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In-house 3D printing – a new link in the digital production chain

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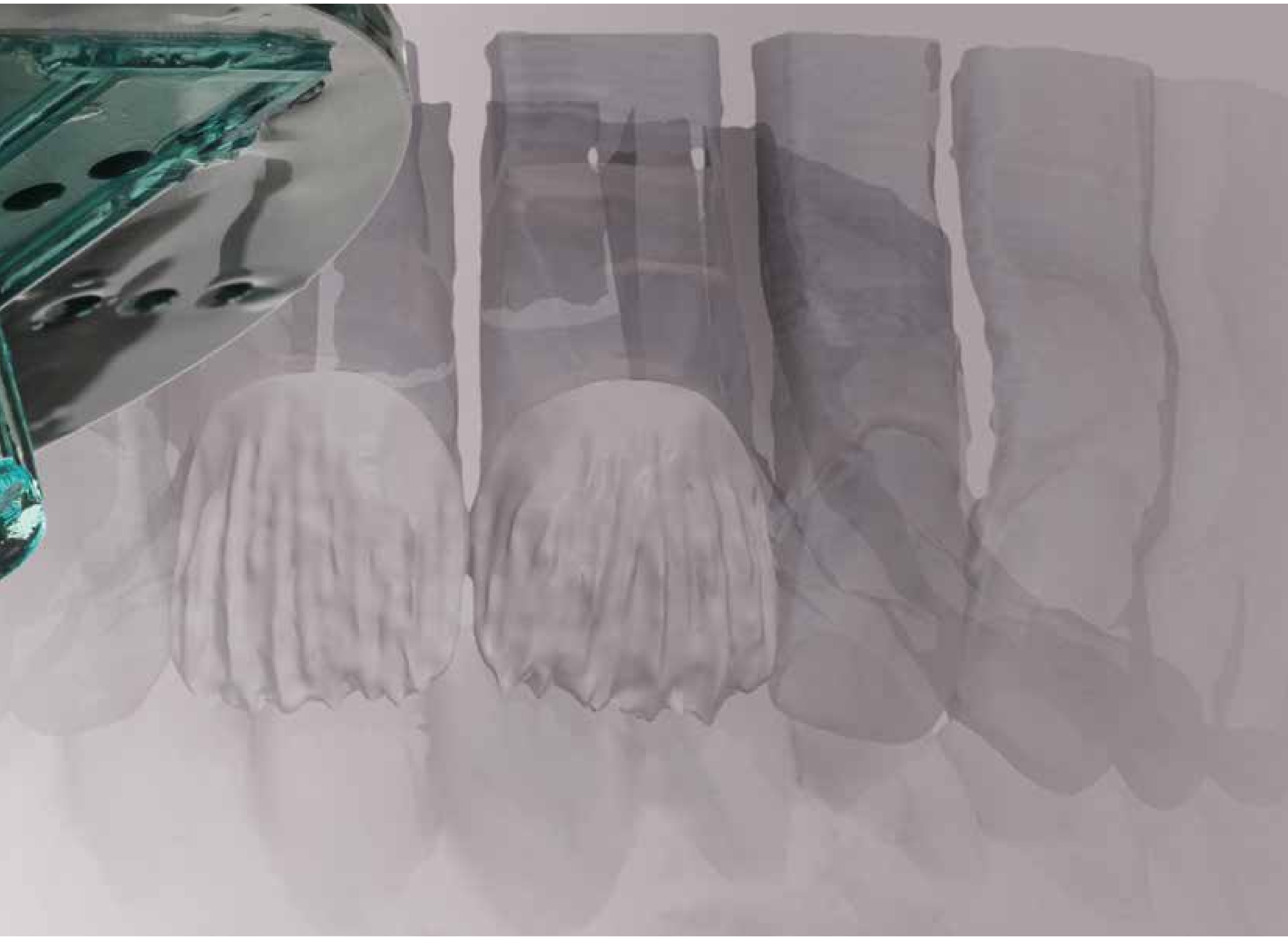


Sometimes the future starts there where you would not expect it, for example right in the middle of the conventional – "Do it yourself". Structural change within dental technology started with CAD/CAM and with innovative materials such as zirconia, but that was quite a few years ago. A new manufacturing technology – 3D printing – has now become available. This article describes, from the perspective of a lab owner, how 3D printing can be usefully integrated into the treatment procedure and laboratory workflow. The author also explains how 3D printing is changing the production process in the laboratory and what the advantages are for the dental technician.

