Three Dimensional Printing: Modern Medical Applications

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Abstract

3-D printing is an additive printing process based on inkjet printing principles. Using this technology, a variety of materials can be used to create a three-dimensional product. Currently this technology is expensive, however it is slowly becoming more affordable. 3-D printing has the potential to change the future of medical model production and prototyping, due to the beneficial products it can produce. The objective of this research study is to discover the technological advancements in 3-D printing that could greatly affect several aspects of the medical industry. The areas discussed includes high-risk surgery, dentistry, and prosthetics. After conducting six interviews with medical professionals, it was discovered that 3-D printing is a viable technological source that all professionals are eager to use and implement into their medical line of work. 3-D printing is a revolutionary technology that has the possibility to positively affect the work of medial professionals, while enhancing the lives of others.

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Chapter 1: Introduction

Three-dimensional (3-D) printing was once a topic that most people associated with science fiction. This developing technology is becoming a common application within many industries such as manufacturing and medicine. As more research is being developed, 3-D printing is rapidly becoming an affordable technology that has the potential to change not only the future of medical model production and prototyping, but also society.

Three-dimensional (3-D) printing is an additive printing process. The original technology is based on ink-jet principles and can print with a variety of materials. When using this technology, a Computer Aided-Design (CAD) file is processed through specialized software and spliced into a series of two-dimensional layers. The printer produces the object layer-by-layer with additional support from a water-soluble material. The support material is used for overhang portions of the object. An example of this would be printing the head of a hammer before it is attached to the body.

Various industries are currently using 3-D technology. In the medical industry, 3-D printing has the potential to be used in many diverse fields. This study focused on prosthetic development, high-risk surgery and dentistry, all of which are highly discussed areas with regard to 3-D printing. Within the medical fields, 3-D printing is highly discussed. This type of printing has the ability to drastically alter the trajectory of medical development. While other industries can benefit from 3-D technology, the inclusion of this technology in medicine will positively impact society as a whole. By uncovering the potential impacts of 3-D printing in medicine, this study highlighted the need for continued development and implementation of this newer technology.

This study will address the question: What technological advancements in 3-D printing will greatly affect the medical industry? Based on current knowledge, it can be predicted that research findings will reveal a positive growth in 3-D printing, specifically in the area of medicine. In prosthetic development, 3-D printing will allow for a faster and more cost effective alternative than traditional prosthetic production. Using this technology will allow for enhanced customization of the prosthetic being produced, resulting in a more satisfied patient. High-risk surgery is another area within the medical field that will greatly benefit from 3-D printing. Surgeons will have the ability to scan and print the portion of the body where the surgery will be conducted. This will allow for more precise and efficient procedures with the aid of a 3-D printed medical model and in turn will produce more successful surgical procedures. Within dentistry, patients will no longer have to suffer through outdated mouth molding techniques. A digital scan will be able to capture the entire patient's mouth. This file will be processed and a 3-D printer will produce an exact replica of the mouth. These major medical advancements are occurring right now due to 3-D printing technology. This type of printing has the potential to change the traditional way doctors conduct medical procedures. This shift towards digitized, machine-based work flows is present in various fields, proving the adaptability of 3-D printing technologies. Adaptability will be the underlying cause for the widespread use of 3-D printing in medicine.

The purpose of this study is to determine the impact of three-dimensional printing on the medical field. This printing technology has the ability to change the traditional approach to methods in medicine. Society may soon rely on this printing device to handle the most difficult medical procedures. Throughout this study, emphasis will be placed on the potential of 3-D printing and how this technology will affect the medical world.

Chapter 2: Literature Review

History of 3-D Printing

In the graphic communication industry, methods of printing have been constantly improving to keep up with the always changing technology in society. In the 1400's Johannes Gutenberg introduced the world to movable type which paved the way for new advancements in print technology in the Western world (Dynodan Print Solutions, 2010). Hand scribing would now become a print method of the past and printing with ink on paper would be the wave of the future. By 1847 the first rotary printing press was developed and by the early 1900's lithography and letterpress machines were the dominant printing methods (Dynodan Print Solutions, 2010). Print quickly expanded and other forms of printing were created including intaglio, screen printing sheet-fed and web offset printing. The late 1960's brought laser printing and twenty years later ink-jet. This inkjet technology which sprays droplets of ink onto a substrate to form an image, would soon pave the way to create a more advanced and futuristic technology called three-dimensional printing, 3-D (Dynodan Print Solutions, 2010).

The invention of 3-D printing was first introduced by 3-D systems in 1987. This global company delivers advanced solid imaging solutions to major markets around the world (3-D Systems, 2010). The invention of 3-D technology was introduced as an additive print process that uses stereolithography to build models and prototypes. Additive print technology creates objects by building them up a layer at a time (Berman, 2007). By using virtual models from a computer-aided design file, a model can then be printed. Once this printing method was introduced, 3-D systems sold its first commercial stereolithography system a year later (Mahalo, 2010). Soon after, 3-D printing based on inkjet principles was developed and patented by the Massachusetts Institute of Technology (MIT) in 1993. Through the use of inkjet technology, one type of

material can be “jetted” onto another type and then can be fused together to enable the fast and accurate production of complex 3-D objects (Lozo, Stanic, Jamnicki,Poljacek, 2008). Once this technology was introduced, major companies emerged like Stratasys and Z Corporation. They saw this technology as a growing new development that could take off in many industries. There are many different types of 3-D printing including Stereolithography, Fused Deposition Modeling, Selective Laser Sintering, Traditional 3-D Printing, Polyjet, and Polyjet Matrix. In society today, many methods of printing are being used that follow traditional print methods with improved capabilities. They produce high quality prints in a fast and efficient manner. 3-D printing is integrating itself into the print world with its advanced technology and versatility, which can be applied to many diverse fields. Scott Crump, CEO of Stratasys states in Fast Company magazine, “We believe the time is right for 3-D printing to become mainstream” (Schwartz, 2010). This shows how this technology is improving rapidly and has the ability to become a major print technology next to offset and digital printing. This print process has tremendous potential to grow because it can be value by many industries.

