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Challenges and Solutions in Design and Fabrication of Finger Prosthesis

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***Abstract:** The finger is important for its function and appearance. Finger loss causes functional and mental health issues. Finger prostheses are frequently not very long-lasting. It must be changed on a regular basis because frequent insertion and removal could cause permanent damage or discoloration. There are numerous clinical and laboratory stages involved in the production of a new finger prosthesis, which takes time. Complex adjustments need to be made during the delivery visit even after the finger prosthesis has been made to ensure a secure fit and the right marginal adaptation.*

***Keywords:** Finger Prosthesis, Design, Fabrication, Rehabilitation, Grasp Pattern.*

1. INTRODUCTION

The case of a 42-year-old male patient who had one right hand finger partially lost as a result of occupational trauma was described by Lakshya Kumar et al. [1]. The patient's normal hand was used to create the wax pattern, which was made using a modified impression technique. In order to create a pattern that could be easily carved and molded, a particular kind of wax was developed. The length of the fingers was determined using two indexed casts. To match the color of the skin that was next to it, both intrinsic and extrinsic staining was done. As a retentive device, a ring was employed. When the patient started wearing the finger prosthesis, the social acceptance he received was greatly appreciated.

Using an FFF (Fused Filament Fabrication) desktop 3D printer, Bq WitBox, Branko Štefanovič, et al [2] designed and manufactured an index finger prosthesis out of PLA (polylactic acid) material. To restore lost gripping function, the mechanical finger prosthesis was used to perform flexion and extension of the missing joints. The prosthesis now has a socket and its components have been redesigned to look like healthy fingers.

A silicone finger prosthesis with an acceptable suspension was designed and manufactured by Mokhtar Arazpour et al. [3]. The socket of the finger prosthesis was reduced by 2 millimeters from its original size. Additionally, a central tunnel of 4 millimeters in width

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and depth was created, whose length corresponded to the distance between the end of the stump and the nail section. As a result, the silicone material extended all the way to the stump, resulting in significant suspension.
A variation of a 3D-printed finger prosthesis designed by Dominika Belvončíková, et al [4] was developed and tested at the Department of Biomedical Engineering and Measurement of the Faculty of Mechanical Engineering at the Technical University of Košice.
Jelle ten Kate et al. [5] provided quantitative data on the various 3D-printed upper limb prostheses that are currently in use. The overview showed prostheses with varying levels of control for all upper limb amputations and a maximum material cost of $500.
The researchers' previous work lacks evidence regarding the 3D-printed hands' user acceptance, functionality, and durability.

A computer-aided method for creating custom-made, aesthetically pleasing finger prostheses was proposed by Takeshi Murayama et al. [6]. First, a calliper was used to measure the dimensions of a patient's healthy finger on the opposite hand. A mold was created using computer-aided design software and 3D modeling tools based on the 3D model. After that, silicone resin was poured into the mold using a 3D printer to make the mold.
It is difficult to design prosthetic hands for children because there is not enough room for electronics and the cost must be reduced to accommodate their constant hand growth. An anthropomorphic hand prosthesis for children was proposed by Alireza Mohammadi et al. [7] using a monolithic design and soft/comfortable 3D printing materials. The battery, actuation, and control systems of the model hand/arm design weighed 230 grams, and its size was comparable to that of a 5-7-year-old child's natural hand. There are two kinds of grips that the hand can make: pinch/tripod and power are controlled by two surface electromyography electrodes in a circular and spherical configuration.

Type of Finger Amputation

1. Partial Finger (or thumb) Amputations

Commonly, an amputation is referred to as a "partial finger amputation" or a "partial thumb amputation" when it occurs anywhere in the finger(s) or around the thumb area of the hand. Any finger amputation or combination of finger amputations can be included in these terms.

a. Distal Interphalangeal Joint, or DIP: The distal interphalangeal joint connects the bones at the tips of the fingers. It is located at the first knuckle from the top of the finger.
b. Proximal Interphalangeal Joint, or PIP: The hinge joints that connect the phalanges of the fingers and enable flexion toward the palm of the hand are the proximal interphalangeal joints.
c. MCP (Metacarpophalangeal Joint): A group of joints called the metacarpophalangeal joints connect the fingers to the palm of the hand.
d. Carpometacarpal Joint, or CMC: The distal row of carpal bones and the proximal bases of the five metacarpal bones are articulated by the wrist's five carpometacarpal joints.

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2. Metacarpal (or transmetacarpal) Amputations.