KEY WORDS

- 3D printing
- Additive process
- Bite splint
- Surgical guides
- CAD/CAM
- CAD/Cast frameworks
- Custom impression trays
- Models

01 & 02 Examples of 3D printing using Bego's Varseo: non-sawed control model and custom impression tray. These applications can be produced very precisely and in very good quality. Here the additive production technology has advantages over subtractive processes

For some time now, the range of production technologies in the dental laboratory has been augmented with an additive manufacturing method: 3D printing. Modern 3D printing methods define new approaches for the dental workflow. It is thanks to innovative equipment with a reasonable price-performance ratio that the tendency in 3D printing is back to local production in the lab. For example, Bego's Varseo 3D printing system can process a great variety of materials and offers ease of handling (semi-automatic) at affordable cost.

For dental laboratories, this is the threshold to future technologies with are predictable high-quality results for known and novel prosthetic indications. This also paves the way for business activities that we previously had to cede to third-party providers, such as the production of surgical guides for navigated oral implantology (guided surgery). Essentially, 3D printing cannot be compared to CAD/CAM milling but must be regarded as a separate and new technology.

Additive beats subtractive

3D printing is considered an efficient manufacturing method, because the production of the component is additive in nature. The amount of material used is essentially just what is needed for the component itself (disregarding the few support structures for a moment). This means that the dental laboratory now has a new technology at its disposal – in addition to subtractive manufacturing – that can create objects within a geometry from a wide variety of materials with high precision – a perfect complement to the CAM milling unit. Many solutions are possible with 3D printing, with higher precision and at lower cost than with manual production (Figs. 1 and 2). These include splints or surgical guides, i.e. long-span structures, where milling can create distortions and produce tension. Here 3D printing is clearly superior.

Basics of 3D technology

Like a milling unit, a 3D printer requires a digital file that contains the information for the component to be printed. This file contains a three-dimensional design (e.g. the STL data of a bite splint) that is converted by the printer's software into two-dimensional, horizontal slices (layers) and fed to the 3D printer core. During printing, the 2D layers are stacked one upon another to create a three-dimensional object. The principle is exemplified by the familiar 3D puzzles of designs such as the Eiffel Tower or the pyramids of Giza.

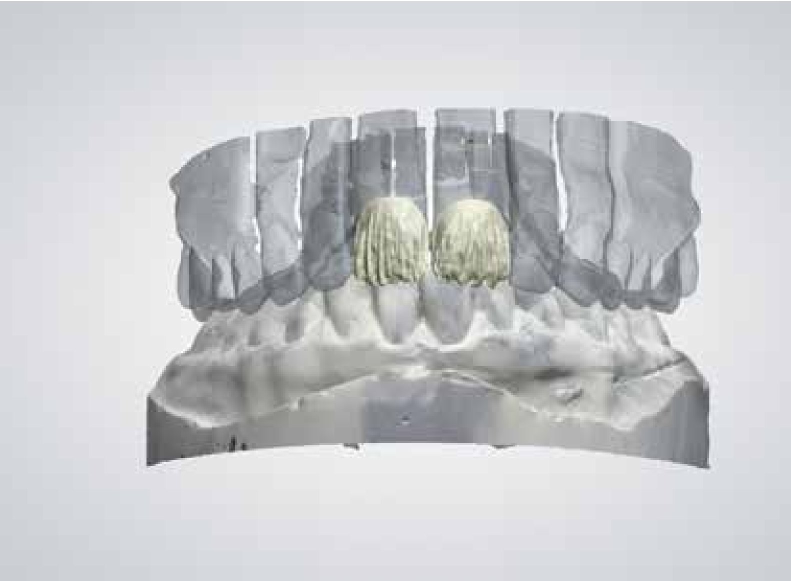
Multiple production methods are subsumed under the designation of 3D printing, a collective term covering quite diverse technologies. They have in common that they are based on the principle of rapid prototyping (also called rapid manufacturing). The following section lists the most common ones.

PolyJet technology

This technology comes closest to how an inkjet printer operates. Like inkjet printers, PolyJet printers have a print head; however, instead of ink, the print heads deliver an adhesive or a curable liquid photopolymer. There are two variants of this technique. For the first variant, an adhesive is added to 2D powder layers that are applied to a build tray by a roller, one at a time. For the second variant, a liquid photopolymer is applied to a 2D build tray (X and Y coordinates) and then cured by means of a light source. Each cured layer lowers the build tray (Z coordinate), incrementally creating the 3D object, which, conversely, gradually grows upward.

