge were studied in two groups of patients: with natural development of crouch gait (group 1) and with iatrogenic crouch gait (group 2). **Results** According to the KSS questionnaire, in group 1, four patients (28.6 %) had a satisfactory function of the knee joint, and 10 patients (71.4 %) had poor function. Pain in the knee joint was reported by 12 patients (85.7 %). In the second group, two patients (20 %) had a satisfactory function, and the remaining eight (80 %) a poor one; pain syndrome was reported in 8 cases (80 %). Local articular cartilage defects were found in 6 out of 14 examined patients (42.9 %) in group 1 and in 6 out of 10 examined patients (60 %) in group 2. More pronounced efforts and high energy intensity of walking were found in patients with iatrogenic crouch gait: a more significant moment of force acting on flexion in the knee joint at initial contact, as well as a more pronounced pelvic tilt, combined with significant energy requirements to overcome the maximum flexion and extension moments in the hip joints. For the group of iatrogenic crouch gait, additional factors were found that predispose to pain and arthrosis of the knee joint: stiff knee gait ("frozen knee"), the shift of the generated energy towards the knee and hip joints. **Conclusions** The crouch gait pattern is heterogeneous in terms of the mechanisms, radiological features of foot deformities, and parameters of computer analysis of gait. An increase in power generation at the level of the hip joints is a common phenomenon in crouch gait, but with the natural development of this gait pattern, a large degree of power generation is also preserved at the level of the ankle joint, while in iatrogenic crouch gait, a decrease in the power generation of the ankle joint and, as a result, the developed increased power at the level of the knee joint contributes to the progression of arthritic degenerative changes. Damage to the articular surfaces of the knee joint is a manifestation of early arthritic changes and requires correction along with the standard elements of surgical intervention in the crouch gait pattern.

**Keywords**: cerebral palsy, adults, gonarthrosis, crouch gait

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## INTRODUCTION

Cerebral palsy (CP) is a persistent non-progressive encephalopathy that affects a person and his environment throughout life [1]. The frequency of occurrence is 0.5–4 cases per 1,000 and significantly depends on the term of preterm birth [2]. Despite the fact that the disease has neurological nature, it is the secondary orthopedic complications of cerebral palsy that seriously impair the quality of life of patients [3]. Currently, most patients with cerebral palsy but without severe neurological disorders reach adulthood [4].

One of the orthopedic problems in the individuals with cerebral palsy is early development of degenerative arthritis in the joints of the lower extremities [5]. It has been shown that, in comparison with the population without spastic paralysis, the incidence of arthritis of both the hip and knee joints in adults with cerebral palsy significantly increases in different periods of adult life [6]. The pathogenetic mechanism of the early development of gonarthrosis in patients with spastic diplegia has not been fully elucidated, but it is obvious that it is associated with the features of anatomy and movement function described as crouch gait that develop in late childhood and adolescence [7]. Correction of contractures, deformities, and pathology of the levers within the framework of multilevel interventions improves gait parameters [8, 9]. However, this does not prevent the development and persistence of pain associated with osteoarthritis of the knee joint in young adults [10].

**The aim** of this prospective study of a continuous cohort was to investigate anatomical and functional disorders, as well as their combination with manifestations of pathological changes in the articular cartilage of the knee joint in patients with cerebral palsy and a gait pattern classified as crouch gait, after the end of the natural growth of the long bones of the lower extremities.

## MATERIAL AND METHODS

The study analyzed the data of 24 patients (20 men and 4 women) with spastic types of cerebral palsy (spastic diplegia), with motor disorders corresponding to level III according to GMFCS (Gross Motor Function Classification System). In all patients, at the time of the study, the growth zones of the femur and tibia were closed. The mean age was 22.4 ± 7.02 years (range, 15 to 42 years). Patients not meeting these criteria were not included in the study. This continuous sample was generated throughout 2020 and 2021.

Their state was assessed using a modified KSS questionnaire (preoperative part): functional scores were adapted for use in patients with cerebral palsy [11]. MRI was used to identify and determine the location of the chondral defect [12]. Computed tomography was used to evaluate the torsion angles of the femur and lower leg bones [13]. Radiography of the knee joints (frontal and lateral projections, including calculation of the Caton-Deschamps index), pelvis, and feet were part of the study [14, 15]. Visual assessment of the articular surface of the femoral condyles was carried out during the intervention, where a capsulotomy at the lower pole of the patella was an obligatory element to bring it down, what enabled to assess the articular surfaces and the state of the articular cartilage according to Outerbridge [16].

Kinematic data were recorded by Qualisys 7+ optical cameras (8 cameras) with passive marker video capture technology, synchronized with six KISTLER dynometric platforms (Switzerland). When installing markers, the IOR model [17] was used. The patterns of the locomotor profile adopted by the Delphi Convention were analyzed [18]. The analysis of kinematics and kinetics was carried out in the QTM (Qualisys) and Visual3D (C-Motion) programs with automated calculation of values [19]. The variables of kinematics and kinetics were exported and processed with the calculation of the peak positive (positive), negative (negative) and total peak power as the sum of the absolute values of positive and negative power of the hip, knee and ankle joints [19, 20].

The results of the study were analyzed in two groups of patients.

