1/2 point CDT documented scientific credit. **See Page 42.**

By Jamie Stover, CDT

3D Printing

Technology and Fabrication of Models In-Lab

Technology continues to shape the way dentistry is done. Every aspect of the restorative process has changed, from the way a dentist acquires an impression of the patient's mouth to the fabrication methods utilized in the dental lab. The transition from labor intensive, hands-on fabrication methods of alloy-based restorations to CAD/CAM design and the latest all-ceramic materials has yielded strong and esthetic monolithic restorations in less time and at a lower price. Dental labs also have viable options for producing models digitally in-house versus purchasing CAD/CAM models from another lab/manufacturer or fabricating traditional stone models.

The two basic forms of technology utilized to fabricate restorations and models today are additive (3D printing) and reductive (milling). This article discusses the common types of 3D printing technology utilized in dental labs and illustrates digital model fabrication from a 3D printer with actual cases and different restorative applications.

Impression Scanning
(Above) Image shows impression scanning at Ziemek Laboratories using the 3shape D2000 digital scanner (www.3Shape.com). Some traditional PVS impressions are scanned and converted to a .dcm digital file and transferred to the 3Shape Model Builder and restoration design software. Models are printed from the Carbon M1 printer instead of being fabricated from stone.

When dental labs create restorations from digital impressions, the workflow options are dictated by the restorative material prescribed. Monolithic restorations such as full zirconia, full gold, and e.max CAD crowns can be fabricated without a model; designing, milling, and finishing the restoration from the digital impression file can be accomplished accurately and with consistent fit. For layered restorations and more complex cases labs often choose to use a model to establish the proximal contacts and occlusion and to achieve specific esthetic results (treatment planning). Implant cases are manufacturer and platform specific which can dictate where models and parts are sourced. Outsourcing model production has inherent challenges such as quality/consistency, cost, and delay in production while waiting for the models to arrive, which can take up to 4-5 business days. Printing in-lab allows the lab to fabricate models quickly, for less than the cost of outsourcing, and opens up other possible workflow options such as transitioning more cases to printed models versus stone by scanning the PVS impressions.

3D printing basics and overview

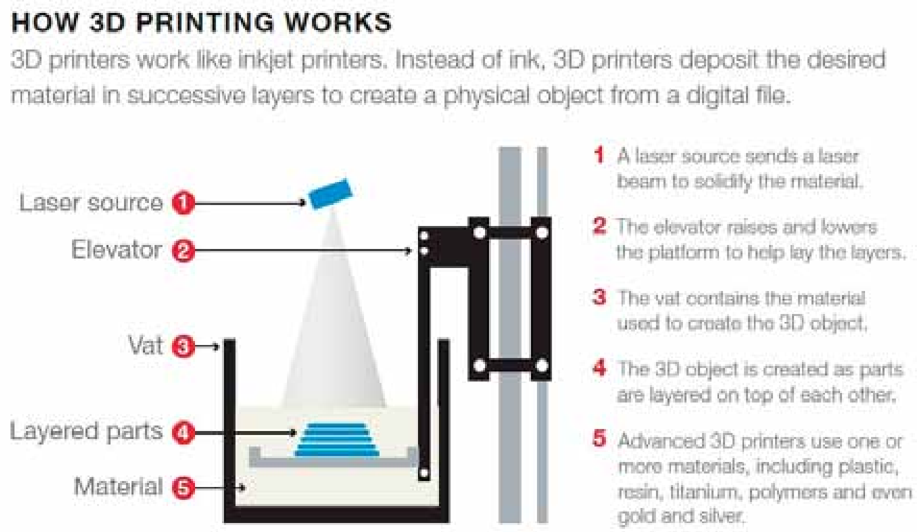
Although 3D printing is considered a relatively new form of manufacturing technology in the general public and consumer awareness, it's been around for over 30 years. The technology is related to the first inkjet printers introduced in 1976; the concept derived from the desire to print materials other than ink. Charles Hull is credited with inventing Stereolithography in 1984,[1] which is the process that enables a 3D object to be printed from a digital file. Industries now utilizing 3D printing processes include automotive, manufacturing, aviation, aerospace, dental and medical. NASA is printing parts for its J-2X and RS-25 rocket engines that will power the Space Launch System (SLS), and 3D printing in the medical industry is offering some very exciting possibilities for the future, from customized 3D printed prosthetic parts to printed organs and tissue.[2] Dental professionals are purchasing small desktop printers to print models, surgical guides, etc. in-office and this will become more common as the printer prices come down and available materials increase.

