The Invention of 3D Printing and Its Impact on Dentistry:
An Interview with Chuck Hull

Michael D. Scherer, DMD, MS

In dental and medical fields almost all devices, procedures, and technical workflows have been impacted by the additive manufacturing processes collectively known as 3D printing. This is especially evident in dentistry, a profession very much involved in designing and producing specialized and unique prosthetics on-demand for individual patients. Dentistry has changed over the past few years with the rapid proliferation of 3D printing in dental manufacturing along with smaller units in dental offices and small laboratories.

While many clinicians enjoy discussing how 3D printing works and how to use it in their offices, it can be helpful to look back at the foundation of the technology. I recently sat down with Mr. Charles (Chuck) Hull, the co-founder of 3D Systems and inventor of 3D printing, to talk about his story of invention and how dentistry is impacted by the technology. What I found was Mr. Hull is a genuinely kind and humble person who is a "tinkerer" at heart much like many dental practitioners.

Michael Scherer, DMD, MS (MS): It is an honor to sit down with you today. Please tell me your story; how did you get started?

Chuck Hull (CH): Thank you, so glad we are here to talk. I've always been a "tinkerer," from my early youth building model airplanes, flying where I grew up in Grand Junction, Colorado. I had teachers there who were influential in mathematics and physics and I got started very early. I immersed in engineering and science at the University of Colorado and had an opportunity to work in a nuclear physics lab where I could continue to tinker with instrumentation and laboratory equipment.

After graduation I went to work for a company that was ultimately purchased by DuPont, making analytical equipment for chemical labs, including mass spectrometry and analytical equipment to characterize drugs for pharmaceutical companies. Later I moved to a company working in ultraviolet technology, including UV curing processes.

MS: Incredible journey! Tell me about light-curing and how it impacted your journey.

CH: I began to work extensively with high-powered lamps for UV curing processes, all the way from high-level industrial down to fingernail polish. We even had to engineer how to properly cure nail polish without burning a hand! We teamed with chemical companies to work out the use of these materials and discovered these lights were curing thin layers of plastic. We had a problem back then with engineering, especially injection molding. We would come up with a design, send it for molding, and several weeks later the part would arrive but wouldn't be right and we'd need to go through the process all over again. As an engineer, I started to tie together the concept that maybe we could "try out the part" and speed up the process with UV curing materials and generate prototypes.

MS: How did you come up with that concept? Do you remember your "ah-ha" moment?

CH: I can't quite recall the moment, but I have always been a "tinkerer" and wondered how I could get from this broad idea down to the specific parts to try out. I kept playing with different concepts in my head and approached my boss who liked the idea but insisted we had plenty of projects to concentrate on and didn't want it disrupting my main job. I kept bugging him, and he finally said I could work on the concept but on my own time. Eventually he let me use the laboratory, still on my own time. I was able to develop my first little printer; it worked, and was enough to file a patent application.

MS: Was this in the early 1980s?

CH: Yes, this was 1982 through 1984. The patent was issued in 1986 to the company I was working for at the time, Ultraviolet Products. After coming up with the idea and concept for a product, I went to a series of seminars at California Institute of Technology on entrepreneurial efforts and decided to spin-off a company specifically on this new technology. Together with a partner we approached venture capital companies and started the company, 3D Systems, in the middle of 1986.

MS: Tell me about your collaborations and the role of the Caltech seminars in your growth.

CH: I collaborated with an informational group started by Massachusetts Institute of Technology called the MIT Enterprise Forum. Many universities had these informational groups at the time. You learn the principles of entrepreneurship and make connections with colleagues. We got the company started and then concentrated on really getting things going, which included working with

technical and engineering journals. We had a lot of articles published, and many interested engineers began reaching out to us on development of this new technology. We focused on automotive and especially US-based manufacturers as their foreign competitors were pushing hard. The car manufacturers in Detroit were looking for help designing and prototyping, and ultimately we expanded to working with aerospace and medical device companies.

MS: How did the computer technology back then impact the development of 3D printing?

CH: The computers to run 3D printers back then were fairly well developed, but the problem was the interface to 3D computer-assisted design (CAD). How could we take that 3D data and put it into a format that could be layered? 3D CAD was just getting started then and wasn't very good. There was no way to take the mathematical data in the file and convert it into layers without a tedious process. We talked to CAD companies about modifying their software to allow this functionality, but they were not interested. Then we developed an intermediate file that could easily be sliced into layered functions; this was the "STL" file. The CAD software companies were not thrilled to use this, but the automotive and aerospace companies helped push the software companies to integrate STL. We [3D Systems] wrote the original file format and it is still in use today, which is kind of amazing. People keep saying that STL is obsolete and keep developing different formats, but we just keep going back to STL.

MS: What does STL mean? Some people say it means "standard tessellation language" or "standard triangle language," but what was your intention?

CH: The format STL means "stereolithography" and these files are designed for that process, which I developed. Those other terms are just kind of made up for the literature. Funny enough, I originally called the process "3D printing" but people thought the term was too basic and wanted to give it a fancier name. Thus, for a while we referred to the 3D printing process as "stereolithography." Thankfully, people now know it again as 3D printing.

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MS: What did you think the potential for 3D printing was back then, and where did you think it would be today?