Group 1 were 14 subjects (28 limbs) aged 16 to 43 years (mean, 22.7 ± 9.67 years), including 10 men and 4 women, body mass index 22.2 ± 6.28 kg/m$^2$. This group included patients in whom the crouch gait pattern was a natural result of the evolution of movement disorders and associated secondary orthopedic complications of spastic paralysis. Group 2 were 10 males (20 limbs) aged 15 to 19 years (mean, 17.0 ± 1.58 years), body mass index 19.5 ± 4.18 kg/m$^2$. Those were patients with early bilateral surgical interventions such as fibromyotomies or lengthening of the Achilles tendon, in addition to spastic diplegia and orthopedic secondary complications due to muscle retraction. In group 2, the studied pathological movement pattern was iatrogenic [9, 21, 22].

Statistical data processing was performed using the data analysis package Microsoft EXCEL-2010 and AtteStat 12.0.5 [20]. In descriptive statistics, the mean value and its standard deviation (M ± σ) were used. Due to the number of groups lower than 28, non-parametric statistics were used to process the results of kinematics and kinetics with a significance level of $p \leq 0.05$. Quantitative characteristics of the kinetics of samples are presented in the table as a median with a level of distribution of percentiles of 25÷75 % and the number of observations (n) equal to the number of limbs. Statistical significance of differences was determined using the unpaired Wilcoxon W-test.

The permission of the Ethics Committee of the Federal State Budgetary Institution Ilizarov National Medical Research Center (protocol No. 4(60) dated November 11, 2020) was obtained. The studies were carried out in accordance with the ethical standards of the Declaration of Helsinki of the World Medical Association "Ethical principles for medical research involving human subjects" as amended in 2000, "Rules of Clinical Practice in the Russian Federation", approved by the Order of the Ministry of Health of the Russian Federation dated June 19, 2003 No. 266 ". The parents of the children gave informed consent to the publication of the results of the studies without identification of the individual.

## RESULTS

KSS questionnaire yielded the following data.

In group 1, four patients (28.6 %) had a satisfactory function of the knee joint, in the remaining 10 patients (71.4 %), the score corresponded to poor function of the knee joint. Twelve patients (85.7 %) reported chronic pain associated with movements in the knee joint, eight of them noted mild pain, and two moderate.

In group 2, according to the modified KSS questionnaire, only 2 patients (20 %) had a satisfactory function of the knee joint, in the remaining eight (80 %), the function of the knee joint was assessed as poor. Four patients reported permanent moderate pain in the knee joint, four patients had moderate periodic pain; only two patients had no pain by movements in the knee joint.

MRI of the knee joints using MRI in group 1 showed damage to the articular surface in 2 patients (14 %), meniscopathies were noted in 4 patients, and in another four, the change in the articular surface was expressed in a decrease in the height of the articular cartilage, flattening of the articular surface, but without local defects . During the operation (Fig. 1, a; Fig. 2, a), local defects of the articular cartilage were found in 6 out of 14 examined patients (42.9 %), two patients had a defect in the condyles of both knee joints; one femoral condyle was more often affected; the average size of the defect was 2.3 $cm^2$, the defects corresponded to Outerbridge grades 2–3. It is important to note that all patients with a verified lesion of the articular cartilage of the knee had an unsatisfactory function according to the results of the questionnaire.

In group 2, the MRI study revealed damage to the articular surface of the femoral condyles in two patients (20 %); no damage to the meniscus or ligamentous apparatus was detected. During the intervention, articular surface defects were found in 6 out of 10 examined patients (60 %): chondral defects of both knee joints were observed in four patients; unlike the first group, cartilage damage of both femoral condyles (6 knees) was more common. The average size of the defect was 1.85 $cm^2$. It is interesting to note that the Outerbridge grade was higher, grade 3–4 (Fig. 1, b; Fig. 2, b).

The results of radiographic parameters, the changes of which are characteristic of the crouch gait pattern, are presented in Table 1.

It is interesting to note significant differences between the groups in terms of the index, reflecting the severity of the high position of the patella (more significant values in the group of the iatrogenic pattern), a smaller angle of talocalcaneal divergence in the sagittal plane in the group of natural development of the pattern and a much lower degree of coverage of the head of the talus by the navicular bone in group 1, indirectly reflecting a more pronounced retraction of the triceps of the lower leg (Fig. 3, Fig. 4).

