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Ways of Development in Children Partial Hand Prosthetics

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Abstract

The aim of our work was to show the evolution of the designs of upper limb prostheses for children with congenital and acquired anomalies of partial hand.

We have studied 923 children aged 6 months to 18 years. Of these, 582 patients (63,1%) had the most severe forms of hand pathology with complete absence of fingers and loss of hand function by 100%.

The study of the clinical and radiological data of the injured hand during the growing up of such children showed a change in the size and shape of the arm segments, a violation of the processes of osteogenesis; the presence of musculoskeletal hypotrophy of the overlying segments (forearm, shoulder); shortening of the length of the upper limb in the range from 1.5 to 10 cm, depending on the level of the lesion.

Initially, due to the lack of active prostheses, to restore any function and aesthetics of the affected hand, we used only cosmetic hand prostheses, starting from 8-10 months of their life.

As a result of scientific research in collaboration with engineers and medical staff was have been designed partial hand prostheses: mechanical and with an external energy source.

***Keywords**: Children; Congenital Anomalies; Amputations; Partial Hand Prostheses*

Introduction

The contingent of patients with congenital anomalies of the hand is quite large, so, for example, in Russia out of 1000 newborns, approximately one child had a congenital anomaly in the development of the hand, which was the cause of disability since childhood [2,25,26,40]. A high proportion was occupied by injuries to the fingers of the hands - the second place after head injuries [37].

Comparative analysis showed that congenital malformations and post-traumatic hand defects occur in a ratio of 1: 4 [25].

In most cases, children with congenital malformations of the hand and with the consequences of its injuries became disabled [7,15,24,26,46].

The presented literature data from the world practice of prosthetics of children with hand defects indicated that there were only individual data on prosthetics of children with hand defects [30,31,35,36,48,50].

In first Russian mechanical cable prostheses [50], the capture and opening of the fingers is carried out by flexion and extension of the hand in the wrist (Figure 1).

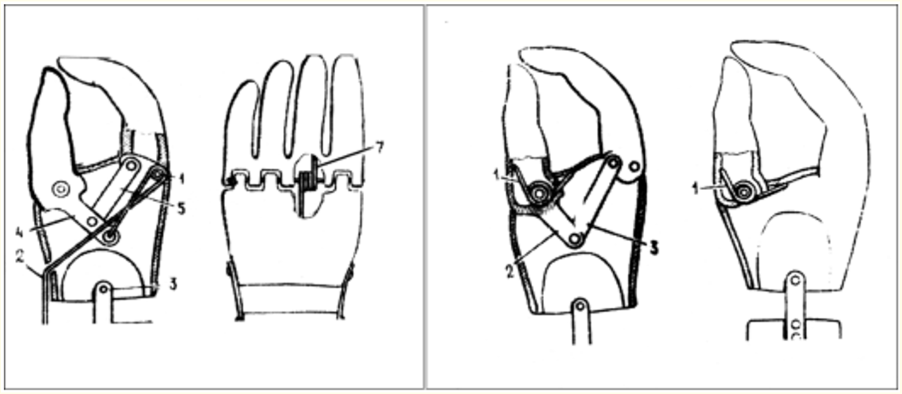

Figure 1: *A hand prosthesis (scheme): I-a roller, 2 - flexible draft, 3 - the hinge, 4 - lever I of a finger, 5 - the lever of block II-IV of fingers, 6 - polyethylene cuff, 7 - a spiral spring (Cit. [50]).*

The opening of the artificial fingers of the prosthesis was possible with the help of a rod, 2 fixed on a rigid lever, 4 and thrown over a roller, 1, mounted on a fixed axis and connecting the block II-V of the fingers, 5 with the body of the hand. The grip was carried out by means of a spiral spring, 7 located on the fixed axis of the block II-V of the fingers. One end of the spring was fixed in the body of the hand, the other in the block of the second-fifth fingers. The prosthesis was held on the stump using a polyethylene cuff, 6.

