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3D Printing in Medical and Dental Markets: An Opportunity Analysis and Ten-Year Forecast

A MARKET FORECAST AND TECHNOLOGY ASSESSMENT

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3d Printing in Medical and Dental Markets: An Opportunity Analysis and Ten-Year Forecast

Report Summary

3D printing has already found substantial traction in the dental implant and hearing aid business and SmarTech believes that the prospects for many other uses of 3D printing in the medical/dental market are rosy. There are numerous applications in the healthcare field where highly customized products, such as implants, must be created quickly. 3D printing fits such needs extremely well and we believe that medical/dental will become a big money spinner for the 3D printing sector in the near future.

In this report SmarTech identifies the main opportunities for 3D printing in the medical and dental environments. It surveys the current use of 3D printers in this area and shows where the business opportunities will be found in the future. It also identifies current weaknesses in 3D printing and where 3D printers, software and services must adapt to make money from these opportunities.

In addition to the 3D printers themselves, the report covers and forecasts the demand for related 3D printing services, scanners, software and materials. The report also includes ten-year forecasts of all the important medical- and dental-related markets for 3D printing with breakouts by type of printers (professional and prosumer), 3D scanners used, as well as related software and services.

While 3D printing of medical and dental products may use conventional 3D printing materials for some applications, such as model building, specialized ceramic, metal and even biological materials will also be required. With this in mind, we have also included a forecast of materials used by the medical/dental community for 3D printing applications. In addition, the report provides a discussion of how the 3D printed medical/dental markets break out by geography, reflecting the many differences in healthcare arrangements around the world.

The report concludes with an assessment of the medical related strategies of 15 leading 3D printer firms that have made medical/dental markets a critical part of their product offerings and market direction.

SmarTech believes that this report will provide invaluable guidance for 3D printing equipment and software companies, service providers, specialty chemical firms and medical equipment firms. We also think that it will prove to be required reading for investors in the 3D printing business as a whole.

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Chapter One: The Business Case for 3D Printing in the Medical and Dental Sectors

3D printing has already found substantial traction in the dental implant and hearing aid industries, and this is just the tip of the iceberg. **SmarTech** believes that the prospects for many other uses of 3D printing in the medical/dental market are rosy. There are numerous applications in the healthcare field where highly customized products, such as implants, must be created quickly and efficiently. 3D printing fits such needs extremely well and we believe that medical/dental will become a big money spinner for the 3D printing sector over the next ten years.

In this report, **SmarTech** identifies the main opportunities for 3D printing in the medical and dental environments. It surveys the current use of 3D printers in this area and shows where the business opportunities will be found in the future. It also identifies current weaknesses in 3D printing and where 3D printers, software and services must adapt to make money from these opportunities.

In addition to the 3D printers themselves, the report covers and forecasts the demand for related 3D printing services, scanners, software and materials. The report also includes ten-year forecasts of *all* the important medical- and dental-related markets for 3D printing with breakouts by type of printer, 3D scanners used, as well as related software and services.

The forecasts were created from information gathered from professionals in the 3D printing industry, as well as professionals working in related medical and dental sectors. We also referenced numerous other industry reports and publicly available financial statements to come up with what we believe to be the most accurate forecasts available on the market.

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When creating our forecasts, **SmarTech** strove to deliver the most detail possible, without standing on delicate assumptions. Forecasts were designed from the bottom up when possible, incorporating numbers from individual 3D printing companies where this information was available. In all forecasts in this report, we strive to lay out the logical progression of our forecasts so that the reader can follow at all times how we came to the conclusions we did.

While 3D printing of medical and dental products may use more conventional 3D printing materials for many applications such as model building, specialized metal and biological materials will also be required. In addition, the report provides a discussion of how the 3D-printed medical/dental markets break out by geography, reflecting the many differences in healthcare arrangements around the world.

The report concludes with an assessment of the medical-related strategies of 15 leading 3D printer firms that have made medical/dental markets a critical part of their product offerings and market direction.