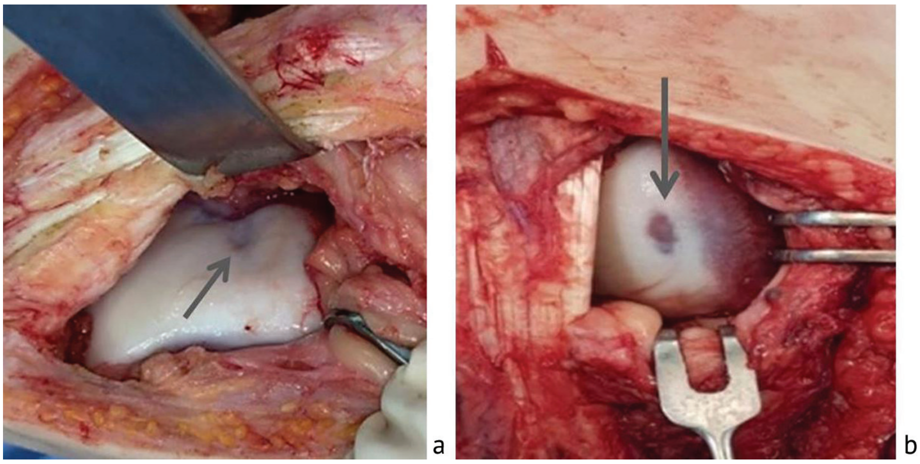



**Fig.1** Photos of cartilage tissue defects in the femoral condyles: ***a*** group 1 sample; ***b*** group 2 sample

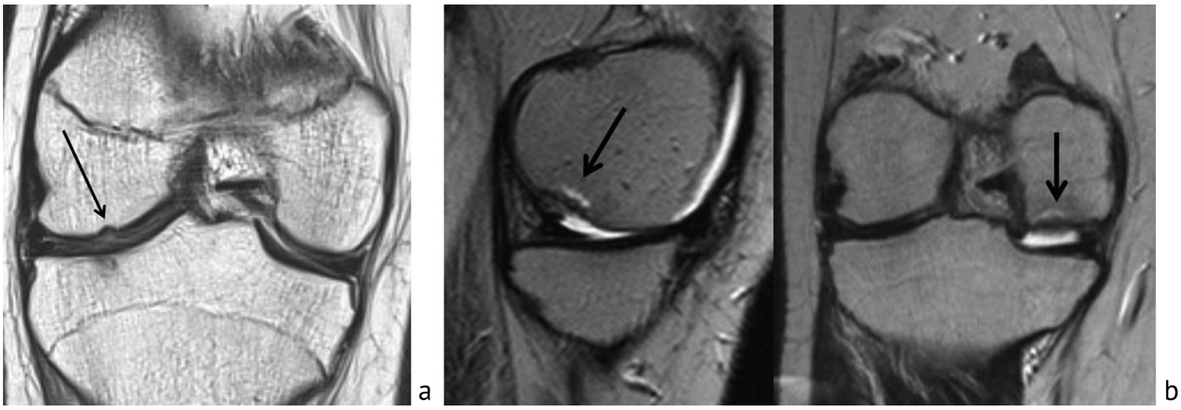



**Fig. 2** Pathology of the femoral condyles revealed by MRI: a defect of the articular surface (arrow), corresponding to Fig. 1, a; ***b*** defect of the articular surface (arrow), corresponding to Fig. 1, b

Table 1

Results of radiographic studies (M ± σ)

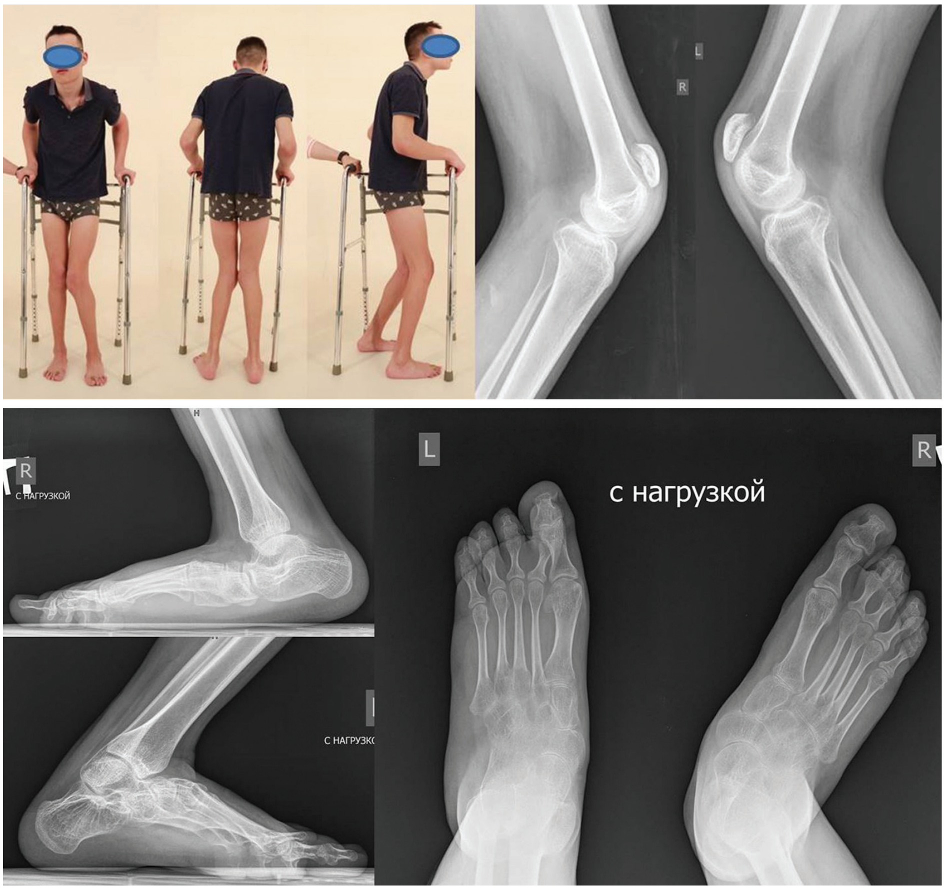
| Parameter | Group 1 (n = 28) | Group 2 (n = 20) |
|---|---|---|
| Caton-Deschamps index | 1.37 ± 0.17 | 1.62 ± 0.16 * |
| Tibiotalar angle, ° | 104.8 ± 9.96 | 105.7 ± 6.95 |
| Angle of talocalcaneal divergence in the sagittal plane, ° | 28.1 ± 4.04 | 42.0 ± 5.31 * |
| % of talar head coverage by the navicular bone | 55.7 ± 13.01 | 72.9 ± 11.84 * |
| Angle between the axes of the 1st metatarsal and proximal phalanx of the big toe, ° | 31.5 ± 15.11 | 25.0 ± 10.18 |