The Process

The 3-D print process consists of printing and post processing of the 3-D object being created. Printing with this technique uses an additive rapid prototyping process, meaning it is based on inkjet technology (Lozo et al., 2008). Similar to an inkjet printer that prints on a substrate with ink, 3-D printing uses this technology as a method to “jet” a binder material in the form of droplets. These droplets then conjoin with powder particles, which is deposited in layers, to create a substance. In this process the powder material acts as the substrate and can be wet or dry (Utela, Storti, Anderson, Ganter, 2010). The liquid binder acts as an ink (Lozo, et al., 2008). When printing, the goal is to distribute each layer as smooth and evenly as possible to

create a consistent and accurate shape of the desired model. As mentioned, 3-D printing uses the principles of stereolithography to print a 3-D model layer by layer. These layers have been sliced by computer algorithms from a Computer Aided Design (CAD) file (Lozo et al., 2008). Companies who support 3-D technology have their own software tools which support CAD files for the creation of 3-D objects. The main elements involved in the 3-D printing of an object include the powder formulation, binder material, printing ink, and post processing which all contribute to the final formulated model (Utela et al., 2010).

An important step when creating a 3-D printed model is the powder formulation. In order to obtain a quality printed object, the correct powder needs to be selected to create the desired thickness (Utela et al., 2010). The raw powder is obtained before other elements are added to it, which gives the powder a specific deposition needed for the object being printed. In order to create even layering during deposition, the powder needs to be spherical or equiangular, having equal angles, in shape. The reason spherical shaped powders are most often chosen is because they create a better flow when being deposited by the print head. Choosing the correct powder for the inkjet printer is important because different particle shapes affect the packing and wetting characteristics. It also impacts the behavior of the ink droplets once the powder is formed into the various layers (Utela et al., 2010). Once the powder is obtained, additives may be blended into the powder to give it different characteristics. These additives can increase packing density of the powder particles, hinder the spreading of the powder in large quantities, and can also lower the amount of holes in the powder. As the layers are being deposited, the ideal thickness is at least three particles thick so the powder obtains the right amount of flow from the print head. When the powder formulation is successfully made, the binder can be chosen to further the creation of the desired object (Utela et al., 2010).

There are many binding methods to choose from which correspond to the formulated powder when printing. A binder is specifically selected to bond with the powder being laid down so it will form the 3-D solid object. The type of binder that is used can be differentiated by two locations, in-liquid or in-bed binder (Utela et al., 2010). An in-bed binder is used because of its reliability when printing, while an in-liquid binder is chosen because of its versatility (Utela et al., 2010). With in-liquid binders, they often create binding without the use of a powder which can create clogging issues within the print nozzle. In-bed binders use a dry binding method that is placed in the powder for printing which is what makes this a more reliable option.

In order for the binding process to begin, liquid ink must be printed in the bed or be part of the binding process itself. When choosing ink it is important to take into account the viscosity, particle size, and surface tension. These components will affect the droplets, which are deposited by the print head (Utela et al., 2010). The formulation of the ink itself contains the carrier fluid and additional elements that are necessary to initiate the binding process.

Once the 3-D object is printed in the bed, the finished object can be taken out and the excess powder can be cleaned off. There are other postprocessing options in addition to depowdering which include infiltration, sintering, or post-printing bed manipulation. Infiltration is used when making composites. The process takes a liquid infiltrant and it is place in the pores of the printed object using capillary action which allows it to solidify (Utela et al., 2010). Sintering has many affects on the printed part with its main uses for strengthening the object, making it more dense, or using sintering for preparation of infiltration step. Manipulation to the object when it is still in the print the bed is useful for forced drying, organic binder polymerization, reducing a salt based binder, or converting a pre-ceramic polymer. Post processing completes the 3-D print process and allows for a solid object to be successful be printed using inkjet

technology (Utela et al., 2010).

3-D Printing: Applications in the Graphic Arts

There are several valuable applications of 3-D printing specifically in the graphic arts. Within the packaging industry, prototype creation is an essential part of the development process when designing a package. By seeing a 3-D model of the package before it is mass produced, the business can improve and asses the package structure to optimize the design. Packaging companies around the world utilize prototype creation. The Creative Services Group of Silgan Plastics Corp, a packaging manufacturer, integrates 3-D printing into their production process because of the benefits they recieve. They note that through the creation of 3-D models, by Fused Deposition Modeling, this not only gives the packaging designer a better sense of the final product, but the customer as well (Casey, 2009). 3-D priniting is still a growing area in the graphic arts world, however t is rapidly expanding into the next big print technology in the graphic arts world. Scott Harmon who is the vice president of business development for Z Corp. states in *Cygnus Business Media Site* that because of 3-D prototypes, the products can be ultimately designed with more user/consumer input. As organizations look to deliver products, 3-D printing is growing. Harmon also notes that, “3-D printing helps companies that need to deliver products faster and on a budget. The benefits of better technology and less expensive costs can help products sell and give them an edge over their competitors” (Cygnus Business Media, 2009). This further shows how 3-D prototyping for packaging can be a beneficial technoldy to a business. The technolody is fas, efficient, and reliable, which make 3-D printing the primary frontrunner in prototype packaging.