Considering the large number of children with finger defects, especially in their complete absence, scientific research in this area of orthopedics became very relevant indeed [3,6,9,11-18,35]. It should be noted that recently there have been many examples from social networks of the Internet, where isolated cases of making hand prostheses using 3D technologies are also presented. But these data are sporadic, scattered and do not carry practical potential. Based on the analysis of known hand prostheses, an original design of a human-machine interface based on EMG sensors, mechanical assemblies and a control system for the main motor functions of the prosthesis is proposed [41-45,47]. With the help of 3D printing, models of the prosthesis are made, as well as new full-fledged models, ready, according to the authors, for mass production [1,19,20-23,38]. A completely new direction in hand prosthetics is aimed at the active use of the ends of peripheral nerves to control prostheses, as well as to prevent the possible development of phantom pain syndrome [13,29,32,33,53].

Materials and Methods

Our many years of experience includes 923 children and adolescents ranging from 6 months to 18 years old. Of the total number of patients, 75.6% had congenital anomalies and 24.4% had post-traumatic hand stumps. Of these, there were slightly more boys (54.5%) than girls (45.5%).

The children were divided into 4 groups according to the level of their anatomical defect:

1. The level of the phalanges of the fingers (214 patients or 23.1%),
2. The absolute absence of some fingers or rays (127 or 13.8%),

3. The level of the metacarpal bones (215 or 23.3%),

4. Level of the carpal bones (367 or 39.8%).

The last two groups (582 patients or 63,1%) included the most complex hand defects with complete absence of fingers. Accordingly, the hand function was impaired within 100%.

After studying the clinical and radiological data, the following signs of pathology were identified during all periods of growing up of children: changing the size and shape of hand segments; violation of the processes of osteogenesis; the presence of musculoskeletal hypotrophy of the overlying segments (forearm, shoulder); shortening of the length of the upper limb in the range from 1.5 to 10 cm, depending on the level of the lesion.

In this work, we presented the most severe group of patients without fingers, who received various types of prostheses.

Results and Discussion

The clinical and radiological characteristics of children with no fingers at all were very interesting.

A hand with underdevelopment (congenital adactylia) or amputation at the level of the metacarpal bones (Figure 2) often has a wide shape, with a good supply of soft tissues, without pronounced trophic disorders.

a b

Figure 2: *Congenital adactylia of the right hand of the patient of 6- years old. Another one is X-ray picture of left hand congenital adactylia of a some 8-ears old baby.*

Instead of fingers, motionless formations in the form of small tubercles, 0.3 - 1 cm in size, are visible. At the same time, the rudimentary first metacarpal bone and wrist joint are mobile.

In patients with congenital adactylia, muscular hypotrophy of the entire underdeveloped limb is observed with a shortening of the forearm by 1.5 - 2 cm and the shoulder up to 1 cm (on average up to 3 cm) compared to the healthy limb.

A child's hand with lesions at the level of the carpal bones (congenital aplasia) at the age of up to three years is a soft tissue formation of a spherical shape, measuring from 1.5 to 3 cm (Figure 3 and 4). In its distal parts, spherical or elongated rudimentary fingers are located, on narrow legs with thin nail plates.

Figure 3: *Congenital anomalies of the left hand, carpal level and rudiments soft tissue formations I-V of fingers*

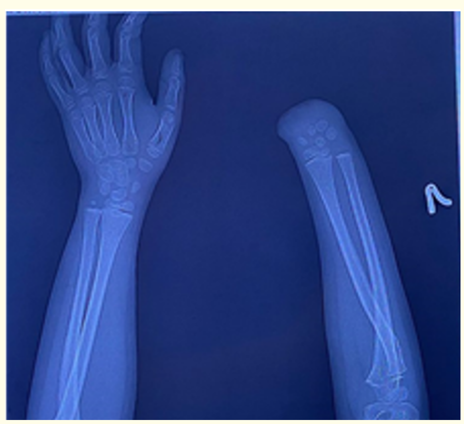

Figure 4: *An example of an X-ray of the hand of a 7-years old child with a congenital malformation at the carpal level.*

During growth in the soft tissues of the hands are compacted, the bones of the wrist are clearly felt. Roentgenological, they are visualized only after three to four years of age and have a spherical shape, the same size. In adolescence, their complete fusion into a single bone conglomerate is observed.