*Note*: * – significant difference between the groups ($p < 0.05$).


a

b

**Fig. 3** Photo and radiographs of the patient from group 1: a typical standing posture, plano-valgus deformity of the feet with equinus of their hind parts, patella alta in the radiographs of the knee joints; b plano-valgus deformity of the feet, violation of the Shade line, verticalization of the talus, equinus in the ankle joints, coverage of talar heads 50 % (right) and 65 % (left)




a

b

**Fig. 4** Photos and radiographs of a patient from group 2: a typical standing posture, almost correct shape of the feet; patella alta in the radiographs of the knee joints; b plano-valgus deformity of the right foot, tibial-talar angle on the left 82°, violation of the Shade line on both sides, talus head coverage 74 % (right) and 85 % (left)

Having analyzed the torsion angles of the femur and tibia, we did not find significant differences between the groups for patients after the closure of the growth zones. The average angle of anteversion of the femoral neck was 28.1° in group 1 and 25.8° in group 2 (exceeding the normal values of anteversion of the femoral neck for adults in both groups), of the tibia, 24.2° and 27.7°, respectively.

Computer gait analysis revealed the following average kinematic and kinetic values that are characteristic for crouch gait pattern in both groups (Table 2).

A significant difference was found in the increase in the forward inclination of the pelvis in the sagittal plane in patients of group 2 in 80 % of cases, which corresponds to one of the criteria for violation of the dynamic sagittal balance. In group 1, this was noted in 40 % of the cases. A significant increase in the strength parameters of the hip flexor/extensor muscles in iatrogenic crauch gait can be considered as the main compensatory capabilities of patients.

Table 3 shows the power parameters of the joints that give an idea of the magnitude and distribution of the generated and total power between the joints.

We should note an interesting difference in the parameters of the power of the knee and ankle joints between the groups (Table 3). In group 1 (natural development of the crouch gait pattern), the portion of ankle joint power generation in the total power generation at the level of limb joints is higher than the portion of the knee joint. And in group 2 (iatrogenic crouch gait), the situation is the opposite: the portion of power generated by the knee joint is higher than the portion of the generated power of the ankle joint.

Table 2

Kinematic indices in groups, (M ± σ)

| Kinematic and kinetic parameters | Group 1 (n = 28) | Group 2 (n = 20) |
|---|---|---|
| Foot position at the start of stance phase in the sagittal plane, ° | 4.9 ± 7.3 | 7.7 ± 9.8 |
| Angle of foot dorsiflexion in stance, ° | 19.2 ± 7.5 | 20.9 ± 12.9 |
| Position of the foot in push-off , ° | -0.96 ± 9.4 | 2.9 ± 14.8 |
| Foot position in swing phase, ° | 10.6 ± 7.8 | 14.0 ± 12.1 |
| Angle of foot orientation relative the vector of walking direction, ° | 25.9 ± 9.6 | 27.8 ± 13.3 |
| Angle of knee bending at the start of stance phase, ° | 41.8 ± 18.3 | 40.5 ± 14.8 |
| Angle of knee bending in the middle of stance phase, ° | 33.2 ± 22.6 | 27.9 ± 22.6 |
| Maximum angle of knee bending in swing phase, ° | 40.4 ± 16.99 | 39.8 ± 15.1 |
| Angle of femur flexion at the moment of initial contact, ° | 39.0 ± 10.1 | 42.3 ± 9.8 |
| Angle of femur flexion in the midstance, ° | 5.4 ± 10.1 | 9.2 ± 13.01 |
| Moment of force for the knee joint in initial contact at the start of the stance phase, N*m/kg | -0.11 ± 0.13 | -0.19 ± 0.16* |
| % of gait cycle of the maximum knee flexion in the swing phase | 78.0 ± 5.6 | 82.0 ± 5.1* |
| Maximum inclination of the pelvis, ° | 13.1 ± 7.4 | 19.2 ± 9.03* |
| Minimum inclination of the pelvis, ° | 2.6 ± 7.2 | 8.1 ± 8.5* |
| Maximum values of the hip extension moment, N*m/kg | 0.7 ± 0.38 | 1.0 ± 0.6* |
| Maximum values of the hip flexion moment, N*m/kg | -0.43 ± 0.42 | -0.68 ± 0.22* |
| % of gait cycle of the initiation of ankle relaxation | 25.95 ± 14.13 | 34.7 ± 14.1* |

*Note*: * – significant difference between the groups ($p < 0.05$).

