DOI 10.18019/1028-4427-2018-24-3-312-320

Operative treatment of orthopedic complications in upper limb in children and adults with cerebral palsy

G.M. Chibirov[1], S.S. Leonchuk[1], K.S. Ezhova[1], E.B. Gubina[1], M.K. Pliev[1], P. Lascombes[2], D.A. Popkov[1]

[1]Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation
[2]Hopitaux universitaires de Geneve, Department of Paediatric Orthopaedics, Geneve, Switzerland

Introduction The benefits of surgical treatment of orthopaedic complications in the upper limb caused by cerebral palsy have been debated by some researchers. Secondary complications developed due to muscle spasticity and retraction are a serious obstacle to a significant improvement in health-related quality of life of CP patients. **Objective** To explore outcomes of CP patients who underwent surgical treatment at the Russian Ilizarov Scientific Centre "Restorative Traumatology and Orthopaedics" between 2014 and 2016. **Material and methods** Total 23 operative interventions were produced for 21 patients aged from 11 to 36 years (mean age of 16.6 years) using an authors' technique. We used integral scales of the Gross Motor Function Classification System (GMFCS) and the Manual Ability Classification System (MACS). Classification systems intended for differential evaluation of upper extremity motor and functional impairment included Van Heest's deformity assessment test, the House upper extremity assessment test and Gshwind and Tonkin classification. **Results** Spastic diplegia was diagnosed in 6 cases including 4 GMFCS III and 2 GMFCS IV. Manual ability was assessed as MACS IV in 3 cases and MACS V in 3. Fifteen patients with hemiparethic spastic CP underwent surgical treatment of upper limbs. Manual ability was assessed as MACS III in 4 cases, MACS IV in 8 and MACS V in 3. The use of the limb by the House's scale showed level 1 in 2, level 2 in 5, level 3 in 10 and level 4 in 6 cases. The Gschwind and Tonkin classification for pronated forearm revealed level 1 in1, level 2 in 8, level 3 in 10 and level 4 in 4 cases. There was correlation between an extent of pronation contracture and impaired function of the thumb. Improved functional abilities of the upper limb, the cosmetic appearance and comfort with the use were recorded in all the cases. **Conclusion** Results of multilevel interventions on upper limbs in CP patients allow us to conclude that differential approach to the choice of technique and extent of surgery to ensure efficacious surgical treatment.

Keywords: CP, upper extremity, forearm and hand pronation contracture, treatment, multilevel intervention

Cerebral palsy (CP) is the most common motor disability in childhood. It is a heterogenic group of clinical syndromes describing impaired motion and posture that are characterized by pathological muscle tone, poorly controlled body movement causing activity limitation that are attributed to nonprogressive disturbances that occurred in the developing fetal or infant brain [1, 2, 3].

Articular contractures of the upper limbs, dislocated and subluxated joints, skeletal deformities of CT patients developing due to muscle retraction and causing serious functional limitations in self-care, social participation are known to be indications to operative orthopaedic treatment [4–13].

Flexion and pronation contracture of the forearm, flexion and adduction contracture of the wrist joint, flexion and adduction alignment of the thumb, finger deformities are major pathological components of orthopaedic CP complications in upper limbs that lead to impaired motor activity of the arm and aesthetic concerns [11, 14–20].

Pronation contracture is observed in 48 to 50 % of the patients with involved upper limb [4] with prevailing incidence in hemiparethic CP (up to 86 %) due to absent functional activity in the involved side [7, 8]. This is the flexion contracture of the wrist joint that defines appearance of the limb and presents considerable limitations to different gripping types [5]. The above complications are associated with prevailing tone of certain muscle groups, flexor digitorium profundus, in particular, as reported in the series of T.A. Cheema et al. [21].

There are reports describing clinical results of surgical correction of thumb contractures and thumb-in-palm deformities in CP patients [14, 16, 22]. Position of the thumb and the functional capabilities determine the level of daily manual activities and get children interested and motivated in physical and mental activities [22–24].

Objective of the study was to explore outcomes of CP patients who underwent surgical treatment at the Russian Ilizarov Scientific Centre "Restorative Traumatology and Orthopaedics" between 2014 and 2016.

Chibirov G.M., Leonchuk S.S., Ezhova K.S., Gubina E.B., Pliev M.K., Lascombes P., Popkov D.A. Operative treatment of orthopedic complications in upper limb in children and adults with cerebral palsy. *Genij Ortopedii*. 2018. T. 24. No 3. pp. 312-320. DOI 10.18019/1028-4427-2018-24-3-312-320. (In Russian)

MATERIAL AND METHODS

The study includes outcomes of operative treatment of upper limbs of 21 CP patients aged from 11 to 36 years (mean age of 16.6 years). There were total 23 surgeries performed between 2014 and 2016. Limited articular function of upper limb of different severity was the main complaint of the patients.

