Future of Dentistry: 3D Printing

What is 3D Printing?

3D printing is the process of using a general-purpose machine to create a physical object, where the design is provided to the machine at build time.

- Usually, the object is created *"additively,"* in a layer-by-layer process.
- Compare to "CNC" (computerized numerical control), which usually refers to a subtractive process, i.e. CAD/CAM.

Why do we care about 3D printing?

- Allows for personalization, i.e. **customization** for surgical preparation.
  - Allows for single copy of a design, improving cost efficiency as compared to traditional manufacturing.
  - 3D printing is better suited for more complex prototyping.

History of 3D Printing

1980-2000

First patent application for RP technology was filed by a Dr Kodama, in Japan, in May 1980.	80
The first patent was issued to Charles Hull for stereolithography apparatus (SLA).	86
SLA-1, was introduced.	87
SLS patent was issued to Carl Deckard.	89
EOS sold its first 'Stereos' system.	90
FDM patent was issued to Stratasys.	92
Sanders Prototype (later Solidscape) and ZCorporation were set up.	96
Arcam was established.	97
Objet Geometries launched.	98

The earliest 3D printing technologies first became visible in the late 1980's, at which time they were called Rapid Prototyping (RP) technologies. This is because the processes were originally conceived as a fast and more cost-effective method for creating prototypes for product development within industry.

1983 Charles Hull invents Stereolithography (SLA) Charles 'Chuck' Hull was the first to develop a technology for creating solid objects from a CAD/CAM file, inventing the process he termed 'stereolithography' in 1983.

SLA works by curing and solidifying successive layers of liquid photopolymer resin using an ultraviolet laser. The field that came to be known variously as 'additive manufacturing', 'rapid prototyping' and '3D printing' was born.

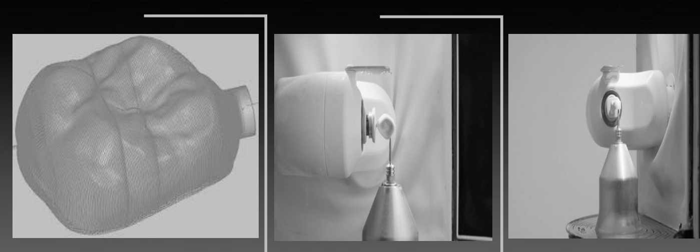
2000-

MCP Technologies introduced the SLM technology.	00
EnvisionTec was founded.	02
Dr Bowyer conceived the RepRap concept of an open source, self-replicating 3D printer.	04
ExOne was established as a spin-off from the Extrude Hone Corporation.	05
The first system under $10,000 from 3D Systems.	07
Desktop Factory was acquired by 3D Systems.	08
The first commercially available 3D printer – in kit form, based on the RepRap concept.	09
Alternative 3D printing processes were introduced at the entry level of the market.	12
Stratasys acquires Makerbot.	13