In congenital aplasia, there are limitations to the range of motion in the wrist joint, (abduction and adduction), a significant shortening of the underdeveloped upper limb is revealed, ranging from 3.5 to 7 cm at the expense of the forearm and up to 2 cm at the expense of the shoulder. The shortening is accompanied by pronounced musculoskeletal hypotrophy of the segments of the entire underdeveloped limb, as well as the corresponding half of the shoulder girdle. The curvature of the spine is revealed.

The restoration of the function of grasping objects was carried out by us using a prosthesis-counter-bearing, which was recommended for a child aged 2 - 3 years. In addition, we also used cosmetic hand prostheses for children aged 8-10 months (Figure 5 and 6). This variant of primary prosthetics is still the basic one [26].

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Figure 5: *Cosmetic glove for congenital adactilya of the left hand (a-b).*

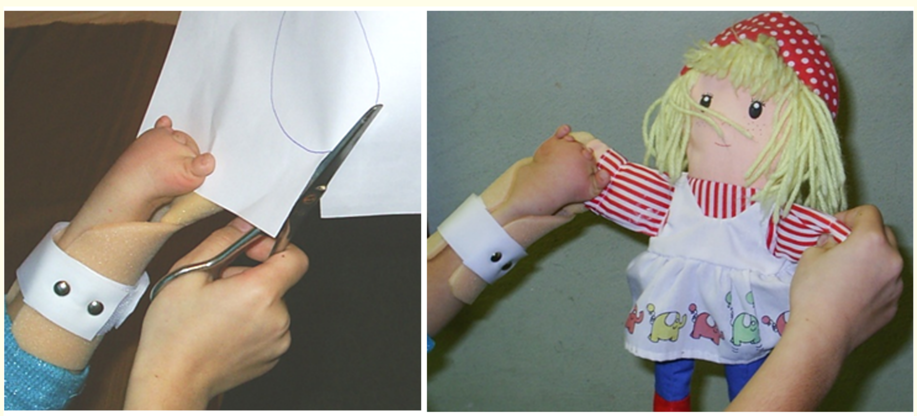

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Figure 6: *The opposition post in our prosthetic practice for children with hand defects (a-b).*

In the process of observing children who used counter-bearing prostheses, we noted that a large palm helps to grip larger objects, but at the same time the force of palmar pressing itself is less (Table 1).

Parameters of the prosthesis	Metacarpal bones	Carpal bones
Gripping force (N)	1.5 - 28	12.5 - 40
Opening palm size (cm)	3.0 - 4.0	1.3 - 3.2
Item size (cm)	4.0 - 6.0	2.0 - 3.5
Item weight (kg)	3.5 - 4.0	2.0 - 3.0

Table 1: *Functional results of the use of the opposition-post prostheses.*

The next step, as an active hand prosthesis in the absence of her fingers, was the use of a mechanical cable below elbow prosthesis. This prosthesis was more often used in children with congenital aplasia of the hand (Figure 7).

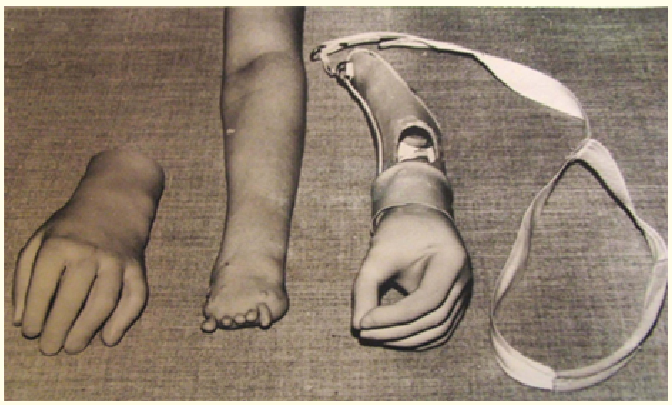

Figure 7: *The mechanical cable below elbow prostheses after modernization for cases of carpal hand defects.*

The design of these prostheses while maintaining its functionality was have been changed [25,26]. For example, the shape of the prosthesis socket, then the attachment system on the arm and the position of the cable. With the help of prostheses, it was possible to partially improve the function of the grip. However, the main disadvantage of such prosthetics was the tightness/closure of the active wrist joint of the rudiment hand.

