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CLINICAL CASE

3D-printed hand prostheses function in adolescents with congenital hand amputation: a case series

Funcionalidad de prótesis de mano impresa en 3D en adolescentes con amputación congénita parcial de mano: una serie de casos

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What do we know about the subject matter of this study?

There are different available models of hand prosthesis for free 3D printing, but little objective information to know if they meet the needs and/or expectations expressed by users to optimize their functionality, activity, and participation.

What does this study contribute to what is already known?

This contribution focuses on describing quantitatively the functionality in users of the Cyborg Beast hand model. There are no previous studies that describe functional outcomes in adolescents.

Abstract

Objective: To describe the effect of the 3D-printed Cyborg Beast prosthesis on upper limbs function in adolescents with congenital hand amputation. **Clinical Cases:** Five patients aged between 12 and 17 years, with congenital hand amputation were selected. All patients were from the Teletón Institute in Santiago, Chile. The patients were trained for prosthesis use in four sessions. Hand function was evaluated without prosthesis, at 1 and 4 months of use with the modified Bilan 400 points scale, and upper limb function perception was evaluated with the 'Upper Extremity Functional Index (UEFI)'. At 1 month and 4 months of use, the percentage change for hand functionality for the unaffected limbs was between -11% and -4%; and -9% and -2% for the affected limb. The percentage change for the upper limbs perceived function was -62%. **Conclusions:** The use of the 3D-printed Cyborg Beast prosthesis was not a functional solution for the 5 patients included in this study. Future research is needed to improve the functionality of these types of 3D-printed hand prostheses.

Keywords:
3D-printed prosthesis;
congenital upper limb differences;
upper limb function

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Introduction

Congenital amputations of the upper limb are alterations that occur during the embryogenesis stage[1], affecting the development and growth of the upper limbs, whether partial, where there is a remaining segment of the limb, or complete, where there is a complete absence of the upper limb[2]. Some of these occur due to a syndrome and may be associated with other organ or body defects[3].

Given the lack of a compulsory registration system, estimating the exact prevalence of these types of malformations is difficult. According to epidemiological studies published in Australia, Finland, and Canada, a worldwide incidence of upper-extremity abnormalities has been estimated at between 3.4 and 5.3 per 10,000 live births[4-6].

Specifically, in hand malformations, there is a wide variety of presentations[3] that can affect one or more fingers, partial carpals, duplications, and overgrowth.

Currently, there are different types of upper extremity prostheses, whether passive or active ones[7,8]. Having one of these devices depends on several factors, such as access to a prosthesis, type of prosthesis, type of residual limb, socioeconomic factors, preferences of the child and her/his family[9]. Generally speaking, the acceptance of prostheses in children with transversal deficiencies, 1/3 or 2/3 under the elbow, has good adherence to the use of their mechanical prostheses[10]. Regarding the use of myoelectric prostheses, the high cost makes them inaccessible and it has also been observed that they limit children's activities due to their brittleness, which prevents their use in everyday activities[11].

For patients with partial hand amputations, there are solutions and surgical treatments, whose final objective is to provide the child with better functionality for holding and gripping objects, which implies many surgeries during her/his life[3,12,13]. The number of remaining functional fingers and their location in the hand influence the result. In patients with preserved wrist flexion-extension function and preserved distal sensitivity, the use of prosthesis is infrequent since, given the associated surgical and rehabilitation treatment, they incorporate their limb to a greater or lesser extent to their functional activities. At the same time, although there are ortho-prosthetic devices, some of them for daily activities and others are only cosmetic, there is no good adherence to their use in general, preferring the use of the free limb[9,14].

In the area of orthotics and prosthetics, the introduction of 3D printing for their manufacture has meant new proposals regarding cost reduction, better accessibility, and design personalization. The spread of 3D printing along with the availability of designs on the web, allows people from different disciplines are interested in developing their products[15].

Among the models that have been developed, the Cyborg Beast hand prosthesis (Figure 4)[16] is characterized by its low cost and easy manufacture. Its design requires minimum anthropometric measurements of the upper limb for proper scaling and adjustment. Previous publications[17,18] have suggested that this design could have a potentially positive impact on functionality in daily life, in addition, no adverse effects associated with its use were reported. The use of 3D printed hand prostheses has been widespread, however, there are no studies on evaluating their impact on specific upper limb functionality in patients[15]. For this reason, the objective of this research is to describe the effect on the upper limb functionality of the use of the Cyborg Beast prosthesis, in a group of patients with partial congenital hand amputation from the Teleton Institute in Santiago.

