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P U B L I S H I N G

3D Printing in Dentistry

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Question: Dental 3D printing has been around since at least the late 1990's. Considering how big of an interest the mainstream dental industry has taken in dental 3D printing in the past two years, what's changed all of the sudden? What are the factors that have seemingly accelerated the interest levels and market potential in the very recent past? Or is that all just a misconception?

Scott Dunham: Well as we all know 3D printing in the dental industry has always been tied to a concept called digital dentistry, which is sort of a loose term that basically just refers to the integration of digital technology in an industry that has for most of its history relied on analog processes. Although there are technical elements for the 'front office' of a dental practice that fall under the concept, what we're really talking about are dental scanning and digitally controlled dental fabrication systems. Obviously, the acceptance of such digital production systems has been growing steadily over the last several years. Digital dental milling systems have been around for probably twice as long as true dental printing systems.

But to address your question, first off, I agree. I think that there's been an interesting and pretty abrupt change in the reception for printers by the mainstream dental industry. Going back five or ten years ago, you didn't see 3D printers represented so heavily –or at all in some cases –by the big names in dental technology and supply. Today, just about every single dental solutions and supply company has some sort of distribution agreement or even their own corporate 3D printer brand or product line. That's really happened in the last two years. What changed is probably nothing more than a growth in the awareness of what today's printers are really capable of, along with better access to the technology through lower costs and greater competition.

Also, for a very long time, dental 3D printers really were for one thing – printing casting patterns so that metal-based dental prosthetic making could become more efficient and repeatable. Then came the printing of dental models directly from a digital impression. Those two applications in a vacuum are no doubt valuable, but they're not revolutionary. They are an adaptation of technology to the existing dental industry workflow and structure to make those areas more efficient, but they aren't inherently disruptive. Today, dental printers are producing real dental appliances and devices like temporary restorations, clear dental aligners, bite splints, bonding trays, and a whole lot more. Often all of these things are created from the same machine using different materials. And increasingly they're able to do so not just in the laboratory, but directly in the dentist's or orthodontist's office. We're ratcheting up the disruption factor, and it didn't take *too* long for the big dental players to see that.

The result is that we believe now that dental 3D printing is not only cemented into the future of the industry, but that the growth potential has significantly increased beyond already very positive outlooks from just a year or two ago. Right now we are projecting around \$3.5B by 2027 in dental printers, materials, and software sales alone. If you take into account dental printing services carried out by laboratories, production centers, and a select few dental 3D printing service providers, you're looking at nearly \$10B in total revenues by 2027. That's *bigger* than any single other vertical segment adopting 3D printing that we've studied.

Question: Okay, so to your point there about disruption, looking at the newest published study *3D Printing in Dentistry 2018*, it looks like there are a lot of potentially interesting scenarios that could play out over the next decade or so which might result in both major dental industry change and simultaneously major growth for dental printing technologies. Walk us through a couple of those scenarios, and what the implications might be of them coming to pass.

Scott Dunham: Definitely. There's a lot to unpack there so let's just focus on one area that I think is probably going to have the biggest overall potential impact. One of the most interesting areas of resin-based dental 3D printing is the printing of what the industry calls micro-filled hybrid resins, which are your basic UV curable resin filled about 50 percent by weight with inorganic composite materials. The result when printed is a prosthetic tooth that is both FDA approved for up to a year in the mouth, and is highly aesthetic to compete with traditional non-metal dental composites or milled ceramics. These printable resins have been around for many years, back to at least 2010, but really their use has only recently begun to gain much traction.

The idea behind these long term temporary dental prosthetics made via 3D printing is that a dentist could use a printer right in his office to provide a very high quality temporary restoration for a patient the same day that they come in for an appointment. The same concept as an in-office milling machine, essentially. In reality, this idea hasn't really truly come to fruition in a big way yet because the total process requirements of printing these temporaries generally won't allow a dentist to really be able to turn them around in a couple hours. So most of the time this is done still in the lab, and at that point a lot of the value proposition is lost. But what's interesting is that, by all accounts including academic study of the process, the printed teeth that result have a lot of superior qualities to the traditional temporary solution.

