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EVALUATION OF THE RESULTS OF FUNCTIONAL PROSTHETICS IN CHILDREN WITH CONGENITAL DEFECTS OF THE HAND AND FINGERS

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Backgraund. Evaluation of the result of functional prosthetics in patients with different upper limb defects is a topical problem of modern prosthetics. Providing patients with non-functional hand stumps with functional prostheses is not wide-scale and refers to atypical and experimental prosthetics. While new functional prosthetic hands appear, there is no algorithm for evaluating the results of prosthetics.
Aim. This study aimed to evaluate the result of functional prosthetics in children with congenital defects of the hand and fingers by active prostheses.
Materials and methods. We observed 67 children with congenital hand defects, of which 22 were included in the experimental prosthetics group. Bench test station was used for an objective assessment of the residual function of the hand. The booth imitated the tasks of an international competition for the users of Cybathlon rehabilitation equipment and allowed users to perform a series of tests, for each of which a certain number of evaluation points were awarded. Samples at the stand were supplemented with a subjective assessment of the function of the hand using the DASH questionnaire validated in Russia.
Results. The best subjective assessment of the supply of an active prosthetic hand was determined in the patients with underdeveloped hand similar to the truncation of the hand proximal to the metacarpophalangeal joints. The lowest functionality score of the active prosthetic hand was obtained in cases of ectrodactyly and hypoplasia of 1–5 fingers, which was associated with a high residual functionality of the hand.
Conclusions. In addition to training functions, the developed bench test station serves a diagnostic function as it evaluates the results of functional prosthetics in patients with upper limb defects in different levels, including defects on the hand and fingers. The results of the study on the station correlate with the results of the DASH questionnaire.

Keywords: congenital defects of the hand; prosthesis; functionality; Cybathlon.

ОЦЕНКА РЕЗУЛЬТАТОВ ФУНКЦИОНАЛЬНОГО ПРОТЕЗИРОВАНИЯ ДЕТЕЙ С ВРОЖДЕННЫМИ ДЕФЕКТАМИ КИСТИ И ПАЛЬЦЕВ

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Обоснование. Оценка результата функционального протезирования пациентов с дефектами верхних конечностей является актуальной проблемой современного протезирования. Несмотря на развитие технологий бюджетного прототипирования и мелкосерийного производства, снабжение пациентов с беспалыми культями

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кисти функциональными протезами не приобрело массового характера и относится к атипичному и экспериментальному протезированию. На фоне появления новых вариантов функциональных протезов кисти отсутствует алгоритм оценки результатов протезирования.

Цель — оценить результат функционального протезирования детей с врожденными дефектами кисти и пальцев активными протезами.

Материалы и методы. Под наблюдением находились 67 детей, имеющих врожденные дефекты кисти, из которых в группу экспериментального протезирования включены 22 ребенка. Для объективной оценки остаточной функции кисти был разработан стенд, который имитирует задания международного соревнования пользователей техническими средствами реабилитации по кибатлону (Cybathlon) и позволяет выполнять пробы, за каждую из которых начисляется определенное количество баллов. Пробы на стенде дополнены субъективной оценкой функции кисти методом анкетирования по валидизированному в России опроснику DASH. Анкетирование проводили три раза на разных этапах: до протезирования, после обучения пользованию протезом и спустя 6 мес. после начала использования.

Результаты. Наилучшая субъективная оценка эффективности снабжения активным протезом кисти отмечена у пациентов с врожденными дефектами кисти, аналогичными усечениям кисти проксимальнее пястно-фаланговых суставов. Эти дети показали удовлетворительные результаты и на стенде. Самый низкий результат функциональности активного протеза кисти получен в случаях эктродактилии и гипоплазии I–V пальцев, что связано с высокой остаточной функциональностью кисти.

Заключение. Разработанный стенд является диагностическим, так как позволяет оценивать результаты функционального протезирования у пациентов с различными уровнями дефектов верхних конечностей, в том числе и дефектов на уровне кисти и пальцев, а также выполняет учебно-тренировочные функции. Он может быть использован для обучения пользованию активным протезом, а также для тренировки навыков с целью успешного прохождения трассы кибатлона или его отечественного аналога — кибатлетики. Результаты исследования на стенде коррелируют с результатами по опроснику DASH.

Ключевые слова: врожденные дефекты кисти; протез; функциональность; кибатлетика.