Clinical Cases

Participants

For this study, we selected patients from the Teleton Institute in Santiago, Chile, which is one of the main institutions that provide rehabilitation of children and adolescents with congenital or acquired health conditions, which cause physical disability. We considered all those patients with partial congenital hand amputation (left or right) aged between 12 and 17 years, who had remnant carpal bones and a minimum wrist flexion-extension range of 20°. Through the review of the active patient database of the Teleton Institute Santiago, we identified potentially eligible patients, filtered by pathology and age. Table 1 shows the characteristics of the participants.

Evaluations

To evaluate the function of the upper limbs, we applied the modified Bilan 400 points guideline[19] before the delivery of the prosthesis, at one month and four months of use. This guideline was adapted for use in children. It quantifies the degree of use of an injured hand, measuring hand mobility, grip strength, single-handed grip, objects movement, and function of both hands, aspects that together provide an overall index and a significant indicator of hand functionality.

In addition, the Upper Extremity Functional Index (UEFI)[20] guideline was applied to evaluate the perceived functionality of upper limbs before the use of the prosthesis and 4 months after its use. In this self-assessment, the user rates 20 activities of daily living performed with upper limbs and scores them depending

Figure 1. Cyborg Beast Prosthesis.

on the level of independence. The final score is translated into the percentage of total independence.

We also carried out a qualitative description of the experiences of the patients and their primary caregivers[21].

Protocol

The participants selected for this study were first evaluated on the objective and perceived functionality of upper limbs, together with the anthropometric measurements required for the manufacture of the prosthesis. Once the patients received the hand prosthesis, training for its use was carried out in 2 weekly sessions of 40 minutes for 2 weeks. This training was focused on the control and use of the prosthesis, especially on daily life activities to be performed with the prosthesis, in addition to education on its care and prevention of possible injuries. This process was carried out by an occupational therapist from the Assisted Technology unit of the Teleton Institute Santiago. We instructed patients to wear the hand prosthesis at least 2 hours a day in the environment they wanted.

Data analysis

The data were tabulated in Microsoft Excel. A descriptive analysis of the data was performed for each participant.

Ethics

This study was approved by the scientific ethical committee of the *Sociedad Pro Ayuda del Niño Lisiado* (project no. 43/2014). All the participants had assent and informed consent signed by their parents.

Hand Functionality

Table 2 detailed according to dimension the hand functionality measured through the modified Bilan 400 points guideline. Dimensions 1, 2, and 4 evaluate each hand separately, dimension 3 of functional activities evaluates the execution of activities with both hands.

Figures 1 and 2 show the evaluation of the overall function of the right and left hand respectively. At one and four months of use, the median percentage of

Table 1. Characteristics of participants

ID	Gender	Age	Diagnosis	Remaining clamp
1	M	14	Congenital left hand deficiency. Agenesia dedos mano izquierda.	No
2	F	13	Congenital left hand deficiency. Thumb hipoplasy, longitudinal finger deficiency	Yes
3	M	14	Parcial left hand deficiency	No
4	F	12	Left hand agenesis	No
5	M	17	Poland Syndrome	Yes

Table 2. Results of Bilan 400 points modified test

ID	Dimension 1: Manual mobility						Dimension 2: Gripping or displacement						Dimension 3: Functional activities						Dimension 4: Hand strengh					
	Basal		1 month		4 months		Basal		1 month		4 months		Basal		1 month		4 months		Basal		1 month		4 months	
	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH	RH	LH
1	100	56	100	36	100	36.1	100	8	100	49	100	54.9	91	91	79	79	82.5	82.5	108	0	71.7	0	82.57	0
2	100	64	100	36.1	100	38.8	100	63	100	54.9	98	58.8	98	98	75.4	75.4	91.2	91.2	120	45	83.2	0	106.2	0
3	100	16	100	41.6	100	33.3	100	27	100	53	96.1	54.9	100	100	94.7	94.7	89.5	89.5	120	35	119.4	0	123.9	0
4	100	56	100	38.8	100	38.8	100	10	100	56.8	100	52.9	91	91	68.4	68.4	84.2	84.2	70	0	66	0	70.3	0
5	100	58	100	30.5	100	33.3	100	75	96	21.6	98	21.6	100	100	87.7	87.7	82.4	82.4	102	23	112	0	108.9	0

RH: right hand; LH: left hand.

change for hand function was -11% and -4% for the unaffected limb and -9% and -2% for the affected one, respectively. The detail by participant is as follows:

P1: The percentage of total functionality in the affected upper limbs increased from 39% to 43%, however, the percentage in the unaffected hand decreased from 100% to 91%. This was mainly due to the drop in the score in the activities dimension.