Thus, there was a real need to create active children's hand prostheses in the complete absence of fingers, which would have the following characteristics:

- In appearance they looked like a healthy child's hand,
- Did not block the wrist joint,
- Have sufficient grip strength,
- Simple attachment system on the patient,
- Convenient receiving sleeve.

Scientific research on the design of children's hand prostheses was carried out in two directions: the creation of active prostheses with external energy sources and a mechanical cable system [5,25]. This was typical not only for Russian scientists, similar studies were conducted abroad [8,10,36,52,53].

A pneumatic-driven children's hand prosthesis was first developed in 1982 by engineer E. Podkopaev (Figure 8) together with us and was recommended for disabled children with hand defects in: bilateral defects of the upper limbs, limitation of mobility of the hand stump in the wrist joint; insufficient energy capacity of the child's body to control traction prostheses; adolescents, who will not do heavy physical work.

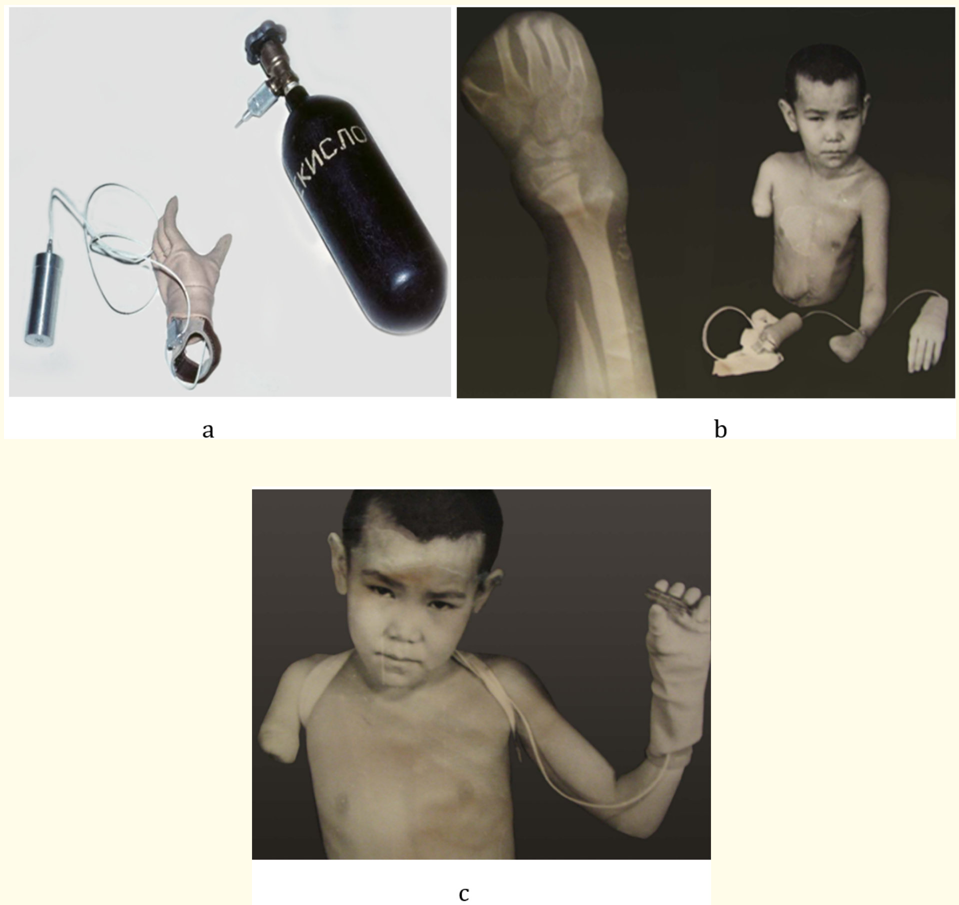

Figure 8: *The pneumatic children partial hand prosthesis, designed by Russian engineer Eugenie Podkopaev, 1988 [25]. The pneumo prosthesis with the pneumo accumulator and the energy device (a). Clinical example of 10-years old boy after electro trauma of both arms (b-c).*

Along with the design of mechanisms with external energy sources, active hand prostheses with a cable control system were created, the main developer of which was engineer I. Pankov (Figure 9a and 9b).