The term metacarpal or transmetacarpal amputation refers to the removal of a portion of the hand but not the wrist joint itself, which is a type of transverse amputation. The patient may or may not require a prosthetic device to fulfil certain functional objectives following a metacarpal amputation, which may leave them with intact portions of their hand and fingers.

Common Finger Prostheses

1. Silicone cosmeses – The look and feel of a non-prosthetic hand or finger are simulated by passive silicone prosthetic devices. Frequently shrouded in various characteristics of high- or low-definition silicone that can be specially painted, aloof prosthetics are very lightweight. However, despite the fact that they offer limited grasping capabilities and no actual active movement, they occasionally enhance the wearer's functionality by providing a stabilized surface. Passive prosthetics are typically chosen for aesthetic or cosmetic purposes rather than high-performance functional ones for all of these reasons. This finger is designed specifically to play the violin and guitar. Most of the time, it's a dual-colored finger with silicone-painted nails and hair that look natural (fig. 1). It facilitates the patient's normal life.

Fig.1 Passive Prosthetic Specific Positioned Silicone Finger with hair, cosmetic (courtesy-Indiamart)

2. Passive mechanical devices - This passive design does not require electronic processing or sensors and is straightforward and efficient. It is capable of passive adaptive grasp, or the ability of the fingers to mold to the shape of an object held in the hand (fig. 2). During getting a handle on, the four fingers and thumb can flex inwards freely, to adjust to the state of the item.

Fig.2 Passive mechanical device (courtesy-GripLock)

3. Body-powered devices- The movement of a body-powered prosthesis is directly correlated with the movements of the body parts to which the harness is attached, and forces generated at the terminal device exert forces on that body part through the harness. Body-powered prostheses can be broken down into three categories: cable-controlled, joint-driven, or wrist-driven These prostheses typically have a high-tech appearance and can be extremely long-lasting. The fact that the force exerted by the prosthesis is directly

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controlled by a person's wrist, or the remaining portion of their hand, makes movement and control feel very natural (fig.3), which is one of the greatest functional benefits.


Fig.3 Body powered device

4. Externally powered devices- In order to produce movement, electrically powered fingers contain tiny motors within each finger. Sensing electrodes or resistors that detect movement of muscles in the remaining portion of the hand or wrist are used to control them (fig. 4). To ensure that the appropriate grip strength is utilized for any given circumstance, the user controls the amount of force that the electric fingers exert. Cosmetic gloves, like passive prostheses, are available in a wide range of flesh tones, and silicone gloves can be made to closely resemble a person's natural hand. Myoelectric prostheses, for instance, are electric devices that are powered externally and controlled by electric signals generated by the wearer's muscles. They mimic the natural anatomy and motion of the human body. As a result, when used for metacarpal or transmetacarpal amputations, they offer remarkable capabilities.


Fig.4 Externally powered device

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Grasp Pattern
Form closer: Form-closure is considered as a purely geometric property of a set of unilateral contact constraints such as those applied on a work piece by a mechanical fixture. Four fingers of the manipulator can restrict the motion (constrained) of the object for grasping and a little force is sufficient to do this.

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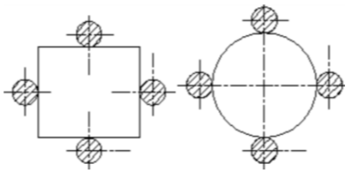

Fig.5: Form and force closure

Force closer: A grasp on an object is in force closure (which is referred to as stable grasp) if and only if one can exert, through the set of contacts, arbitrary force and moment on this object. Four fingers of the manipulator cannot restrict the motion completely, as rotation may still be possible. To restrain all motions during grasping larger force is required (fig.5)

Injection Molding VS 3D Printing Technology

The injection molding process follows,

1. Clamping (Mold Close) - The mold shuts at this point, and tonnage is used. The A side and the B side are typically the two parts of a mold. There are numerous instances where it is possible to divide the mold into additional portions.
2. Injection – The majority of the molten plastic is injected into the mold at this point.
3. Packing and Holding (also known as dwelling) – To fill out the remaining portions of the mold, pressure is applied to the system. The pressure is then maintained for a predetermined period of time.
4. Cooling – In order to create the final form, the heated plastic must cool. The cooling process can last a few seconds or several minutes.
5. Mold Open – After the tonnage is released, the mold opens.
6. Ejection – The component is taken out to be processed further or sent. The final phase of an injection cycle might be either automatic or manual. The technique then continues from the clamping step onward for the next part.