Medical Applications of 3-D Printing

In its primitive stages of development, 3-D printing was an extremely slow, inefficient and

inconsistent process. In medicine, these aspects are ones that can be detrimental to successful medical practice. Today, however, the precision, speed and accuracy of 3-D printing are the main reasons that it is being implemented into the fields of dentistry, prosthetic development and high-risk surgery. 3-D printing is transforming each of these fields into more digitized processes (Sodian et al., 2008).

Traditional dentistry practices can be very uncomfortable for patients, usually long drawn out processes. Valuable time is spent waiting for molding substances to set and harden. Although there have been advancements within the process of mouth molding, the process is still relatively slow. One of the problems with using traditional casting to create a teeth casting is getting an impression of the soft tissue anatomy of the mouth. Often, the soft tissue of the mouth is a vital aspect in dental procedures (Cohen, 2010).

The implementation of 3-D printing in dentistry solves some of the problems common in traditional dentistry. According to worlddental.org,

> The old days when a patient went to a dentist office - the dentists had to ladle quantities of goo into patients' mouths to take impressions for the construction of crowns, bridges and implants, has gone. Instead, exciting new high technology has been developed that will do a two-minute digital scan of a patient's entire set of teeth. Once the information is captured by an intraoral scanner the dentist passes around the teeth, it is delivered to a dental lab where milling or 3-D printing machines are used to craft the artificial dentition, most of which is now made from zirconium dioxide (Cohen, 2010).

The digitization of many of the traditional processes is speeding up the procedure times. "…

The 3-D printing technology bullet train continues to accelerate the pace of change in dentistry, and patient experience. For those that have predicted the day when everything from scheduling to finished restoration can be handled digitally, the day is here" (Cohen, 2010). Due to the fact that the printed product is produced by a normal CT scan, dentists can select which portions they want printed and are able to scale them accordingly. A CT scan, is a series of x-rays that are performed at various angles. When complied the x-rays create a 3-D image (Mayo Clinic staff, 2010). With this technology, it is now possible to print not only teeth dentition but also the jaw. By having an accurate 3-D printed mold, it will be possible to create appropriate implants for jaw, mouth facial reconstruction. According to Dimitri Dimitrov, a professor in the Rapid Product Development department at Stellenbosch University, in Stellenbosch South Africa, the university's medical school is using 3-D printing to examine anatomy without surgery or dissection. "Students are working closely with a craniofacial specialist to create models of head and facial structures" (Stellenbosch University, 2010). For many dental and facial reconstruction surgeries models are needed to enable surgeons to plan surgical procedures. The inclusion of 3-D printing in the Stellenbosch University's medical school curriculum proves the increasing investment into this technology.

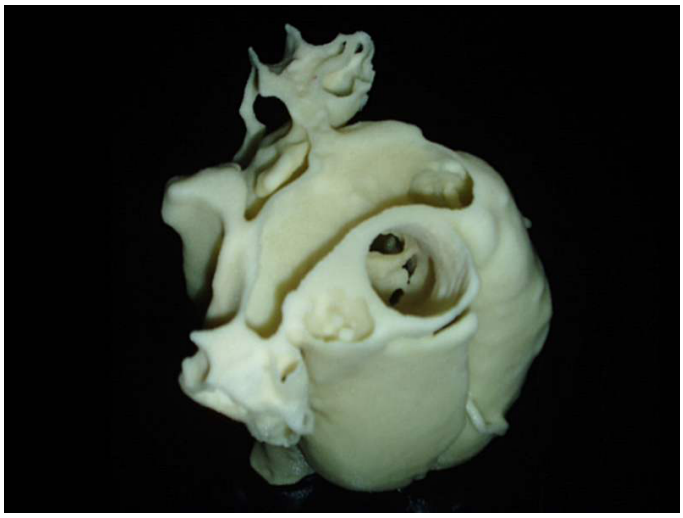
Surgery, most specifically high-risk surgery, is another area that 3-D printing is greatly influencing. Traditional surgery procedures and training consisted of using generic anatomic models. Time in the operating rooms included the actual operation plus any procedural assessment. Generic medical replicas are not a strong representation of the population because everyone's anatomical features are slightly different. For high-risk surgery, the preoperative planning is only as good as the doctor's experience. Many times, surgeons encounter situations during the procedure that were not planned for. CT scanning and 3-D printing technology are

addressing these issues and are improving surgical success rates for specific surgeries (Sodian et al., 2008).

One of the highest risk surgical procedures is heart surgery. In 2007, doctors from the Department of Cardiac Surgery at Ludwig-Maximilians University in Munich, Germany published a study entitled, "Three dimensional Printing Creates Models for Surgical Planning of Aortic Valve Replacement After Previous Coronary Bypass Grafting." This study addresses the issue of patient anatomical differences and unpredictable high-risk surgeries. Similar to the process used in dentistry, a CT scan was taken and processed through a stereolithography machine. The scan was sliced into 0.1mm to 2mm sections are printed using ink-jet technology.

> In this newly created model, the grafts and the anatomic relationships could be clearly identified. This enabled us to comprehend the anatomic difficulties and restrictions, and this understanding of the patient's exact anatomy allowed us to determine the surgical procedure. We were also able to sterilize the model and take it into the operating room for better intraoperative orientation. The three-dimensional model was helpful for reopening the strenum without damaging the bypass grafts or other cardiac structures (Sodian et al, 2008).