"3D printing" is a term that covers a broad spectrum of technologies that varies in the exact way that the end product is produced but shares basic principles. The most common currently available printing technologies for dental applications and examples of printer brands utilizing each are:

- Stereolithography (SLA): Envisiontec, Formlabs, 3D Systems
- Material Jetting Processes: PolyJet- Stratasys, MJP- 3D Systems
- Selective laser sintering (SLS): EOS, Formlabs
- Digital Light Processing (DLP): Envisontec, Bego, Asiga,
- Continuous Liquid Interface Production (CLIP): Carbon (the newest form of this technology applicable to our industry)[3].

(See Figure 1.)

Figure 1
Diagram showing the basic components of a 3D Printer.
Image from: A Brief History of 3D Printing http://individual.troweprice.com/staticFiles/Retail/Shared/PDFs/3D_Printing_Infographic_FINAL.pdf



Is it the right time to print in-lab?

In order to answer this question a lab should refer to their ability to navigate the CAD/CAM landscape, to accept/process digital impression files, to increase productivity and efficiency utilizing the latest CAD/CAM technology and to guide and provide dentists with digital case support of all kinds as its "Digital IQ." Assess your lab's Digital IQ and current CAD/CAM infrastructure/staff. Printing models and other materials in-lab requires a dedicated team of CAD/CAM technicians to receive the digital impression files (and/or scan PVS impressions), process them accurately, build the models in CAD/CAM software, operate and maintain the printer, etc.

There are many factors to consider when selecting a 3D printer: accuracy, build speed, size of the build table, reliability, price, life expectancy of parts, required service and maintenance, material options and more. Calculating what is spent monthly on printed or milled models and other outsourced printed products is a good place to start when calculating ROI but is not the only factor. Could you make a payment on a lease or a loan for a printer with the dollar amount currently spent on purchasing outsourced models? There are many printer models on the market that accommodate almost any volume of work and budget. Modular systems are also available that allow you to add additional printers as your volume grows instead of purchasing a unit that provides more capacity than needed for your current volume and plans to "grow into it."

The majority of printed models are purchased for cases originating from digital impressions. Currently the number of dentists with impression scanners is on the rise, yet varies greatly from lab to lab. At our laboratory the number of digital impression cases received daily is over 30 percent while at other labs it may be more or less, which also means the dollar

The majority of printed models are purchased for cases originating from digital impressions.

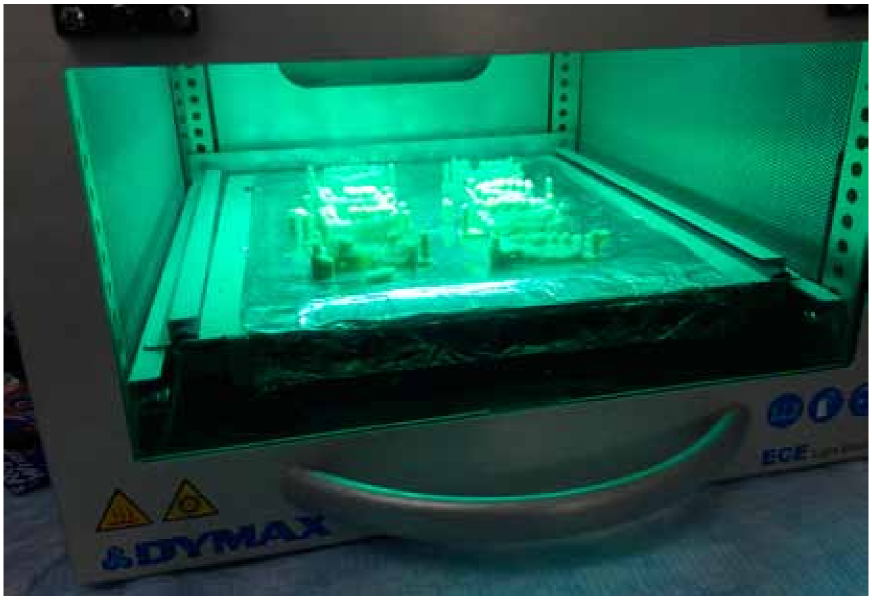
amount spent on purchased models per month will vary greatly. Will you need a printer dedicated to printing one material for models, or will you be printing other materials as well? Will you be able to print everything daily with your current volume of work and forecasted growth?

