УДК 616.727.2+616.727.3]-053.2-07-06:616.72-008.1
https://doi.org/10.17816/PTORS7135-42

KINEMATIC INSTRUMENTAL ANALYSIS OF THE SHOULDER AND ELBOW JOINT IN NORMAL CONDITIONS AND WITH HYPERMOBILITY OF THE JOINT IN THE GAIT CYCLE

© ***O.I. Vorontcova[1], L.A. Udochkina[2], M.S. Baranets[1], M.V. Grechitaeva[3], L.A. Goncharova[2]***

[1] Astrakhan State University, Astrakhan, Russia
[2] Astrakhan State Medical University, Astrakhan, Russia
[3] Belgorod National Research University, Belgorod, Russia

Received: 29.10.2018 Revised: 23.01.2019 Accepted: 05.03.2019

Background. There is evidence for violation or a complete change in the arm swing cycle during walking in a number of pathologic conditions.

Aim. We assess the functional state of the shoulder and elbow joints in normal conditions and with joint hypermobility syndrome (JHS) using the kinematic instrumental method of analyzing gait.

Material and methods. We studied 27 adolescent girls 12–15 years old with JHS and healthy subjects. A Vicon motion capture analysis system (Vicon, Oxford, Great Britain) was used to record biomechanical parameters.

Results. A decrease in limb movement amplitudes was noted in the shoulder joint around the frontal and sagittal axes in patients with JHS compared to the norm. During the arm swing cycle in the normal state, the shoulder is in a state of internal rotation, whereas in the girls with JHS, the shoulder is in a state of external rotation for most of the arm swing cycle. The elbow joint in the JHS subjects showed a significant increase in flexion angle of the forearm in the swing phase of $41.5^\circ \pm 0.90^\circ$ and a decrease in this angle in the stance phase. The JHS group also showed a decrease in power of the muscles acting on the shoulder joint.

Conclusions. A common sign of changes in the range of motion of the links of the upper limb in the shoulder and elbow joints in subjects with JHS was decreased amplitude of their flexion and decreased power of the joints. In the adolescents with JHS in the shoulder joint, a significant decrease in the internal rotation angles and reduction of the limb was found.

Keywords: gait cycle; motion capture and analysis system; shoulder and elbow joints; hypermobility syndrome of joints.

КИНЕМАТИЧЕСКИЙ ИНСТРУМЕНТАЛЬНЫЙ АНАЛИЗ СОСТОЯНИЯ ПЛЕЧЕВОГО И ЛОКТЕВОГО СУСТАВОВ В НОРМЕ И ПРИ СИНДРОМЕ ГИПЕРМОБИЛЬНОСТИ СУСТАВОВ В ЦИКЛЕ ШАГА

© ***О.И. Воронцова[1], Л.А. Удочкина[2], М.С. Баранец[1], М.В. Гречитаева[3], Л.А. Гончарова[2]***

[1] Астраханский государственный университет, Астрахань;
[2] Астраханский государственный медицинский университет, Астрахань;
[3] Белгородский государственный национальный исследовательский университет, Белгород

Поступила: 29.10.2018 Одобрена: 23.01.2019 Принята: 05.03.2019

Обоснование. Имеются данные о нарушении или полном изменении цикла переноса рук при ходьбе при ряде патологических состояний.

Цель — оценка функционального состояния плечевого и локтевого суставов в норме и при синдроме гипермобильности суставов (СГМС) с использованием кинематического инструментального метода анализа походки человека.

Материал и методы. Объектом исследования были 27 девочек подросткового в возрасте 12–15 лет с СГМС и здоровые испытуемые. Биомеханические параметры регистрировали при помощи системы захвата и анализа движения Vicon (Оксфорд, Великобритания).