Background

Evaluation of the results of functional prosthetics of patients with upper limb defects is an urgent problem of contemporary prosthetics; however, no conventional algorithm exists in the evaluation of prosthetics results. Hand and finger prostheses of foreign manufacture are criticized because of the insignificant grip strength and fragility of the product [1]. New active prostheses are often not tested properly because they are developed using three-dimensional (3D) printing technology and without the involvement of doctors. 3D printing technology has been rapidly developing over the last 3 years [2]. During this time, it has become relatively inexpensive and available for common use [3, 4]. The possibilities of 3D printing enable the production of high-precision products of various strengths in small batches and by piece, depending on the chosen material and printing technology [5]. In most cases, prototypes manufactured in this way are not evaluated or tested.

As a rule, tests for an objective analysis of the prosthetics results are based on taking and releasing objects of various shapes and sizes from different positions and at different distances from the patient, moving objects in different directions, and performing proportioned movements with the fingers of the prosthesis [6, 7].

Tests different in terms of difficulty characterize one or another degree of mastering the skills of using prostheses, correctness of the prosthesis structure, and ultimately, the functional result of the prosthetics [8–10]. In 2016, in Zurich, the first international cybathlon sports competition was held under the auspices of the National Centre of Competence in Research Robotics for users of assistive devices using bionic prostheses or other mechanical devices [11]. The cybathlon route for users of functional upper limb prostheses served as the basis for creating a stand that can simultaneously solve three tasks: evaluating the functional result of the prosthetics, serving as a complex for training in prosthesis use and simulator to prepare for the competition of users of assistive devices.

We aimed to evaluate the result of functional prosthetics of pediatric patients with congenital defects of the hands and fingers with active prostheses.

Materials and methods

Sixty-seven pediatric patients with congenital defects of the hand were under supervision. Of these, 22 pediatric patients were included in the experimental prosthetics group. Among them, malformation in boys and girls was registered with a frequency of 44% and 56%, respectively.

The predominance of patients with congenital defects of the left upper limb was noted (69% on the left and 31% on the right).

The study enrolled pediatric patients with the following types of congenital hand defects:

- Group 1: those with reduction hypoplasia of the hands, corresponding to the hand stumps proximal to the metacarpophalangeal joints, namely, brachydactylia, aplasia of rays I–V in four patients (three of them with paired hypoplasia); brachydactylia, aplasia of rays II–V in three cases (one of them with a paired hypoplasia); and ectrodactylia, aplasia of rays II–IV in five patients.
- Group 2: those with reduction hypoplasia of the hands, corresponding to the stumps of the hand and fingers distal to the metacarpophalangeal joints and oblique excision, namely, ectrodactylia, hypoplasia of fingers I–V in eight patients and longitudinal ectromelia in two patients.

The mean age of the pediatric patients was 6.3 ± 3.8 years. The groups had similarities in age, sex, defect side, and type of prosthetics (primary/repeated).

Advanced active prostheses of the hand were manufactured for pediatric patients, which consisted of a removable liner of high-temperature vulcanization silicone and a carrier orthocryl bucket of prosthesis, which was attached to the block of hinged artificial fingers. The fingers were actuated by thrusts operated from flexion movements in the radiocarpal joint. The prosthesis could also have an active opposed artificial articulated first finger with the possibility of passively adjusting the opposition angle (Fig. 1). If medically required, full silicone active prostheses with metal elements embedded inside were created in a number of cases.

In the study, a stand was used, which imitated the tasks of an international competition for users of cybathlon technical means, which enabled them to perform a series of tests, for each of which they accrued a certain number of points. The types of actions were evaluated, namely, unscrew and screw in a light bulb in the illumination lamp — 10 points; pass over the ring, holding it by the handle, along a curved path — 10 points; move the clothespins between parallel horizontal and vertical posts — 2 points for each clothespin (five items in total); move the clothespins between the horizontal and vertical posts—4 points for each clothespin (five items in total); and unscrew/screw on the bottle cap — 5 points (Fig. 2). The results were recorded separately for the left and right hands if the stand test was performed by a patient with bilateral excision or hypoplasia of the hand.

The methodology assessed consistent performance of the subject of certain actions with the prosthesis. Time is not limited; the fact of the task performance was registered. The tasks for pediatric patients were presented in a game form to avoid excessive psychological coercion. The maximum number of points gained was recorded in the study form.

Physical examination on the stand was conducted before the prosthetics to assess the residual functionality of the hand, as well as after the initial prosthetics with an active prosthesis of the hand and training on how to use it to evaluate the functional results of the prosthetics.

