Literature review

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Current state of functional prosthetic application in disabled persons with hand and finger stumps (literature review)

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The literature reviews the status of the issue of prosthetic application for partial hand and finger truncation and deficiencies in Russia. Special attention is paid to functional prostheses. Active prostheses that were previously produced or available at present were analyzed. The possibilities of using 3D printing for hand prosthetics are shown. Objective and subjective quality evaluation methods of functional prosthetics are presented.
Keywords: prosthetics, hand stump, active prosthesis, hand deficiencies, finger stump, finger module

The value of the hand in a person's life cannot be overestimated. The hand is not just an organ for labor activity but also a creative body part that moves the human being further along the evolutionary path. Humans unjustifiably forget to protect their hand and put it at risk. High incidence of industrial injuries to the hand in the working population under the age of 39 was reported that makes 60 % from all the industrial trauma [1]. The share of hand injuries in the total of all the injuries to the upper limb is 61.8 % [1, 2, 3, 4]. Traumatic amputation of fingers or parts of the hand happens in 2.6 to 5.4 % of cases and leads to disability in 52.8 % [1].

All over the world, the frequency of reduction defects of the upper limb ranges from 4-5/10 000 to 1/100 of newborns [5]. There is a critical need for practical, easily replaceable, individual, aesthetic, and low cost prostheses for children [6].

Amputation of the hand, for whatever reason it happens, has a destructive impact on the psychological, physical, and economic state of any person. Its consequences are grief, depression, loss of self-esteem and, frequently, social isolation [7]. Rehabilitation measures, which component is a qualitative and timely prosthetic application, should level the problems associated with the loss of the limb, though not completely.

Prosthetic management of the hand and fingers stumps is one of the most difficult practices for doctors and prosthetic technicians. It is extremely difficult to manufacture an active prosthesis of the hand that provides a sufficient grasp needed for everyday life and which is within the boundaries of its normal anatomy. It equally refers to production of an active prosthesis of a finger that would be able to retain the existing functions of the patient's hand.

In the beginning of 2000s, the RKK *Energia* and the scientists Y.I. Zamilatsky and I.V. Pankov from the G.A. Albrecht Research Institute for Prosthetics designed active prostheses PROE-1, PROE-3 for the hand stump and PROE-2, PROE-4 for a hand stump with a saved thumb (not manufactured at present) (Fig.1). The prosthesis had carcass finger simulators the opening of which was performed with the help of an axillary loop and its closure with the help of a spring. In addition, there was a mechanism for fixing the 4th finger simulator in a "hook". However, it did not find wide use. The compensatory possibilities of the hand stump were not taken into account by the designers. Also, the receptacle of the stump transition zone frequently restricted the movements in the radiocarpal joint [8].

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Fig. 1 Components 2B021 (on the left) and 2B023 (on the right) for the manufacture of prostheses PROE-1 and PROE-2

The commercially available accessories for the manufacture of a prosthetic hand with an external power source produced by *Touch Bionics* and *Vincent-systems* belong to the world experience of prosthetic application for adactylia hand stumps. The *I-digits Touch Bionics* prosthesis (**Fig. 2**) was designed for the patients that suffered partial reduction of the hand at different levels but not higher than the articulations in the metatarsophalangeal joints. The design of the prosthesis is based on the use of separate modules of phalangeal electric fingers. The control signals are transmitted from the muscles of the hand by myographic sensors located inside the transition receptacle. The cumbersome bracelet for control and power system is one of this prosthesis shortcomings along with the inability to use the esthetic shell, and, of course, the cost which reached 18 thousand UK pounds in 2015.

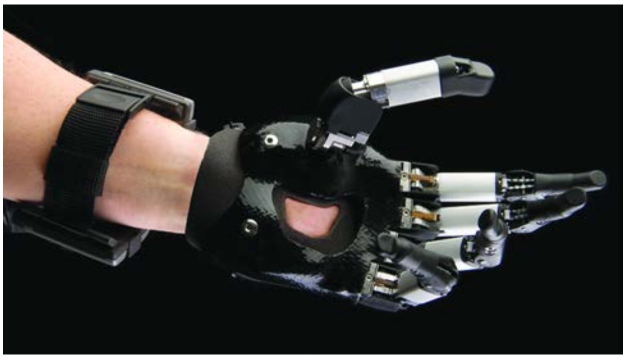

Fig. 2 I-digits prosthesis

The provision of patients with active hand prostheses is not a mass manufacture. It is referred to atypical and experimental prosthetic applications [9].