Table 3

Peak power parameters of joint work, Me (25÷75 %)

| Joint/limb | Parameter | Group 1 (natural crouch gait) | Group 2 (iatrogenic gait) |
|---|---|---|---|
| **Hip** | Generation. W/kg | 1.13 (0.62÷1.4) | 1.3 (0.8÷1.7) |
| | Portion in the total generation | **0.39** (0.25÷0.54) | **0.40** (0.33÷0.47) |
| | Total power. W/kg | 1.5 (1.04÷1.8) | 1.9 (1.3÷2.3) |
| | Portion in the total power | 0.32 (0.24÷0.40) | 0.34 (0.24÷0.43) |
| **Knee** | Generation. W/kg | 0.43 (0.34÷1.5) | 0.9 (0.6÷1.4) |
| | Portion in the total generation | **0.25** (0.14÷0.28) | **0.31** (0.19÷0.39) |
| | Total power. W/kg | 1.6 (1.1÷3.6) | 2.1 (1.5÷3.3) |
| | Portion in the total power | 0.36 (0.32÷0.39) | 0.39 (0.30÷0.50) |
| **Ankle** | Generation. W/kg | 1.0 (0.48÷1.5) | 0.8 (0.6÷1.4) |
| | Portion in the total generation | **0.33** (0.25÷0.48) | **0.26** (0.17÷0.41) |
| | Total power. W/kg | 1.6 (0.9÷2.5) | 1.6 (1.1÷2.1) |
| | Portion in the total power | 0.29 (0.24÷0.37) | 0.25 (0.19÷0.37) |
| **Total generation in all joints, W/kg** | | 2.8 (1.8÷4.5) | 2.97 (2.34÷3.92) |
| **Total power of work of all joints**, **W/kg** | | 5.1 (3.3÷8.4) | 5.6 (4.4÷7.1) |

## DISCUSSION

In their work, Rodda et al [23] present a classification of pathological gait patterns in children and adolescents with spastic diplegia, which has become generally accepted and is the starting point for deeper research. The crouch gait pattern is defined as a symmetrical gait when the foot is in a dorsiflexion throughout the entire stance phase of the gait cycle. There is excessive flexion in the knee and hip joints. The pelvis may be in a normal position or tilted backwards.

Orthopedic disorders, found in crouch gait in adults, include retraction of the knee and hip flexors, torsion deformities of the hip, external rotation of the foot (external deviation of the foot), usually associated with severe plano-valgus deformity, and high position of the patella [23. 24]. These disorders cause dysfunction of the biomechanical levers leading to the location of the support reaction vector in a permanent position towards backwards from the axis of rotation of the knee joint [24, 25, 26].

A slightly different mechanism for the development of the crouch gait pattern is the situation if the weakness of the triceps of the lower leg becomes a trigger for disorders due to fibromyotomies performed at an early age and unreasonable and isolated lengthening of the Achilles tendon [9]. In this situation, the initial compensatory flexion of the knee joint, combined with the activated function of the quadriceps femoris, inevitably progresses into the so-called iatrogenic crouch gait pattern as the patient grows and increases in weight [21, 22, 27].

In adult patients with the crouch gait pattern, in addition to gait disturbances, pain in the knee joint was described [28]. In general, the incidence of pain in the knee joint in patients with movement disorders is 21 % [29]. At the same time, it is stated that the causes of pain syndrome have not been fully defined [30].

An increased mechanical pressure on the articular surfaces due to a violation of the kinematics of movements is noted in the pathogenesis of pain syndrome and early development of arthritic lesions of the knee joint with crouch gait [29] along with high position of the patella [28, 29], high moments of force arising from increased muscle work leading to the occurrence of excessive compression forces between the articular surfaces [31], and chronic microtraumatization of the articular cartilage [33].

Steele et al [31] showed that in severe crouch gait, peak efforts reach a 6-fold analogue of body weight which exceeds twice the effort occurring during normal movements in the knee joint. A large role in the development of pathological femorotibial compression is given to great efforts due to constant or almost constant contraction of the quadriceps femoris muscle as a compensatory mechanism for stiff knee gait [31, 33, 34]. Rethlefsen et al [30] also found a positive correlation between the pain syndrome and the patient's age, and a higher incidence of pain in women with a crouch gait pattern.

The data published by Lundh et al [35] in the study of fatigue, quality of life and gait characteristics in adult patients compared with healthy ones seem interesting. It was found that power generation (including useful power due to concentric muscle contractions providing advancement) in patients with crouch gait is transferred proximally during hip movements. At the same time, the generated power of the extensors of the knee joint and the flexors of the foot is reduced by half in comparison with the control group. These changes correlate with fatigue and a decrease in the quality of life.

The effectiveness of orthopedic surgery, aimed at improving the biomechanics of lower limb movements, improves kinematic and kinetic parameters of gait and also reduces the intensity of pain in the knee joint, but does not eliminate it completely [7, 33, 36, 37]. Pelrine et al [38, comparing two groups (operative and conservative treatment) of older children with a crouch gait pattern, showed that after one-year follow-up 42 % of patients after surgery still had pain in the knee joint and 50 % after conservative treatment.

The results of our study did not reveal significant differences in the degree of arthritis of the knee joint in the patients of both natural development of crouch gait and in iatrogenically determined gait disorders. Both MRI and visual examination of the articular surfaces revealed significant arthritic lesions in the form of articular surface defects in a number of patients. We should note that in group 1 the incidence of articular surface defects was 42.9 % and in the group of iatrogenic crouch gait pattern it was 60 %. The sizes of defects in our series are quite limited and certainly suppose interventions to stimulate the reparative processes of articular surfaces within the framework of multilevel interventions. Pain syndrome and a decrease in the KSS score correlate with the severity of damage to the articular surfaces even if the changes were not detected by MRI. We assume that the difficulties in detecting articular surface defects using magnetic resonance imaging were due to the fact that the diagnostic procedure ran without general anesthesia.