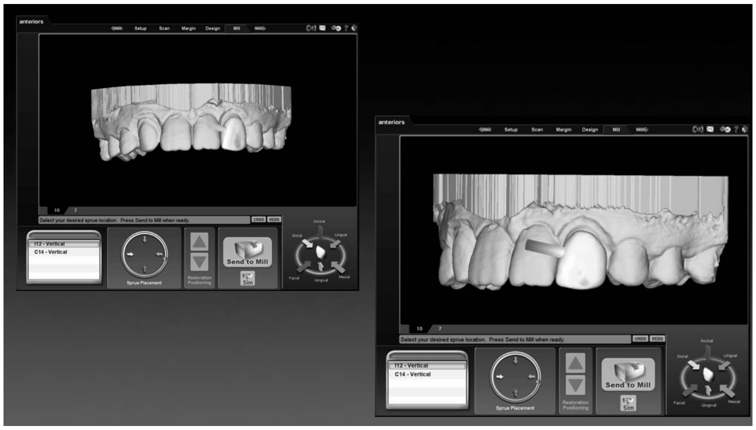
PrograMill One

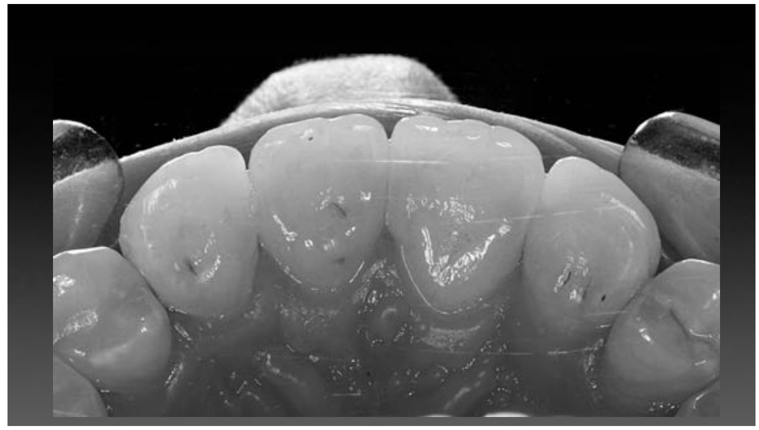
5XT

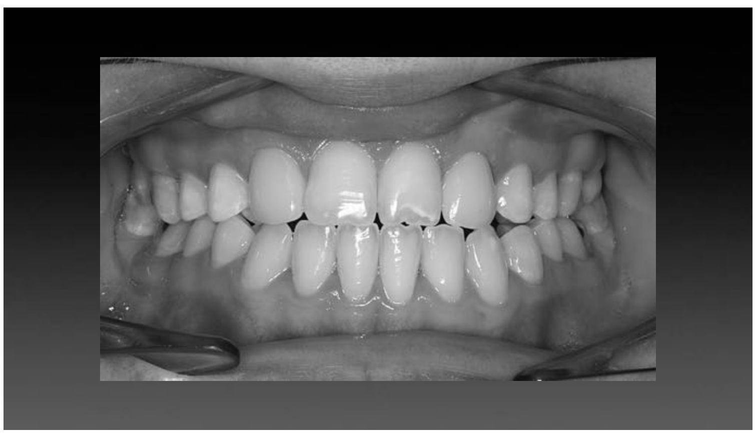
- Innovative 5-axis turn milling technology
  → Quality & Efficiency

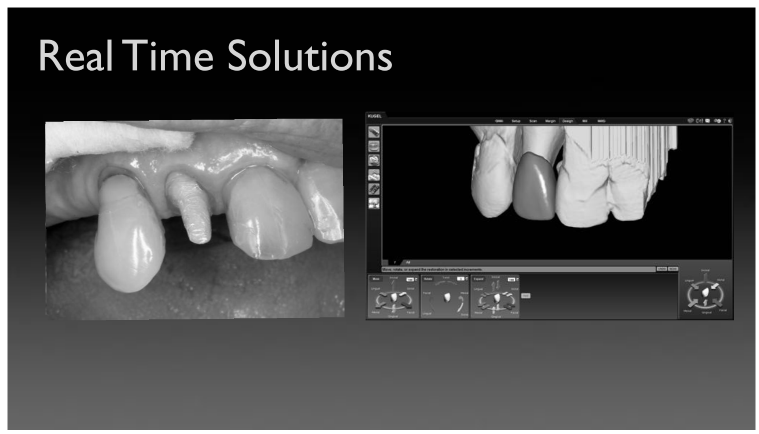


Digital Wax-up

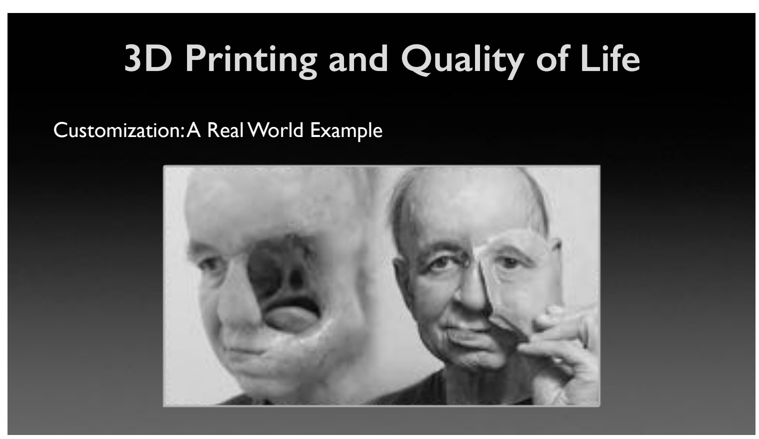

anteriors
Send to Mill
I12 - Vertical
C14 - Vertical
Sprue Placement



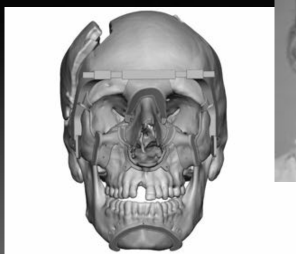



Real Time Solutions


Outcome


3D Printing and Quality of Life
Customization: A Real World Example

Andy's Story



A second chance at life

Advantages

- **Speed**

You can create complex parts within hours , with limited human resources..

- **Customisation**

3D printing processes allow for mass customisation — the ability to personalize products according to individual needs and requirements.