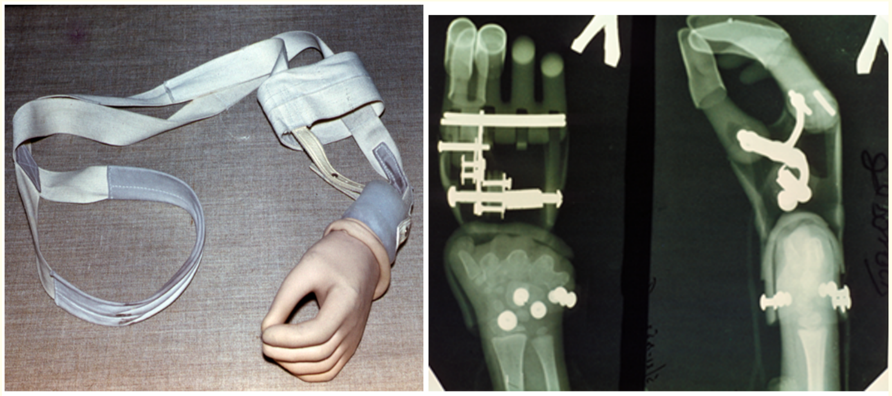

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Figure 9: *a. The first Russian mechanical cable prosthesis for children with partial hand, designed by Russian engineer Ivan Pankov. I - a hand; 2 - a socket; 3 - elements of harness; 4 - manual draft; 5 - stabilizing draft; 6 – soft cuff on an elbow; 7 - an axillary loop. b. Prosthetics by an active mechanical cable prosthesis of the patient, 13 years with congenital adactilya the left hand, X-ray picture. The ratio of the parts of the prosthesis and the bones of the hand is clearly visible.*

Note that when using a cable prosthesis, a correctly selected mechanical load on the injured limb serves to prevent musculoskeletal atrophy during the child's growth. In this case, the prosthesis itself serves as a working simulator in order to stimulate the hypotrophy muscles of the arm.

The artificial child's hand was made of plastic with 5 fingers. It was attached to a polyethylene socket for the stump with rivets and plastic strips.

The mechanical prosthesis (Figure 9a) had two cables: one to control the prosthesis, and the other to stabilize the prosthesis on the stump. The cables were connected with a ring cuff at the elbow. The round cuff eliminated sagging of the cables and controlled the prosthetic arm in the upper position (for example, near the face and above the head) and was also used as an elbow support during the manipulation of the prosthesis.

The plastic hand was wrapped in a cosmetic glove. The following illustrations show the various steps to operate this partial hand prosthesis (Figure 10).

Figure 10: *Actions in an artificial limb of 6-years old patient. The new design cuff at the elbow level has already been replaced with 2 leather straps.*

On the basis of previous biomechanical studies [4], the main type of grip, which is realized in normal hand and prosthetic hand, was the end grip. The following regularity of the grip force was determined depending on the child's age: for children under 7 years old - 350 - 500g; for children from 7 to 14 years old - 500 - 1000g; for children over 14 years of age over 1000g.

Initially, the system of fastenings on the patient's body was made in the form of 8 figures with a cross on the middle part of the back, between the shoulder blades. Then the mount was made in the form of a 9, and later completely changed.

In order to avoid the cable sagging during the direction of the hand prosthesis at the chest level and above, we made a plastic cuff at the elbow level (Figure 11).