■ For citation: Vorontcova OI, Udochkina LA, Baranets MS, et al. Kinematic instrumental analysis of the shoulder and elbow joint in normal conditions and with hypermobility of the joint in the gait cycle. *Pediatric Traumatology, Orthopaedics and Reconstructive Surgery*. 2019;7(1):35-42. https://doi.org/10.17816/PTORS7135-42

Результаты. Установлено снижение амплитуды движений конечности в плечевом суставе вокруг фронтальной, сагиттальной осей у пациентов с СГМС по сравнению с нормой. На протяжении всего цикла шага в норме плечо находится в состоянии внутренней ротации, тогда как в группе девочек с СГМС большую часть цикла переноса плечо находится в состоянии наружной ротации. В локтевом суставе в группе обследуемых с СГМС выявлено значимое увеличение угла сгибания предплечья в фазе переноса вперед 41,5 ± 0,90° и уменьшение значений этого угла в фазе переноса назад. В группе девушек с СГМС определено снижение мощности работы мышц, воздействующих на плечевой сустав.

Заключение. Общим признаком изменений объема движений звеньев верхней конечности в плечевом и локтевом суставах в группе обследуемых с СГМС было уменьшение амплитуды их сгибания и снижение мощности работы суставов. В группе подростков с СГМС в плечевом суставе наблюдалось значительное уменьшение углов внутренней ротации и приведения конечности.

Ключевые слова: цикл шага; система захвата и анализа движения; плечевой и локтевой суставы; синдром гипермобильности суставов.

Background

Joint hypermobility syndrome (JHMS) is the major clinical manifestation of genetically determined systemic connective tissue dysplasia. The problem of diagnosing hereditary disorders of the connective tissue is one of the most complicated diagnoses in pediatrics and pediatric orthopedics because of the diversity of mutations and clinical polymorphisms. The ICD-10 includes only five nosological forms of hereditary disorders of the connective tissue (e.g., JHMS) (M35.7). JHMS is characterized by an increase in the range of movements in the joints compared with the average statistical norm detected in adolescence with a frequency from 6.7% to 39.6% [1]. The kinematic instrumental gait analysis estimates the numerical indicators of the functional state of the joints of the upper and lower extremities. The majority of previous studies have concentrated on the analysis of the state of the supporting, spring, and motor functions of the passive part of the musculoskeletal system, and the function of skeletal muscles in the normal condition as well as under the pathological conditions of the lower extremities, pelvis, and spine. In this case, the movement of the upper extremities while walking in a step cycle is poorly understood. When the motion-capture optoelectronic systems were developed, the role of the upper extremities in the step cycle attracted scholars' attention. Several scholars demonstrated that the restriction of hand movements during walking affects the decrease in gait stability in the mediolateral, anteroposterior, and vertical directions [2]. Hand movement with impaired balance plays a significant role in restoring lost body balance [3]. In addition, moving hands during walking help to reduce the vertical component of the support reaction force [4, 5]. As a result of restriction or the complete absence of hand movements during walking, the amplitude of shift of the mass center along the vertical increases [6].

The analysis of these studies enabled us to put-forward a hypothesis on the effect of hand movements during walking to reduce energy consumption as a consequence of minimizing neuromuscular efforts aimed at stabilizing the body balance [7, 8]. A disorder or a complete alteration in the hand-swing cycle during walking was noted in several pathological conditions. The kinematic characteristics of gait have been studied in patients with patellofemoral pain syndrome [9] and hypermobile form of the Ehlers-Danlos disease [10, 11]. However, these studies were performed for studying the kinematics of the lower extremities and pelvis during walking. No study has concentrated on the analysis of the biomechanical parameters related to the joint condition of the upper extremities during walking in patients with JHMS.

This study aimed to assess the functional state of the shoulder and elbow joints in normal condition as well as in JHMS using the kinematic instrumental method of analyzing a human's gait. To achieve this aim, the following tasks were set: 1) Determine the quantitative indicators related to the functional state of the shoulder and elbow joints in the norm and 2) Identify the kinematic aspects of the shoulder and elbow joints in adolescent girls with JHMS.