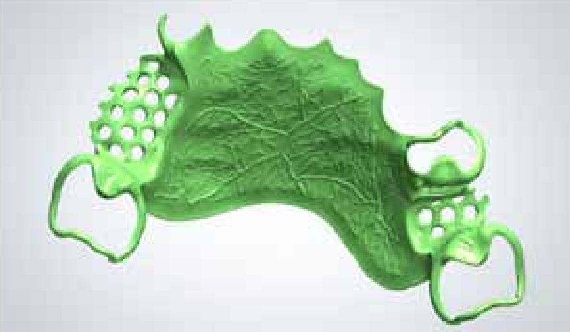
The number of team members dedicated to the model printing process depends on the volume of cases and the lab's Digital IQ. 3D printed parts require a post-processing procedure and while the process varies, it always involves thoroughly cleaning the printed parts of uncured resin and often also involves some final curing of the material with U/V light, as well as articulating the models. This hands-on time (technician wage) has to be factored into the true cost of printing in-house, along with the time it takes a technician to build the models in CAD software, load and unload the resin material for each print job, the cost of the materials, and the monthly payment/cost of the printer. Most 3D printer manufacturers/distributors have spreadsheets that allow you to plug in your lab's unique criteria in order to determine ROI and which printer model is best suited. When using one of these ROI calculators make sure you use the correct number of operational hours. A lab that is operational 20 hours a day with all 20 hours available to print will have completely different needs than a lab that only has eight hours each day available to print.

Current printing materials on the market include castable wax/resin (copings and frameworks for PFM's, full contour e.max crowns, full gold crowns, partial denture frameworks, etc.). Nightguards and surgical guides, aligners, metal partial frames, denture bases, and more applications are also available, just being introduced to the market currently, or are in development and await FDA clearance for use in the mouth. Purchasing one piece of equipment and utilizing it to produce everything possible in-lab to achieve the maximum ROI seems like a good move, but what happens to your workflow when the machine needs repair and is out of commission for multiple days? Most printer manufacturers have emergency back-up plans to print files for you in the event your printer goes down but this will most likely affect your workflow. Purchasing multiple printers and mills for different materials improves efficiency and builds in redundancy for times a machine is offline.

Part Washing Carbon Models
(Below) Model parts from the Carbon M1 printer are removed from the printer platform and washed twice in 99% Isopropyl Alcohol, once for 3 minutes and again in clean alcohol for 2 minutes before light curing.

U/V Curing Carbon Models
(Below) After models parts are clean, they are U/V cured in a light curing unit from Dymax (www.Dymax.com) for 6 seconds x 2 on each side. Models are then matched to case pans and restorations for finishing by technicians.





Partial Framework Design
(Above) Image shows a partial denture framework designed at Ziemek Laboratories using 3Shape's Removable Partial Design software.

Partial Framework SLM
(Below) Image shows the laser sintered chrome cobalt partial framework from 3D RPD on the model and ready for a try-in. (www.3drpd.com)

Another factor to consider is which printing technology to select for model production. A common opinion up to this point when printing models has been the need for a printer with a large build table so each print job yields the maximum number of models. This is due to the fact that to produce accurate models, the print cycles need to be run on a high resolution setting and therefore a lot of time is required per job (sometimes as much as 4-6 hours). Our laboratory (Ziemek Laboratories, Olympia, Wash.) purchased an Envisontec DDP4 printer in 2013 and since then we have utilized it to generate wax patterns for any cast or pressed restoration. When the time became right for Ziemek Laboratories to print models in house, we chose to lease a Carbon M1 printer due to its CLIP technology and ability to produce highly accurate printed parts in less time than other options on the market. This allows our team to run smaller batches of models faster instead of larger batches in longer print cycles. This is beneficial when the goal is to maintain a fluid and interchangeable workflow and to accommodate rush case requests, as models can be inserted into production every hour or so versus waiting 4-6 hours. Also, in the event that a print job fails during production, the number of cases affected is much lower and a large scale disruption to the lab workflow is mitigated. The Carbon CLIP technology differs from the other printing technologies currently on the market as stated in the following excerpt:

"Additive manufacturing processes such as 3D printing use time-consuming, stepwise layer-by-layer approaches to object fabrication. We demonstrate the continuous generation of monolithic polymeric parts up to tens of centimeters in size with feature resolution below 100 micrometers. Continuous liquid interface

Envisiontec DDP-4 Printer
(Left) Ziemek Laboratories' Envisiontec DDP-4 Printer is utilized to produce wax frameworks for casting and pressing. The printer uses DLP printing technology.

Envisontec Print Job
(Below) Image shows a finished print job of copings and full contour crowns (material is WIC-300A by Envisiontec) from the Envisontec DDP-4 printer. A technician will remove the job from the printer's build table and post process.

Carbon M1 Printer
(Right) Ziemek Laboratories' Carbon M1 Printer is currently utilized to produce 95% of the lab's CAD/CAM case models. The printer utilizes CLIP printing technology.

Carbon Print Job 1
(Above) Image shows a model print job finished with the platform (build table) raised out of the cassette (vat of liquid resin) on the Carbon M1 printer.

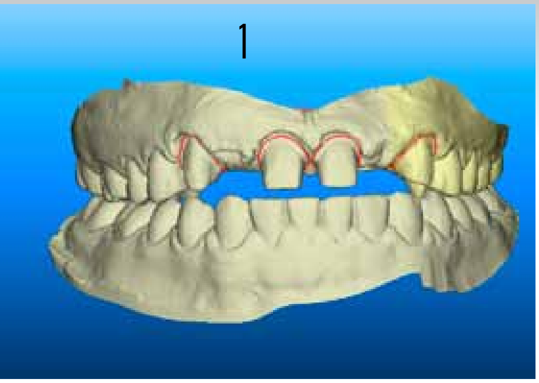
Carbon Print Job 2
(Above) Image shows a close up of the platform with the models and removable dies still attached to the platform with residual liquid resin ready to be removed and post processed.

Adidas Printed Shoe
Image shows the Adidas Futurecraft shoe created in an exclusive partnership with Carbon and features the customizable sole printed on the Carbon M1 printer using the CLIP printing technology. (www.carbon3d.com).

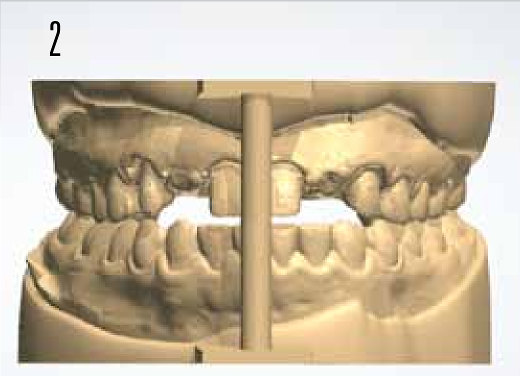
production is achieved with an oxygen-permeable window below the ultraviolet image projection plane, which creates a "dead zone" (persistent liquid interface) where photopolymerization is inhibited between the window and the polymerizing part. We delineate critical control parameters and show that complex solid parts can be drawn out of the resin at rates of hundreds of millimeters per hour. These print speeds allow parts to be produced in minutes instead of hours." -Carbon [4]

The Carbon printer differs from others on the market currently not only because of its CLIP technology but because it is a subscription business model, leasing the printer instead of purchasing it. Leasing expensive hardware has definite advantages versus purchasing a costly new piece of equipment and then attempting to hit the break-even point of productivity versus depreciation over time. A lease agreement allows the equipment to be upgraded when the next iteration comes to market instead of owning a piece of hardware that becomes outdated