3-D printed model of a patient who has suffered cardiac arrest. The data was extracted from a MRI scan. Photo source: Inov8 Design Services LLP http://www.inov8design.co.uk/section2.asp?sid=3&id=26



3-D printed model of the internal valves of a patient's heart. The data was extracted from a MRI scan. Photo source: Inov8 Design Services LLP http://www.inov8design.co.uk/section2.asp?sid=3&id=26

Even though the 3-D printed model may not change the way in which traditional surgery is conducted, it serves as an additional aid in the operating room and can improve surgical success. "Stereolithography has been shown to be a useful tool in maxillofacial surgery, reconstructive surgery, orthopedics and in pediatric cardiac operations." Maxillofacial surgery is a corrective surgical procedure on the mouth and jaw portion of an individual including mouth and jaw disorders (AAOMS Information, 2010). "By using this technology, surgical templates or customized implants can be tested on the models, or anatomic structures can be reconstructed before the operation. These three-dimensional, life like models might also be helpful for preoperative planning of surgical procedures in a wide variety of clinical situations" (Sodian et al, 2008).

3-D printed model of a patient that required maxillofacial reconstruction. The implant was developed to fit perfectly before surgery began. The printed model aided in preoperative, surgical planning. Photo source: 3D Ventures http://www.3dventures.com/implants-orthopedics-maxillo-facial-3d-printing/

Walter Reed Army Medical Center is one of the most influential hospitals that are currently using 3-D imaging and printing for high-risk surgical procedures. Using a similar process as discussed earlier, the scanning of the portion of the patient's body is scanned and processed. It is then 3-D printed, sterilized and used for surgeon training. For example, a soldier in Iraq had a bony tumor lodged between a nerve and a major artery behind his knee. The surgeon was able to develop a surgical plan and implement it before the actual surgery began. According to Walter Reed Army Medical Center senior medical engineer, Peter Liacouras, "With 2-D images, it may be hard to visualize the full extent of the injury or the condition of the patient. We've had doctors say that with these 3-D models, they get the feeling that they've been there before" (King, 2008). By adequately preparing surgeons for high-risk procedures with the use of 3-D printed anatomical models, time in the operating room has decreased drastically. According to Dr. George Brown, the chief of the Division of Spine Surgery at the University of New Mexico Health Science Center, the use of 3-D printed models for the creation of plates used in pelvic and acetabula fractures reduced the time in the operating room by two hours (Medical Modeling Solutions, 2010).

Traditionally, prosthetic development was an expensive and lengthy process. Scott Summit, an industrial engineer located in Northern California, is one of the leaders in 3-D prosthetic printing research. Instead of having to mass produce generic prosthetics, it is now possible and cost effective to produce just one. While Summit argues that the future of prosthetic development is customized 3-D printed prosthetics, he believes that the price of the printers must drop before open-source prosthetic development can compete. Summit believes that "the peak of what's possible with 3-D printing may be found in the medical and prosthetic fields. Because of 3-D scanners, it's possible to craft prosthetics that almost perfectly mold to

a wearer's body unlike more standard models from the past (Teriman, 2010). With a similar process as described before, the patients body is scanned and the digital file is processed. With the improved accuracy of 3-D scanners and printers, anatomically correct prosthetics can be developed. Using the remaining limb as a model, the digital files can be altered to produce a more attractive prosthetic.

Client wearing a customized 3-D printed prosthetic. Design of the piece are fit to the individual. The prosthetic was printed by Scott Summit at Bespoke Innovations. Photo source: Bespoke Innovations http://www.bespokeinnovations.com/prosthetics/home/home.html

Scott Summit demonstrating the flexibility that 3-D printed prosthetics have. Both of the models shown were printed by Scott Summit at Bespoke Innovations. Photo source: Bespoke Innovations http://www.bespokeinnovations.com/prosthetics/home/home.html

Chapter 3:Research Methodology

The purpose of this study was to determine the impact of 3-D printing in medicine. High-risk surgery, prosthetic development, and the dental industry are the specific areas that were researched. By using elite and specialized interviews and content analysis, information was gathered about 3-D printing in the medical field.

Elite and Specialized Interviews

Professionals in various fields of the medical industry were interviewed about 3-D printing applications. Elite and specialized interviews entail the conduction of interviews with experts in the individual fields being researched (Aderbach and Rockman, 2002). The interview questions for each individual were targeted towards their field of study in order to obtain specialized answers. Only questions that are applicable to the area of expertise were asked. General questions were asked to all of the professionals as well as more specific questions pertaining to their field. The questions included:

General Questions:

What is your experience with 3-D printing or rapid prototyping?

Have you utilized 3-D printing technologies? If not, why?

What improvements can be made to 3-D models to improve your field? Time? Price? Accuracy?

What are the potential positive and negative affects to using 3-D modeling?

How could you use this technology in your field? What are the potential positive and negative affects of this technology in your field?

- If cost was not an issue, would you be interested in implementing 3-D printing into your practice?

Field Specific Questions:

- How do you think 3-D printing can benefit pre-operative planning?
- How do you think 3-D printing can advance current dental/orthodontic practices?
- Why do you feel 3-D printing has not replaced traditional mouth-molding techniques?