Fig. 1. Active hand prosthesis

Fig. 2. Stand for evaluation of the results of prosthetics and training in prosthesis use

Table 1

Analysis of changes in indicators of the variables Stand and DASH for each group of congenital hand defects*

Indicator	Group of congenital defects of the hand		p
	$M \pm S$ Group 1	$M \pm S$ Group 2	
Age	6.4 ± 3.7	6.1 ± 4.1	0.8889
Stand, before prosthetics	12.8 ± 14.6	46.0 ± 8.8	<0.0001
Stand, after prosthetics	40.6 ± 9.3	39.0 ± 17.1	0.4972
DASH, before prosthetics	33.2 ± 10.5	16.8 ± 7.1	0.0006
DASH, after prosthetics	19.4 ± 8.4	26.9 ± 9.1	0.0608
DASH, in the long-term period	17.7 ± 7.1	31.9 ± 7.8	0.0005

Table 2

Analysis of changes of the Stand variable indicator for each group of congenital hand defects*

Group of congenital defects of the hand	$M \pm S$, before prosthetics	$M \pm S$, after prosthetics	Dynamics (%) before and after prosthetics	p
1	12.8 ± 14.6	40.6 ± 9.3	217.1	0.0010
2	46.0 ± 8.8	39.0 ± 17.1	–15.2	0.0679

Table 3

Analysis of changes of the DASH variable indicator for each group of congenital hand defects*

Group of congenital defects of the hand	$M \pm S$ (%), before prosthetics	$M \pm S$ (%), after prosthetics	$M \pm S$ (%), in the long-term period	p
1	33.2 ± 10.5	19.4 ± 8.4 (–41.5)	17.7 ± 7.1 (–46.7)	<0.0001
2	16.8 ± 7.1	26.9 ± 9.1 (60.2)	31.9 ± 7.8 (89.8)	0.0008

Table 4

Results of the analysis of Duncan's post hoc test for comparison of the indicators of groups 1 and 2 of the Stand variable (only levels of statistical significance)*

Group of congenital defects of the hand	Period	{1}	{2}	{3}	{4}
1	Before prosthetics		0.000065	0.000055	0.000125
1	After prosthetics	0.000065		0.302873	0.754001
2	Before prosthetics	0.000055	0.302873		0.081904
2	After prosthetics	0.000125	0.754001	0.081904	

Table 5

Results of the analysis of Duncan's post hoc test for comparison of the indicators of groups 1 and 2 of the DASH variable (only levels of statistical significance)*

Group of congenital defects of the hand	Period	{1}	{2}	{3}	{4}		
1	Before prosthetics		0.000056	0.000033	0.000073	0.089370	0.705667
1	After prosthetics	0.000056		0.469156	0.477114	0.034086	0.001025
1	In the long-term period	0.000033	0.469156		0.800311	0.013114	0.000305
2	Before prosthetics	0.000073	0.477114	0.800311		0.000246	0.000033
2	After prosthetics	0.089370	0.034086	0.013114	0.000246		0.043270
2	In the long-term period	0.705667	0.001025	0.000305	0.000033	0.043270	

Note. *Cells highlighted in gray show statistically significant data.

Samples at the stand were supplemented with The Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, which was validated in Russia. The questioning was performed thrice: before the prosthetics; after training how to use an active hand prosthesis personally with the patient; and after 6 months of using the prosthesis based on a telephone conversation. The questionnaire was filled out while considering the parents' opinion if pediatric patients younger than 9 years were tested.

A statistical analysis of the changes for the Stand and DASH variables was performed. The variable Stand was measured twice; hence, its values were designated "Measurement 1" (before prosthetics) and "Measurement 2" (after training how to use the active prosthesis). The variable DASH was measured thrice; hence, its values were designated "Measurement 1," "Measurement 2," and "Measurement 3" (in the long-term period, after 6 months of prosthesis use). In addition to the traditional statistical processing of the data obtained, a two-way analysis of variance for a mixed experimental scheme with Duncan's post hoc test was performed for the analysis of differences in changes of the Stand and DASH variables. One factor (congenital hand defect group) was an intergroup variable, whereas the second factor (measurement) was an intragroup variable.

Results

Table 1 presents the results of a statistical analysis of the comparison of various values of the "Group of congenital defects of the hand" variable by quantitative variables.

On the basis of the analysis of data in Table 1, we can conclude that the values of the Stand variable in group 2 were significantly higher than those in measurement 1 ($p < 0.0001$), and these values did not differ in the groups in the measurement 2 ($p = 0.4972$). In measurement 1, the DASH variable values were significantly higher in group 1 ($p = 0.0006$), and when the measurement was repeated, the values were the same in both groups ($p = 0.0608$), and in measurement 3, the values in group 2 already exceeded the values in group 1 ($p = 0.0005$).