Material and methods

In this study, the cycle of transferring hands during a person's walk was used [12]. Overall, 27 adolescent girls aged 12–15 years were enrolled

Table 1

Maximum angles of movement of limb segments in the hand-swing cycle

Joint	Movement	Forward swing phase		Backward swing phase	
		Period of falling	Period of rise	Period of falling	Period of rise
Shoulder	Flexion		×		
	Extension	×			×
	Adduction		×		
	Abduction	×			×
	Internal rotation		×	×	
	External rotation	×			×
Elbow	Flexion			×	
	Extension	×			×

in the study, according to the accepted biological scheme of age division into periods, proposed in 1965 by the Institute of Physiology of Children and Adolescents [13]. In addition, 22 healthy female subjects (height, 1.64 ± 0.26 m; weight 49.5 ± 2.3 kg, and the length of the lower extremities, 0.80 ± 0.02 m) were recruited. The inclusion criteria were the absence of any cardiovascular, neurological, or musculoskeletal disorders; visible postural or motor impairments; the normal range of movement preserved; and the level of muscle strength. The study group comprised five female patients with JHMS (height, 1.70 ± 0.12 m; weight, 47.5 ± 3.4 kg; length of the lower extremities, 0.85 ± 0.04 m).

The studies were performed in real-time mode. The subjects were asked to perform a series of seven passes along a dynamometric platform with an arbitrary speed of 1.2 ± 0.1 m/s in the healthy subjects and 0.92 ± 0.1 m/s in patients with JHMS.

Biomechanical parameters were recorded using the Vicon motion-capture and analysis system (Oxford, UK), which included 10 Vicon N40 infrared cameras, AMTI two-section dynamometric platform (OR6-5-1000, Watertown MA, USA), and Vicon Nexus and Vicon Polygon software (UK). We investigated the angles of flexion–extension and adduction–abduction, rotation of the extremities in the shoulder joints, flexion–extension of the forearms in the elbow joints, and the power of the shoulder and elbow joints. The power of the joints used in the skeletal model was determined as the scalar product of the moment of forces and the angular velocity of movement in the joint, which was considered as an absolute value with a unit of W/kg.

The Plug-in Gait full body model with 39 markers was mounted on the subjects in accordance with the guidelines [14]. According to the analysis of the graphic materials obtained by registering the movements of the upper extremities during walking in the healthy subjects, the maximum angles of movement of the limb segments in the hand-swing cycle were calculated (Table 1).

All data were statistically analyzed using Mathcad software. Intergroup differences were considered significant at $p \leq 0.05$.

Results

The movements of the upper extremities during walking were typically cyclical. The cycle onset was the achievement of the extreme posterior upper position with the hand, the middle of the cycle was the extreme anterior upper position of the hand, and the end of the cycle was the return of the hand to the extreme posterior upper position. The cycle of the swing of the upper limb coincided in time with the step cycle of the ipsilateral lower limb. This enabled us to integrate the cycles of movement of the lower and upper extremities in the temporal parameter.

The hand-swing cycle included two phases: the upper forward limb swing phase and the upper backward limb swing phase, and each phase took 50% of the cycle-time. Each phase comprised one rising and one falling period (25% of the cycle-time each). Borders between phases and periods represented the moments of the occupation of the

Table 2

Kinematic parameters of the shoulder and elbow joints in the step cycle in healthy subjects (Control) and patients with JHMS

Joint	Movement	Forward swing phase		Backward swing phase	
		Control	JHMS	Control	JHMS
Shoulder	Flexion	−4.2 ± 0.30	−5.7 ± 0.50*	0	0
	Extension	−23.9 ± 1.10	−16.6 ± 0.70*	−26.6 ± 0.90	−18.5 ± 0.60*
	Adduction	21.3 ± 0.50	12.5 ± 0.70*	0	0
	Abduction	17.4 ± 0.40	7.4 ± 0.60*	16.8 ± 0.50	6.5 ± 0.40*
	Internal rotation	22.9 ± 0.80	3.9 ± 0.50*	23.5 ± 0.60	0*
	External rotation	15.2 ± 0.60	−4.9 ± 0.40*	14.2 ± 0.60	−6.7 ± 0.50*
Elbow	Flexion	0	41.5 ± 0.90*	53.3 ± 1.10	0*
	Extension	35.3 ± 1.20	30.8 ± 0.90*	33.9 ± 1.10	32.0 ± 0.80

Note. * significant differences of mean values in group with $p < 0.05$; JHMS, patients with joint hypermobility syndrome; Control, healthy subjects

extreme upper backward and forward position of the hand as well as two moments of the symmetric position of the hands.