The radiographic study showed the expected differences between the groups which consisted in bone changes reflecting the impact of tibia triceps retraction on the formation of the shape and position of the foot bones (more pronounced changes in group 1). A higher position of the patella in the group of iatrogenic crouch gait pattern may occur due to an increase in the compensatory function of the quadriceps muscle executed over a long period in the absence or critical decrease in the strength of the soleus muscle, when secondary proximal displacement of the patella occurs [26]. The "stiff-knee gait" pattern can be considered as a manifestation of a decompensated crouch gait pattern [39. 40]. A pathological manifestation, characteristic of stiff knee gait in our study, was a significantly later onset of the moment of maximum flexion of the knee joint in the non-support phase in patients of the iatrogenic group (group 2).

Our study revealed differences between groups and results of computerized gait analysis. We found more pronounced efforts and higher power consumption of walking in patients with iatrogenic crouch gait. This is indicated by a significantly more significant moment of force, acting on flexion in the knee joint at initial contact, as well as a more pronounced tilt of the pelvis, combined with significant power requirements to overcome the maximum moments of flexion and extension in the hip joints, occurring during walking. We also should note that the above figures also explain the need for a higher proportion of the total generated (positive) power of movements in the total power in group 2 patients necessary for walking in iatrogenic crouch gait.

Earlier relaxation at the level of the ankle joint which is the beginning of a push with the foot which was marked in group 1 is characteristic of retraction of the plantar flexors (deficiency in the length of this muscle group). This explains the differences in the values of this kinetic parameter between the groups.

Finally, we should note the preservation of the generated power at the level of the ankle joints to a greater extent in patients without previously performed surgical interventions. This situation is a favorable prognostic factor in terms of maintaining motor abilities and less fatigue [35]. In our previous study, it was shown that the share of power generated at the level of the ankle joint is 60–62 % of the total power during normal walking [40]. High power generation during movements in the knee joint in patients with iatrogenic crouch gait should be interpreted as an unfavorable development of the compensatory mechanism for the loss of strength of the foot flexors which leads to increased stress on the articular surfaces of the knee joint, thus predisposing to the onset and progression of pain and arthritis.

In general, this study identified special factors, predisposing to knee joint arthritis for the iatrogenic crouch gait group which are stiff knee gait, the transfer of the generated energy towards the knee and hip joints along with the ones, common for the natural development of this pattern (typical kinematics and high position of the patella, age of patients).

## CONCLUSION

The crouch gait pattern with clinical similarity of manifestations is heterogeneous in terms of the mechanisms, radiological features of foot deformities and indicators of computer analysis of gait, especially in terms of kinetic indicators of power developed at the level of the knee and ankle joint. Increased power generation at the level of the hip joints is common in crouch gait, but in the natural development of this gait pattern, a greater degree of power generation at the level of the ankle joint is preserved, while in iatrogenic crouch gait, the increased power developed at the level of the knee joint will contribute to progression of arthritic degenerative changes. Damage to the articular surfaces of the knee joint is a manifestation of early arthritic changes and requires correction along with the standard elements of surgical intervention for deformities of the femur, foot, muscle retraction and high position of the patella.

## REFERENCES

1. Rosenbaum P., Paneth N., Leviton A., Goldstein M., Bax M., Damiano D., Dan B., Jacobsson B. A report: the definition and classification of cerebral palsy April 2006. *Dev. Med. Child Neurol. Suppl*., 2007, vol. 109, pp. 8-14.
2. Arnaud C., Ehlinger V., Delobel-Ayoub M., Klapouszczak D., Perra O., Hensey O., Neubauer D., Hollódy K., Virella D., Rackauskaite G., Greitane A., Himmelmann K., Ortibus E., Dakovic I., Andersen G.L., Papavasiliou A., Sellier E., Platt M.J., Krägeloh-Mann I. Trends in prevalence and severity of pre/perinatal cerebral palsy among children born preterm from 2004 to 2010: a SCPE collaboration study. *Front. Neurol*., 2021, vol. 12, pp. 624884. DOI: 10.3389/fneur.2021.624884.
3. Davids J.R. The foot and ankle in cerebral palsy. *Orthop. Clin. North. Am*., 2010, vol. 41, no. 4, pp. 579-593. DOI: 10.1016/j.ocl.2010.06.002.
4. Manikandan M., Kerr C., Lavelle G., Walsh M., Walsh A., Ryan J.M. Health service use among adults with cerebral palsy: a mixed-methods systematic review. *Dev. Med. Child Neurol*., 2022, vol. 64, no. 4, pp. 429-446. DOI: 10.1111/dmcn.15097.
5. Tosi L.L., Maher N., Moore D.W., Goldstein M., Aisen M.L. Adults with cerebral palsy: a workshop to define the challenges of treating and preventing secondary musculoskeletal and neuromuscular complications in this rapidly growing population. *Dev. Med. Child Neurol*., 2009, vol. 51, no. Suppl. 4, pp. 2-11. DOI: 10.1111/j.1469-8749.2009.03462.x.
6. French Z.P., Torres R.V., Whitney D.G. Elevated prevalence of osteoarthritis among adults with cerebral palsy. *J. Rehabil. Med*., 2019, vol. 51, no. 8, pp. 575-581. DOI: 10.2340/16501977-2582.
7. Kedem P., Scher D.M. Evaluation and management of crouch gait. *Curr. Opin. Pediatr*., 2016, vol. 28, no. 1, pp. 55-59. DOI: 10.1097/MOP.0000000000000316.
8. Galey S.A., Lerner Z.F., Bulea T.C., Zimbler S., Damiano D.L. Effectiveness of surgical and non-surgical management of crouch gait in cerebral palsy: A systematic review. *Gait Posture*, 2017, vol. 54, pp. 93-105. DOI: 10.1016/j.gaitpost.2017.02.024.

