Application of 3-Dimensional Printing in Hand Surgery for Production of a Novel Bone Reduction Clamp

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Three-dimensional printing is being rapidly incorporated in the medical field to produce external prosthetics for improved cosmesis and fabricated molds to aid in presurgical planning. Biomedically engineered products from 3-dimensional printers are also utilized as implantable devices for knee arthroplasty, airway orthoses, and other surgical procedures. Although at first expensive and conceptually difficult to construct, 3-dimensional printing is now becoming more affordable and widely accessible. In hand surgery, like many other specialties, new or customized instruments would be desirable; however, the overall production cost restricts their development. We are presenting our step-by-step experience in creating a bone reduction clamp for finger fractures using 3-dimensional printing technology. Using free, downloadable software, a 3-dimensional model of a bone reduction clamp for hand fractures was created based on the senior author's (M.V.M.) specific design, previous experience, and preferences for fracture fixation. Once deemed satisfactory, the computer files were sent to a 3-dimensional printing company for the production of the prototypes. Multiple plastic prototypes were made and adjusted, affording a fast, low-cost working model of the proposed clamp. Once a workable design was obtained, a printing company produced the surgical clamp prototype directly from the 3-dimensional model represented in the computer files. This prototype was used in the operating room, meeting the expectations of the surgeon. Three-dimensional printing is affordable and offers the benefits of reducing production time and nurturing innovations in hand surgery. This article presents a step-by-step description of our design process using online software programs and 3-dimensional printing services. As medical technology advances, it is important that hand surgeons remain aware of available resources, are knowledgeable about how the process works, and are able to take advantage of opportunities in order to advance the field. *(J Hand Surg Am. 2014;39(9):1840–1845. Copyright © 2014 by the American Society for Surgery of the Hand. All rights reserved.)*

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Surgical Technique

IN ANCIENT GREECE, HIPPOCRATES and other early physicians incorporated iron, copper, bronze, and brass to develop surgical instruments.[1] The majority of surgical instruments consisted of knives, scissors, and saws to allow for bloodletting and amputations. Early surgical tools were fashioned by blacksmiths at the direction of surgeons.[2] However, after the establishment of general anesthesia and

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aseptic technique in the late 1800s, there was a boom of nickel-plated stainless steel surgical instrument creation.[3] Stemming from the Industrial Revolution, many manufacturers and large international enterprises are working solely in the production of surgical equipment.[1] Currently, most surgeons rely on the collaboration with manufacturers in order to produce new surgical equipment.

The majority of surgical instruments are still mainly made by hand today.[1] Many instruments require up to 13 steps prior to completion.[4] There is often the utilization of casting, where the instruments are manufactured by pouring liquid metal into cast molds. Another technique used is the process of machining or subtractive manufacturing (SM). This process starts with a piece of raw material that is shaped into the final product by cutting, grinding, or laser etching.

The advent of rapid prototyping and additive manufacturing (AM), also known as 3-dimensional printing, has transformed the design industry.[5–7] Computer-assisted design (CAD) software eliminated the need for manual computation of shapes and angles required in the designing process. These software systems streamline the creation of models that can be used by architects and others to create electronic blueprints from ideas. With 3-dimensional printing, these digital blueprints can be transformed into an object, with items as large as small cars and airplane parts being printed.[8]

Three-dimensional printing was developed in the 1980s, but was initially limited to consumers by the large size of printers and cost.[9,10] Over the subsequent 30 years, the technology has been developing rapidly, resulting in numerous versions of smaller, affordable printers.

The AM process involves creating the end product by adding material layer by layer. This can be accomplished by a number of different printing techniques and can use different materials such as glass, metal, and plastic. The more affordable consumer models are predominantly composed of plastic. These printers frequently use fused deposition modeling (FDM) in which a heated nozzle extrudes a fine filament of molten thermoplastic material that is allowed to cool.

In metal 3-dimensional printing, powder is used and is converted to a solid by the application of energy. Electron beam melting (EBM) is one such technology. ARCAM is a company using this specific technique for the production of orthopedic implants and in the aerospace industry.[11]

Direct metal laser sintering (DMLS) is another form of AM. DMLS printers involve the application of a thin layer of powdered metal on the bottom plate of the printing chamber. A recoater blade applies it evenly on the printing plate. A laser is used to fuse the metal powder into a solid part.[10] After a layer of powder is fused, a new layer of powder is added and laser treated, gradually building the object.[12,13]

Because 3-dimensional printing initially was developed without much emphasis for medical practice, there has been some delay in its translation into clinical use. However, uses for 3-dimensional printing are becoming evident throughout the medical community. Three-dimensional printing is being incorporated in the medical field to produce external prosthetics for improved cosmesis and fabricated molds to aid in presurgical planning.[5,14] Biomedically engineered products from 3-dimensional printers are being utilized in maxillofacial surgery to create custom mandible plates. Custom-made, patient-specific hearing aid shells are also being produced in Denmark using 3-dimensional printing.[15] Companies are also developing the technology to print useable organs; bone 3-dimensional models have also shown promise.[16,17]

Although at first expensive and conceptually difficult to construct, 3-dimensional printing is now becoming more affordable and widely accessible. In fact, once the design data are available, many 3-dimensional printing companies are able to deliver products within 48 hours. In hand surgery, many surgeons desire customized surgical instruments for specific procedures or challenging cases. The aim of this study is to present our step-by-step experience in creating a novel bone reduction clamp utilizing 3-dimensional printing technology with rapid prototyping and creation of the final product.

METHODS AND MATERIALS

The decision to create a novel surgical reduction clamp was based on multiple changes desired by the senior author. First, traditional bone reduction forceps were found to be imprecise for reducing transverse and comminuted fractures of the hand. The senior author (M.V.M.) found that the traditional reduction clamp's 2-point reduction does not provide adequate contact along the fracture site. As a result, the two points of contact only offer a single vector force. The senior author desired a clamp with multiple points of contact at the fracture site, thereby stabilizing the fracture in multiple vectors.

Second, the bulkiness and shape of the standard bone reduction clamp generally requires a significant amount of exposure. If the clamp could be disassembled into smaller parts or rotated in situ, less