In addition to standard orthopaedic evaluation we used integral scales of the Gross Motor Function Classification System (GMFCS) [2] and the Manual Ability Classification System for children with Cerebral Palsy (MACS) [13]. Classification systems intended for differential evaluation of upper extremity motor and functional impairment included Van Heest's test [25], the House upper extremity assessment test [11] and Gshwind and Tonkin classification [17].

Van Heest classification of impaired hand function identifies 8 levels with level 1 assessing most severe motor disorders of upper limb to level 8 indicating to mild limitation of the hand function [25]. Table 1 presents detailed classification used in the work.

The House classification [11] was used to assess position and function of the thumb. The classification grouped patients depending on the type and severity of contracture of the first metacarpal-phalangeal and interphalangeal joints. Patients with type I impaired function of the thumb had spasticity of the muscle that adducted the thumb and also of the first dorsal interosseous muscle adducting the first metacarpal bone. Type II included the above complications with the metacarpal-phalangeal being flexed. Type III was characterized by adduction of the first metacarpal bone and specific overextension in the metacarpal-phalangeal joint. Addiction contracture of the thumb, fixed flexion contracture of metacarpal-phalangeal bone (in many cases more than 90º) were typical for patients type IV.

Gshwind and Tonkin classification [17] was used to assess severity of pronation contracture of the forearm that was classified into four groups:

patients of group 1 were capable of active supination beyond neutral;

group 2 were able to supinate to the neutral position or less;

group 3 patients had no active supination with the possibility of a full range of passive supination to be achieved;

group 4 had no active and passive supination.

Different combinations of surgical elements were used during interventions depending on presence and extent of orthopaedic disorders. Z-tendon lengthening of m. biceps brachii and aponeurotomy of m. Brachialis were performed to eliminate flexion contracture of the elbow joint [12, 16, 26]. **Figure 1** shows schematic drawing of an approach and surgical manipulations used to eliminate flexion contracture of the elbow joint.

Pronator teres was transferred to radial extensors, ulnar flexor transferred to the radius in addition to stitching of the distal tendon of brachio-radial muscle or extensor carpi radialis longus, aponeurotomy of pronator teres, tenotomy of pronator quadratus muscle and osteotomy of the radius to improve supination and/or correct pronation deformity.

Table 1

Classification of impaired hand function in CP using Van Heest's test

Class	Designation	Activity level
0	Does not use	Does not use
1	Poor function, passive assist	Uses as stabilizing weight only
2	Limited function, passive assist	Can hold onto object placed in hand
3	Limited function, passive assist	Can hold onto object and stabilize it for use by other hand
4	Poor function, active assist	Can actively grasp object and hold it weakly
5	Extremely limited function, active assist	Can actively grasp object and stabilize it well
6	Limited function, active assist	Can actively grasp object and manipulate with it
7	Spontaneous use, partially limited function	Can perform bimanual activities and occasionally uses hand spontaneously
8	Spontaneous use, complete function	Uses hand completely independently without reference to the other hand