CASE 1

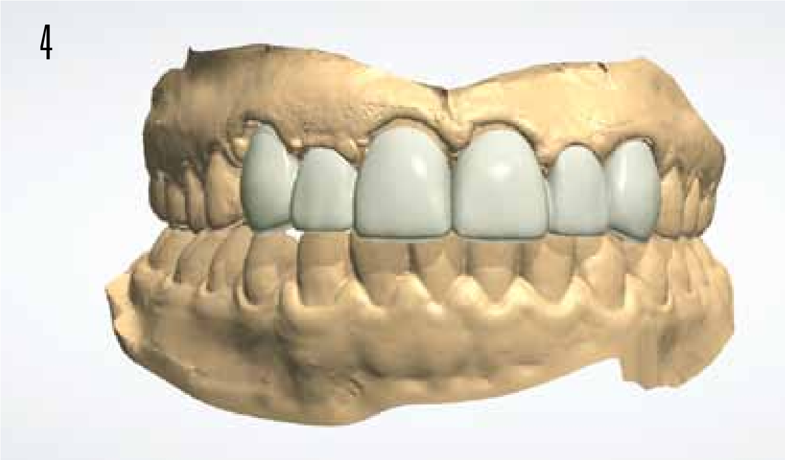


Digital Impression – Image shows the digital impression file from an iTero Element digital scanner for a 6 unit anterior case (www.itero.com).



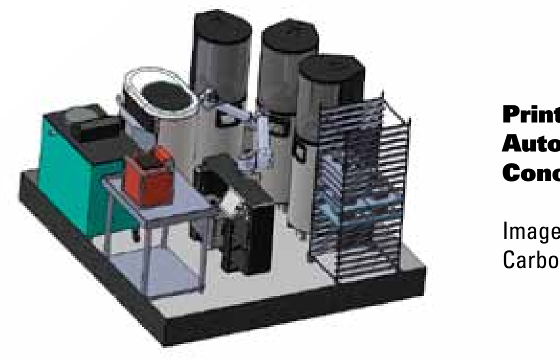
(2) Model Design – Image shows the model being built in the 3Shape Model Builder software.

(3) Printed Model – Image shows the model after being printed in the Carbon M1 Printer and post processed. The holes in the base of the model allow it to be removed from the printer build platform quickly and easily.



(4) Restoration Design – Image shows two 3-unit High Translucency Full Zirconia bridges #6-8 and #9-11 designed in the 3Shape software.

(5) Post-op – Image shows the final restorations seated in the mouth 1 day post-op. Monolithic full zirconia bridges #6-8 and #9-11 fabricated using Noritake Katana STML High Translucency Zr with a strength of 748 MPa (www.katanazirconia.com). Restorations are full contour, no cutback or layering, and are externally stained using e.max Ceram stains and the Ivocolor glaze paste to a shade of A1 incisal and body and A2 gingival (www.ivoclar.com). Photo courtesy of Dr. Bruce Cooper, DDS, Olympia, Wash.



Printer Automation Concept

Image courtesy of Carbon

or obsolete and worth less than when purchased due to depreciation. All scheduled and unscheduled maintenance is also included in the Carbon lease agreement; you pay nothing out of pocket for normal service or repairs.

3D printing technologies will continue to evolve and the development/introduction of new materials and corresponding products with wide-ranging applications will improve the efficiency and quality with which we manufacture items for all aspects of human life. In our industry we will soon see more automation of print production steps in dental labs made possible by robotics as that technology becomes more affordable. Companies such as Carbon and formlabs are introducing automatic part washers which eliminate the need for a technician to clean printed parts with alcohol manually, streamlining production and lowering production costs. These companies and others are designing their printers to interface with robotics so new print jobs can be loaded and finished print jobs unloaded and put into an automatic part washer for cleaning without a technician on hand. This will greatly increase productivity as print jobs can be run around the clock without the need for extra staffing or night shifts.

CASE 2

(1) Digital Impression – Image shows the digital impression file from an iTero Element digital scanner for a 4 unit posterior case (www.itero.com).