P2: reports a decrease in the total percentage of functionality of the affected hand from 68% to 42% per month, and 43% after 4 months of use of the prosthesis. In the case of the non-affected limb, it presents a decrease from 100% to 90% per month of use, which increases to 9% after 4 months.

P3: The variation in total functionality in the affected hand increased from 45% to 47% per month, and decreased by 44% at 4 months. Regarding the unaffected hand, this remains at over 100% functionality.

P4: In this case, the affected upper limbs presented an improvement in functionality from 39% to 44% at 4 months of using the prosthesis, however, the functionality of the unaffected hand decreased from 93% to 84% per month and increased 89% at 4 months.

P5: The functionality in the affected hand decreases from 64% to 35% per month and 34% at 4 months. Concerning the non-affected hand, the percentage of functionality varies from 101% to 97% at 4 months.

Perceived upper limbs functionality

Figure 3 details the perceived functionality of upper limbs evaluated through UEFI. The median percentage of change was -62%, where participants 2 and 5 had the greatest difference compared with the first evaluation without prostheses. Figure 3 shows a description of each participant.

Adverse events

Four of the five participants had pressure points

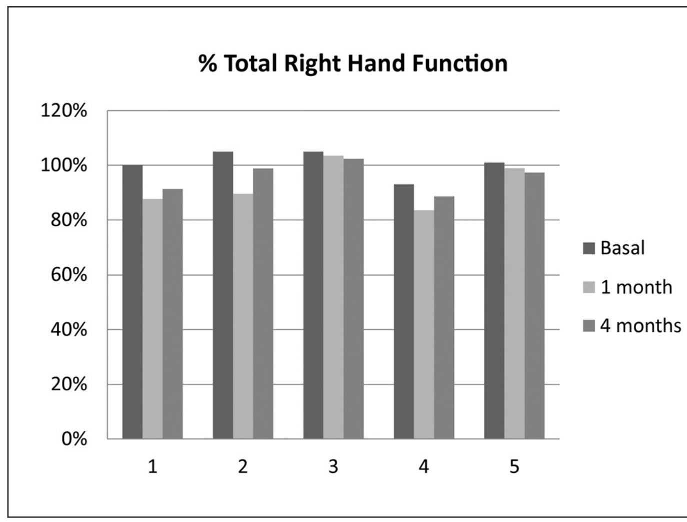

Figure 2. % Total Right Hand Function (Bilan 400 points modified test).

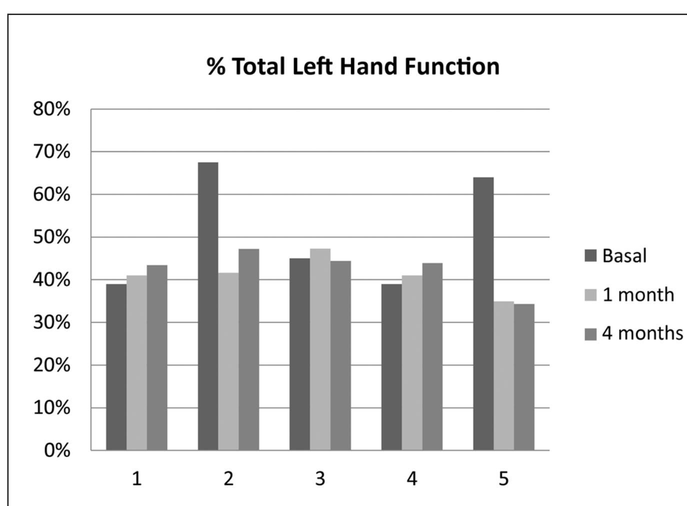

Figure 3. % Total Left Hand Function (Bilan 400 points modified test).