3D printing with powder

3D printing with powder is commonly known as selective laser sintering (SLS) or selective laser melting (SLM). In SLS, the powdery raw materials are applied in layers and compressed into a 3D object by a laser. The



03 & 04 An example of a CAD/Cast framework. Two ceramic veneers are virtually designed in the 3Shape software (version 2015) and manufactured by 3D printing from a special castable resin. The right image shows the removal of the printed objects from the cartridge

production process is generally carried out under pressure and in the presence of heat. SLM works on the same principle, except that it uses metal powder incrementally fused locally in layers using a high-performance laser (metal 3D printing).

3D printing with molten materials

If the material to be built up in 3D is already molten, the process is called fused deposition modelling (FDM). Its principle is similar to that of hot glue gun from the hardware store. The method can only process materials that become soft on heating (waxes or thermoplastics). The print head has a hot nozzle into which the raw material is fed. On heating, the material melts and emerges on the other side of the nozzle in liquid form. A cooling device stabilizes the material, which – as in the previously described technologies – is applied continuously in horizontal layers.

3D printing with liquid materials

One example of printing with liquid materials is stereolithography (SLA). The SLA method is the first method that was devised for 3D printing. The object gets its shape in a vat filled with liquid resin (photopolymer). This resin cures selectively in pre-defined positions under UV or laser light. The individual layers of the 3D model are projected onto the surface of the liquid material by means of LED light or selectively exposed to a laser. Each layer solidifies and connects with the object on the underlying movable printing bed. A mechanical arm then moves the object upwards by the thickness of one layer, and liquid material once again starts collecting below it, so that the next layer can be projected.

Two technologies have proven to be particularly suitable for the dental industry, namely the SLM and the SLA technologies. The SLA technology is the foundation of additive manufacturing. Bego's Varseo 3D printers use DLP technology, which is a state-of-the-art exposure method.

The great variety of available 3D technologies allows for the use of materials of which we may not have thought yet but which will start appearing in the near future – presumably at a phenomenally fast rate. Therefore, dental laboratories should investigate additive manufacturing as soon as possible. The technology is now sufficiently mature. Dentists and their patients will expect more and more of us in the dental laboratory along with the broader portfolio of materials available (Figs. 3 to 8).

Using the Varseo 3D printer in everyday laboratory procedures

From a macroeconomic point of view, 3D rinting is a game changer in the industrial value chain. Dental technicians stand to gain from 3D printing. Our own laboratory has been working with the Varseo printing system for some time now. We believe that this 3D printer with its favourable cost-benefit ratio is the first viable 3D printing device for everyday laboratory use.

But the establishment of the 3D printing technology does not mean that proven CNC production units will disappear from the dental lab. Rather, we will be able and expected to offer an increasing range of computer-aided manufacturing processes. Dental technicians will have to learn to "think hybrid": the choice between milling/grinding or printing is determined by the indication. For example, zirconia has become established as a very economical millable material that we do not want to do without. The 3D printer, on the other hand, is used to realize objects that can be milled only with great effort were not at all, such as bite planes, surgical guides or metal denture frameworks.
What is so convincing about the Varseo is the range of materials it can work with. There is

05 - 08 After cleaning in ethanol (96%), the printed objects are placed on the model. Subsequent steps follow the normal protocol; in the case presented here, the veneers were pressed in ceramics