SmarTech believes that this report will provide invaluable guidance for 3D printing equipment and software companies, service providers, specialty chemical firms, dental labs, and medical equipment firms. We also think that it will prove to be required reading for investors in the 3D printing business as a whole.

1.1 Progress In Medical/ Dental Sectors Rests In Rapid Advancement of 3D Printing Technology

3D printing's progress into the medical and dental industries has been enabled by the recent advancement of 3D printing technology. New technologies are able to create medical and dental products of comparable quality to conventionally manufactured parts and, in some cases, even exceed them. Furthermore, parts are produced more efficiently, using fewer resources, and requiring less labor hours.

The new generation of 3D printers is continually vying against conventional manufacturing processes for more market share in the medical and dental industries. They do this by offering viable manufacturing alternatives in terms of quality and cost. Together, 3D printers have the potential to radically shift the established supply chains of long-established medical industries.

Over the last decade, a lack of qualified materials prevented applications in and around the body; lower material density and inaccurate parts prevented any type of durable products from being introduced; slow print speeds restricted any sort of scaling of operations and kept prices high. With these restrictions, 3D printing was

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developed to address very narrow applications in the hearing aid, modeling, and medical prototyping industries.

With recent advancements, these limitations have all but disappeared. A whole new world has opened up for 3D-printable solutions in the medical and dental industries. Although materials may still be functioning as a bottleneck to the industry, the list of qualified metal and plastic materials is increasing every day, and with it, new opportunities for 3D printing to address.

3D printing companies, as well as medical equipment manufacturers are working quickly to implement 3D printing to recognize cost savings and an edge over competitors. The newest generation of 3D printers is bigger, faster, and more accurate than their predecessors, allowing them to address a wide array of new markets in the medical and dental sector.

More powerful lasers, as well as technology like DLP have enabled printers to quickly increase their print speeds, without reducing print accuracy or quality. Similarly, new technologies have enabled 3D printer manufacturers to enlarge their print bed volumes to address larger parts. But by far the biggest advancement to affect the medical and dental industries is the ability of 3D printers to print many objects at once.

Low-volume production runs reduce dental labs' and OEM's fixed and variable costs per printed part, creating new opportunities to produce small, complicated medical and dental products. For example, EOS's EOSINT M 270 and 280 are regularly used to produce over 250 metal dental units a day by spacing parts strategically over the print beds.

Since many new 3D printers are equipped to reuse unused materials, manufacturers no longer have to worry about material waste with larger print beds. However, 3D printer manufacturers understand the need to find the best print bed size for the types of customers they serve, in order to optimize throughput. In many cases, bigger may not always mean better.

1.2 Importance of Customization for Medical and Dental Products

One of the most significant attributes 3D printing brings to the medical and dental industries is the ability to provide customized medical and dental products in a way that wasn't possible before. Customized products have the ability to improve medical care, by ensuring better fitting implants that encourage healing. At the same time, these customized products have the potential to dramatically reduce healthcare costs

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by decreasing time spent under the knife and improving success rates, reducing the need for additional surgeries and malpractice lawsuits.

For example, a custom-fit acetabular cup implant in the hip creates better body parallelism, which makes the patient more comfortable and satisfied with the surgery. At the same time, the custom fit acetabular cup fits better on the patient's hip, while the porous structures printed on the back of the implant encourages osseointegration. These positive attributes increase the success rates of the surgery.

Another example of the benefits 3D-printed mass customization is customized dental abutments. Abutments rest at the gum line of permanent dental implants. Improperly fit, abutments can wear on the gum line, causing it to recede. This can allow bacteria to get underneath the implant, which will eventually cause decay and the implant to fail. Customized abutments fit better in the patient's mouth. They can minimize the wear between the implant and the gum line, improving customer comfort and implant success rates.

These mass-customization forces are enabled by all-digital production processes, of which 3D printers are an integral part. Customer-specific data can be quickly transmitted to the equipment manufacturer, who can then quickly convert it into CAD/CAM data using medical software. The bespoke product then be printed and shipped back to the medical or dental office in a fraction of the time it takes conventional processes.