9. Dolganova T.I., Gatamov O.I., Chibirov G.M., Dolganov D.V., Popkov D.A. Clinical and biomechanical results of multilevel orthopaedic inerventions in crouch-gait patients. *Genij Ortopedii*, 2020, vol. 26, no. 3, pp. 325-333. DOI: 10.18019/1028-4427-2020-26-3-325-333.
10. Boyer E.R., Stout J.L., Laine J.C., Gutknecht S.M., Araujo de Oliveira L.H., Munger M.E., Schwartz M.H., Novacheck T.F. Long-term outcomes of distal femoral extension osteotomy and patellar tendon advancement in individuals with cerebral palsy. *J. Bone Joint Surg. Am*., 2018, vol. 100, no. 1, pp. 31-41. DOI: 10.2106/JBJS.17.00480.
11. Scuderi G.R., Bourne R.B., Noble P.C., Benjamin J.B., Lonner J.H., Scott W.N. The new Knee Society Knee Scoring System. *Clin. Orthop. Relat. Res*., 2012, vol. 470, no. 1, pp. 3-19. DOI: 10.1007/s11999-011-2135-0.
12. Ota S., Sasaki E., Sasaki S., Chiba D., Kimura Y., Yamamoto Y., Kumagai M., Ando M., Tsuda E., Ishibashi Y. Relationship between abnormalities detected by magnetic resonance imaging and knee symptoms in early knee osteoarthritis. *Sci. Rep*., 2021, vol. 11, no. 1, pp. 15179. DOI: 10.1038/s41598-021-94382-3.
13. Gose S., Sakai T., Shibata T., Akiyama K., Yoshikawa H., Sugamoto K. Verification of the Robin and Graham Classification System of hip disease in cerebral palsy using three-dimensional computed tomography. *Dev. Med. Child Neurol*., 2011, vol. 53, no. 12, pp. 1107-1112. DOI: 10.1111/j.1469-8749.2011.04130.x.
14. Seil R., Müller B., Georg T., Kohn D., Rupp S. Reliability and interobserver variability in radiological patellar height ratios. *Knee Surg. Sports Traumatol. Arthrosc*., 2000, vol. 8, no. 4, pp. 231-236. DOI: 10.1007/s001670000121.
15. Tomov A.D., Diachkov K.A., Popkov D.A. Parameters of radiographic coxometry in reconstructive operations on the hip joint as part of multilevel surgical interventions in children with cerebral palsy. *Genij Ortopedii*, 2019, vol. 25, no. 3, pp. 337-347. DOI: 10.18019/1028-4427-2019-25-3-337-347.
16. Spahn G., Klinger H.M., Hofmann G.O. How valid is the arthroscopic diagnosis of cartilage lesions? Results of an opinion survey among highly experienced arthroscopic surgeons. *Arch. Orthop. Trauma Surg*., 2009, vol. 129, no. 8, pp. 1117-1121. DOI: 10.1007/s00402-009-0868-y.
17. Aksenov A.Yu., Heath G.H., Klishkovskaya T.A., Dolganova T.I. Optimising video-based data capture for pathological gait analysis in children with cerebral palsy using a limited number of retro-reflective cameras (literature review). *Genij Ortopedii*, 2019, vol. 25, no. 1, pp. 102-110. (in Russian, English) DOI: 10.18019/1028-4427-2019-25-1-102-110.
18. Umberger B.R., Martin P.E. Mechanical power and efficiency of level walking with different stride rates. *J. Exp. Biol*., 2007, vol. 210, part 18, pp. 3255-3265. DOI: 10.1242/jeb.000950.
19. Zelik K.E., Honert E.C. Ankle and foot power in gait analysis: Implications for science, technology and clinical assessment. *J. Biomech*., 2018, vol. 75, pp. 1-12. DOI: 10.1016/j.jbiomech.2018.04.017.
20. Gaidyshev I.P. *Reshenie nauchnykh i inzhenernykh zadach sredstvami Excel, VBA i C/C++* [Solving scientific and engineering problems using Excel, VBA and C/C++]. BKhV-Petersburg, 2004. (in Russian)
21. Borton D.C., Walker K., Pirpiris M., Nattrass G.R., Graham H.K. Isolated calf lengthening in cerebral palsy. Outcome analysis of risk factors. *J. Bone Joint Surg. Br*., 2001, vol. 83, no. 3, pp P. 364-370. DOI: 10.1302/0301-620x.83b3.10827.
22. Dietz F.R., Albright J.C., Dolan L. Medium-term follow-up of Achilles tendon lengthening in the treatment of ankle equinus in cerebral palsy. *Iowa Orthop. J*., 2006, vol. 26, pp. 27-32.
23. Rodda J.M., Graham H.K., Carson L., Galea M.P., Wolfe R. Sagittal gait patterns in spastic diplegia. *J. Bone Joint Surg. Br*., 2004, vol. 86, no. 2, pp. 251-258. DOI: 10.1302/0301-620x.86b2.13878.