To date, there is a need to create a new generation of prosthetic appliances. Active hand prostheses raise a great interest. Their continuous reverse control of the mechanism is performed by the residual segment of the hand, that is, by metacarpals or preserved segments of the fingers. In this case, the feedback on position and effort is provided with the transmission of the load action directly to the control organ [8]. Creation of a unified set of parts and connecting elements should be considered in further development and manufacturing of prosthetic hands [8].

3D printing technologies have been actively explored in the world for solving design issues and small-scale production of components in the recent years [10]. This technology has become widespread and affordable as well as relatively inexpensive for use [11, 12]. Rapid prototyping has been used in numerous medical industries over the past decades. It includes research, education, individual patient care, surgery, and prosthetic application [13].

There are companies in developing countries that use low cost 3D printers to manufacture prostheses. Despite being cumbersome and requiring further design, these artificial limbs have significantly increased the independence of patients with amputated upper limbs. This work represents a huge step forward in ensuring the high quality of health care in poor countries [14, 15, 16].

To date, electronic data have been distributed worldwide for independent printing and assembly of active prosthetic hands for children. The requirements for pediatric prostheses are complex because of the child's continuous growth and psychosocial development [17, 18, 19]. Most modern prostheses do not re-adapt to the normal size of the children's limbs and require regular visits to health facilities for adjustment or replacement. These facts result in a refusal to use them [20]. Advances in computer modeling programs, layered printing, and open source software offer the possibility of designing, printing and individualizing active prosthetic hands at a very low cost [13, 19]. They also make it possible to change prostheses more frequently as the child grows.

One example is an inexpensive 3D active hand prosthesis called *Cyber Beast* (**Fig. 3**). It was developed with the help of a modeling software program *Blender 7.2* (Blender Foundation, Amsterdam, the Netherlands) and fabricated at a scientific laboratory using a desktop 3D-printer *Makerbot Replicator*.

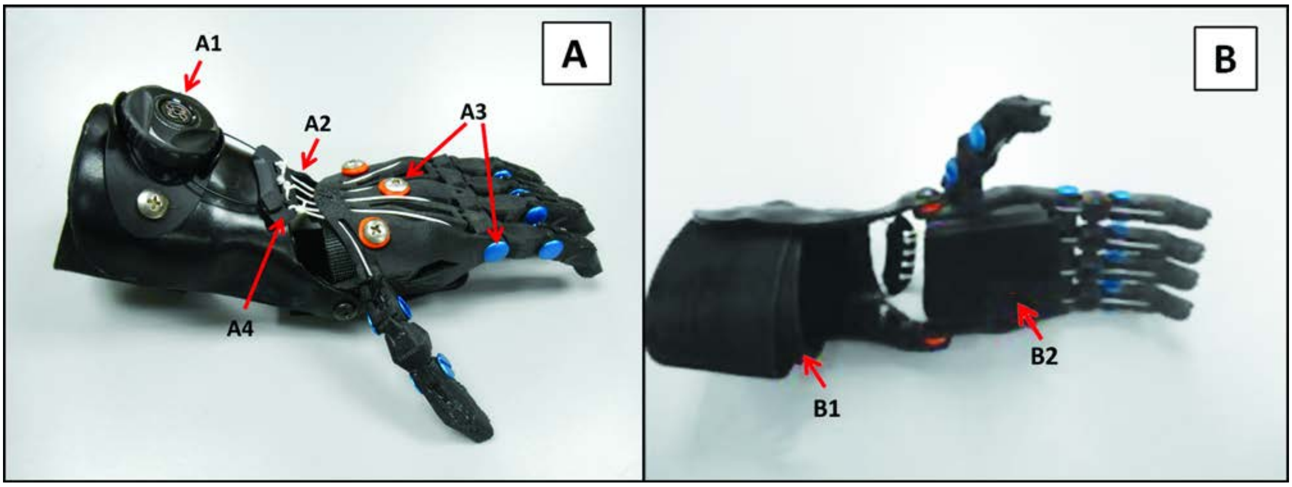

Fig. 3 Active prosthesis of the hand *Cyborg Beast*: A) top view (A1 – tensioning disc, A2 – nylon rods, A3 – fastening screws, A4 – tension system); B – bottom view (B1 – forearm sleeve, fixed with Velcro strap, B2 – handpiece case with artificial fingers, fixed with Velcro) [19]

The authors of this project conducted a survey that was not considered statistically significant. However, it provided useful information related to the use and feeling of improving the quality of life. Nine children reported using the prosthesis for one or two hours a day, three of using the hand prosthesis for more than two hours and one reported that he used it only if necessary. The children talked about the use of a hand prosthesis for entertainment (n = 10), for household activities (n = 10), for playing (n = 6), for work at school (n = 4), and for sports (n = 2). The development of low-cost prostheses that are practical, esthetic and manufactured remotely will have a significant social impact on children around the world [19].