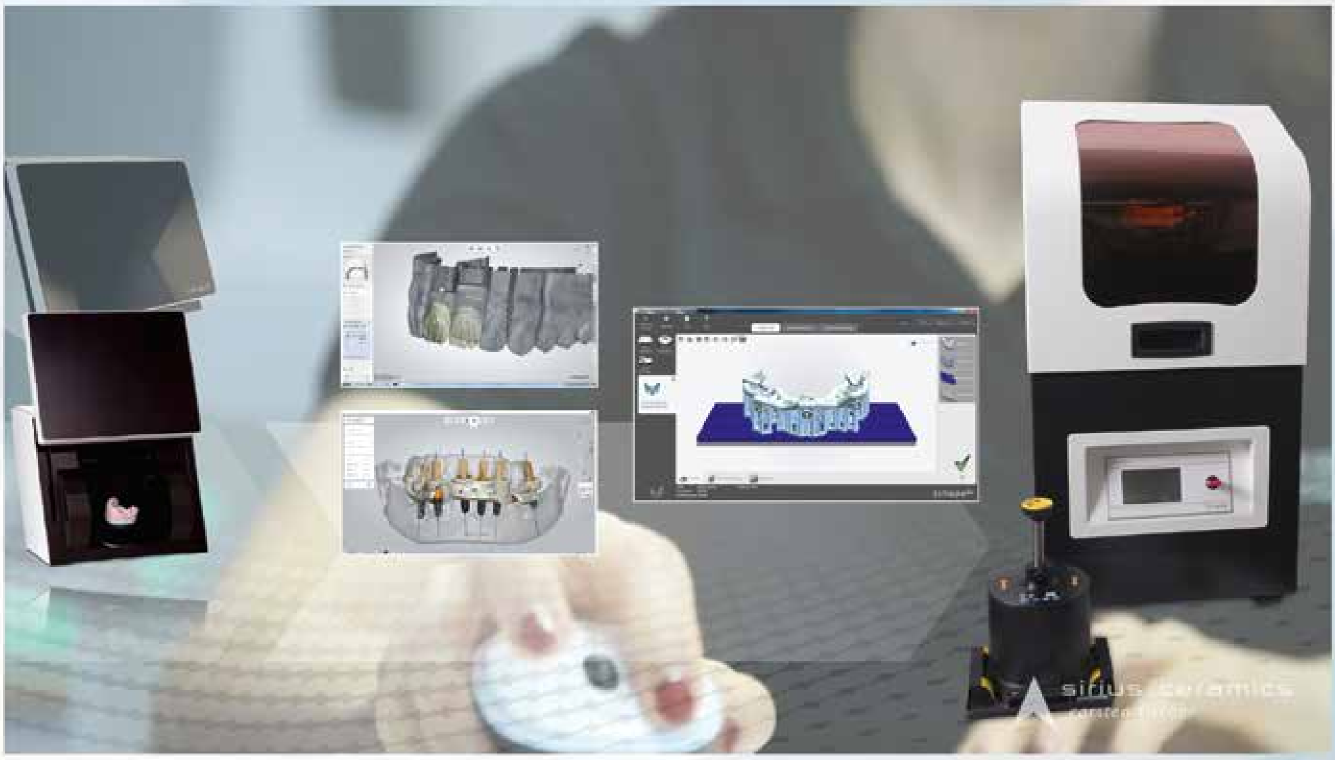
currently a choice between five special resins for different applications. It is expected that more resins – and more applications – will follow in the near future. The major selling point of the Varseo 3D printer is its ease of use. Its developers have created a one-button system that can be used intuitively in just three steps. A cleverly engineered cartridge system makes changing materials uncomplicated. A separate cartridge should be used for each material, so it is recommended to purchase multiple cartridges. As the cartridges are sealed, the risk of contamination and any unnecessary exposure of the resin are reduced to a minimum.
The printer uses open STL files and is therefore compatible with all dental software solutions. Data transfer can be transferred easily via a USB stick, or the system can be integrated into the laboratory network for even greater convenience.

The Varseo is a classic semi-automatic unit, which is something we particularly like about this device. The dental technician is fully involved in the process and remains an important part of the production chain, which is proof that today's dental technician continue to be irreplaceable even when working with 3D technology.

Overview of current Varseo indications

- Bite splints
- Surgical guides
- CAD/Cast frameworks (crowns, bridges, partial dentures)
- Custom impression trays
- Models

In our laboratory, the technology is used for the production of surgical guides, splints and CAD/Cast frameworks, although we increasingly use the Varseo printer to produce impression trays. At this point, it may be justified to ask how CAD/CAM-based fabrication of an impression tray compares with the expense of a CAD design. But the dental technician's job does not necessarily become much more attractive if apprentices keep having to grind trays. It is so much more convenient for everyone involved to set up the printer the night before and to retrieve



09 Laboratory workflow integrating 3D printing with the Varseo 3D printer: scanning, CAD, CAM and manufacturing (3D printing)

the finished tray the next morning. Modern technology makes our profession more interesting – not only for apprentices.

The 3D printing workflow

We did not need to make any changes to the design process of the existing CAD/CAM equipment. Our laboratory uses use the 3Shape system for implementation. Digital acquisition of the situation (3Shape scanner) is followed by the design of the object in the DentalDesigner software. A so-called build job must be created for the CAM, which can be achieved with the CAMbridge software module. The design is then configured for 3D printing based on the output file and transferred to the printer (Fig. 9). Since the design data are stored, the object can always be reprinted, which can be useful for temporaries or splints.