The individuals that were interviewed:

- Dr. Mark Orloff is a professor of surgery at the University of Rochester Medical Center. He specializes in multi-organ transplantation, hepatobiliary surgery, portal hypertension and vascular access. He was awarded the NATO scholarship in 1984. He practices in Rochester, New York.
- Dr. Daryl Sybert is a orthopedic spine surgeon specializing pathologic conditions involving the Cervical, Thoracic and Lumbar spine. Dr. Sybert graduated fourth in his class from Ohio Universities College of Osteopathic Medicine. He is the director of the spineMed division of orthoNeuro. He practices in Columbus, Ohio.
- Scott Summit is an industrial design engineer who founded SummitID, an industrial design firm in San Francisco area. He is also to co-founder of Bespoke, a printed prosthetic company serving the San Francisco Bay area. His designs have been recognized by the

IDSA and the Chicago Athenaeum Museum of Architecture and Design. He has been a lead researcher in the design of printed prosthetics.

- Dr. Michael Huguet is a certified general and cosmetic dentist. He graduated with honors from the University of California, Santa Barbara. He received his dental training from the University of California, San Francisco. Dr. Huguet is a active member of many organizations including the American Dental Association, California Dental Association, Academy of General Dentistry and the Academy of Cosmetic Dentistry. His practice is currently located in Pleasant Hill, California.

- Dr. Jeff Sumsion is a certified orthodontist specializing in gold brackets, ceramics, Invisalign, dentofacial , oral sedation and braces. He currently practices in Park City, Utah.

- Dr. Kent Johnson is a certified restorative and cosmetic dentist. He graduated with honors from the University of Southern California Dental School. He specializes in anything from minor cosmetic procedures to full mouth reconstruction. He is a member of the American Dental Association, a nationally-published author and Clinical Instructor at the Las Vegas Institute for Advanced Dental Studies. He is the official dentist of the U.S. Ski and Snowboard teams. He currently practices in Park City, Utah.

The interviews that could not be conducted face-to-face were conducted via telephone and email. The topics that were covered for high surgery were presurgical planning, the importance of printer precision and surgical success rates. In the prosthetics field, topics that were covered included printed prosthetics and open source prosthetic development. For the dental and orthodontic professionals topics such as 3-D dentition printing and mouth scanning devices,

were discussed. After the interviews were conducted, a majority of the responses were positive towards 3-D printing. Once this technology becomes even more precise and accurate, it is expected that many professionals will be eager to use the printing device.

Content Analysis

Content analysis is a method for quantifying the qualitative information that has been previously gathered (Colorado State University, 2010). This information was derived from the interviews. By looking at the Elite and Specialized interviews, from different professionals in various medical fields, the responses were categorized into groups that are in favor of 3-D printing in the medical industry and ones that are against its implementation. On a scale of 1-5, those who are in favor of 3-D printing and support the implementation of the technology in the medical field would rank a 5. A rank of 4 corresponds to full support of the technology but with some doubt about its place in medicine. A score of 3 corresponds to neutral feelings about the topic. A score of 2 corresponds to no strong support for 3-D printing in medicine. Finally, a score of 1 corresponds to complete disapproval of the technology and its implementation within the medical field. It was important that the responses were interpreted without bias. Due to the variety of answers that were produced with the elite and specialized interviewing, patterns were sought out in order to quantify the data. The first time the responses were analyzed, key terms were recorded. The key terms were words or phrases that have a positive or negative value with regards to 3-D printing in the medical field, such as “viable alternative” or “not accurate enough”. Then, the key terms were gathered into broader groups that may contain rational and reasoning. Finally, the groups were ranked on the scale previously discussed. At this stage, the number of professionals that fell into each of these categories was quantifiable data. The professionals were then be separated depending on their

area of expertise in efforts to analyze the responses in the individual fields of high-risk surgery, prosthetic development and dentistry.

Chapter 4: Research Results

These are the interviews results collected from each professional. As discussed, the individuals' responses were ranked on a scale of 1-5 depending on key words and phrases that were present in their response. The quantified results can be seen presented following the interview analysis. The actual questions were assigned a numerical value that correspond to their answer. Not all of the professionals addressed every question listed yet general themes were present throughout most of their responses.

General Questions

1.What is your experience with 3-D printing or rapid prototyping?

2. Have you utilized 3-D printing technologies? If not, why

3. What improvements can be made to 3-D printed models to improve your field? Time? Price? Accuracy?

4. What are the potential positive and negative affects to using 3-D printing?

5. How could you use this technology in your field?

6. If cost was not an issue, would you be interested in implementing 3-D printing into your practice?

Field Specific Questions

7. How do you think 3-D printing can benefit pre-operative planning?

8. How do you think 3-D printing can advance current dental/orthodontic practices?

9. Why do you feel 3-D printing has not replaced traditional mouth-molding techniques?

Interview Results

Dr. Mark Orloff, Transplant Surgeon

1. We use computer enhanced flat screen representation of 3-D digital data generated by contrast enhanced computer tomography. This is then processed with software. We have not tried to have these models built in 3-D through printing processes but would be interested.

2. no. Ignorance. Availability. I am interested – can you put me in touch with someone?

3. Have no experience but would say all could be improved.

4. A positive aspects is the hands on ability to analyze for pre-operative planning. Negatives include cost and labor of production.

5. A positive is the hands on ability rather than computer interface. One can physically play with the model. Negatives would be cost and complexity of generating the model. There will be a lot of data points for a small machine to process. Would seriously like to speak with someone who can represent this technology.

7. Intuitively – yes – bring it on.

Dr. Daryl Sybert, Spine Surgeon

1. I know that rapid prototyping is a big deal in orthopedics but I do not have any experience with 3-D printing. Hip replacements are being done with traditional molding for the implant. MRI scanned and the jig is used to produce the part for a total hip replacement. This is done while the patient is asleep. No 3-D printing is currently used on the spine because none of the companies offer the technology. I work to contour the spine using plates and screws.