Where previously customized products required specialized labor and hours of toil, 3D printers don't take any additional time to print unique parts. An array of 40 unique parts can be printed in the same time as 40 identical parts. This liberation of restrictions opens up new opportunities to deliver customized products for the right applications.

1.3 The Role of "Prosumer" 3D Printers In Medical/Dental Markets

Prosumer is an emerging 3D printer class priced from $3,000 to $5,000. The prosumer class is differentiating itself from the personal printer class by offering superior printer performance, as well as an expanded selection of materials that allow it to address more applications than personal 3D printers.

Outlook is mixed whether compact, lower-end printers will be adopted by the industry. Some believe that prosumer printers will be glossed over by the medical and dental industries. Others believe there is a potential for every hospital to have a 3D printer on hand to print models and guides for use in the operating room.

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The difference between these two viewpoints is that the former is being espoused by insiders in the industry, while the latter is being promulgated by bloggers, enthusiasts, and makers. Here at **SmarTech**, we tend to side with industry insiders. We are doubtful that prosumer printers will have any significant effect on the medical and dental industry over the next ten years.

People excited about prosumer printers imagine a world where models can be printed while patients sit in waiting rooms. Having a prosumer printer in house will extend the benefits and efficiencies 3D printers create in the first place. Medical models can be printed off in the other room, and then be brought in to show the patients exactly what the procedure entails using models of their own bodies.

The fact is this: the printing technology is not advanced enough to recognize clear benefits from having an in-house printer, and would probably just sit there if it were in the hospital. Doctors would rather not have to learn another technology, and instead focus on saving people lives.

Prosumer printers cannot print fast enough or accurately enough to produce useful medical models in time for appointments or surgeries. Hospitals would need larger, faster 3D printers that cost upwards of $50,000 to accomplish what these prosumer supporters have in mind. This would be an inefficient deployment of capital for hospitals to take on, when they can easily outsource this to an outside firm and have insurance pay for it.

This is not to say that smaller printers are not successfully being developed for the medical and dental industries. Compact printers fit easily into existing businesses, which minimize installation costs. Furthermore, smaller printers can be located in more easily-accessible locations, allowing companies to integrate them more successfully into their operations.

Compact 3D printers for printing wax models for dental temporaries are becoming more popular in the dental industry. These small printers, which are produced by companies like EnvisionTEC and DWS, have found moderate success selling to smaller dental labs and offices. Some can even print dental temporaries in colored resins while the patient is in the office, eliminating the need for a second visit.

While these printers bear the closest resemblance to prosumer printers in the medical and dental industries, they are definitely not the same as prosumer printers for multiple reasons. First off, they are more expensive, reaching anywhere from $5,000 - $25,000 per printer. Secondly, these are printers developed for specific purposes. Prosumers are designed to address more applications, but not in a way that could really benefit the medical or dental industry anytime soon.

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1.4 Specialized 3D Printing Services Required for Medical/Dental Markets

More than likely, medical models will continue to be manufactured by outside specialty service bureaus over at least the next ten years. These service bureaus will put up the capital investment to purchase the 3D printers necessary to produce high quality models, as well as maintain trained staff to oversee efficient production of the models.

This will be the standard for custom made 3D-printed tools, cutting guides, and implants as well over the next ten years. Practicing medical professionals need outside firms to manage the operations of providing 3D-printed medical solutions so that they can focus of providing care to the patient. The OEM's and other dedicated firms that take on these challenges will be able to maintain healthy margins from an industry that has historically been able to protect large margins for its suppliers.

Strategically, it is imperative that specialty companies not only provide 3D printing services, but provide entire medical and dental solutions. This necessitates designing and controlling manufacturing processes from top-to-bottom, to ensure the process is easy to use for the customer, cost-effective, and produces a high quality product.