CH: Back then, in the late 1980s, the focus was on prototyping but quickly

moved to various types of tooling, fixtures, and patterns. Although today 3D printing is highly developed and addressing everyday production applications, back then it had very humble beginnings and simple applications. I never thought I would be able to print metal or materials other than resins on a regular basis, but in the back of my mind I believed it could be done. The invention of 3D printing was born of the need to more quickly prototype a plastic part; without that need I would have never tinkered with it.

MS: What was your first printed project, and the first printed medical/healthcare object?

CH: The first printed object was a tiny little "eye cup," one like you would use at a doctor's office. I was playing around in the lab late at night, and it was the first part that printed all the way out. So I called my wife and asked her to come over right away, but she was in her pajamas and said, "This better be good!" My wife now has the eye cup in a special little box and some day it will end up in a museum.

The first medical object was generated from a CAT scan. I made it along with a radiology team researcher at UCLA. He was working with his surgical teams to envision a physical model of a skull with a bullet wound. It was novel at the time—taking CAT scan data and converting it into a physical object—and we took it as a challenge. He published a journal article; it was a proof of concept and now it's routine.

The first dental model was produced in conjunction with the US Armed Services/Air Force focusing on head and neck injuries and reconstructions from military injuries of the teeth and jaw. They would take the "good side" of the face and mirror it to the damaged side for facial reconstruction. I immediately became aware of the value of 3D printing in dentistry and medicine. In fact, 3D Systems has a Healthcare division that creates 3D-printed models to assist in surgical procedures.

MS: It sounds like the development of 3D printing in medical and dentistry were analogous. What were some early commercial applications?

Fig 1. Chuck Hull holds a 3D-printed dental model for laboratory procedures. **Fig 2.** An early 3D-printed mandible used for dental reconstruction.

CH: When you see users and their stories, you start to identify the natural fit of 3D printing and the anatomical features needed in dentistry.

MS: So the role of the user is essential?

CH: It's so important! In the 1990s two graduate students at Stanford called and said they had a new idea for a dental application and were wondering if we could help them. We started talking and realized they couldn't afford a printer, but there was something very compelling about their idea and we decided to help them. These students went on to found Align Technology, makers of the Invisalign® system of clear aligners for straightening teeth. They are one of our biggest customers, employing stereolithography for the production of the models for the vacuum molding process. There was a lot of effort back then on both sides, and now it's amazing to see the wonderful results of collaboration.

In fact, many of the current developments in dental applications are driven by dentists and dental laboratories. Back in the early development of 3D Systems there was a lot of talk with regard to dentistry, but the problem was obtaining the data. Someone needed to come up with a dental scanner to get data. Once there was data, the next question was how to take that data and make it useable to dentists and dental labs.

MS: What are the challenges of 3D printing within the field of dentistry?

CH: Wow, that's a big question. It really depends on the application. In medicine, the focus presently is on bioprinting to make living tissues and organs, such as lungs. This printing is done at the cellular level in very fine detail. An important component for bioprinting is the materials. How do you make tissue materials that the body will accept? The importance of materials conveys to dentistry as well. In fact, 3D Systems acquired NextDent, a company that manufactures dental materials that enable biocompatible 3D printing for dentistry. The materials must fit the application, and that company was highly visionary early on to obtain regulatory approvals

for its materials. Biocompatibility is a huge issue, and, historically, traditional engineering resins are not good to work with in the mouth. The materials scientists at NextDent learned how to create biocompatible resins that are also economically viable. These resins both work from a technological standpoint and are safe to use in dental applications.

MS: I know you don't describe yourself as a "futurist," but what would you like to see in the evolution of dentistry?

CH: I believe the first step is to expand dental laboratories to address all applications with 3D printing. Materials and economics will drive expansion, so it has to make sense financially. The next step is to move the procedures into the dental office, however I also know that some dentists won't like getting into the laboratory steps, whereas others will naturally want to get involved. I expect that both dental offices and dental labs will have more and better applications. The future is bright for really good labs that want to become better, faster, and less expensive, and for dentists wanting to do similar tasks in their own office.

MS: Interesting! Do you think that having a 3D printer in a dental office gives an advantage over other dentists?

CH: For dentists who want to get involved in the laboratory side, it allows them to save time and money by not having to go back and forth between their offices and the labs. The economics of it make sense. The dentist needs to have the training and qualify the process to ensure that it is safe for use in the mouth. Having the ability to use 3D printing in their own offices gives dentists certain advantages.

MS: That is inspiring. As a dentist who is living it, I cannot imagine going back to traditional ways of making things. For example, I can go from scan to produced denture in less than 2 hours. Could you ever imagine back in the 1980s that you would be able to do these tasks, and how do you think 3D printing and dentistry can grow further?

CH: No, all of this always amazes me—both that it happened and the technology itself. As for the future growth of 3D printing and dentistry, I rely on the users to tell me that—I am not the visionary there. Some dentists will have all of the technology right there in their office; others will rely on their laboratory partner. Some are "tinkerers" much like myself, and it will depend on how things evolve over the years. It will take some time. It will likely be more clinically driven, and it will take hard work to get there.

ABOUT THE AUTHOR

Michael D. Scherer, DMD, MS
Assistant Clinical Professor, Restorative Dentistry, School of Dentistry, Loma Linda University, Loma Linda, California; Private Practice limited to Prosthodontics and Implant Dentistry, Sonora, California