Such dynamics of indicators indicates positive results of use of experimental active prosthesis in group 1, which is also confirmed by the indicators of the DASH variable in the analysis after 6 months of the prosthesis use, whereas the use of the prosthesis in group 2 only deteriorated the hand function, which was confirmed both objectively and subjectively.

Table 2 shows the results of a statistical analysis of changes in the Stand variable separately for each of the groups of congenital hand defects.

Table 2 data confirm the previously formulated conclusion that the values of the Stand variable increased significantly in group 1 ($p = 0.0010$) with measurement 1; that is, the use of the active hand prosthesis in the patients of this group improved the hand function significantly. In group 2, no significant changes in indicators occurred ($p = 0.0679$); before the prosthetics, the patients in this group had objective high residual hand functionality, the supply with active prostheses did not improve the stand test, and in some cases even worsened its results.

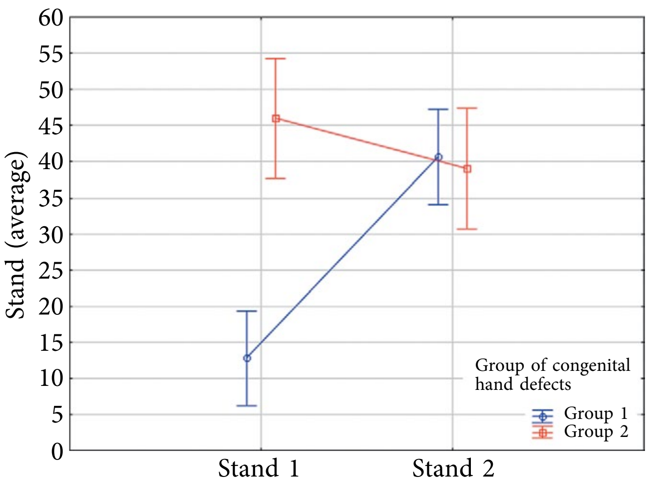

Fig. 3. Changes in the indicators of the Stand variable for groups 1 and 2 in measurements 1 and 2

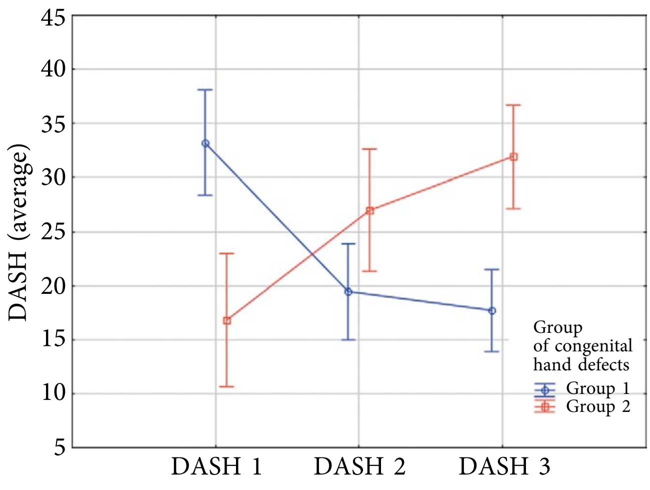

Fig. 4. Changes in the indicators of the DASH variable for groups 1, 2, and 3

Table 3 shows the results of a statistical analysis of the change in the DASH variable separately for each of the groups of congenital hand defects.

In group 1, the DASH indicator decreased by 41.5% and 46.7% in measurements 2 and 3, respectively, indicating a subjective improvement in the hand function immediately after prosthetic repair and 6 months after the use of an active prosthesis. In group 2, the DASH indicator increased, which confirmed subjectively the deterioration of the hand functional state as a result of the use of active prostheses.

The analysis of Duncan's post hoc test (Table 4) enabled to establish that the indicators for the Stand variable in group 1 differed significantly from those in group 2 ($p < 0.0001$) in measurement 1, and they became equal ($p = 0.7540$) in measurement 2 (Fig. 3).

The results of the analysis of Duncan's post hoc test when comparing groups 1 and 2 for the DASH variable (Table 5) indicated that the indicators of group 1 exceeded significantly those of group 2 in measurement 1 ($p < 0.0001$), and on the contrary, the indicators in group 2 significantly exceeded those in group 1 in measurement 2 ($p = 0.0341$). The same differences were preserved in measurement 3 ($p = 0.0003$) (Fig. 4).

Thus, the results of an objective analysis of the residual function of the hand based on the Stand test and patients' subjective perception of their condition regarding the hand defect correlate with each other.