Table 2 shows the kinematic parameters of the shoulder and elbow joints obtained in the study of healthy subjects and patients with JHMS of the same age.

In patient with JHMS, as in the healthy subjects, during walking, the shoulder was in a state of extension, and the amplitude of changes depended on the phases and periods of the hand-swing cycle. There was a decrease in the amplitude of limb movements in the shoulder joints around the frontal axis in patients with JHMS compared with the healthy subjects. Thus, in the forward limb swing phase, the mean value of the extension angle in healthy subjects was −23.9 ± 1.10°, whereas it was −16.6 ± 0.70° in patients with JHMS; in the

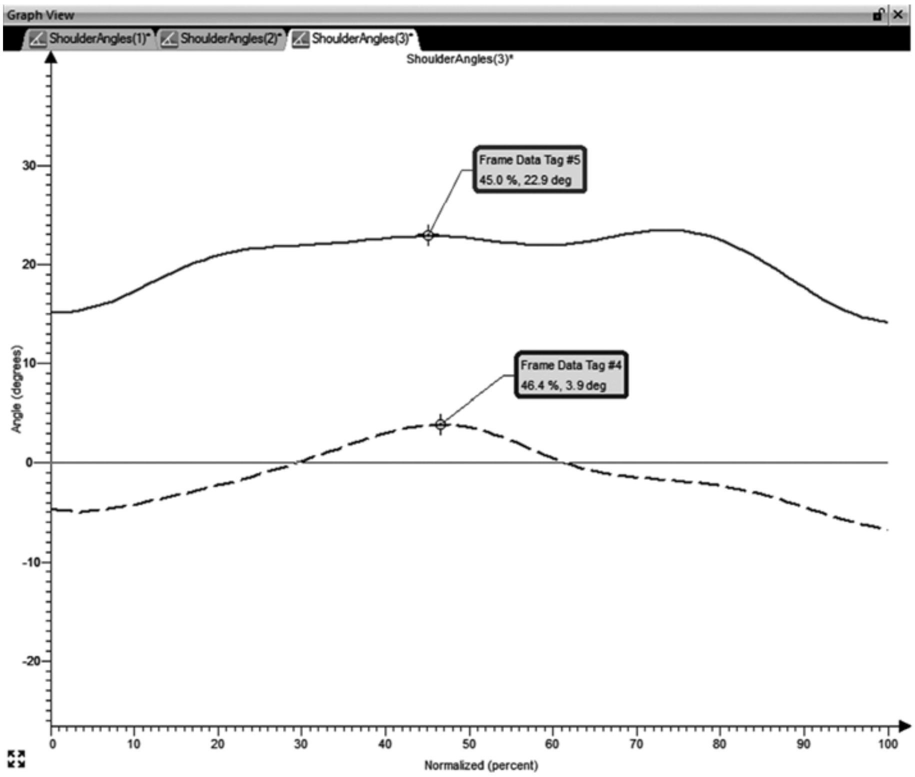

Fig. 1. Illustration of the shoulder joint rotation (screenshot of the Vicon Polygon program). The dashed line represents patients with joint hypermobility syndrome, and the solid one represents healthy subjects

