3D printing in dentistry

Balázs Kiss, MD, PhD

kissb3@gmail.com

Nanobiotechnology and Single Molecule Research Group,
Department of Biophysics and Radiation Biology,
Semmelweis University

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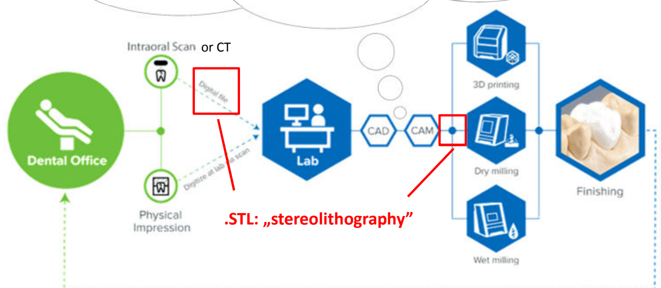
3D workflow

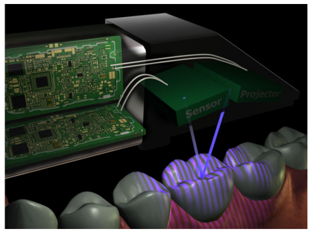
CAD: computer-aided design, CAM: computer-aided manufacturing

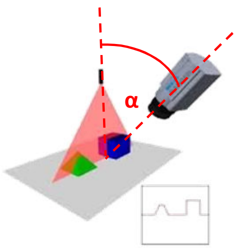
Software:

- Autodesk Fusion 360 (www.autodesk.com/products/fusion-360/overview)
- 3D-Slicer (www.slicer.org/)
- InVesalius (invesalius.github.io/download.html)
- Ultimaker Cura (ultimaker.com/software/ultimaker-cura)



3D intraoral scanners /1



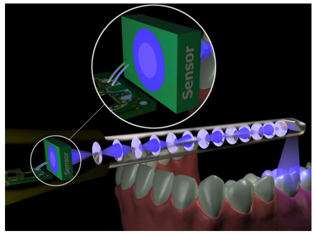


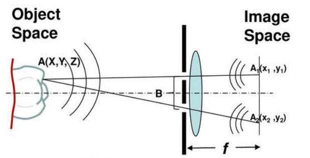
1st generation devices: **titanium oxide powder is required to prevent light reflection.**

e.g.: Cerec

- a light stripe pattern is projected onto the object,
- as each light ray is reflected back on the sensor, the distance between the projected ray and reflected ray is measured,
- **Triangulation**: because the fixed angle between the projector and sensor (α) is known, the distance to the object (and thereby the dimensions of the object) can be calculated.

3D intraoral scanners /2





$$Z = \frac{fB}{x_1 - x_2}$$

1st generation devices: **titanium oxide powder is required to prevent light reflection.**

e.g.: Lava COS

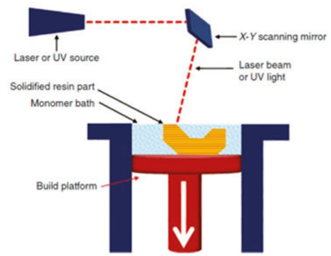
- **Active wavefront sampling:**
- the image reflected from the teeth is led through a lens system and eventually projected onto a sensor,
- if the image is in focus, the distance of the object coincides with the focal length of the lens,
- if the image is out of focus, the distance from the lens to the object (Z) can be calculated from the size of the blurred image.

Vat Photopolymerization

more widely known as stereolithography (SLA) or Digital Light Processing (DLP)

Basic components:

- **high intensity light source:** typically ultraviolet, UV-A or UV-B;
- **vat or tray:** holds an epoxy- or acrylic-based photo-curable liquid resin which contains monomers and oligomers;
- **controlling system:** directs the light source to selectively illuminate the resin



Max. resolution:

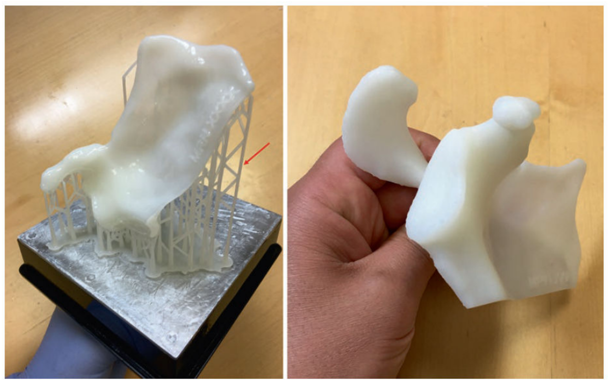
- X-Y-axis: 5 µm
- Z-axis: 10 µm

Vat Photopolymerization

- Layers of the resin are sequentially cured by exposing it to the light source in the shape of a pre-defined region of interest (ROI) perpendicular to the printer's Z-axis.
- The light initiates a chemical reaction in the resin which causes the monomers and oligomers to polymerize and become solid.
- Once a layer of the object becomes structurally stable, the model is lowered (or raised, for bottom-up printers) by one layer thickness away from the active layer.
- After printing, excess resin is drained, and a solvent or alcohol rinse is used to clean the model.
- Lattice support structures that are automatically added by the printer to achieve printing of overhangs also need to be manually removed.
- final post-processing step is required, which involves "curing" the model in a UV-chamber to complete polymerization.

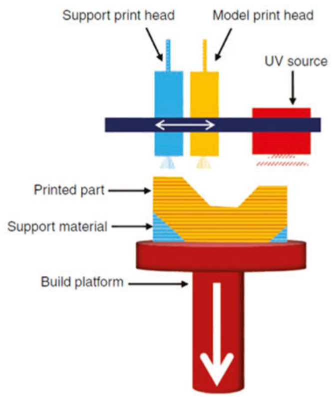
Vat Photopolymerization

Scapula 3D-printed with bottom-up vat photopolymerization



Polyjet or Multijet Printing (PJP or MJP)

also known as Photopolymer Jetting (PPJ)



Operating principle:

- droplets of photopolymer are ejected onto a surface and then cured by UV light;
- in each layer, the photopolymer is cured with the previous layers;
- it can combine multiple colors and materials in one print;
- wax or gel might also be used for the supporting structure (easier removal);
- Example: mouth guard with hard and soft parts and with different colors.

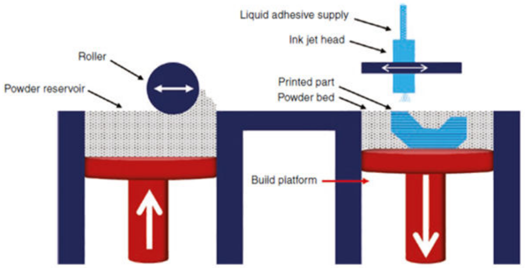
Max. resolution:

- X-Y-Z-axis: 15 µm

Inkjet Printing /1

Operating principle:

- an inkjet is used to eject small ink drops of binding liquid material toward a substrate of powder (plaster, ceramic, or resins);
- starts with spreading a thin layer of the substrate powder across the binding platform;
- liquid-binding material is applied on top of the powder; this connects together the exposed particles leaving the unexposed particles loose



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Inkjet Printing /2

Operating principle (cont.):

- a heat treatment is applied, and the unbound powders are removed from the building platform;
- different colors of the liquid-binding material can be used for printing multiple color objects;
- ceramic suspension was used in some studies to print zirconia dental restorations

Max. resolution:

- X-Y-Z-axis: 50 µm

Application:

- dental models,
- orthodontic diagnosis models,
- experimentally: to print bone graft materials

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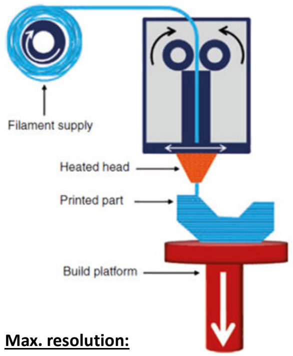
Fused Deposition Modeling (FDM)

also known as Fused Filament Fabrication (FFF)



Operating principle:

- builds up an object by laying down a wire of thermoplastic material onto a building platform through a heated nozzle;
- the 3D object is built from the bottom up, one layer at a time;
- nozzle movement is directed in both horizontal and vertical directions;
- the thermoplastic material is partially melted in the nozzle, and upon deposition on the building base, it solidifies immediately within 0.1 s;
- the layers of the deposited materials can be bonded together by the use of chemical agents or by temperature control.

Max. resolution:

- X-Y-Z-axis: 60 µm

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Fused Deposition Modeling (FDM)

Creality Ender-3

Advantage: no post-processing treatment is required.