Preparing a splint for 3D printing

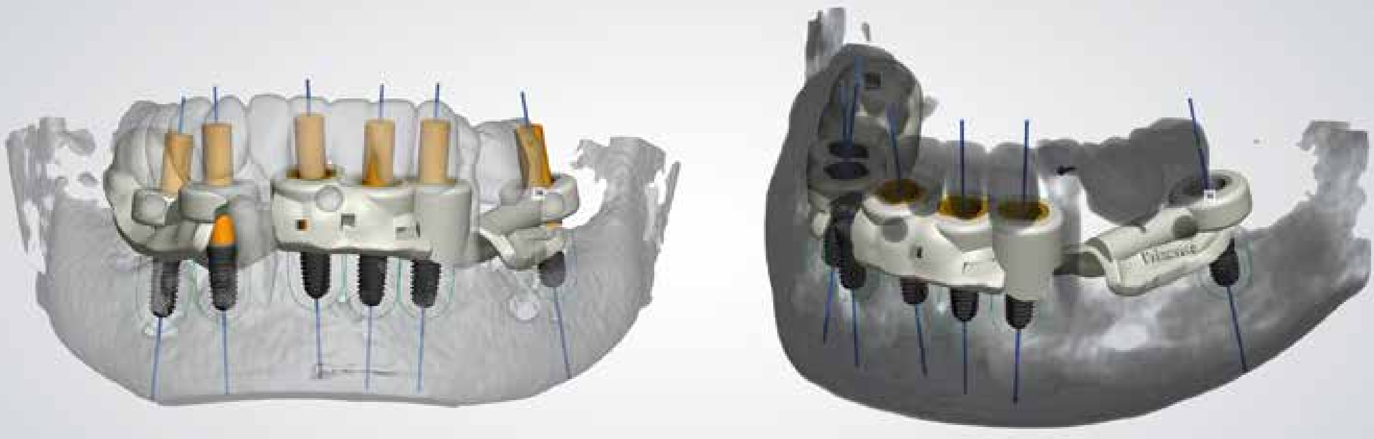
Splints are integrated in the prosthetic treatment sequence more and more frequently. In addition to the treatment of dysfunctions, any bite elevations can be validated with splints.
Many of our customers have taken to treating patients who are to receive larger restorations with a splint first, which is tantamount to "test-driving" the final restoration. In orthodontic treatments, too, splints are useful treatment adjuncts; aligners are a good example.

After scanning the plaster cast or loading the intraoral impression data, the result is a virtual diagnostic model that can be evaluated by the dentist or the dental technician in all three dimensions. The splint is designed as per the usual procedure provided by the software. Note that the minimum wall thickness is 1.0 to 1.5 mm.

Once the splint design has been approved, the "Send design to manufacturing" option is selected because we want to print the splint in-house. Using the 3Shape CAMbridge software module, the design is prepared as a job (printing object) by creating a job file and selecting the Varseo printer. VarseoWax Splint is available as a special material for splints.

10 - 13 The printed splint is removed and carefully detached. The fit on the model is unprecedented. After a final polymerization in the light-curing unit (on the model), the splint is ready for insertion. The entire procedure was comprised of only a few steps

14 & 15 The 3D-printed splint in the mouth. The data are accurately implemented; experience shows that very little rework and/or adjustment are necessary



16 & 17 Example of implant planning in 3Shape's software Implant Studio. The software is fairly intuitive to use, but we will have to see how it will develop in future

The STL data are loaded into the job order. In order to reduce the number of machine hours and to utilize the machine more efficiently, it makes sense to set up the printer to create multiple objects in a single job order. The splint design is positioned in the printer by the CAMbridge software. Changes may be made along the X- and Y-axes. The supports (for the building plate, resembling many small sprues) are generated automatically by the software; their distribution can be controlled in the 3D view. Overlapping or incorrectly positioned supports can be moved or deleted.
"Produce" is the button that allows the job to be automatically processed and stored. The file will then be transferred directly to the printer or stored on a USB flash drive (see page 11 for subsequent steps). The 3D printer will now process the file and produce a printed splint (Figs. 10 to 15).