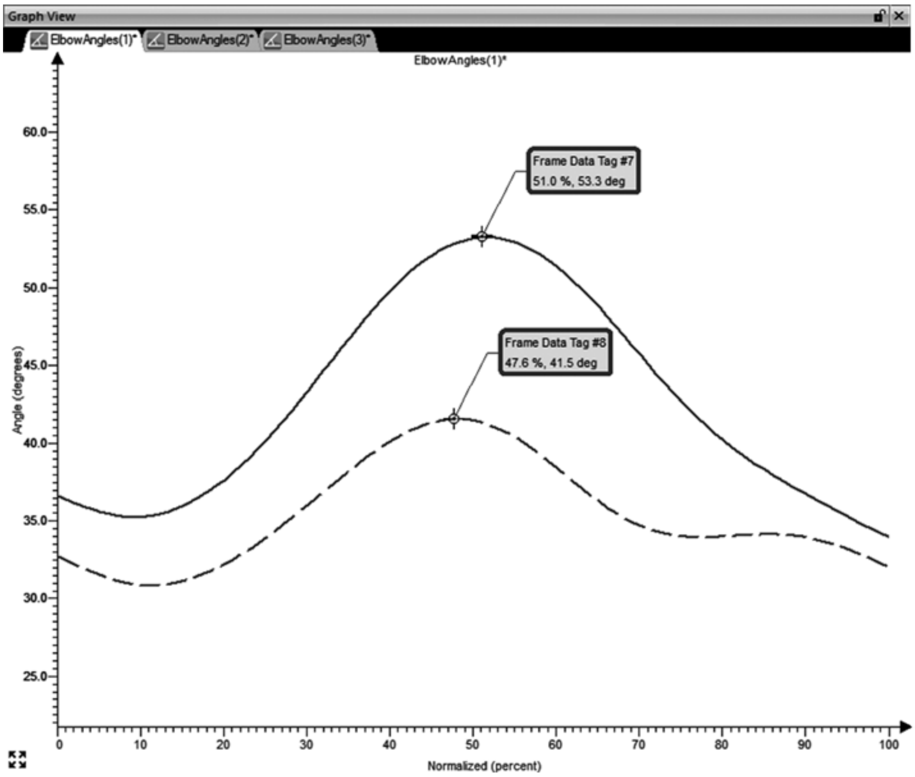

Fig. 2. Illustration of elbow joint flexion (screenshot of ViconPolygon program). The dashed line represents patients with joint hypermobility syndrome, and the solid one represents healthy subjects

backward swing phase they were –26.6 ± 0.90° and –18.5 ± 0.60°, respectively. Extension in the backward limb swing phase was uneven; the gradual increase in extension in the falling period loses momentum and slows down.

During walking, the shoulder is constantly in a state of adduction, minimally coinciding with the beginning and end of the swing cycle and maximally falling in the period of the rise of the forward swing phase [12]. The movements of the limb in the shoulder joint around the sagittal axis in patients with JHMS were different from those in the healthy subjects. As presented in Table 2, in the forward swing phase, the mean value of the adduction angle in healthy subjects was 21.3 ± 0.50°, whereas it was 12.5 ± 0.70° in patients with JHSM.

During the entire cycle of a step in the normal condition, the shoulder is in a state of internal rotation; the indicators may change, and reach the peak in the period of the rise in the forward swing phase and the period of the fall in the backward swing phase. The minimum value coincides with the beginning and end of the swing cycle [12]. In patients with JHMS, during most of the swing cycle, the shoulder was in a state of external rotation, and the maximum value coincided with the beginning and end of the swing cycle. The maximum value of internal rotation in the period of the rise of the forward swing phase was 3.9 ± 0.50°, whereas it was in the period of the fall of the backward swing phase (Fig. 1).

In the study of the elbow joint kinematic profile in patients with JHMS, a significant increase in the angle of flexion of the forearm was noted in the forward swing phase (41.5 ± 0.90°), whereas a decrease in the backward swing phase was detected (Fig. 2).

Changes in the kinematic parameters of movements of the segments of the upper limb in the shoulder and elbow joints are accompanied by marked changes in their kinetic parameters. This was clearly observed in the changes of the power of the muscles acting on the shoulder joint. Thus, the extreme posterior and anterior positions with the upper extremity were accompanied by decrease in the power of the shoulder joint to 0.0075 W and 0.01 W, respectively (Fig. 3).