This means companies will have to balance software, imaging, hardware, material, and service operations to optimally produce a specific type of medical product. Those who do will position themselves for rapid growth. The reward for designing these business solutions will be a differentiated product that will allow companies to charge a premium, as well erect staunch barriers to entry.

An example of this is Oxford Performance Materials. OPM manufactures cranial/facial implants using high performance PEKK plastics materials. In order to offer the service of producing these implants, it had to qualify materials with the ISO and FDA, coordinate hardware, software, imaging equipment, quality control equipment, and manufacturing operations. The result of the hard work is an facial implant solution for doctors that is extremely hard and costly to replicate. OPM has positioned itself to gain a large portion of the cranial/facial implant market over the next ten years.

Another example is Materialise, which has positioned itself in the cardiac modeling market with its Heart Print service. Its strategy necessitated developing proprietary clear and flexible modeling materials specially designed for cardiac models, along with state-of-the-art medical imaging software. This makes it difficult for Materialise's position to be threatened.

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1.5 Opportunities for 3D Scanners and Scanning Equipment

3D printing's inroads to the medical and dental industries have been facilitated by the earlier adoption of scanners and medical imaging equipment by the industry. Moving forward, however, it will be 3D printers that will fuel 3D scanner and scanning equipment sales.

3D scanners fill a number of important roles in the dental industry. They can help visualize and plan treatments, but mostly they are used to create CAD/CAM files for production of dental implants. Many of these implants were being produced in the past with processes such as CNC milling. Companies like Renishaw and Sirona even offer compact CNC milling devices to produce implants and temporaries in the dental office itself.

There are a few different types of dental scanners available in the market today. Generally, there are dental model scanners and intraoral scanners.

1.5.1 Dental Model Scanners

Dental model scanners create a CAD/CAM file of a patient's teeth by scanning a dental stone model. This model is created from wax impressions that are made by dentists in their office, and subsequently shipped to the dental lab. Dental model scanners enabled dental labs to reap some of the benefits of a digital system, without requiring a dental office to change long-established practices of making impression, or to invest in expensive new equipment.

Some of the major players in this industry include MEDIT, 3Shape, Dental Wings, and Carestream.

1.5.2 Intra-Oral Scanners

Of course, it is much more efficient to create a CAD/CAM file from the patient's mouth directly. The abundant opportunity in supplying intra-oral scanners to the dental industry lead many companies to develop competitive products.

The more prominent companies in the industry include Sirona, Renishaw, Cadent, D4D Technologies, 3Shape, IOS Technologies, Densys Ltd, Dimensional Photonics International, 3M, Dental Wings, Zimmer, and Carestream, among others. Of these, Sirona's CEREC System is by far the most popular.

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CAD/CAM files constructed from these intra-oral scans can be directly used to design dental products to be 3D printed. Because of the abundance of different scanners already in the market by the time 3D dental printers were developed, nearly all 3D printer manufacturers have had to adopt open-source interfaces to ensure that their systems work with all the different kinds of commercially available scanners and software.

The dental industry certainly seems to be headed towards universal adoption of intra-oral scanners, as they offer significant benefits over impressions and impression scanners. More and more, dental offices are ponying up for new digital equipment to increase their productivity and stay competitive.

Moving forward, 3D printers will demand scanners that create detailed and accurate scans for use with dental implant design software. Intra-oral scanners that support standard CAD/CAM file types such as .stl will be the clear favorites for 3D printer manufacturers.

1.5.3 The Role of Medical Imaging In 3D-Printed Medical/Dental Markets

Increasingly, complex medical imaging can be used to create CAD/CAM files for 3D printing. Medical images such as CAT scans and MRIs can be translated in to solid object files using advanced software. These CAD files can be used in 3D printing to enhance the offerings of 3D printers to the medical model, surgical instrument, cutting guide, splint, and orthopedic implant market.