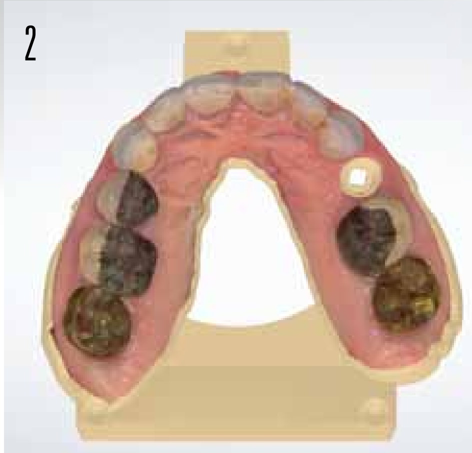
(2) Model Design – Image shows the model being built in the 3Shape Model Builder software.

(4) Restoration Design – Image shows a 4-unit Full Zirconia bridge #28-31 designed in the 3Shape software.

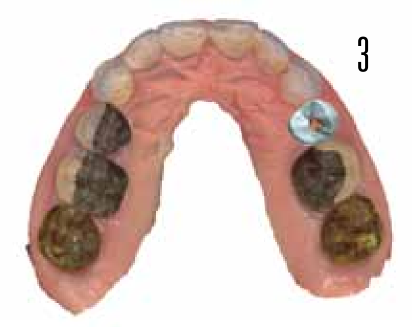
(3) Printed Model – Image shows the model after being printed in the Carbon M1 Printer and post processed. Models are printed with removable dies which provide highly accurate margin replication while maintaining the soft tissue captured in the digital impression. This allows the designers to follow the tissue contour and create a very natural (not bulky) emergence profile for the restorations.

(5) Post-op – Image shows the final restoration seated in the mouth immediately after cementation. A monolithic full zirconia bridge #28-31 was fabricated using Sagemax NexxZr T zirconia with a strength of 1150 MPa (www.sagemax-dental.com). The bridge is full contour, no cutback or layering, and was externally stained using GC Initial IQ Lustre Paste to a shade of 3L1.5 (www.gcamerica.com). Photo courtesy of Dr. Kim Rioux, DDS, Gig Harbor, Wash.

(1) Digital Impression – Image shows the digital impression file from a 3Shape Trios digital scanner for a single unit #12 hybrid screw-retained zirconia restoration (www.3shape.com).



(2) Model Design – Image shows the model being built in the 3Shape Model Builder software.



(3) Restoration Design – Image shows the restoration being designed in the 3Shape software.

(4) Printed Model – Image shows the model after being printed in the Carbon M1 Printer and post processed, and the restoration being finished by the technician. A monolithic full zirconia restoration was fabricated using Noritake Katana UTML High Translucency Zr with a strength of 557 MPa (www.katanazirconia.com). The restoration was stained and glazed using GC Initial IQ Lustre Paste to a shade of Bleach 030 (www.gcamerica.com). The prescribed restoration features a screw access hole on the occlusal surface and is cemented in the lab to a Straumann Variobase titanium hybrid abutment (www.straumann.us) using Multilink Hybrid Abutment cement, shade Opaque White (www.ivoclar.com). It is delivered to the dentist as a one-piece hybrid restoration.

(5) Post-op – Image shows the final restoration seated in the mouth immediately after placement. The dentist torqued the restoration in place to 35 N-cm and filled the screw access hole on the occlusal surface with GC Gradia Direct, shade A02 as a base and shade BW to cover (www.gcamerica.com). Photo courtesy of Dr. Adam Zangrillo, DDS, Madras, Ore.

In my opinion this technology will become as commonplace in the dental industry as inkjet printers are for office use currently. It is up to each individual laboratory to decide when to adopt and exactly how to utilize this amazing technology and meld it with the time-tested knowledge and techniques so crucial to our industry. The possibilities are virtually limitless and very exciting. **JDT**

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About the Author

Jamie Stover, CDT, is the Chief Operating Officer of Ziemek Laboratories in Olympia, Wash. Jamie utilizes over 18 years of experience at the bench as a dental lab technician to manage and oversee all daily operations at Ziemek Laboratories. Jamie has written numerous articles for national dental publications including Inside Dental Technology, Dental Lab Products, Inside Dental Assisting, and Dental Products Report. Jamie is a member of the Straumann Speaker Bureau, he is on the team of professional contributors at Dentalcompare.com, is a Special Section Editor at Inside Dental Assisting, and a member of the Dental Technician Alliance of the American College of Prosthodontists.

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