Three-Dimensional Printing of Prosthetic Hands for Children

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Children with hand reductions, whether congenital or traumatic, have unique prosthetic needs. They present a challenge because of their continually changing size due to physical growth as well as changing needs due to psychosocial development. Conventional prosthetics are becoming more technologically advanced and increasingly complex. Although these are welcome advances for adults, the concomitant increases in weight, moving parts, and cost are not beneficial for children. Pediatric prosthetic needs may be better met with simpler solutions. Three-dimensional printing can be used to fabricate rugged, light-weight, easily replaceable, and very low cost assistive hands for children. *(J Hand Surg Am. 2016;41(5):e103−e109. Copyright © 2016 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Three-dimensional printing, upper limb prosthesis, assistive hand devices, pediatric upper limb deficiency.

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MEDICAL APPLICATIONS FOR 3-DIMENSIONAL printing are rapidly evolving. The technology is currently being investigated for use in tissue and organ fabrication, drug dosage, and delivery, and the fabrication of custom implants and anatomical models.[1] Especially widespread has been the 3-dimensional printing of upper limb prostheses. Because of advancements in CAD (computer aided design) programs, online open-source file sharing, and increasing availability of 3-dimensional printers, there has been a surge of interest in the development of low-cost custom prosthetic hands.

Children have unique requirements for prostheses and assistive devices. They need to be durable, inexpensive, customizable, and easy to fix or replace when they are inevitably broken or outgrown. Rugged, durable construction is preferred over delicate electronic components. Functionally, they should allow a child to more easily participate in tasks or activities. Socially, the need depends on the child's age, emotional development, and personality—whether they want something "cool" that stands out, or something as inconspicuous as possible to "fit in." Optimal prosthetics management in children is not defined, and there is no single prosthetic design that is preferentially used or prescribed.[2] Overall upper limb prosthetic rejection rate in children is approximately 30% to 50%, and even higher for children with below wrist reductions.[2] The main reasons given by children for prosthetic rejection are: (1) limited functionality, (2) uncomfortable, (3) too heavy, and (4) unattractive appearance.[3] James et al[4] showed that many children with congenital limb deficiency simply find it easier to perform tasks without a prosthesis. The financial resources of a child's family play a significant role in prosthetic management as well. A body-powered prosthesis ranges from $4,000 to $8,000; myoelectric prostheses can range from $25,000 to $50,000.[5] These sums are significant enough as one-time costs, but with growth and use, prostheses for children need to be frequently repaired and replaced, adding to the lifetime cost of limb deficiency.

A prosthesis or assistive hand is only useful if it provides enough benefits to outweigh the disadvantages, yet this is a highly individual-dependent assessment.

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Three-dimensional printing, together with the online availability of free downloadable and modifiable templates, offers inexpensive and rapid prototyping of different hand designs. Individual prostheses can be optimally designed based on wearer-specific feedback, as there is no "one-size-fits-all" design for children.

INDICATIONS

The best candidates for 3-dimensional printed hand prosthesis are children with unilateral congenital or traumatic limb reductions at the distal carpal or transmetacarpal level, for example children with peromelic symbrachydactyly, or amniotic band syndrome resulting in complete loss of all digits. A candidate should have an active wrist flexion and extension arc of 30° to power composite grasp. At such a distal level of limb reduction, there are few therapeutic options. Conventional prosthetics are rarely indicated. These children are highly functional, yet they and their parents routinely seek out options to allow them to perform grasp and release. Prostheses for more proximal limb reductions can also be 3-dimensional printed, but the process becomes more challenging and complex.[6,7]

CONTRAINDICATIONS

Contraindications are similar to those for any orthosis with direct skin contact, including the presence of skin abrasions or wounds, acute injury to the affected limb, sensory deficit impairing ability to recognize areas of skin pressure, hypersensitivity to the prosthetic material, and cognitive impairment precluding safe prosthetic use. Contraindications specific to 3-dimensional printed prostheses include a lack of sufficient active wrist motion, a very small residual carpal segment, and the presence of partial or complete fingers, which existing designs cannot accommodate.

ANATOMY OF A 3-DIMENSIONAL PRINTER

Three-dimensional printing is a type of additive manufacturing. There are many different processes through which a computer image can be converted into a 3-dimensional object; the process used to print upper limb prostheses is called material extrusion or fused deposition modeling (FDM). FDM printers are more commonly available and inexpensive than printers for other techniques. Many desktop 3-dimensional printers are currently commercially available from a variety of manufacturers. FDM-based 3-dimensional printers can be broken into the following core components:

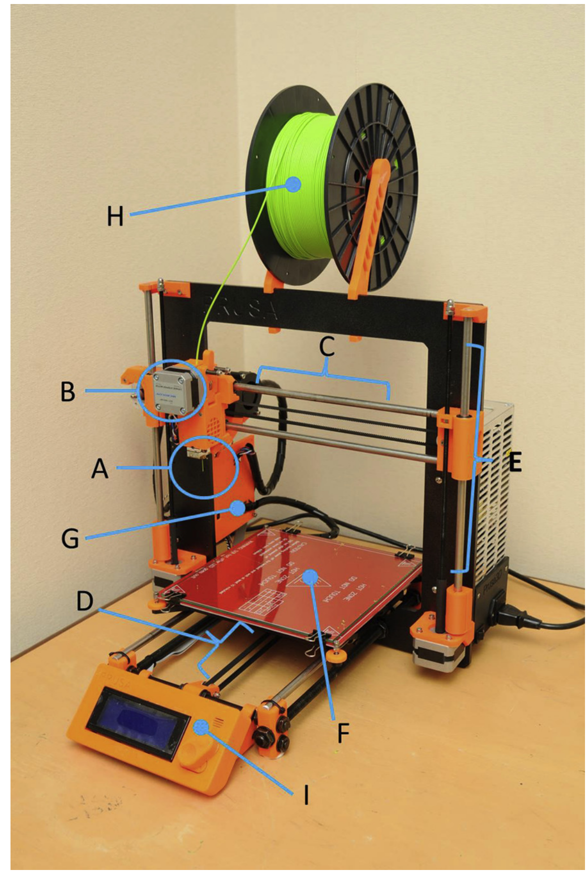

FIGURE 1: Anatomy of a 3-dimensional printer, Prusa3D i3 (Prusa Research, Prauge, Czech Republic) pictured. **A** Heating element and nozzle; **B** extrusion motor mechanism; **C** *X*-axis; **D** *Y*-axis; **E** *Z*-axis; **F** print bed; **G** motherboard; **H** filament spool; **I** control panel.

1. Hot end (Fig. 1A): the heating element that melts the thermoplastic filament for the extrusion process; also contains the nozzle, which determines the diameter of the extruded bead.
2. Cold end (Fig. 1B): motor mechanism that feeds the filament stock into the hot end, creating the extrusion force.
3. *X*, *Y*, and *Z* axes (Fig. 1C−E): together, each of these independent axes allows for 3-dimensional motion during the printing process.
4. Print bed (Fig. 1F): flat surface where the object is produced.
5. Motherboard (Fig. 1G): the brains of the 3-dimensional printer; it controls the motion of the *X*, *Y*, and *Z* axes as well as the temperature of the hot end and the print bed. This component accepts and executes the instruction set from a slicer program.

This is the most common setup for commercially available FDM-based 3-dimensional printers, although alternative configurations exist. The fabrication material is a plastic monofilament (Fig. 1F), usually acrylonitrile butadiene styrene or polylactic acid. These are the same thermoplastic materials used in conventional orthotics,