Materialise, Visualization Sciences Group, and Autodesk are active in developing software for these applications. Materialise's Mimics Innovation Suite quickly translates files from 2D to 3D, supports a number of different file types, supports accurate measurement taking, and allows users to easily segment images into important parts. VSG's Amira program also supports model segmentation and surface reconstruction, with an emphasis on mathematical quantification of models for complex analysis.

Programs like Mimics and Amira open up new opportunities in the medical field for the 3D printing industry. These software programs expand the addressable market for 3D-printed models. They also increase the accuracy of these models, which consequently increases their value to surgeons. These software programs bolster the performance of many other 3D printed products as well, including tools, cutting guides, and implants.

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This new category of software will continue to open up new opportunities for 3D printers over the next ten years. Software manufacturers must ensure their software works seamlessly with commercially available 3D printers. They must also work with 3D printer manufacturers to meet the product requirements for 3D printed products based on the medical images.

On the other hand, 3D printer manufacturers need to make sure they develop their 3D printers to take advantage of the opportunities opened up by these new medical imaging systems. In the end, both medical imaging software companies and 3D printer manufacturers must work together to develop integrated medical solutions using the two technologies.

1.6 Opportunities to Supply Materials Into the 3D-Printed Medical/Dental Market

Printing materials are extremely important to 3D printing in the medical and dental sectors because they ultimately determine the applications of the technology. There is ample opportunity to generate revenues in 3D printing materials over the next ten years because of high performance requirements, as well as high regulatory barriers.

The dominant metal materials in the medical and dental 3D printing industry are cobalt chrome and titanium. These materials are championed because of their biological inertness and high strength-to-weight ratios. Nearly every company that produces metal 3D printers has developed its own titanium and cobalt chrome materials. The difficulty of processing these metals into useable powder forms makes these materials expensive. They can cost anywhere from $800 to over $1,000 per kilogram.

There is a wider array of plastic materials used in the medical and dental industries. There are a number of photosensitive resins used for modeling and dental products, such as temporaries and partial denture frames. There are also polyamide based powders used to create models and medical tools. Finally, there are high performance PEKK materials that are being used for select types of implants.

The prices for these materials are also quite high. Polyamide powders and photosensitive resins can reach upwards of a $100 dollars per kilogram, and PEKK plastic prices are closer to that of the metal powders per kilogram.

Most every 3D printer manufacturer develops its own proprietary materials for use in its printers. The 3D printer design process almost necessitates that 3D printer manufacturers have a complex knowledge of material design, and actually have a

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hand in designing materials for their printers. The process of fine-tuning printer performance involves tweaking both printer and material to deliver optimal results.

Already having a complex understanding of material design, it is usually in 3D printing companies' best interest to patent their materials. This raises barriers to entry for potential competitors, who have to bear the cost of developing their own materials. At the same time, any materials that gain regulatory clearance or a reputation for high performance create a competitive advantage for that company. Superior material selection can function as a differentiating factor when potential customers' are selecting which 3D printer system to invest in.

3D printing material production is outsourced by 3D printer manufacturers to specialty materials manufacturers. While the order quantities are still relatively small for most medical and dental applications, order sizes must, increase rapidly over the next ten years as 3D printing in the medical and dental industry takes off. We forecast that the market for medical and dental materials will be worth $297 million by 2018, and will top $1.1 billion dollars by 2023.

The large increase in demand for 3D-printed medical and dental products will require innovation in the 3D printing material supply chains. Materials suppliers will have to figure out how to scale-up production in a cost-effective manner.

Opportunity in 3D printing materials may be fueled by large growth in many 3D-printed product categories, but it is sustained by the high prices materials manufacturers can charge for their products. The finite amount of qualified materials limits the supply and pushes up prices. Furthermore, the make-up of the medical and dental industries has historically protected material margins with its lack of emphasis on process efficiency. 3D materials manufacturers will be able to maintain healthy margins on their products for the foreseeable future.