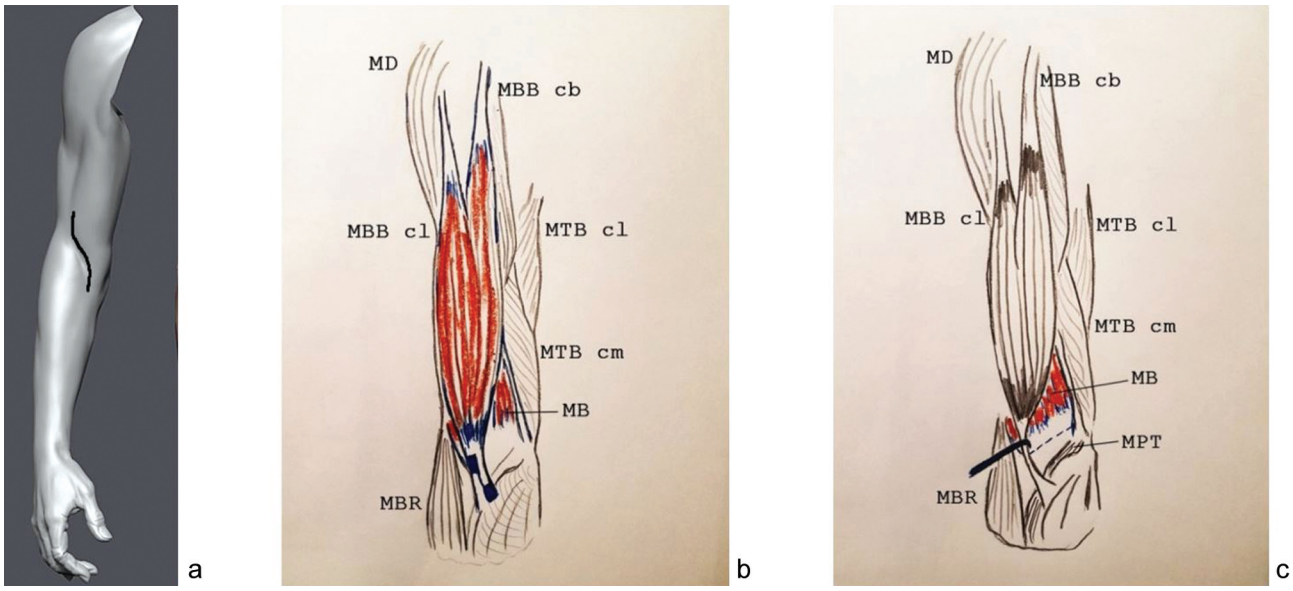

Fig. 1 Schematic drawing of the approach and surgical manipulations used to eliminate flexion contracture of the elbow joint (pictures 1b, 1c were drawn by G.M.Chibirov, PhD) showing (a) approach for lengthening of elbow flexors, (b) Z-tendon lengthening of biceps tendon, (c) location of aponeurotomy of the brachial muscle. Abbreviations: MD – m. deltoideus, MBB cb – m. bicipitis brachii caput breve, MBB cl – m. bicipitis brachii caput longum, MTB cl – m. tricipitis brachii caput longum, MTB cm – m. tricipitis brachii caput mediale, MB – m. brachialis, MBR – m. brachioradialis, MPT – m. pronator teres

Transposition of the flexor carpi ulnaris muscle to the radius is the authors' technique (application for an invention № 2018108034 «Technique for elimination of pronation deformity of forearm joints in CP patients in multilevel surgeries of upper limbs», priority date 05.03.2018, authors: G.M. Chibirov, S.S. Leonchuk, D.A. Popkov) (**Fig. 2**).

Ulnar flexor tendon of the hand was exposed out of medial approach in the lower and middle third of the forearm and distally stitched at the attachment site with tendon tenotomy and mobilization onto the distal two thirds produced. Radius was subperiosteally exposed out of lateral S-shaped approach in the lower third of the forearm. Abductor pollicis longus muscle and distal tendon of the brachioradialis muscle being