Still indispensable, now and in the future

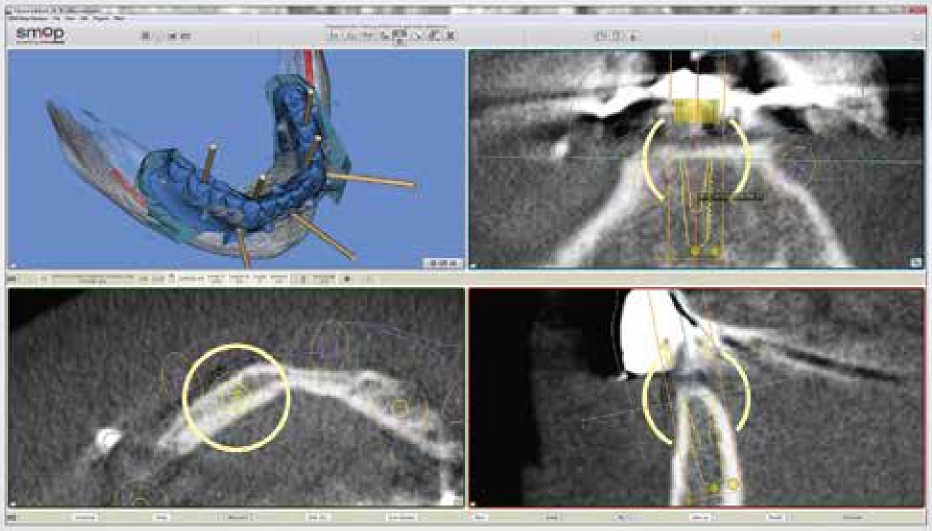
One service the laboratory can start offering – or offer more of – with 3D printing is pre-implantological planning. Even a small or medium-sized laboratory should seek to be integrated into the implantological production chain from the outset, in its capacity as a consulting partner. The dentist/oral surgeon also deserves proper respect. Any design must be approved by the dentist/oral surgeon, ideally in writing.
Using new technologies, dental technicians will not only render the workflow less costly and more efficient but can also shed the image of being mere accessories to the overall procedure. If we have the appropriate expertise, we may well start being consulted at an earlier stage of the implant/prosthodontic treatment. Three-dimensional treatment planning (the classic backward planning) requires communication within a team, making the dental technician indispensable. It is true that final responsibility for treatment planning still rests with the dentist/oral surgeon, but the dental technician can perform valuable preparatory steps, generating value for the treatment provider.

Preparing a surgical guide for 3D printing

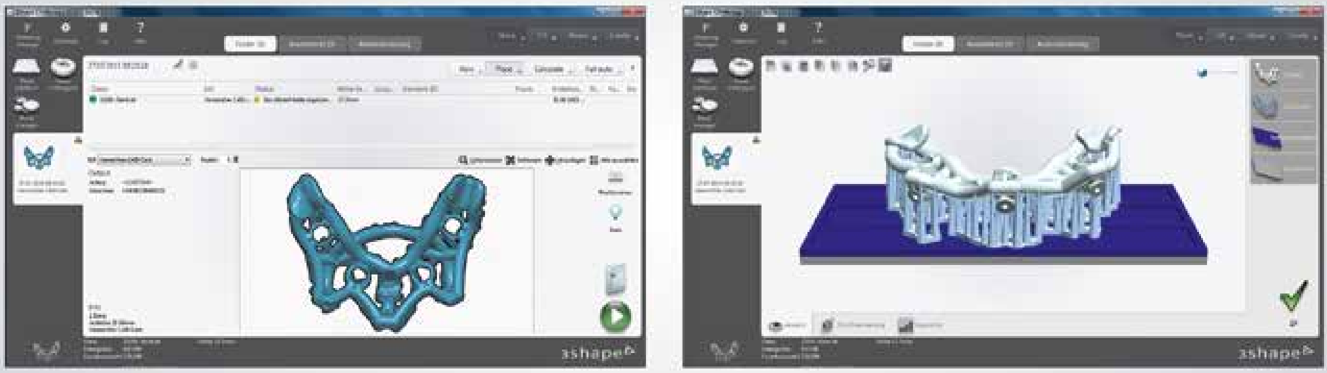
With 3D printing, preparing the surgical guide after the virtual planning is easy. Previously, surgical guides were manufactured manually at the laboratory (for example with a hexapod and with a Lego brick incorporated) or by an external service provider. Looking at the direct manufacturing/material costs for 3D printing, it soon becomes clear why this is one of the most economical production methods. The process is amazingly fast, accurate and cheap.

We use the implant-planning programs Implant Studio (3Shape) and SMOP (Swissmeda). Both programs provide open STL datasets that can be fed into the printer. The relatively recent Implant Studio software implement some very good ideas, but we will have to see how it will develop in future (Figs. 16 and 17). The SMOP software is mature and practical. The advantage of this intuitive software is its optimized overall process – from treatment planning to the finished surgical guide. It is not necessary to prepare a scanning template before the CT or CBCT recording.
Interdisciplinary communication within the healthcare team is supported by a server-based system; the cumbersome and time-consuming shipment of physical media is no longer necessary. The DICOM data of the CT or CBCT image are also imported, as are the STL data of the oral situation and the set-ups.

After superimposing the data, all of the relevant information is shown in a single representation (Fig. 18). This three-dimensional representation of the jawbone visualizes the anatomical structures. The set-up provides the specifications for the prosthetic alignment. The software integrates all major implant systems, so that the desired system can be selected and virtually positioned in the local bone.