Discussion

When analyzing the changes of the Stand variable, significant changes were shown in the indicators of this variable in the group of patients with congenital hand defects corresponding to the hand stumps proximal to the metacarpophalangeal joints; namely, the values of the Stand variable in this group were much higher in measurement 2, that is, after prosthetics with active hand prostheses. Furthermore, no significant changes were shown in patients of group 2 with stumps of the hand and fingers distal to the metacarpophalangeal joints and oblique excision. Before prosthetics, patients of this group objectively had a high residual function of the hand, and the supply with active prostheses did not improve in the Stand test, and in some cases even worsened its results.

The pronounced positive changes in group 1 in indicators of the Stand variable after prosthetics, as well as a decrease in the DASH variable, detected in measurement 2 and preserved after 6 months, show the efficiency of an active hand prosthesis of the presented design in patients with reduced hypoplasia of the hands corresponding to the stumps of the hand proximal to the metacarpophalangeal joints.

Thus, the congenital defects of the hand should be considered indications for the prescription of this prosthesis, namely, brachydactylia, aplasia of rays I–V; brachydactylia, aplasia of rays II–V; and ectrodactylia, aplasia of rays II–IV.

When prescribing an active hand prosthesis to patients with these defects, the assessment of the radiocarpal joint function should be considered, the range of movements in which must be at least 30°, as well as the strength of the flexor and extensor muscles of the hand and fingers because their force is directly proportional to the grip strength of artificial fingers of the prosthesis.

The lack of positive changes in group 2 is due to the high level of residual hand function of patients in this category, which is indicated by the data of both the stand test and the questionnaire. Prosthetics with active prostheses of such hand stumps lead to the restriction of residual movements by the bucket of prosthesis, which often worsens the situation. In addition, in such cases, making a prosthesis that does not protrude beyond the dimensions of a normal hand is practically impossible. Thus, contraindications to the prescription of an active hand prosthesis of the presented design should be considered in congenital defects of the hand, similar to excisions at the level of the fingers, from the heads of the proximal and distal phalanges.

Conclusions

The study conducted enabled to evaluate the functional result of prosthetics with active hand prostheses in pediatric patients and to clarify the indications for their use.

The best subjective estimation of the supply with an active hand prosthesis has been proven in patients with hand hypoplasia corresponding to the excision proximal to the metacarpophalangeal joints. This is confirmed by the changes in the indicators of the DASH questionnaire (26.1 ± 8.0; $p < 0.0001$) with satisfactory Stand test results.

Pediatric patients respond subjectively more positively to the use of an active hand prosthesis, despite lower Stand test scores. In case of congenital hand defects corresponding to the excision proximal to the carpal bones, preference should be given to prostheses with an external source of energy due to the low potential of the compensatory movements of the residual segment of the patient's hand.

The lowest result of the active hand prosthesis functionality was obtained with ectrodactylia and hypoplasia of fingers I–V. In this case, a sufficiently high residual function of the hand is retained, and the prescription of an active prosthesis does not provide an expected increase in its functionality.

The stand presented in this study is diagnostic because it enables the evaluation of the residual function of the hand, results of functional prosthetics in patients with different levels of defects of the upper limbs, including defects at the level of the hand and fingers, and also performs training functions. It can be used for teaching the use of an active prosthesis and training skills to complete the cybathlon route successfully. The results of the study on the stand coincide with the DASH questionnaire results.

Additional information

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Conflict of interest. The authors declare no obvious or potential conflicts of interest related to the publication of this article.

Ethical review. The parents of all patients, as legal representatives, gave their written consent to participate in this study, to the processing and publication of personal data. The article publication is permitted by the ethics committee of the North-Western Scientific and Practical Center for Rehabilitation and Prosthetics "Orthotics" in accordance with the principles of the Helsinki Medical Declaration (Protocol No. 1 of February 15, 2019). The article presents the results of research without personal identification of the patients that do not contradict the ethical standards of the Helsinki Declaration of the World Medical Association Ethical Principles for Medical Research Involving Human Subjects, amended in 2000, and the Rules of Clinical Practice in the Russian Federation, approved by Order No. 266 of the Ministry of Health of the Russian Federation dated 19.06.2003. The research participants and their legal representatives were informed about the aims, methods, expected benefits of the research, and risks and discomfort associated with the participation in the study.

Contribution of the authors

A.V. Kruglov is involved in collection and processing of materials, analysis of the data obtained, and writing of the text.

I.V. Shvedovchenko created the concept and design of the study and edited the text.

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