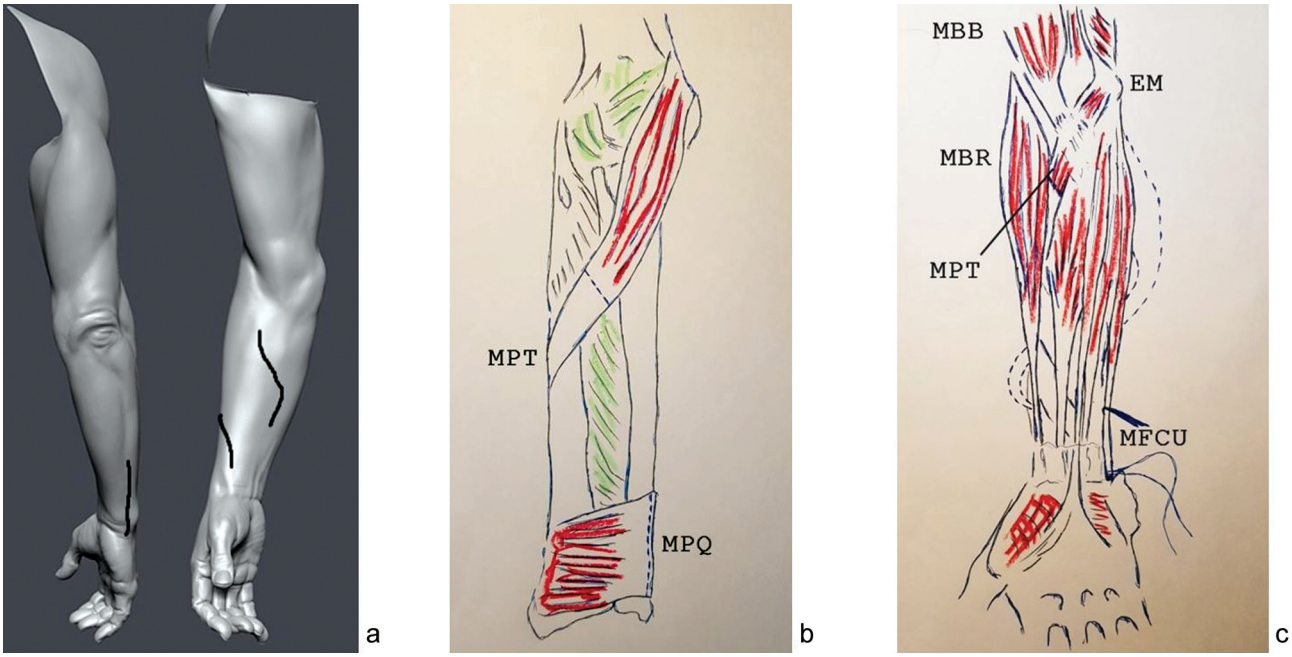

Fig. 2 Schematic drawing of the approach and surgical manipulations used to improve supination and/or eliminate pronation deformity (pictures 2b, 2c were drawn by G.M.Chibirov, PhD) showing (a) approaches used, (B) tenotomy of pronators with dashes, (c) transposition of the flexor carpi ulnaris using the authors' method. Abbreviations: MBB – m. bicipitis brachii, MBR – m. brachioradialis, MPT – m. pronator teres, MFCU – m. flexor carpi ulnaris, EM – epicondylus medialis, MPQ – m. pronator quadratus

adjacent to the radial subperiosteum at the level were exposed. Canal was made in the radius at the distal third of the radial shaft or metadiaphysis by blunt dissection in an oblique descending manner under the muscles of posterior forearm, the wrist and digital flexors, to pass on the ulnar flexor tendon. The stitches fastening the flexor carpi ulnaris muscle and a part of the tendon passed through the canal and then back to the same tendon and then to brachioradialis tendon and periosteum with separate stitches. The forearm and the hand were placed in maximum supination.

Transposition of pronator teres muscle to the extensor carpi radialis was produced in addition to the above maneuvers in cases of limited active dorsal flexion of the hand.

Z-plasty of the first web space was alternatively combined with tenotomy of the transverse portion of the adductor pollicis longus, aponeurotomy of the flexor pollicis longus, transfer of the palmaris longus to the abductor pollicis to eliminate disturbed function of the thumb by loop stiches under the distal tendon of the brachioradialis muscle.

RESULTS AND DISCUSSION

Patients were subdivided into two groups after clinical examination. Group I included patients with spastic diplegia (n = 6) and Group II patients with hemiparetic CP (n = 15). There were four GMFCS III, two GMFCS IV cases, three MACS IV and three MACS V preoperatively in Group I. Surgery was performed for 15 patients with hemiparetic spastic CP, among them 4 MACS III, 8 MACS IV and 3 MACS V cases in Group II. There were 2 House type I, 5 House type II, 10 House type III and 6 House type IV cases. Pronation contracture was assesses as type 1 (n = 1), type 2 (n = 8), type 3 (n = 10) and type 4 (n = 4) according to Gshwind and Tonkin classification. There were correlation found between severity of pronation contracture and disturbed function of the thumb.

Table 2 presents mean range of motion in the joints of upper limbs pre-, postoperatively at short- and long-term follow-ups.

Table 2 shows postoperatively increased range of motion in the joints of interest from the surgical point view. Improvements were seen in extension of the elbow joint by 17º on average at a long-term follow-up, in supination of the wrist and forearm by 84º, dorsiflexion of the wrist by 28º, and abduction of the thumb by 79º.

Improved orthopaedic status reflected in measurements of integral classification scales (Table 3).

There were total 23 interventions performed for the patients including 2 cases of spastic diplegia who underwent consecutive procedures on both upper limbs. Operative treatment of 6 patients were performed with simultaneous interventions on upper and lower limbs. Improved functional capabilities of upper limb, aesthetic appearance and comfortable usage were observed in all the cases and confirmed by improved class with Van Heest classification.

Outcomes of multilevel interventions on upper limbs of CP patients indicated to efficacious practice and differentiated approach to the tactics and volume of surgery was an important aspect of operative treatment.

Table 2

Mean range of motion in the joints of upper limbs pre-, postoperatively at short- and long-term follow-ups

Range of motion in the joints of upper limb		Preoperatively	Postoperatively	
			Short-term follow-up (from 6 to 12 months)	Long-term follow-up (more than 12 months)
Elbow joint	flexion/extension	142º/37º/0	145º/14º/0	150º/20º/0
	supination/pronation	0/41º/81º	37º/0/76º	43º/0/85º
Wrist joint	Dorsal flexion/palm flexion	17º/0/76º	38º/0/81º	45º/0/87º
	adduction/abduction	5º/0/26º	13º/0/31º	15º/0/29º
Thumb	flexion/extension	56º/8º/0	45º/0/16º	47º/0/18º
	abduction/adduction	0/14º/46º	78º/0/51º	65º/0/55º