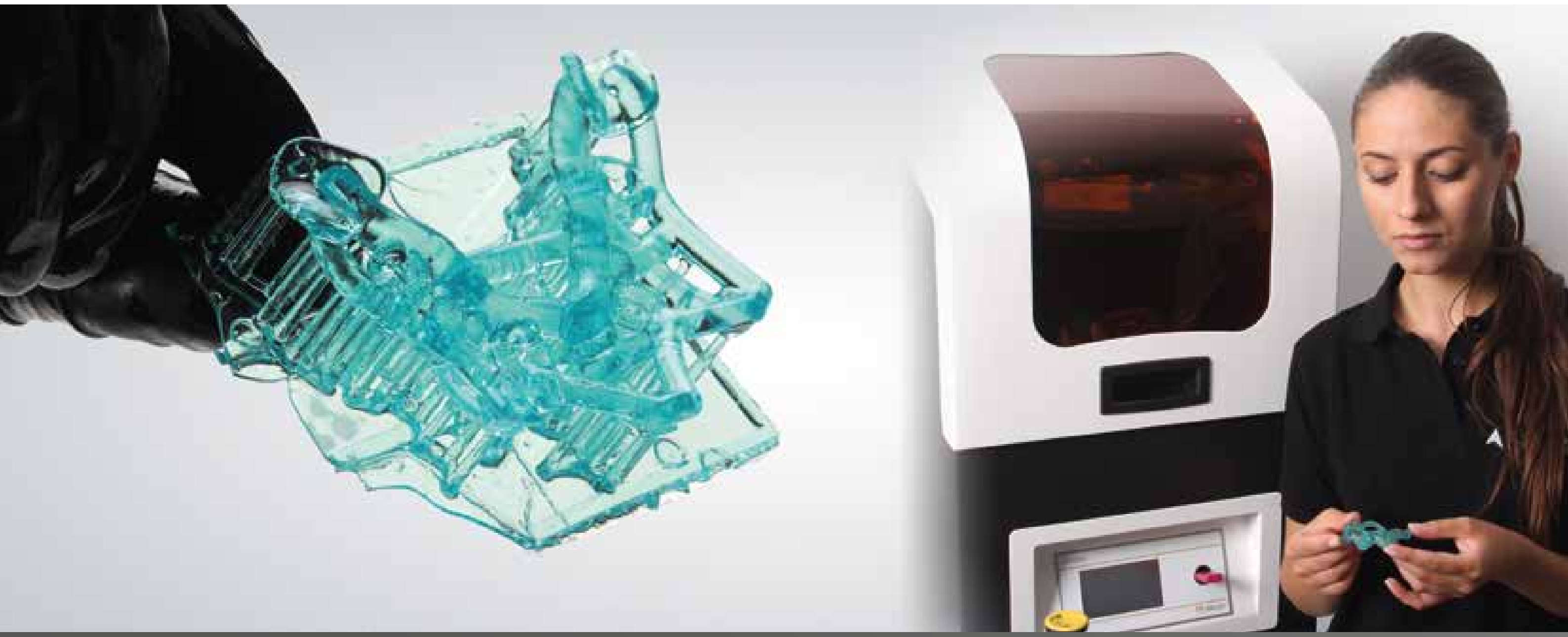
18 Implant planning using the SMOP software by the Swiss company Swissmeda. Here: four implants in the edentulous mandible



19 & 20 Once the oral surgeon has approved the virtual treatment planning, a mucosa-supported surgical guide is designed in Bego's CAMbridge software, and a job order for 3D printing is created

The implant is dragged with the mouse to its correct position. Following virtual implant placement, the planned situation is displayed on an overview screen and sent to the implantologist for inspection, who checks the implant axes and adapts them if necessary. After a final check, the data are "locked" by the dentist and returned to the laboratory. Based on these data, the surgical guide/drilling template is designed in the planning software. Only the outer boundary of the template needs to be specified. The software combines the information with the data on the planned implant positions and automatically creates a draft design, which can then be customized according to the practitioner's special wishes.

As with the fabrication of splints, the surgical guide (Fig. 19) is nested for printing in the CAMbridge software. The surgical guide is positioned horizontally (upside down). When checking the supports, care must be taken to ensure to stay clear of the edges of the drilling sleeves (Fig. 20). If necessary, the supports in these areas must be deleted or moved.



21 & 22 The surgical guide is removed from the Varseo immediately after 3D printing and detached

23 The implant sleeves are manually inserted into the surgical guide/drilling stent. The sleeves are secured in place using with the original stent material

Once the precise positioning of the template has been established, the job order is created and transmitted to the printer as a file.