- **Tool-less**

For industrial manufacturing, one of the most cost-, time- and labour-intensive stages of the product development process is the production of the tools. 3D printing can eliminate the need for tool production and, therefore, the costs, lead times and labour associated with it.

Advantages

- **Sustainable / Environmentally Friendly**

3D printing is also emerging as an energy-efficient technology that can provide environmental efficiencies in terms of both the manufacturing process itself, utilising up to 90% of standard materials, and, therefore, creating less waste.

- **No storage cost**

Since 3D printers can "print" products as and when needed, and does not cost more than mass manufacturing, no expense on storage of goods is required.

- **Increased employment opportunities**

Widespread use of 3D printing technology will increase the demand for designers and technicians to operate 3D printers and create blueprints for products.

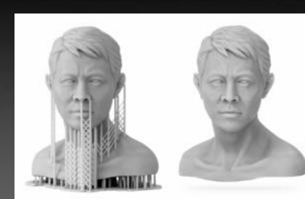
Disadvantages

- **Questionable Accuracy**

While 3D printers have made advances in accuracy in recent years, many of the plastic materials still come with an accuracy disclaimer. For instance, many materials print to either +/- 0.1 mm in accuracy, meaning there is room for error.

- **Support Material Removal**

When production volumes are small, the removal of support material is usually not a big issue. When the volumes are much higher, it becomes an important consideration. Support material that is physically attached is of most concern.



Disadvantages

- Limitation of Raw Materials

At present, 3D printers can work with only approximately 100 different raw materials. few with FDA approval for long term use in the body.

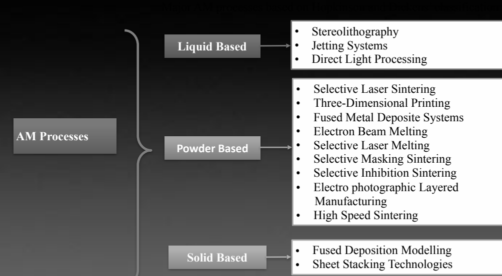
- Material Cost

Today, the cost of most materials for additive systems (Powder) is slightly greater than that of those used for traditional manufacturing .

- Material Properties

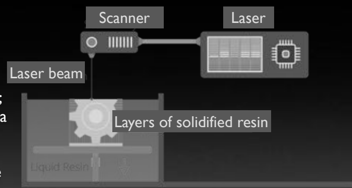
A limited choice of materials is available. Actually, materials and there properties (e.g., tensile property, tensile strength, yield strength, and fatigue) have not been fully characterized.

3D Printing
Additive Manufacturing



Stereolithography

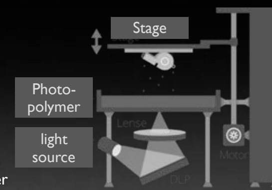
Stereolithography (STL)



is widely recognized as the first 3D printing process; it was certainly the first to be commercialised. SL is a laser-based process that works with photopolymer resins, that react with the laser and cure to form a solid in a very precise way to produce very accurate parts.
It is a complex process, but simply put, the photopolymer resin is held in a vat with a movable platform inside. A laser beam is directed in the X-Y axes across the surface of the resin according to the 3D data supplied to the machine (the .stl file), whereby the resin hardens precisely where the laser hits the surface. Once the layer is completed, the platform within the vat drops down by a fraction (in the Z axis) and the subsequent layer is traced out by the laser. This continues until the entire object is completed and the platform can be raised out of the vat for removal.

Digital Light Processing

Digital Light Processing (DLP)

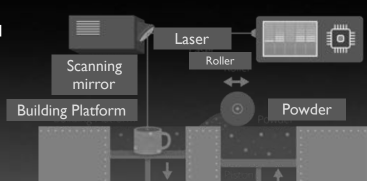


Similar process to Stereolithography in that it is a 3D printing process that works with photopolymers. The major difference is the light source. DLP uses a more conventional light source, such as an arc lamp, with a liquid crystal display panel or a deformable mirror device (DMD), which is applied to the entire surface of the vat of photopolymer resin in a single pass, generally making it faster than SL.

Include the same requirements as SLA for support structures and post-curing. However, one advantage of DLP over SL is that only a shallow vat of resin is required to facilitate the process, which generally results in less waste and lower running costs.