Table 3

Distribution of patients by assessment levels of impaired hand function

Severity of motor disorders, class		Type of CP			
		Spastic diplegia (n = 6)		Spastic hemiparesis (n = 15)	
		preoperatively	postoperatively	preoperatively	postoperatively
GMFCS	III	4		8	
	IV	2		7	
MACS	II			4	
	III	0		4	
	IV	3		4	
	V	3		3	
Van Heest	2	3		3	
	3	2		4	
	4	1	1	8	4
	5		3		7
	6		2		4

Clinical instance. A 16-year-old patient E. was diagnosed with spastic diplegia, articular contractures of upper and lower limbs, torsion deformities of lower limbs, pes cavus equinovalgus deformity (**Fig. 3**). Surgical treatment was produced in several stages. Reconstructive procedures on the foot and femoral bones was produced at the first stage. Tendon and muscle plasty of the right upper limb including transposition of the flexor carpi ulnaris muscle to the radius with the authors' technique was performed at the second stage. The treatment resulted in active supination of 40° (preoperative range of motion measuring 0/40º/80º of supination/pronation), capability to write, produce different grasps, spherical and cylindrical, in particular (**Fig. 4**). There were no postoperative complication and the patient was comfortable exercising the joints and doing daily routines.

Fig. 3 Preoperative clinical appearance of a 16-year-old patient E. showing pronation and flexion deformity of the hand and ulnar deviation

Fig. 4 Appearance of the 16-year-old patient E. 6 month after the surgery demonstrating active supination, dorsiflexion of the hand and active abduction and adduction of the thumb

DISCUSSION

The majority of researchers suggest that the main purpose of orthopaedic surgical treatment in CP patients is elimination of fixed contractures and deformities of the joints and bones of upper limbs to improve functional capabilities [16, 25, 26].

Surgical correction of flexion contracture of the elbow joint can be achieved with tendon and muscle releases alternatively combined with lengthening of the m. flexor carpi ulnaris [12, 26]. Selective neurotomy of the median or musculocutaneous nerves can be employed to reduce flexors' tone in absent retraction [27, 28] with a high recurrence rate of 14 % [29].

Forearm is the segment of interest from surgical point of view [10, 13, 15, 18, 30]. Limited supination of the forearm and the hand to a different degree is the major concern of CP patients with orthopaedic complications in upper limbs [30, 31]. Retracted m. pronator teres primarily contributes to contractures [30–33]. Elimination of malaligned forearm and initiation of active supination are the main objectives of treatment of pronation deformity [20, 30–33]. There is a variety of techniques to address the contracture including tendon and muscle releases, transposition of flexor and pronator tendons to extensors carpi, correcting detorsion osteotomies as the method of choice in severe contractures complicated with torsion of the forearm bones, etc. [15, 26, 31]. Transposition of the flexor carpi ulnaris muscle can be advocated to improve dorsiflexion of the hand. The surgery was first described by Green [34] and was found practical by different authors [16, 32, 33, 35, 36]. According to Green m. extensor carpi radialis brevis/longus is an optimal site for transplantation of the m. flexor carpi ulnaris to ensure correction of the wrist flexion and ulnar deviation of the hand with the changed vector of the muscle tension. Patterson et al. [35] reported the development of a postoperative extension deformity of the wrist. Our series showed the transfer of flexor carpi ulnaris to the radius being an efficacious procedure to address ulnar deviation and the wrist flexion procedure and restore active pronation. CP patients are likely to actively use the flexor carpi ulnaris for functional needs [20, 37].

Flexion contractures of the wrist and fingers are often present in CP patients [5, 18]. Flexion and adduction of the thumb coupled with flexion contracture of the wrist entail more serious functional concerns [14, 22]. Surgical treatment is primarily aimed at the correction of fixed contractures and establishment of a functional balance between spastic flexors and weak extensors [30]. The transfer of the flexor carpi ulnaris solely fails to address flexion in the radiocarpal joint due to presence of other short flexors of the wrist. Several surgical options are available for the condition [18, 21, 36] including aponeurotic release of short muscles to lengthen slightly short muscles and improve spasticity, and Z-lengthening of short muscles. There are publications describing complications with the technique of surgical treatment. Length gain is difficult to control and there is a high risk of either underlengthening or overcorrection [38]. However, the risk is high in case of wrist flexor elongation only. The risk of complications is minimal in Z-lengthening of adductor pollicis longus and skin plasty [22].

Results of our investigation support tendon and muscle plasty as an efficacious method to address wrist deformities and improve functional capabilities of CP patients. The choice of technique and prognosis of results would rely on the level of neurological deficiency, reasonable intelligence and motivation of the patients to use the limb preoperatively and postoperatively [2, 10, 13, 24].