I bring all this up because what we and many others involved in R&D in dental printing believe is on the near horizon is kind of extension and perfecting of this same concept, except instead of for a long term temporary tooth, for a truly permanent restoration. The ability to print a crown or bridge that is approved for permanent use in the mouth and can perform with an acceptable level over a long period of time is one of those scenarios that has huge implications. We probably don't have time to really go into all of them, honestly. But I'm pretty confident that such a capability would provide a much more compelling solution than the current practice of milled zirconia, with benefits ranging from automated and software controlled tailoring of the shading and aesthetics of the tooth, to vastly improved total productivity, to reduced waste, to superior fit and patient outcome.

Assuming such a solution hits the market in the next two to four years –which believe me is a very good possibility at this point given what we're seeing in the printing of long term temporaries –would probably ultimately be the end for milling technologies in the dental industry within ten to fifteen years.

Question: So what happens if the 3D industry is not able to produce a viable and accepted solution for permanent restorations to compete with milled dental ceramics?

Scott Dunham: Well, in that case, you'd just see a continued extension of the past two years of growth where printers and milling systems continue to be used alongside one another in both the laboratory and the dental office. Milling systems would remain the leader for producing metal-free permanent restorations, while 3D printing would handle just about everything else. The growth of printing in dentistry is not at all dependent on the ability to print a permanent non-metal restoration. Most of the world still utilizes metal-based restorations outside of the U.S. and Canada, and metal additive manufacturing systems are already set to take over that market from milling technology, and in-fact are well on their way today.

Don't get me wrong, dental mills are still used for a lot of the same devices that printers are used for and probably will be for the foreseeable future. But I think the advantages of printing to produce things like models, orthodontic devices, surgical guides, denture components, metal restorations and implants components, and a whole host of direct custom elements are beginning to speak for themselves.

Question: One of the biggest emerging trends in the dental 3D printing industry according to the report, which we do see born out in the real market in a directly observable way, is the shift, or perhaps the potential for massive growth, to 3D printing technologies in a clinical setting. I think there is a lot to unpack in this trend alone. What's happening to

empower this? And maybe more importantly, what's the potential impact from the perspective of the broader dental industry as well as the 3D printing industry?

Well the first part of that question is an easy one. What's powering the infiltration of printers into the dental office? Low cost printers finally being coupled with certified dental printing resins and a halfway decent supply chain and support network. There's a number of companies chasing this nowadays, but let's not kid ourselves, Formlabs can pretty much take the credit here. 3D Systems kind of danced around it with the ProJet 1200 for the last several years but they never got the marketing and vision right. But now there are a lot of companies going after it because of what Formlabs catalyzed in the dental community, and honestly everybody will benefit. Your companies like EnvisionTEC which have been selling some dental printers at just under \$10,000 for years will probably see bigger demand for those product lines.

Really the potential impact for 3D printing in the office is massive. For a long time the only real viable customer for the dental printer was a laboratory –and while we're at it let's not undersell the importance of the lab market, but for the sake of discussion consider this: most estimates put the global number of dental laboratories somewhere between 75,000 and 100,000, but nobody truly knows the exact number. We think it's somewhere in the middle. That's a very nice little market for 3D printers, especially when you consider that labs live on volume. But by comparison, there's somewhere right around ten times that amount of various dental practices in the world. So if you open up that part of the industry to printers, then all the sudden you went from a nice respectable market opportunity for a dozen or so relatively small providers of dental print technology to a much, much larger picture.

When you think about it, printers compare very favorably today for producing stuff that makes sense to use right in the office. Stuff like models, bonding trays, custom impression trays, surgical guides, etc. As long as the industry can provide a justifiable reason to invest in the ability to print those things in the dental office, then for many it then just becomes an issue of “do I want to do things the way I've always done them,” or “do I want to provide a higher level of innovation and care to my patients?”

Question: Perhaps the most compelling value driver for 3D printing technologies in the dental industry today is what you touched on earlier in the opening question, which is the great breadth of application for which additive technologies can be applied to in dental care. Many of these applications are areas where competing processes like milling or

analog production just don't make sense anymore. What are some of the best long term specific applications that you see growth in?