In contrast, 3D printing is a method of the additive manufacturing process family that integrates various technologies to produce parts from base materials. As the technology has become reasonable and advanced enough to facilitate the production of complex geometries, its use has increased. 3D printing typically uses CAD data to create the desired part layer by layer, merging those layers to "grow" the part. Some of the common materials used in 3D printing include polymers, composites, glass, metals, and photopolymers.

Components created through this process are often of the "prototype" type, or at least small-scale production. Since 3D printing has mostly become an automated process, the expertise required to operate the machines is not high, allowing businesses and individuals to participate in production trials. When making small parts, the only significant recurring cost associated with 3D printing is the material used. For large ones, different and more expensive machines are required, which significantly increases the cost of the entire production process.

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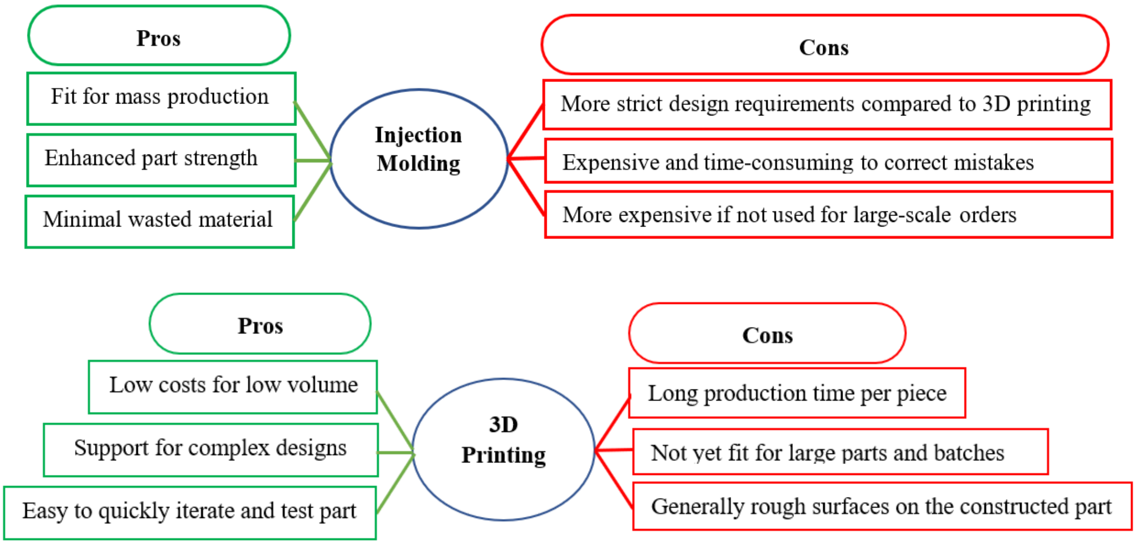

Fig.6: Pros & Cons of Injection molding and 3D printing

Benefits and Challenges of Fabricating Finger Prostheses

In terms of both function and aesthetics, fingers and digits are significant. Functional and psychological issues result from digit loss [8-10]. The silicone finger prosthesis seems realistic [11]. In patients with microangiopathy of the fingers, finger or digital prostheses have also been used to prevent and shield ulcerated finger tips [12].

Comparing finger prostheses to facial prostheses, the former is frequently less durable. It needs to be changed periodically because frequent insertion and removal might cause it to become permanently damaged or discoloured. Making a new finger prosthesis takes time and involves a number of clinical and laboratory stages [13]. Intricate changes are required during the delivery visit even after the finger prosthesis has been made to ensure a secure fit and correct fitting.

2. CONCLUSION

Future research in finger prosthetic devices appears to be well defined in light of the current understanding of fundamental movements, grab patterns, and sources of control presently proven as valuable to the amputee. The issue of sensory feedback has immediate implications for design. Definite cues that show fingertip pressures, finger openings, and the position of the hand in rotation are required in this field of study. The amputee would be able to do more casual and lifelike movements thanks to these cues, which are extremely helpful.

The skeleton system of the hand underneath the cosmetic glove has also been improved, with the goal of giving the gadget a "feel" similar to that of a real hand. This issue is not a simple one given the structural needs of hands, the requirement for simple replacement or interchange of cosmetic gloves, the space constraints within the hand shells for the relatively complex mechanism, and the lack of suitable component materials for higher wear resistance that have an affinity for both metal and cosmetic gloves. Instead, it is one that calls for extensive research and development. Of course, the development of an anatomical arm should be coordinated with this phase of future research. It consequently becomes a component of materials research.

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