CONCLUSION

1. Acute multilevel interventions on the forearm and the wrist are indicated for orthopaedic conditions of upper limbs in CP patients taking into consideration a complex nature of the involvement.

2. Transposition of the flexor carpi ulnaris muscle to the radius has been shown to be an effective method to address pronation contracture of the forearm joints and can be used in combination with different elements of surgical intervention.

REFERENCES

1. Stavsky M., Mor O., Mastrolia S.A., Greenbaum S., Than N.G., Erez O. Cerebral Palsy-Trends in Epidemiology and Recent Development in Prenatal Mechanisms of Disease, Treatment, and Prevention. *Front. Pediatr.*, 2017, vol. 5, pp. 21. DOI: 10.3389/fped.2017.00021.
2. Rosenbaum P.L., Palisano R.J., Bartlett D.J., Galuppi B.E., Russell D.J. Development of the Gross Motor Function Classification System for cerebral palsy. *Dev. Med. Child. Neurol.*, 2008, vol. 50, no. 4, pp. 249-253. DOI:10.1111/j.1469-8749.2008.02045.x.
3. GuzevaV.I., Kurenkov A.L., Zmanovskaia V.A., Batysheva T.T., Semenova K.A., Zherebtsova V.A., Vladykina L.N., Popkov D.A. *Detskii tserebralnyi paralich. In: Guzeva V.I., red. Federalnoe rukovodstvo po detskoi nevrologii* [Children cerebral palsy. V.I. Guzeva, ed. Federal Guidelines for Pediatric Neurology]. M., MK, 2016, pp. 169-185. (in Russian)
4. Novikov V.A., Umnov V.V., Zvozil A.V. Khirurgicheskoi lechenie pronatsionnoi kontraktury predplechia u patsientov s detskim tserebralnym paralichom [Surgical treatment of the forearm pronation contracture in patients with cerebral palsy]. *Ortopediia, Travmatologiia i Vosstanovitelnaia Khirurgiia Detskogo Vozrasta*, 2014, vol. 2, no. 1, pp. 39-45. (in Russian)
5. Novikov V.A., Umnov V.V., Zvozil A.V. Taktika lecheniia sgibatelnoi kontraktury luchezapiastnogo sustava u detei s detskim tserebralnym paralichom [The tactic of treating the wrist flexion contracture in children with cerebral palsy]. *Ortopediia, Travmatologiia i Vosstanovitelnaia Khirurgiia Detskogo Vozrasta*, 2014, vol. 2, no. 3, pp. 40-46. (in Russian)
6. Novikov V.A., Umnov V.V. Khirurgicheskoe lechenie sgibatelno-privodiashchei kontraktury pervogo paltsa kisti u detei s detskim tserebralnym paralichom [Surgical treatment of adduction-flexion contracture of the hand first finger in children with cerebral palsy]. *Ortopediia, Travmatologiia i Vosstanovitelnaia Khirurgiia Detskogo Vozrasta*, 2015, vol. 3, no. 2, pp. 25-31. (in Russian)
7. Tupikov V.A. Sposoby khirurgicheskoi korrektsii pronatsionnogo komponenta kontraktur sustavov verkhnei i nizhnei konechnosti u detei s detskim tserebralnym paralichom [Techniques of surgical correcting the pronation component of the upper and lower limb joint contractures in children with cerebral palsy]. *Vestnik Travmatologii i Ortopedii im. N.N. Priorova*, 2009, no. 1, pp. 53-57. (in Russian)
8. Umnov V.V., Novikov V.A., Zvozil A.V. Diagnostika i lechenie spasticheskoi ruki u detei s detskim tserebralnym paralichom: obzor literatury. Ch. 2. Konservativnoe i khirurgicheskoe lechenie verkhnei konechnosti [Spastic arm diagnosis and treatment in children with cerebral palsy: review of the literature. Part 2. Conservative and surgical treatment of the upper limb]. *Travmatologiia i Ortopediia Rossii*, 2011, no. 3 (61), pp. 137-145. (in Russian)
9. Andreev A.V., Ryzhikov D.V., Gubina E.V. Khirurgicheskoe lechenie kontraktur i dvigatelnykh ustanovok verkhnei konechnosti u detei so spasticheskimi formami DTsP (obzor literatury) [Surgical treatment of the upper limb contractures and motor systems in children with CP spastic forms (review of the literature)]. *Travmatologiia i Ortopediia Rossii*, 2016, no. 3 (81), pp. 135-143. (in Russian)
10. Klevberg G.L., Elvrum A.G., Zucknick M., Elkjaer S., Østensjø S., Krumlinde-Sundholm L., Kjeken I., Jahnsen R. Development of bimanual performance in young children with cerebral palsy. *Dev. Med. Child. Neurol.*, 2018, vol. 60, no. 5, pp. 490-497. DOI: 10.1111/dmcn.13680.
11. House J.H, Gwathmey F.W, Fidler M.O. A dynamic approach to the thumb-in palm deformity in cerebral palsy. *J. Bone Joint Surg. Am.*, 1981, vol. 63, no. 2, pp. 216-225.
12. Mital M.A. Lengthening of the elbow flexors in cerebral palsy. *J. Bone Joint Surg. Am.*, 1979, vol. 61, no. 4, pp. 515-522.
13. Park E.S, Sim E.G, Rha D.W. Effect of upper limb deformities on gross motor and upper limb functions in children with spastic cerebral palsy. *Res. Dev. Disabil.*, 2011, vol. 32, no. 6, pp. 2389-2397. DOI: 10.1016/j.ridd.2011.07.021.