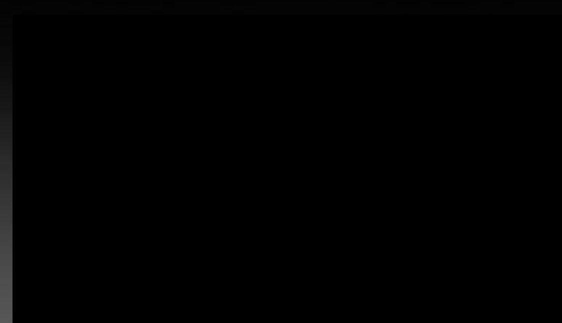
Laser Sintering & Melting

Laser sintering and laser melting (SLS, SLM) are interchangeable terms that refer to a laser based 3D Printing process that works with powdered materials.



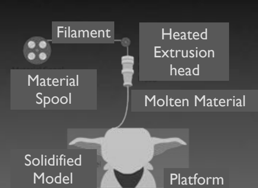
The laser is traced across a powder bed of tightly Compacted powdered material, according to the 3D data fed to the machine, in the X-Y axes.
As the laser interacts with the surface of the powdered material it sinters, or fuses, the particles to each other forming a solid. As each layer is completed the powder bed drops incrementally and a roller smoothes the powder over the surface of the bed prior to the next pass of the laser for the subsequent layer to be formed and fused with the previous layer.

SLM Printing

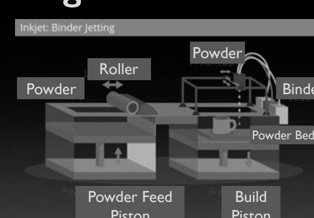


Fused Deposition Modeling (FDM)

- Fused Deposition Modeling (FDM) - The longest-standing and most popular name for the 3DP process is Fused Deposition Modelling **(FDM)** however, this is a trade name, registered by its original developer, Stratasys. FDM technology has been around since the early 1990's and today is an industrial grade 3D printing process.
- Freeform Fabrication (FFF) – FFM came about as the result of the proliferation of entry-level 3D printers that have emerged since 2009. FFM utilizes a similar process as FDM, but in a more basic form due to patents still held by Stratasys.



Binder Jetting



.
Binder jetting: The material being jetted is a binder, and is selectively sprayed into a powder bed of the part material to fuse it a layer at a time to create/print the required part. Once a layer is completed, the powder bed drops incrementally and a roller or blade smoothes the powder over the surface of the bed, prior to the next pass of the jet heads, with the binder for the subsequent layer to be formed and fused with the previous layer.

Advantages of this process, like with SLS, include the fact that the need for supports is negated because the powder bed itself provides this functionality. Furthermore, a range of different materials can be used, including ceramics and food.

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October 8 – 12, 2017, David L. Lawrence Convention Center, Pittsburgh, Pennsylvania USA

DOI 10.7449/2017/MST_2017_289_291

BINDER JET PRINTING OF PARTIAL DENTURE METAL FRAMEWORK FROM METAL POWDER

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Keywords: Dentistry, additive manufacturing, sintering, micro-computed tomography

Introduction
Rapid prototyping technologies are the most extensively applied methods based on additive manufacturing (AM) principles, but the first complex-shaped AM parts are already in serial production for commercial aircrafts [1]. The main advantage of rapid prototyping includes the fabrication of models and prototypes for concept assessment as well as functional testing of new products. AM methods have been used to manufacture dental prostheses such as removable partial denture frameworks that retain artificial replacement teeth [2], implants [3], and substructures for crowns and bridges [4]. Additive manufacturing, in general, is best suited for production of small

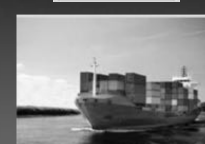
Conclusion
This study shows that binder jetting can be a potential method for manufacturing complex geometries with fine features in dentistry and in general. With the advantage of minimum material waste, easy powder reuse, and a no-tooling requirement, BJP offers an economical method to manufacture parts with complex shapes, overhangs and no thermal stresses with large build volumes. We aim to extend BJP method for other dental materials such as Ti-based and Co-Cr-Mo materials. Therefore, more research is necessary to acquire a thorough understanding of the correlation between the property of the powder, printing parameters and mechanical properties of the resulting parts, to ensure repeatability and consistency in the final product.

3D Printing Controversies

- Guns or printing of other restricted items, i.e. anyone can make anything as long as its plastic and the sixe of a loaf of bread
- Printing of bioproducts
  - Printing custom pills with exact dosages
  - Printing organs for transplant
  - Printing biotoxins and chemical weapons


3D Printing Controversies

- Information ownership
  - Many corporations are identifiable by their physical products, i.e. coke bottles, toys associated with movies, shoes, etc.
  - Design patents prevent confusion by disallowing one company from manufacturing a product with similar or the same "trade dressing"
- Economics/Industry
  - What happens to the economy when anyone can print whatever they need at home?