2. No I have not because it is not available in spine surgery.

3. All of the above could be improved. Cannot sacrifice accuracy in medicine. Cost and cost of the materials is also important. It also has to be reproducible.

4. Positive: Interesting technology. I think that it can be very beneficial for surgeons to conduct a simulated surgery and get the practice especially if it is a high-risk field. Could be great training for students as well.

7. Yes, as mentioned above. Another factor is the health care in this country. Insurance companies do not pay for preoperative planning. 3D printing would have to fall under the umbrella of surgery.

Scott Summit, Industrial Engineer

- After reviewing Scott Summits lecture at Singularity University, these are the main points that are relevant to our interview topics.

With a degree in industrial engineering, Scott Summit set out to research new ways prosthetics could be produced without mass production techniques. He described the mass production of prosthetic parts as a “garage sale of dissimilar parts that are offensive to the user” (The Future of 3D Printing). By looking at 3-D printing as a solution, Summit discovered a new way prosthetics could be created without the mass production of its parts. This included 3-D scanning, parametric modeling and 3-D printing (digital fabrication). His new design of prosthetics aims to provide a person with better symmetry (see figure---). The structure of the prosthetic is described as having a seven bar linkage which allows the motion of the knee to calibrate to a person’s motions. Unfortunately, Summit notes that the materials used in 3-D printing are expensive and the machines are not getting cheaper, however there are still many positives which outweigh this negative. With an extremely strong build, lightweight structure,

and symmetric shape, 3-D printed prosthetics are slowly becoming more desired by amputees. "This is about returning a sense of self to the person and sense of wholeness… a sense that the person is actually back to their original shape at least to some degree."

Dr. Michael Huguet, Cosmetic and Reconstructive Dentist

1. I have minimal experience with 3-D printing.

2. I have no experience with 3D printing.

3. Cost effective models of teeth and jaw would have a big impact in my field. Specifically in planning and restoration and especially in the field of dental implants.

4. I do not see any negatives only upsides to using this technology.

6. Yes, I do.

8. CAD-cam technology ie Cerec by Sirona has changed the way we plan and make implant abutments for teeth and porcelain crowns. It will also advance the field of dental implants.

9. Cost, education and training. A Cerec machine costs over $100,000 currently to make scanned crowns. There is an issue with esthetics comparing scanned crowns to "in-lab" crowns.

Additional information provided by Dr. Huguet:

"I do see a big future with this technology in my field. Sirona's Cerec is the leading company at this time. I just had a demo of a scanned then milled crown, it was cool stuff. A few dentists have this technology in our area and it is slowly growing. They are on a second generation of software. The advantage for us is less lab costs and chair time for a second appointment to seat a crown. Lab costs are around $10,000 a month. Heny Schein's ED40 is a competitor as well.

Big start up costs of over $100,000."

Dr. Jeff Sumsion, Orthodontist

1. Personally, nothing. The closet thing is the instant crowns that General Dentists are using. Their product is a reverse type product where they start with a block of material, and have cutters to remove the unwanted material. In orthodontics, Invisalign scans a physical model, then a machines also cuts a block for a model, then the retainer is hand molded and cut from there. Also, braces can be custom cut from metal blocks, but once again, these are done in large factories off site or out of the country. There is nothing on any front done in the orthodontic office directly.

2. No.

3. It would be great to scan teeth, and have a retainer manufactured directly, and accurately, right on the spot when braces are removed. This would help with better retention, shipping, disinfecting, etc. On the brace side of things, an instant custom brace would allow for faster results.

4. Cost is always the big stumbling block. Currently, custom braces add an additional $750 to the cost of treatment with an average reduction of treatment time of approximately 25%. When treatment is only a year, this is only a couple month savings. The results should be the same. The positives, are noted above.

6. Yes, I would love to.

8. How do you think 3-D printing can advance current orthodontic practices? Once again as noted above. The WOW factor only lasts until it becomes mainstream. The ability to have accurate on the spot retainers would be huge (especially if they could be made off a direct scan of the teeth).

9. Accuracy and cost.

Additional information provided by Dr. Sumsion:

“Once again, think about your Invisalign or a retainer. If you could walk into the office, scan the teeth, adjust movements on a computer chair-side, manufacture on the spot, and the patient leaves with working retainers would be huge. As is, there are lengthy impressions, mailing, downloading, manufacturing then mailed back. This usually takes 4 weeks.”