14. Van Heest A.E. Surgical technique for thumb-in-palm deformity in cerebral palsy. *J. Hand Surg. Am.*, 2011, vol. 36, no. 9, pp. 1526-1531. DOI: 10.1016/j.jhsa.2011.06.014.
15. Leafblad N.D., Van Heest A.E. Management of the spastic wrist and hand in cerebral palsy. *J. Hand Surg. Am.*, 2015, vol. 40, no. 5, pp. 1035-1040. DOI: 10.1016/j.jhsa.2014.11.025.
16. Miller F. *Cerebral palsy*. New York, Springer Science, 2005. 1055 p.
17. Gschwind C., Tonkin M. Surgery for cerebral palsy: Part 1. Classification and operative procedures for pronation deformity. *J. Hand Surg. Br.*, 1992, vol. 17, no. 4, pp. 391-395.
18. Van Heest A.E., Ramachandran V., Stout J., Wervey R., Garcia L. Quantitative and qualitative functional evaluation of upper extremity tendon transfers in spastic hemiplegia caused by cerebral palsy. *J. Pediatr. Orthop.*, 2008, vol. 28, no. 6, pp. 679-683. DOI: 10.1097/BPO.0b013e3181831eac.
19. Van Heest A.E., Bagley A., Molitor F., James M.A. Tendon transfer surgery in upper-extremity cerebral palsy is more effective than botulinum toxin injections or regular, ongoing therapy. *J. Bone Joint Surg. Am.*, 2015, vol. 97, no. 7, pp. 529-536. DOI: 10.2106/JBJS.M.01577.
20. Fitoussi F., Diop A., Maurel N., El Laasel M., Ilharreborde B., Penneçot G.F. Upper limb motion analysis in children with hemiplegic cerebral palsy: proximal kinematic changes after distal botulinum toxin or surgical treatments. *J. Child. Orthop.*, 2011, vol. 5, no. 5, pp. 363-370.
21. Cheema T.A., Firoozbakhsh K., De Carvalho A.F., Mercer D. Biomechanic comparison of 3 tendon transfers for supination of the forearm. *J. Hand Surg. Am.*, 2006, vol. 31, no. 10, pp. 1640-1644.
22. Alewijnse J.V., Smeulders M.J., Kreulen M. Short-term and long-term clinical results of the surgical correction of thumb-in-palm deformity in patients with cerebral palsy. *J. Pediatr. Orthop.*, 2015, vol. 35, no. 8, pp. 825-830. DOI: 10.1097/BPO.0000000000000380.
23. Arner M., Eliasson A.C., Nicklasson S., Sommerstein K., Hägglund G. Hand function in cerebral palsy. Report of 367 children in a population-based longitudinal health care program. *J. Hand Surg. Am.*, 2008, vol. 33, no. 8, pp.1337-1347. DOI: 10.1016/j.jhsa.2008.02.032.
24. Simon-Martinez C., Jaspers E., Mailleux L., Desloovere K., Vanrenterghem J., Ortibus E., Molenaers G., Feys H., Klingels K. Negative Influence of Motor Impairments on Upper Limb Movement Patterns in Children with Unilateral Cerebral Palsy. A Statistical Parametric Mapping Study. *Front. Hum. Neurosci.*, 2017, vol. 11, pp. 482. DOI: 10.3389/fnhum.2017.00482.
25. Van Heest A.E., House J.H., Cariello C. Upper extremity surgical treatment of cerebral palsy. *J. Hand Surg. Am.*, 1999, vol. 24, no. 2, pp. 323-330. DOI: 10.1053/jhsu.1999.0323.
26. Gharbaoui I., Kania K., Cole P. Spastic Paralysis of the Elbow and Forearm. *Semin. Plast. Surg.*, 2016, vol. 30, no. 1, pp. 39-44. DOI: 10.1055/s-0035-1571255.
27. Gigante P., McDowell M.M., Bruce S.S., Chirelstein G., Chiriboga C.A., Dutkowsky J., Fontana E., Hyman J., Kim H., Morgan D., Pearson T.S., Roye B.D., Roye D.P. Jr., Ryan P., Vitale M., Anderson R.C. Reduction in upper-extremity tone after lumbar selective dorsal rhizotomy in children with spastic cerebral palsy. *J. Neurosurg. Pediatr.*, 2013, vol. 12, no. 6, pp. 588-594. DOI: 10.3171/2013.9.PEDS12591.