Scott Dunham: Some of the things we're printing today in pretty high volumes probably won't last if the ultimate goal of the industry is to go digital. So it's not entirely all rosy and greenfield growth opportunities for printing. The original dental printing application, which is casting patterns for various metallic dental devices and restorations, is probably eventually going to begin to decline because using *either* milling or printing we'll be able to fabricate things directly. I would argue that printed casting patterns continue to survive and thrive today mostly because there a lot of dental professionals out there who just aren't entirely sold on the capabilities of milling, but still want to introduce greater efficiency into their analog workflow.

Stuff that really is going to thrive, though, will definitely be the clear aligner market which is inherently tied to printing. The amount of growth that the leaders in clear aligners have seen in the past five years is really impressive. And now there's quite a few more startups in this area trying to come in and capture share. And think about this, if somebody like Align Technologies is providing a clear aligner solution to a few hundred thousand patients, that translates to tens of millions of 3D printed components because essentially everybody in this market prints a forming tool which is then vacuum formed to make the aligner. Each patient needs somewhere between 20 and 40 individualized aligners to correct their teeth during a treatment cycle. You do the math there and that's a nice area all its own.

What will be interesting, and again something that I am sure will come to pass, will be a total rethinking of that whole production cycle when printers can print the aligners themselves directly. We're already printing FDA approved bite splints. There isn't a huge amount of difference between a bite splint and a clear aligner from an engineering perspective.

Question: Let's close with a big conceptual type of discussion or idea where we draw some parallels between industrial additive manufacturing markets and the broader healthcare printing segment. At this point we've all heard of this term "design for additive manufacturing" where cost barriers can be shattered and functionality can be radically increased by redesigning an entire part or system based on an additive fabrication process. Maybe for a relevant example, let's use the patient-specific orthopedic implant idea. Is there any of that same industry-changing potential for the application of print technologies in dentistry? Or is the long term play just taking all of these well established dental treatments and providing a superior method of making them via additive production?

Scott Dunham: Thus far we haven't really seen what you're describing in terms of major commercial impacts. In dentistry, there's essentially always existed a patient specific solution through impression taking and casting. It's just that that solution is really time consuming, laborious, and hard to get perfect without digital control. The same concept applies to lots of other dental treatments where we see printing having an impact, so yes the current play is to leverage printing to introduce value into the same treatment processes.

Stepping out into some more radical ideas, though, yes I believe there is also some opportunity to really shake things up in dental treatment by utilizing additive fabrication. Probably the most likely area is in the area of implantology, which is one of the fastest growing treatments in the global dental industry. That's where when somebody needs to replace a tooth, you affix the tooth to the jawbone just like a real tooth would be, rather than just fixing a fake tooth to the surrounding existing teeth or using a set of full dentures which are popped in and out of the mouth.

There are companies out there which are experimenting with what would be considered a somewhat radically different implant system which makes use of 3D printing. The traditional implant design uses a screw that is drilled through the gum into the jaw bone, and then on top of that there's something called an abutment which joins the actual prosthetic tooth to the screw.

And, if you consider that the ultimate goal should be to use technology to recreate the human body's own natural structures as closely as possible to achieve the best treatments, then what may ultimately begin to happen is a rethinking of the design of implant based treatments. There's already at least one company out there that is marketing a system in which an entire metallic prosthetic tooth –roots and all –is placed into the gum rather than relying on a multi-part mechanically adhered system. The idea being that you can make the metallic implant roots in a porous manner that will encourage the residual jawbone to grow into the structure to cement it naturally and permanently. That's a pretty radical shift in methodology for implants compared to the traditional solution.

Overall, though, I think the industry will tend to go more of the route of optimizing existing treatments and workflows. That's what we're seeing now, and as mentioned previously

it's expected to result in a huge market opportunity. But you can't count out the ability for additive processes to totally change the paradigm like in the example of implantology.

If you are interested in learning more about Scott's latest report on 3D printing and dentistry, please visit the SmarTech website for more information.

[3D Printing in Dentistry 2018, An Opportunity Analysis and Ten Year Forecast](#)