Discussion

The movement of the upper extremities in a walking person is poorly understood. This is partly because of the entrenched view about the insignificant contribution of hand movements to

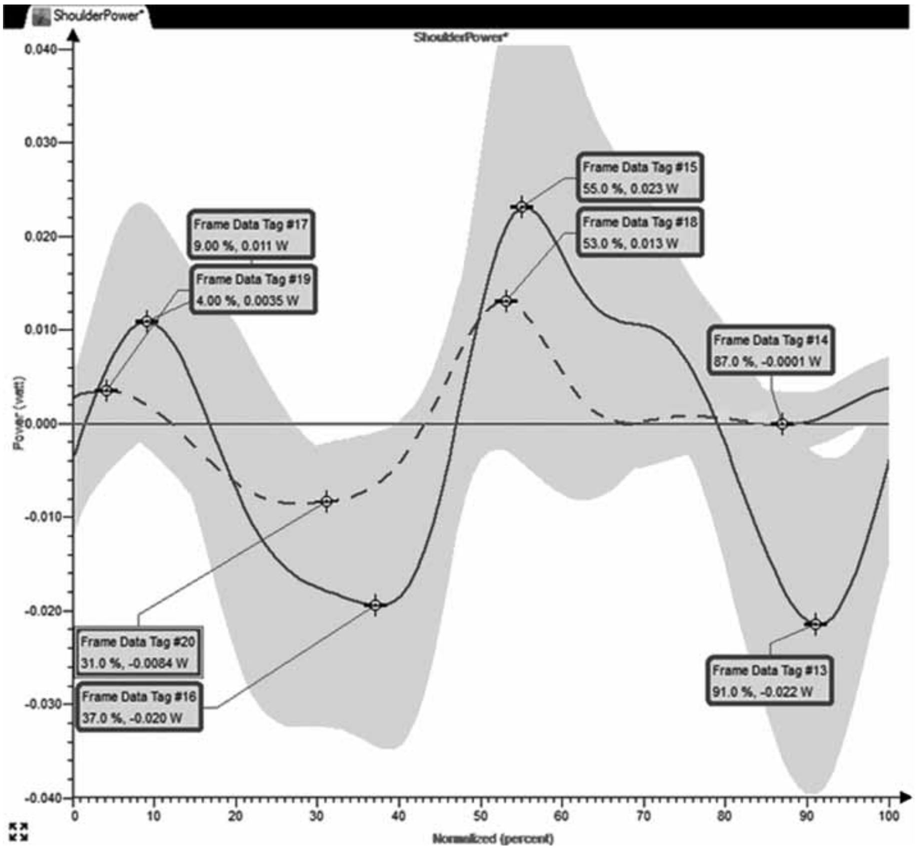

Fig. 3. Illustration of the power of the shoulder joints in patients with joint hypermobility syndrome (dashed line) and healthy subjects (solid line)

the human gait pattern. Another reason is related to ineffective efforts to analyze hand movements using the step cycle or recreating the cyclical actions of the hands [15]. For the first time, to study arm locomotion during walking, we developed and applied the hand moving cycles during walking, synchronized in real-time with a step cycle, using the Vicon optical-electronic motion-capture system. This enabled us to achieve detailed parameters related to the kinematics and kinetics of the shoulder and elbow joints and implement three-dimensional modeling of the movements.

No similar clinical studies have been reported in the literature.

A reduction in the amplitude of movement of the segments of the upper limb in the shoulder and elbow joints in patients with JHMS was noted, that may serve as a compensatory response to hypermobility of the joints to ensure an optimal performance.

Conclusion

The kinematic study of the joints of the upper extremities for the analysis of a human's gait using the motion-capture technique provides a quantitative assessment of the state of the movement using three-dimensional modeling, and it can be used as a diagnostic technique for JHMS and other pathological conditions of the musculoskeletal system.

In this study, quantitative data were obtained, which characterized the kinematics and kinetics of the shoulder and elbow joints of healthy subjects and patients with JHMS during walking. A common sign of changes in the range of motion of the links of the upper limb in the shoulder and elbow joints in patients with JHMS was a decrease in the amplitude of flexion and in the power of the joints.

In patients with JHMS, a significant decrease in the angles of internal rotation and the limb adduction in the shoulder joint were recorded.

Additional information

Source of financing. The study was performed within the framework of the State task of the Ministry of Education and Science (Grant No. 12.9588.2017/7.8).

Conflict of interest. The authors have no conflict of interests.