28. Vermeulen R.J., Becher J.G. Long-term outcome in selective dorsal rhizotomy in spastic cerebral palsy: differentiation in mobility levels is needed. *Dev. Med. Child. Neurol.*, 2015, vol. 57, no. 5, pp. 408-409. DOI: 10.1111/dmcn.12695.
29. Novikov V.A. *Kompleksnoe lechenie patsientov s detskim tserebralnym paralichom s porazheniem verkhnei konechnosti*. Diss. kand. med. nauk [Complex treatment of patients with cerebral palsy with the upper limb involvement. Dr. med. sci. diss.]. SPb., 2018. 38 p. (in Russian)
30. Zancolli E.A., Zancolli E.R. Jr. The infantile spastic hand. Surgical indications and management. *Ann. Chir. Main*, 1984, vol. 3, no. 1, pp. 66-75.
31. Gschwind C.R. Surgical management of forearm pronation. *Hand Clin.*, 2003, vol. 19, no. 4, pp. 649-655.
32. Veeger H.E., Kreulen M., Smeulders M.J. Mechanical evaluation of the Pronator Teres rerouting tendon transfer. *J. Hand Surg. Br.*, 2004, vol. 29, no. 3, pp. 259-264.
33. Bunata R. Pronator teres rerouting in children with cerebral palsy. *J. Hand Surg. Am.*, 2006, vol. 31, no. 3, pp. 474-482. DOI: 10.1016/j.jhsa.2005.11.009.
34. Green W.T., Banks H.H. Flexor carpi ulnaris transplant and its use in cerebral palsy. *J. Bone Joint Surg. Am.*, 1962, vol. 44-A, pp. 1343-1430.
35. Patterson J.M., Wang A.A., Hutchinson D.T. Late deformities following the transfer of the flexor carpi ulnaris to the extensor carpi radialis brevis in children with cerebral palsy. *J. Hand Surg. Am.*, 2010, vol. 35, no. 11, pp. 1774-1778. DOI: 10.1016/j.jhsa.2010.07.014.
36. Čobeljić G., Rajković S., Bajin Z., Lešić A., Bumbaširević M., Aleksić M., Atkinson H.D. The results of surgical treatment for pronation deformities of the forearm in cerebral palsy after a mean follow-up of 17.5 years. *J. Orthop. Surg. Res.*, 2015, vol. 10, pp. 106. DOI: 10.1186/s13018-015-0251-3.
37. Hoffer M.M. The use of the pathokinesiology laboratory to select muscles for tendon transfers in the cerebral palsy hand. *Clin. Orthop. Relat. Res.*, 1993, no. 288, pp. 135-138.
38. Zagorulko A.K., Nenko A.M., Kushnir G.M., Vlasenko S.V. Osobennosti morfologicheskogo statusa spastichnoi myshtsy pri detskom tserebralnom paraliche [Special features of spastic muscle morphological status in cerebral palsy]. *Vestnik Fizioterapii i Kurortologii*, 2010, no. 6, pp. 14-17. (in Russian)

Received: 27.04.2018

Information about the authors:

1. Georgy M. Chibirov, M.D., Ph.D.,
   Russian Ilizarov Scientific Centre for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation
2. Sergei S. Leonchuk, M.D., Ph.D.,
   Russian Ilizarov Scientific Centre for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation
3. Kseniia S. Ezhova, M.D.,
   Russian Ilizarov Scientific Centre for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation
4. Elizaveta B. Gubina, M.D.,
   The Red Cross Kurgan Regional Children Clinical Hospital, Kurgan, Russian Federation
5. Mairbek K. Pliev,
   Russian Ilizarov Scientific Centre for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation
6. Pierre Lascombes, M.D., Ph.D., Professor,
   Hopitaux universitaires de Geneve, Department of Paediatric Orthopaedics, Geneve, Switzerland,
   Email: pierre.lascombes@hcuge.hcuge.ch
7. Dmitry A. Popkov, M.D., Ph.D.,
   Russian Ilizarov Scientific Centre for Restorative Traumatology and Orthopaedics, Kurgan, Russian Federation,
   Email: dpopkov@mail.ru