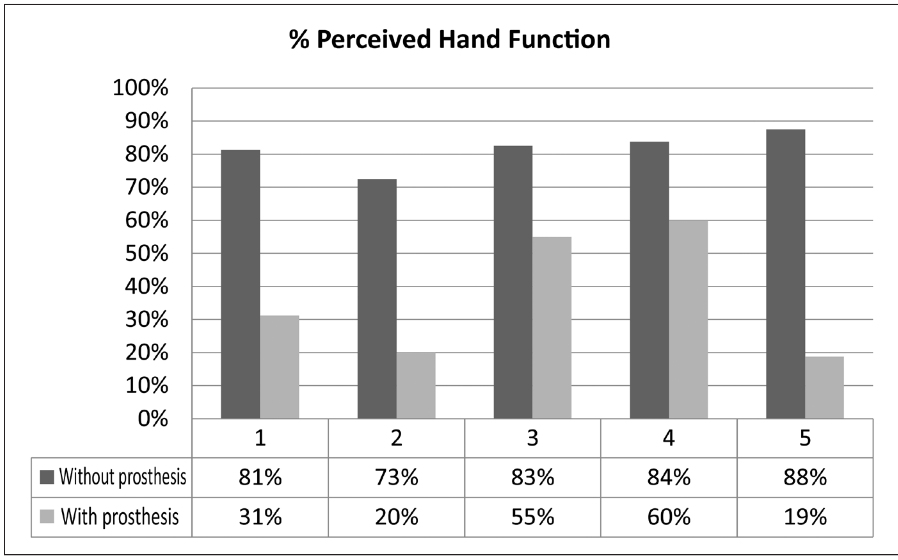

Figure 4. Perceived Hand Function with and without prosthesis (UEFI test).

due to the use of the prosthesis, which were repaired by the occupational therapist in charge of the training, using elements to decrease the friction between the prosthesis and the skin during its use.

Three of the five participants had problems with structural elements of the prosthesis, in two of them the adjustment piece located in the forearm was detached and in one case the thumb of the prosthesis was broken. The adjustment pieces were repaired and the thumb was reprinted.

Discussion

The results of this research show that the use of the Cyborg Beast hand prosthesis was not a functional solution for the patients who participated in this study, both for objective hand functionality and the perceived functionality of upper limbs.

Regarding the hand functionality evaluated with the modified Bilan 400 points guideline, which provides an overall index of upper limbs function, it shows that there was a better performance at the 4th month of prosthesis use compared with the 1st month, however, none of the patients exceeded the baseline score without prosthesis.

Patients 1, 3, and 4 presented the best results in dimension 2 of displacement. These patients increase their score compared with the basal one because the prosthesis allows the tenodesis grasp and release when performing the wrist flexion-extension movement, which allows, according to the size of the hand, to take cylindrical, spherical, cubic, thick, and light objects.

Regarding the grip strength, the 3 patients (2, 3, and 5) who had a remaining grip strength, that is, who make some kind of clamp or grip, lose it when using the prosthesis.

It is worth mentioning that, unlike what is expected, the score on activities with both hands (dimension 3) decreases in all 5 cases regarding the baseline. This may be because these patients have already developed strategies throughout their lives, which allow them to be functional in activities with both hands, without using prostheses[22].

In this study, the perception of functionality evaluated through the UEFI, which shows the direct response of the patient in relation to whether or not she or he has difficulties in carrying out daily life activities with or without the prosthesis, was the one that showed the greatest differences.

Although all patients lowered their scores when using the prosthesis, the worst results obtained were presented by patients who had remnant grip function, this because the prosthesis eventually hindered fine motor skills activity. This is because these patients were already skilled in their functional activities of daily living without prostheses. In addition, it is important to mention that both superficial and deep sensitivity remains intact in their residual limb[23].

The results of this study are consistent with previous research, in which users of mechanical hand prostheses have reported that this type of prosthesis generates difficulties with moving and holding objects, which translates into low adherence in its use[11,24-26].

The possible limitations are related to the variability among participants and the presence of a clamp in two patients (patients 2 and 5). These patients were selected according to the availability of prostheses and the inclusion criteria.

The low functionality of the prosthesis may be related to the presence of remaining clamp along with the design of the prosthesis. It should also be noted, that the correct use of this type of prosthesis is not free of difficulties for users, therefore, it is necessary training and therapeutic support. It may be necessary, even during training, to reprint parts and pieces and/or adjust the design according to the requirements of each patient. The supervision of specialized professionals is recommended for the training and adjustment of this type of printed hand in 3-D technology.

The results of this research represent a first approach to the functionality that can be achieved in patients with partial hand amputations when using the printed hand prosthesis in 3-D technology (in this case the Cyborg Beast design). Future research should address aspects related to design, functionality, and adherence to this type of prosthesis.

Ethical Responsibilities

Human Beings and animals protection: Disclosure the authors state that the procedures were followed according to the Declaration of Helsinki and the World Medical Association regarding human experimentation developed for the medical community.

Data confidentiality: The authors state that they have followed the protocols of their Center and Local regulations on the publication of patient data.

Rights to privacy and informed consent: The authors have obtained the informed consent of the patients and/or subjects referred to in the article. This document is in the possession of the correspondence author.

Conflicts of Interest

Jorge Zúñiga is the 3D-printed hand prosthesis Cyborg Beast designer. There is no other conflict of interest in the research team.

Financial Disclosure

Authors state that no economic support has been associated with the present study.

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