Disadvantages: low-resolution, slow speed, low surface quality.

Limited to thermoplastic materials:

- PLA (polylactic acid),
- ABS (acrylonitrile butadiene styrene),
- PVA (polyvinly acetate),
- HIPS (high impact polystyrene).

PLA is more suitable to be used in dental application since it is more biocompatible than ABS.

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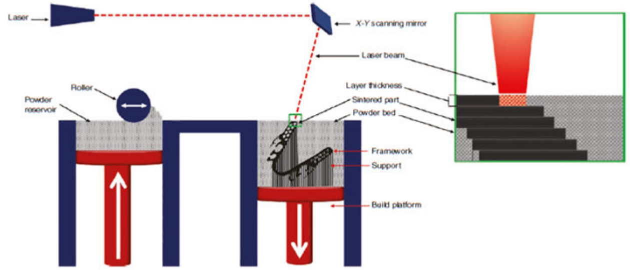
Powder Bed Fusion (PBF)

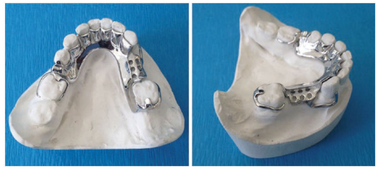
- **Laser sintering and laser melting**: layer-by-layer pattern;
- high-power laser melts or fuses successive layers of compacted powder;
- laser beam is focused on an area defined by the CAD data file to fuse the powder particles in that area, while the remaining particles remain unfused;
- the production platform is lowered, a new layer of powder is applied again on top of the previous one, and the laser fuses the powder with the previous layer.

Selective Electron Beam Melting (SEBM)

- Similar to laser sintering and laser melting, but the processing **occurs in a high vacuum and with an electron beam;**
- another approach of SEBM is to use an electron beam to melt wire of metal onto a surface to build up an object that is similar to the FDM technique but with metal rather than plastics.
- Application:
  - ability to produce porous objects by different alloys such as cobalt-chromium and titanium,
  - customized implants for maxillofacial surgery.

Powder Bed Fusion (PBF)





metallic framework of a partial removable dental prostheses (PRDPs) processed by laser melting

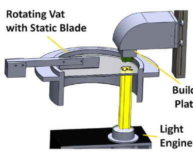
Example: ZrO_2 dental implant

3D Printing of Zirconia–What is the Future?

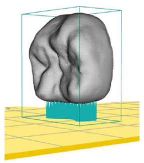
J Schweiger[1] · D Bomze[2] · M Schwentenwein[2]

Current Oral Health Reports (2019) 6:339–343
https://doi.org/10.1007/s40496-019-00243-4

Bending rigidity
- enamel: 200 Mpa
- porcelain: 120-190 Mpa
- zirconia: 1200 MPa



CeraFab 7500 dental 3D printer



STL (stereo-lithography) file

bottom: blue support material

„green body" cross-linked organic binder and zirconia particles

„white body" cleansing, thermal post-processing (1000 °C)

finished crown after the stain/ glaze firing (770 °C)

3D printing methods - Summary

Technique	Materials		Advantages	Disadvantages	Dental applications
	Form	Type			
SLA	Liquid	Polymers, PLLA, PEG-DMA, PPF, PTMC, PMMA; ceramics, PLGA/ TCP, alumina	High accuracy, smooth surface, high density, low-cost materials	High-cost technology, limited strength. requires support structures, and requires post-processing treatment	Dental models, surgical guides, custom trays, temporary crown and bridge, prosthesis pattern, maxillofacial prosthesis, orthodontic prosthesis, and bone
Polyjet/ multijet	Liquid	Waxes, resins, and silicone	High accuracy, variety of materials and colors, average-cost technology	High-cost materials	Dental models, custom trays, surgical guides, temporary prosthesis, mouth guards, and orthodontic appliances
Inkjet	Powder	Plaster of Paris and ceramic suspension	Low cost, and variety of materials and colors	Low accuracy, low strength, and rough surfaces	Dental models, ceramic dental restoration, bone graft materials
FDM	Filament	Polymers: PLA, PC, ABS, PCL, PPSU, and waxes	Low cost, good strength, and variety of materials and colors	Low accuracy and density, rough surfaces, and limited to thermoplastic materials	Custom trays, surgical guides, and prosthesis patterns

Thank

YOU

for your attention!