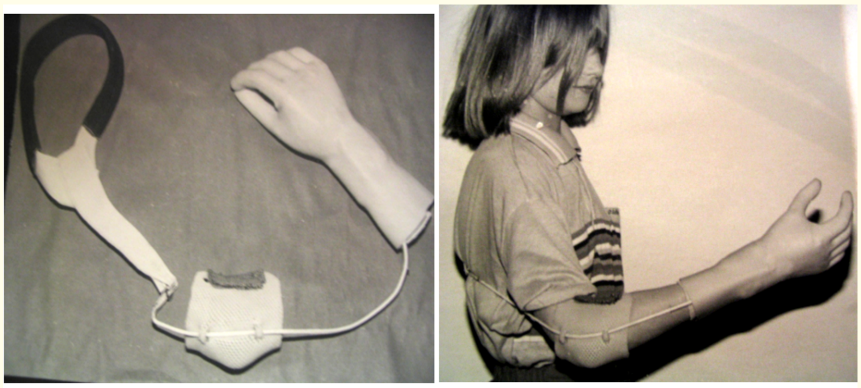

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Figure 11: *The additional plastic elbow cuff in harness partial hand prosthesis (a-b).*

We ran the control cable through two holes on the back of the cuff [27]. Thus, the cable did not sag during operations with the prostheses [26-28].

The next stage of research in the field of designing a mechanical cable hand prosthesis in children, together with I. Pankov, Yu. Zamiladsky and some specialists from the Energia space corporation, was characterized by the development and manufacture of a metal traction hand prosthesis for partial hand (Figure 12). This prosthesis consists of the following main components: a metal frame and fingers, a short socket, plastic or combined (rubber and plastic), a special wiring harness and a control cable [26,28,39].

a b

Figure 12: *The metallic artificial hand. New direction in children partial hand prosthetics.*

The main components: 1-metallic frame and fingers, 2-short socket, plastic or combined (rubber and plastic), 3- the special harness and control cable (a). The child and prostheses (b).

The results of studies on the effect of loads on the growth of the bones of the hand and forearm were used to develop a children's hand prosthesis with unloading of the growth zones of the forearm bones, due to our proposed attachment system, made in the special form of a harness [40]. The objective of the invention was to reduce the load on the distal parts of the hand and forearm, while increasing the reliability of fixation of the prosthesis.

The first clinical trials (5 patients) showed good results with this prosthesis and served as a prospect for the continuation of future research work in this direction.

Our comparison of the characteristics of mechanical and pneumatic prostheses of a child's hand made it possible to identify the advantages and disadvantages of each type of product (Table 2).

Technical Parameters	Pneumatic Prostheses	Plastic Cable Prostheses	Metal Cable Prostheses
Denture weight (g)	168	185	300
Maximum opening of fingers (mm)	65	70	60
Hand opening force (N)	30	60	88
End gripper (N)	10	13	25

Table 2: *Comparative characteristics of active hand prostheses in children.*

The advantages of a pneumoprosthesis were lower weight, small efforts spent by patients when managing it, simplicity of fastening, ease of putting on, and the ability to manipulate the hand in various planes. The disadvantage of this prosthesis was the difficulty of recharging with gas, loud effects and uncontrolled activation of the pneumoprosthesis.

Giving the characteristics of mechanical cable prostheses, we note their higher power characteristics in comparison with pneumoprosthesis and a larger size of finger opening.

In 2015, the young Russian prosthetic company "Motorica" under the leadership of engineer I. Chен presented new technologies and new hand prostheses for children: with a traction control system and bionic hand prostheses (Figure 13).

a b

Figure 13: *The using of the partial hand prostheses, designed by "Motorica" (a-b).*

The positive qualities of the new constructions, not only their functionality and cosmeticity, ease of use, but also the ability of each child to emphasize their individuality by choosing the color of the prosthesis in different colors. More than 300 children have already been provided with hand prostheses both in Russia and in the countries of the former Union State. There are cases of making new prostheses for children from other foreign countries - Italy, Israel, the United Arab Emirates, India.

Conclusion

Of the total number of patients, we observed, about 60% of children were provided with various partial hand prostheses. Prostheses were prescribed for children depending on the type of defect, age and level of psychological development of children, the nature of their manual activity and functional capabilities of the upper limb. The fitting of any prostheses was carried out strictly individually.

Our experience has shown that primary prosthetics for children with hand pathology can be started in the first years of life. They accept cosmetic, mechanical cable prostheses, self-care appliances. Patients over 3 years old are recommended to use all types of orthopedic products, including limb prostheses with external sources.

Conflict of Interest

None.

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