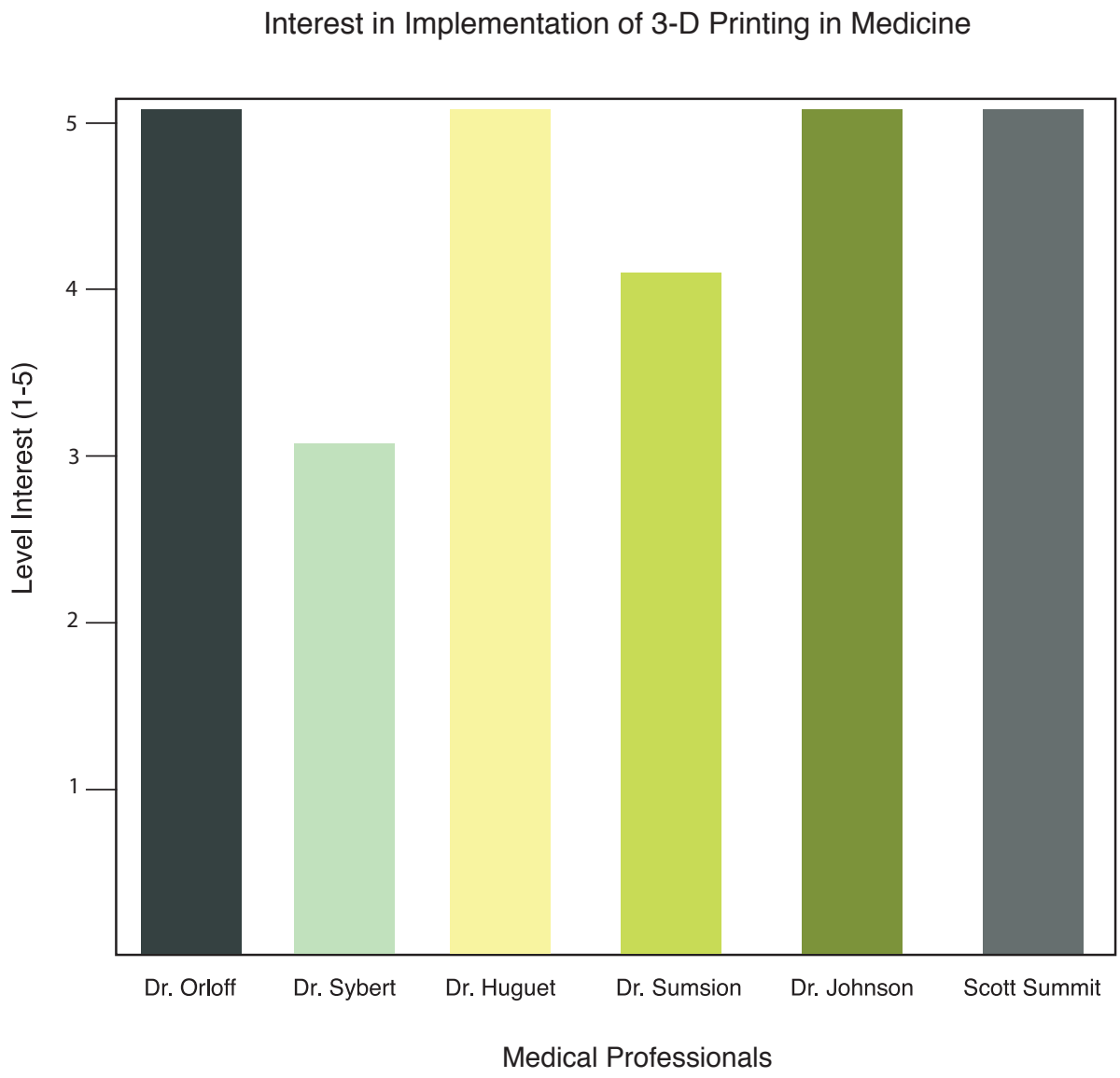
Dr. Kent Johnson, Cosmetic and Reconstructive Dentist

The following was taken from an e-mail interview that was conducted. Dr. Johnson stated the following,

“I have had no experience with 3D printing. In fact, the first I had heard of it was when visiting the Skull Candy offices last week. They had one and they use it to make prototypes of new headphones. We are now able to take digital impressions of teeth. If someone is contemplating a smile makeover, impressions are taken of their existing teeth and then computer manipulated to an ideal smile. A model could be created that could be used to show a patient their new smile and also use it to make temporary veneers for them. It might be cost prohibitive, but it would be cool. That makes a lot more sense. I was trying to visualize how it would be used in a dental practice like mine, when most of it’s uses are probably going to be in a dental lab setting. A lot of offices have laboratory services right in their offices but it isn’t something that I have in this office. The labs that I use will probably make use of the technology in the future, if they aren’t using it right now. It is pretty amazing stuff.”

Data Analysis

As discussed in the research portion, the interview answers will be ranked on a scale of 1-5. On a scale of 1-5, those who are in favor of 3-D printing and support the implementation of the technology in the medical field would rank a 5. A rank of 4 corresponds to full support of the technology but with some doubt about its place in medicine. A score of 3 corresponds to neutral feelings about the topic. A score of 2 corresponds to no strong support for 3-D printing in medicine. Finally, a score of 1 corresponds to complete disapproval of the technology and its implementation within the medical field.



Positive and Negative Terms Regarding 3-D Printing

Medical Professionals	Positive (+)	Negative (-)
Dr. Mark Orloff, Transplant Surgeon	Hands on Ability, Interested	Availability, No Experience, Cost, Labor of Production
Dr. Daryl Sybert, Spine Surgeon	Good for Training	Not Available, No Experience, Cost
Scott Summit, Industrial Engineer	Strong, Lightweight Model	Expensive
Dr. Michael Huguet, Cosmetic and Reconstructive Dentist	Big Future, Slowly Growing, Less Lab Costs	No Experience, Education, Training
Dr. Jeff Sumsion, Orthodontist	Convenient, Fast, Accurate	Cost, Same Results
Dr. Kent Johnson, Cosmetic and Reconstructive Dentist	Amazing, Will Use in the Future	No Experience, High Cost

Surgical Field

Dr. Orloff and Dr. Sybert have not used the 3-D printing process, however both surgeons have experience with 3-D digital data. They are extremely interested in the technology, but it has yet to become mainstream within their fields. Traditionally industry suppliers determine the trajectory of the medical field. Surgeons have little control as to the implementation of technologies. Both surgeons stress the importance of time, price, and accuracy for the improvements of 3-D printing. Due to the intricacies of the medical field, Dr. Sybert notes that accuracy can never be sacrificed. They agree that a major positive of 3-D printing technology is the pre-operative benefits. Dr. Sybert notes that 3-D printed models within medical schools is a way for students to practice unique surgical procedures. This is extremely beneficial for high-risk surgical fields that rely on precision. Both surgeons are interested in implementing this technology into high-risk surgery. Dr. Sybert mentions however that the costs is such a big underlying factor which makes the technology harder to implement without addressing the cost. He also addresses health care in that insurance companies would not pay for 3-D printing

because it would fall under pre-operative planning and they only cover surgical planning.