Ethical review. All subjects were volunteers, and their parents gave written consent to participate in this study. The study was approved by the Ethical Committee of the Astrakhan State Medical University, protocol No. 12 dated 17.09.2018.

Contribution of the authors

O.I. Vorontsova and *L.A. Udochkina* created the concept and design of the study.

M.S. Baranets contributed in data collection and processing of the materials.

M.S. Baranets and *M.V. Grechitaeva* performed statistical analysis and data processing.

O.I. Vorontsova, L.A. Udochkina, L.A. Goncharova, and *M.V. Grechitaeva* performed the analysis and interpretation of data.

O.I. Vorontsova and *L.A. Udochkina* drafted the paper.

References

1. Острополец С.С. К проблеме недифференцированной дисплазии соединительной ткани у детей // Педиатрические аспекты дисплазии соединительной ткани. Достижения и перспективы. – М.; Тверь; СПб.: ООО РГ «ПРЕ100», 2010. – С. 62–65. [Ostropolez SS. K probleme nedifferentsirovannoy displazii soedinitel'noy tkani u detey. In: Pediatricheskie aspekty displazii soedinitel'noy tkani. Dostizheniya i perspektivy. Moscow; Tver'; Saint Petersburg: PRE100; 2010. P. 62-65. (In Russ.)]
2. Nakakubo S, Doi T, Sawa R, et al. Does arm swing emphasized deliberately increase the trunk stability during walking in the elderly adults? *Gait Posture*. 2014;40(4):516-520. https://doi.org/10.1016/j.gaitpost.2014.06.005.
3. Pijnappels M, Kingma I, Wezenberg D, et al. Armed against falls: the contribution of arm movements to balance recovery after tripping. *Exp Brain Res*. 2010;201(4):689-699. https://doi.org/10.1007/s00221-009-2088-7.
4. Ortega JD, Fehlman LA, Farley CT. Effects of aging and arm swing on the metabolic cost of stability in human walking. *J Biomech*. 2008;41(16):3303-3308. https://doi.org/10.1016/j.jbiomech.2008.06.039.
5. Umberger BR. Effects of suppressing arm swing on kinematics, kinetics, and energetics of human walking. *J Biomech*. 2008;41(11):2575-2580. https://doi.org/10.1016/j.jbiomech.2008.05.024.
6. Collins SH, Adamczyk PG, Kuo AD. Dynamic arm swinging in human walking. *Proc Biol Sci*. 2009;276(1673):3679-3688. https://doi.org/10.1098/rspb.2009.0664.
7. Massaad F, Lejeune TM, Detrembleur C. Reducing the energy cost of hemiparetic gait using center of mass feedback: a pilot study. *Neurorehabil Neural Repair*. 2010;24(4):338-347. https://doi.org/10.1177/1545968309349927.
8. Yizhar Z, Boulos S, Inbar O, Carmeli E. The effect of restricted arm swing on energy expenditure in healthy men. *Int J Rehabil Res*. 2009;32(2):115-123. https://doi.org/10.1097/MRR.0b013e32830d3675.
9. Barton CJ, Levinger P, Menz HB, Webster KE. Kinematic gait characteristics associated with patellofemoral pain syndrome: a systematic review. *Gait Posture*. 2009;30(4):405-416. https://doi.org/10.1016/j.gaitpost.2009.07.109.
10. Celletti C, Galli M, Cimolin V, et al. Use of the gait profile score for the evaluation of patients with joint hypermobility syndrome/Ehlers-Danlos syndrome hypermobility type. *Res Dev Disabil*. 2013;34(11):4280-4285. https://doi.org/10.1016/j.ridd.2013.09.019.
11. Galli M, Cimolin V, Rigoldi C, et al. Gait strategy in patients with Ehlers-Danlos syndrome hypermobility type: a kinematic and kinetic evaluation using 3D gait analysis. *Res Dev Disabil*. 2011;32(5):1663-1668. https://doi.org/10.1016/j.ridd.2011.02.018.
12. Воронцова О.И., Удочкина Л.А., Мазин И.Г., Гончарова Л.А. Цикл движения верхних конечностей при нормальной ходьбе человека // Медицинский вестник Башкортостана. – 2016. – Т. 11. – № 6. – С. 53–58. [Vorontsova OI, Udochkina LA, Mazin IG, Goncharova LA. The cycle of upper extremities motion in normal walking of a man. *Bashkortostan medical journal*. 2016;11(6):53-58. (In Russ.)]
13. Безруких М.М., Сонькин В.Д., Фарбер Д.А. Возрастная физиология (физиология развития ребенка). – М.: Академия, 2009. [Bezrukih MM, Sonkin VD, Farber DA. Vozrastnaya fiziologiya (fiziologiya razvitiya rebenka). Moscow: Akademia; 2009. (In Russ.)]
14. wweb.uta.edu [Internet]. Plug-In-Gait [cited 2018 Feb 17]. Available from: http://wweb.uta.edu/faculty/ricard/Classes/KINE-5350/PIGManualver1.pdf.
15. Baker R. Measuring walking: A handbook of clinical analysis. London: Mac Keith Press; 2013.