1.7 Opportunities In Medical/Dental Software

There are many different kinds of software involved in the 3D printing process: software to deliver the printing instructions to the 3D printer hardware; software to translate the CAD/CAM designs into files readable by 3D printers; software to design the medical and dental products. All in all, software design is critically important to the entire 3D printing process. Software presents a large opportunity both for medical and dental product creation, as well as for 3D printer manufacturers to differentiate themselves from competitors.

Essentially, medical and dental solutions are, at their core, software. 3D-printed products are designed first in CAD software. Many times, product design software

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uses other CAD/CAM file input, images, or other information to customize the product for a specific patient. For example, dental crown design programs use CAD scans provided by intra-oral scanners to design the specific dimensions of the crown.

To the extent that software programs provide a novel medical or dental solution, there is great opportunity to generate substantial revenues. Patented software can raise barriers to entry, and sustain competitive advantage over competitors. There is opportunity for software companies with backgrounds in CAD design for other manufacturing industries to design software for medical and dental product creation. Examples of such companies may be such as Autodesk or Dassault Systemes.

One company that has embraced this concept of creating novel solutions is Within Technologies. Within develops CAD/CAM software for designing advanced medical meshes, to be implemented in 3D-printed implants. Its software advances the capabilities of 3D printing by being able to manufacture superior, 3D-printed implants with unique strength properties. As more companies look to develop 3D- printed orthopedic implants, its novel technology portfolio positions the company well for future growth.

On the 3D printer manufacturer's side, software can be a large differentiating factor for customers. 3D printer manufacturers have many factors to consider when designing their printer's software. These include the balancing of complexity with and ease of use, increasing compatibility with external devices, and meeting the specific demand of customer segments.

1.8 Assessment for 3D Printing In Medical/Dental Markets by Geography

This report does not purport to be able to discuss geographic implications on 3D printing in the medical and dental applications field in any detail. Information on the state on 3D printing in emerging and developing markets is hard to come by, and even harder to verify. Most of the companies we interviewed were much more focused on applications of these technologies in North America and Europe.

Of the dental companies we interviewed, many were looking at the U.S. dental industry as their major source of growth over the next ten years. Production capacity for many dental products in Europe seems to be large enough to adequately address future demand.

Meanwhile, only 10 percent-15 percent of dental offices in the U.S are currently using digital dental equipment. There is also enough access to capital in the U.S. for dental labs and offices to fund these new expenditures. There are many opportunities to

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provide smaller dental labs and offices with 3D printing equipment that can improve their efficiency and reduce costs.

The U.S is also being looked at as a major growth area for 3D printer related medical products and equipment, given the amount of U.S. healthcare expenditures, as well as the U.S.'s insistence on receiving the best possible healthcare, regardless of the cost. The U.S. medical market could become an important driver of demand-customized 3D-printed parts over the next decade.

The outlook for 3D printing in emerging markets is much more muddled. 3D printing has the potential to bring better healthcare by obviating limitations such as insufficient infrastructure. For example, a locally or regionally located 3D printer could speed up treatment time for a region and alleviate supply strains for medical or dental products.

This seems to be especially true for dental 3D printers, where one metal printer could supply nearly 90,000 patients with implants annually by our estimates. Even less expensive dental model or temporary 3D printers could help bring a quality of dental care to countries where it is sorely lacking. These benefits alone could be large enough to encourage foreign governments to invest heavily in 3D printing technology heavily over the next ten years.

But it is not that simple. After considering how to maintain and supply an expensive, industrial 3D printer, it is harder to imagine rapid adoption of 3D printing technologies by these countries. Many of these countries may choose to focus on providing lower cost dental and medical solutions to a larger citizen base before even considering investing in state-of-the-art 3D printing technology. Especially in an economic environment where labor cost is low and education is inadequate but improving, more conventional dental care solutions may be more effective.

Still, there are signs that many of the large 3D printing companies are expecting future growth in emerging economies. Many companies like 3D Systems, Voxeljet, and ExOne have announced they are opening sales or service centers in many of the BRIC countries. These events may signal a perceived demand for 3D printers in these countries.

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