Prosthetic Field

Scott Summit has been improving the design of prosthetics for several years and has supported the 3-D printing technology as a means to build them for amputees. Although the 3-D printing of prosthetics is expensive, Summit is a strong advocate for the technology because of its tremendous advantages. With accurate precision and a lightweight construction the 3-D printing of prosthetics is ideal for any person needing a prosthetic model to improve their lifestyle. His innovative designs for the models also give a more desirable look and feel for a person compared to older prosthetic models. The only major disadvantage to the 3-D printing of prosthetics is the price. Scott notes in his lecture that the cost for his prosthetic model can be around $5,000-$6,000. This may seem like too much money, but Summit emphasizes how purchasing one of his prosthetics can change a persons life. Due to the size and shape of the prosthetic, a person feels more complete and "symmetric," as Scott underlines in his lecture. Like other medical professionals, the cost of implementing 3-D printing as a regularly used technology is extremely pricey, however all agree that it is provides a huge advantage to any medical field.

Dental Field

All three dental professionals have minimal experience with 3-D printing. While 3-D scanning has been integrated into the field for almost a decade, 3-D printing has not become a mainstream alternative for traditional molding techniques. Dr. Huguet and Dr. Johnson note the importance of cost in this technology. Unlike the surgical field, time is not as essential, but rather cost is the primary concern. However, in orthodontics, Dr. Sumsion stresses the

importance of turn around time for retainer manufacturing. He talks about the removal of braces and the possibility of improved retention with the creation of retainers on-sight. Cost is a negative aspect across all dental fields. Specifically in short-term treatment orthodontics, 3-D printing costs are extremely high. All professionals are eager to use and implement 3-D printing within their field specifically dental implants, temporary veneers, braces, and retainers. Different materials would need to be used in the fabrication of dental implants and veneers in order for them to be successfully used on a patient. The main concerns dental professionals have is cost and accuracy. These issues need to be addressed before they can be a viable alternative to traditional dental practices.

Chapter 5: Conclusions

3-D printing is a technology that is still in the development stage of the product life cycle. After a comprehensive literature review and interviews with professionals in the medical industry, it is clear that there is interest in the implementation of 3-D printing in medicine. While the technology has been in the marketplace since 1993, due to the limited material usage, variable accuracy, high price and slow production time, 3-D printing has not been a viable alternative to traditional medical modeling. Currently it is being used only in unique cases.

In addressing the original research question; What technological advancements in 3-D printing will greatly affect the medical industry? The interviews point out that medical industry professionals believe the price of 3-D printing needs to be reduced in order for the technology to compete with traditional technologies. Unless 3-D printing offers more advantages which outweigh this major disadvantage, it will be difficult for the technology to transition into various medical fields. 3-D printing has been introduced within the fields of high-risk surgery, prosthetic development and dentistry, but only in specific and specialized areas.

In high-risk surgery, 3-D printing has been discussed among professionals specifically its usage for pre-operative purposes. Currently, however, this advanced technology is rarely seen in the surgical world because it is not easily funded. In some cases, the technology has been available to medical professionals and has been successfully used to assist in the planning of a difficult surgery. Unfortunately, 3-D printed models have a better chance of making their way into medical schools to provide training for students than on the surgical floor of a hospital. The professional surgeons interviewed, noted they only have experience with 3-D digital data because 3-D printing for preoperative purposes is not provided by their suppliers and costs are not covered by insurance companies. If the technology were made available to these medical

professionals, the success rate of high-risk surgeries has the potential to increase due to the ability to practice on a 3-D printed model. The ability to provide this technology, however, all comes down to cost.

The future of 3-D printed prosthetics is seen in the model created by Scott Summit. By using this relatively new technology, Summit has created a prosthetic that stands out among the rest. 3-D printing has allowed Summit to create a new prosthetic featuring an innovative design, lightweight structure, and enhanced mobility for the wearer. The price to purchase a prosthetic is expensive yet reasonable for any person looking to enhance their everyday lives. Currently, there are not many professionals looking at 3-D printers as a means to create prosthetics because the equipment is extremely pricey. This means that the printing of prosthetics with 3-D printing technology is only just beginning and will continue to grow in the future. Summit has opened a new door into the world of prosthetics through his use of 3-D printing.

Many dental professionals are enthusiastic on implementing 3-D printing into their practice. This technology will allow for the creation of common dental procedures and models to happen in a faster and more accurate manner allowing for quicker service to each patient. By decreasing the time it takes to create a retainer or veneer, a dental professional can fit in more patients and enhance customer satisfaction due to the cutting edge technology. Like other medical fields, using 3-D technology requires a high initial cost. This is the major factor that is causing the 3-D printing of dental models from being a common technology in the field.

Although the medical professionals notes their high interest in the technology, this does not mean that the technology can immediately be implemented as a viable substitute for existing technologies. In order for 3-D printing to become a common technology within medical fields,

the cost for 3-D printers needs to decrease. Unfortunately, due to the technology's early stages of development, it may take a few years before prices become reasonable. If the price drops, 3-D printing will become even more desirable by medical professionals due to its exceptional precision and quick turn around times.

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