Information about the authors

Olga I. Vorontcova — PhD, Associate Professor, the Head of Center of Collective Facilities "Three-dimensional study of the biomechanics of human movements". Astrakhan State University, Astrakhan, Russia. https://orcid.org/0000-0002-4037-3990. eLibrary SPIN 6255-7878. E-mail: aspuvorontsova@gmail.com.

Ольга Ивановна Воронцова — канд. полит. наук, доцент, руководитель Центра коллективного пользования «Трехмерное исследование биомеханики движений человека». Астраханский государственный университет, Астрахань. https://orcid.org/0000-0002-4037-3990. eLibrary SPIN 6255-7878. E-mail: aspuvorontsova@gmail.com.

Larisa A. Udochkina — MD, PhD, Associate Professor, the Head of Department of Anatomy. Astrakhan State Medical University, Astrakhan, Russia. https://orcid.org/0000-0001-5016-0633. eLibrary SPIN 9142-4447. E-mail: udochkin-lk@mail.ru.

Marina S. Baranec — Specialist of Center of Collective Facilities “Three-dimensional study of the biomechanics of human movements”. Astrakhan State University, Astrakhan, Russia. https://orcid.org/0000-0003-4496-7021. eLibrary SPIN 6158-5630. E-mail: marinka_bants@mail.ru.

Marina V. Grechitaeva — BD, PhD, Professor, Professor Department of Biology, Director of the Museum of Nature. Belgorod National Research University, Belgorod, Russia. https://orcid.org/0000-0002-3712-1557. eLibrary SPIN 8576-6490. E-mail: loza65@mail.ru.

Ludmila A. Goncharova — MD, PhD, Professor, Professor Department of Pediatric Surgery. Astrakhan State Medical University, Astrakhan, Russia. https://orcid.org/0000-0002-1450-7158. eLibrary SPIN 8233-1743. E-mail: sanomed@rambler.ru.

Лариса Альбертовна Удочкина — д-р мед. наук, доцент, заведующая кафедрой анатомии. Астраханский государственный медицинский университет, Астрахань. E-mail: udochkin-lk@mail.ru.

Марина Сергеевна Баранец — специалист 2-й категории, Центр коллективного пользования «Трехмерное исследование биомеханики движений человека». Астраханский государственный университет, Астрахань. https://orcid.org/0000-0003-4496-7021. eLibrary SPIN 6158-5630. E-mail: marinka_bants@mail.ru.

Марина Вячеславовна Гречитаева — д-р биол. наук, профессор, профессор кафедры биологии, директор Музея природы. Белгородский государственный национальный исследовательский университет, Белгород. https://orcid.org/0000-0002-3712-1557. eLibrary SPIN 8576-6490. E-mail: loza65@mail.ru.

Людмила Анатольевна Гончарова — д-р мед. наук, профессор, профессор кафедры детской хирургии. Астраханский государственный медицинский университет, Астрахань. https://orcid.org/0000-0002-1450-7158. eLibrary SPIN 8233-1743. E-mail: sanomed@rambler.ru.