3D printing with the Varseo

Once the file has been sent to the printer, the device lists the file found in the Begojob1 column next to number of image layers and the anticipated time required for printing. Before the print job can be started, the cartridge (resin containers) should be cleaned of any material residue. Any stains or deposits on the glass plate of the cartridge can be removed with some ethanol. The Start Print Job button starts the printing process.
The individual layers of the object are projected onto the surface of the liquid material using ultraviolet light and the so-called mask projection method. The exposed layer sets and connects the object to the upper movable rod (i.e. the object to be printed grows downward). A mechanical arm then moves the object upwards by the thickness of one layer; liquid material once again starts collecting below the object, and the next layer can be projected.

24a & b The surgical guide produced by the Varseo 3D printer in the patient's mouth. Why should we as dental technicians have surgical guides made by a third party if in-laboratory 3D printing provides this application for us?

Step by step, the surgical guide is created. The build-up rate at 50 µm per layer is 20 mm/hour; at 100 µm, it is 40 mm/hour. The printing time thus depends on the height of the object and not on the number of components per printing process.

After printing, the object is removed from the unit (Fig. 21) and detached. It is first cleaned in an ultrasonic ethanol bath. Any residue can be removed with a brush dipped in ethanol. The cleaning process in a fresh ethanol bath takes 5 minutes, after which the supports can be detached with a separating disc or a pair of pliers. Care must be taken to ensure that the printed object is neither damaged nor deformed. In the case of surgical guides, particular caution is mandated around the drilling sleeves.

The printed object is definitively polymerized in the curing unit. It is not until this point that the final material properties are achieved and the drilling sleeves can be inserted in the surgical guide (Figs. 22 and 23). It is fixated with a drop of VarseoWax Surgical Guide resin and renewed curing. The splint or surgical guide is now ready for use in the mouth and does not require any more finishing (Figs. 24 a and b).

Outlook

The Varseo 3D printer can be currently used to produce models, impression trays, CAD/Cast frameworks (i.e. frameworks for

TAB. 1 – DIRECT COST OF THE MATERIALS FOR 3D PRINTING (IN-HOUSE CALCULATIONS)

Application	**Average weight with panel (more objects = less weight)**	**Net price of materials**
Denture base (CAD/Cast process)	About 8 g	€ 3.03
Surgical guide	About 15 g	€ 7.15
Splints	About 12 g	€ 5.64
Impression tray	About 20 g	€ 7.58

PRODUCTS

Product	Name	Company
3D printer (RP)	Varseo	Bego/Henry Schein
CAD/CAM system	ConnectDental	Henry Schein
CAD software	DentalDesigner	3Shape
CAM software	3Shape CAMbridge	3Shape
Implant planning software	ImplantStudio	3Shape
	SMOP	Swissmeda
Lab scanner	GC Aadva Lab Scanner	GC Germany/Henry Schein
Light polymerization unit	HiLite power	Heraeus Kulzer
Material		
▪ Bite splint	▪ VarseoWax Splint	▪ Bego/Henry Schein
▪ Surgical guide	▪ VarseoWax Surgical Guide	▪ Bego/Henry Schein

crowns, tertiary structures, union structures, metal frameworks for partial dentures), splints and surgical guides. In the near future, there will certainly also be tooth-coloured materials, so the printer can also be used for producing tabletops or provisionals. Ultimately, it is expected that ceramics, too, will be incorporated into the dental 3D printing process. In the "non-dental" world, this is not just a visionary idea more. In April 2015, 3D printers were presented at the Hannover Messe industrial fair that were able to print high-performance ceramics; here, ceramic particles are homogeneously dispersed in the photosensitive resin.

Conclusion

After a decade in which CAD/CAM milling has become established in dental technology, it is now being joined by 3D printing. Advantages for the laboratory include, in addition to efficiency, the high precision, the high speed of production, the availability of any geometry, a broad diversity of materials diversity, resulting in a broad range of possible applications. "Do it yourself" is the motto under which 3D printing can expand our range of services at the laboratory and optimize our production processes. This means that more of the value created accrues to the laboratory without sacrificing manufacturing precision (Tab. 1). ▪

CURRICULUM VITAE

Carsten Fischer has been an independent dental technician running his own laboratory in Frankfurt, Germany since 1996. He has been an internationally renowned speaker since 1994, supporting his activities through publications in several countries (Brazil, Argentina, Japan, Australia and Europe). Carsten Fischer is a member of several professional advisory boards and a long-time consultant for major players within the dental industry. His areas of expertise include CAD/CAM, ceramic double crowns, custom abutments and all-ceramic materials. From 2012 to 2014, Carsten Fischer was a part-time employee of the University of Frankfurt and continues to work together closely with it. In 2013, his presentation was voted best in class by the Association of Dental Technologies (ADT). The award-winning publications co-authored with Dr Peter Gehrke have met with considerable interest in the trade press; they are regarded as yardsticks for the evaluation of custom abutments.

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