In Russia, the development and implementation of printed prostheses has been carried out by the *Motorika* company. However, it should be noted that this company uses 3D printers of the top level. Therefore, their final product cannot be called low-cost.

The solutions of creating medical and technical requirements for functional prostheses has been searched for in all developed countries of the world [21], including Russia. Due attention to the appearance of the final active hand and finger prosthesis design is necessary along with functional properties. Prostheses should be the hand element of the style for a person with a defect, a kind of decoration that is very individual. Examples include Grace Mandeville, an actress, Rebecca Marina, a fashion model, Viktoria Moskalova, a singer, or Emmy Malins, a model athlete, and many others. Designers involved in the development of decorated prostheses have become known, for example, Sophie del Oliveira Barata from Great Britain.

A rational method for an objective assessment of the immediate and long-term results of active hand and fingers prostheses has not been currently developed. All methods of their assessment can be divided into objective (various power and functional tests) and subjective (interviewing and questionnaires).

Objective assessment methods

The literature describes a variety of tests to assess the motor function of the upper limb which can be divided into power and functional.

Power tests:

1) Manual Muscle Test (MMT) [22, 23];

2) Manual dynamometry [24, 25].

Functional tests:

3) Minnesota Rate of Manipulation (MRM) test [26];

4) Upper Extremity Function Test (UEFT) [27];

5) Purdue Pegboard Test [28];

6) Jebsen test of hand function [29, 30];

7) Sollerman Hand Function Test. The Sollerman test [27].

A test to assess the quality of the prosthetic application can be composed by combining several tests to maximize the objectification of the results.

Methods of expert assessment

To date, various tests and questionnaires have been widely used to assess the function of the hand. Although, they are subjective tools but are able to depict in detail the function of the patient's limb [31].

The DASH questionnaire [32] is based on the patient's self-assessment of the level of inabilities and symptoms in both upper limbs simultaneously. It was designed to measure the function and symptoms associated with the diseases and consequences of upper limb injuries, as well as to evaluate treatment outcomes. In 2005, the DASH questionnaire underwent a process of intercultural adaptation in Russian. Its Russian version is available on the website of the Institute for Work and Health (Canada) [33].

To objectify the patient' feedback on the prosthesis use, it is advisable to apply the SF-36 quality of life (QL) questionnaire. Quality of life (QL) is an integral characteristic of the patient's physical, psychological, emotional and social functioning, based on his subjective perception [34]. The SF-36 questionnaire was developed in 1992 by American doctors John E. Ware and Cathy D. Sherbourne at the Center for the Study of Medical Results [35]. This questionnaire was validated for Russia. In 2007, TP. Ionova with co-authors conducted a population-based QL study using the SF-36 questionnaire for the first time in Russia. QL was assessed in a healthy population of St. Petersburg [34].

Application of the international classification of functioning (ICF)

In the international practice, the ICF is widely used in both its detailed and short versions. In recent years, the amount of information about the results of studies using the ICF has increased in several directions, and, namely, the use of classification fragments for various purposes such as professional rehabilitation [36], physiotherapy practice, medical practice, comparative analysis of functioning in various forms of diseases, and evaluation of treatment efficiency [37].

It is necessary to focus the attention on the fact that we did not meet any national publication dealing with an objective and subjective evaluation of the hand function before and after prosthetic application, as well as with the quality of life. Probably, it is due to the fact that the process of prosthetic application has formally ceased to be a medical service, despite the fact that the prosthesis is a product for an exclusively medical purpose. In part, this information vacuum resulted in the situation when medical and technical requirements were no longer made. And as a consequence, not only new components and prostheses but also improved hand receptacles, more comfortable and functional, have ceased to be designed.

All of the above confirms that the problem of prosthetic management for patients with recutions at the level of the hand and fingers exists and necessitates the development of a modular active prosthesis, improvement of receptacles with the use of the newest materials for prosthesis construction.

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