24. Arnold A.S., Anderson F.C., Pandy M.G., Delp S.L. Muscular contributions to hip and knee extension during the single limb stance phase of normal gait: a framework for investigating the causes of crouch gait. *J. Biomech*., 2005, vol. 38, no. 11, pp. 2181-2189. DOI: 10.1016/j.jbiomech.2004.09.036.
25. Hicks J.L., Schwartz M.H., Arnold A.S., Delp S.L. Crouched postures reduce the capacity of muscles to extend the hip and knee during the single-limb stance phase of gait. *J. Biomech*., 2008, vol. 41, no. 5, pp. 960-967. DOI: 10.1016/j.jbiomech.2008.01.002.
26. Miller F. *Cerebral palsy*. New York: Springer. 2005.
27. Pilloni G., Pau M., Costici F., Condoluci C., Galli M. Use of 3D gait analysis as predictor of Achilles tendon lengthening surgery outcomes in children with cerebral palsy. *Eur. J. Phys. Rehabil. Med*., 2018, vol. 55, no. 2, pp. 250-257. DOI: 10.23736/S1973-9087.18.05326-1.
28. Murphy K.P. Cerebral palsy lifetime care – four musculoskeletal conditions. *Dev. Med. Child Neurol*., 2009, vol. 51, no. Suppl. 4, pp. 30-37. DOI: 10.1111/j.1469-8749.2009.03431.x.
29. Pelrine E., Novacheck T., Boyer E. Association of knee pain and crouch gait in individuals with cerebral palsy. *J. Pediatr. Orthop*., 2020, vol. 40, no. 6, pp. e504-e509. DOI: 10.1097/BPO.0000000000001487.
30. Rethlefsen S.A., Nguyen D.T., Wren T.A., Milewski M.D., Kay R.M. Knee pain and patellofemoral symptoms in patients with cerebral palsy. *J. Pediatr. Orthop*., 2015, vol. 35, no. 5, pp. 519-522. DOI: 10.1097/BPO.0000000000000304.
31. Steele K.M., Demers M.S., Schwartz M.H., Delp S.L. Compressive tibiofemoral force during crouch gait. *Gait Posture*, 2012, vol. 35, no. 4, pp. 556-560. DOI: 10.1016/j.gaitpost.2011.11.023.
32. Nhan D.T., Garcia M.R., Lee R.J. Bilateral Bicondylar Osteochondritis Dissecans in a Child with Spastic Diplegia and Crouch Gait: A Case Report. *JBJS Case Connect*, 2018, vol. 8, no. 2, pp. e41. DOI: 10.2106/JBJS.CC.17.00271.
33. Rodda J.M., Graham H.K., Nattrass G.R., Galea M.P., Baker R., Wolfe R. Correction of severe crouch gait in patients with spastic diplegia with use of multilevel orthopaedic surgery. *J. Bone Joint Surg. Am*., 2006, vol. 88, no. 12, pp. 2653-2664. DOI: 10.2106/JBJS.E.00993.
34. Brandon S.C.E., Thelen D.G., Smith C.R., Novacheck T.F., Schwartz M.H., Lenhart R.L. The coupled effects of crouch gait and patella alta on tibiofemoral and patellofemoral cartilage loading in children. *Gait Posture*, 2018, vol. 60, pp. 181-187. DOI: 10.1016/j.gaitpost.2017.12.005.
35. Lundh S., Nasic S., Riad J. Fatigue, quality of life and walking ability in adults with cerebral palsy. *Gait Posture*, 2018, vol. 61, pp. 1-6. DOI: 10.1016/j.gaitpost.2017.12.017.
36. Stout J.L., Gage J.R., Schwartz M.H., Novacheck T.F. Distal femoral extension osteotomy and patellar tendon advancement to treat persistent crouch gait in cerebral palsy. *J. Bone Joint Surg. Am*., 2008, vol. 90, no. 11, pp. 2470-2484. DOI: 10.2106/JBJS.G.00327.
37. Das S.P., Pradhan S., Ganesh S., Sahu P.K., Mohanty R.N., Das S.K. Supracondylar femoral extension osteotomy and patellar tendon advancement in the management of persistent crouch gait in cerebral palsy. Indian *J. Orthop*., 2012, vol. 46, no. 2, pp. 221-228. DOI: 10.4103/0019-5413.93677.
38. Pelrine E.R., Novacheck T.F., Boyer E.R. Knee pain and crouch gait in individuals with cerebral palsy: what impact does crouch-

related surgery have? *Dev. Med. Child Neurol*., 2020, vol. 62, no. 6, pp. 709-713. DOI: 10.1111/dmcn.14438.
39.Richards J. *The Comprehensive Textbook of Clinical Biomechanics: with access to e-learning course* [formerly Biomechanics in Clinic and Research]. United Kingdom, Elsevier Health Sciences, 2018, 380 p.
40.Dolganova T.I., Popkov D.A., Dolganov D.V., Chibirov G.M. Indicators of the kinetics of locomotor stereotypes in healthy children in different speed ranges of movement. *Genij Ortopedii*, 2022, vol. 28, no 3, pp. 417-424. DOI: 10.18019/1028-4427-2022-28-3-417-424.

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