Additive Manufacturing

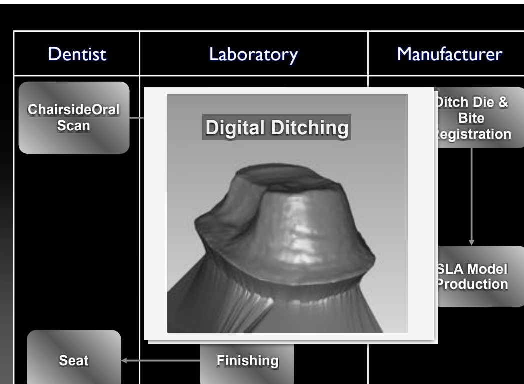
"3D printing's potential to revolutionize manufacturing is quickly becoming a reality."

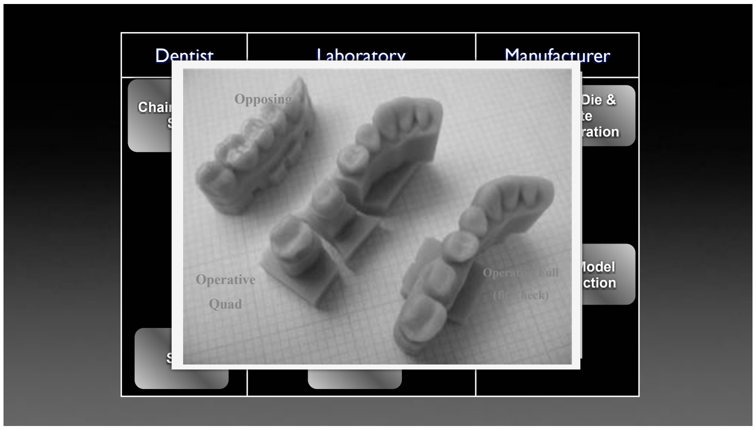
Global 3D printing market
Estimates and forecast of market value to 2018, in USD

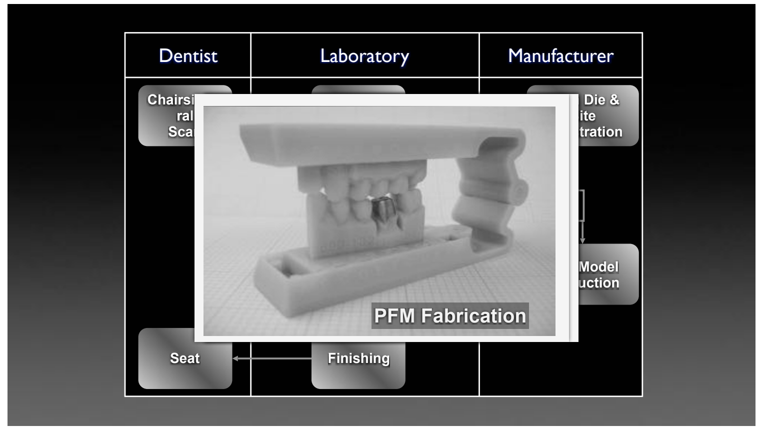
Category	2013 estimates	2014 forecast	2018 forecast
Total	$2.5b	$3.8b	$16.2b

In the frame of the Horizon 2020 project many European and National Networks are founded to see the potential of the technology.

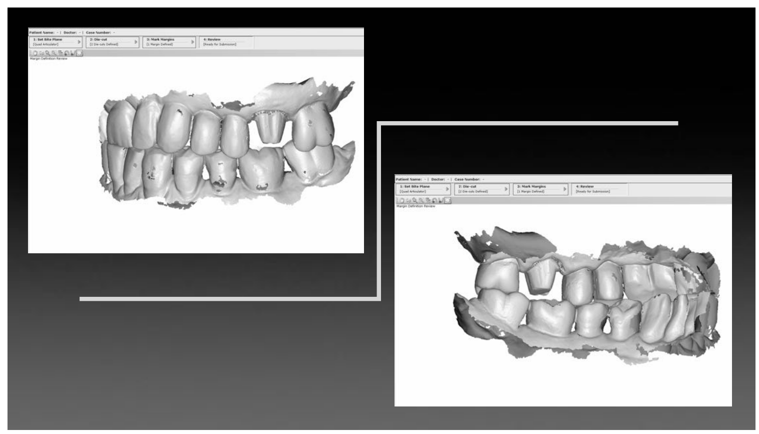
President Obama announced his plan to invest $1 billion to catalyse a national network of up to 15 manufacturing innovation institutes…
Pilot institute : National Additive Manufacturing Innovation Institute (NAMII) with a budget of 30 M$ in 2013

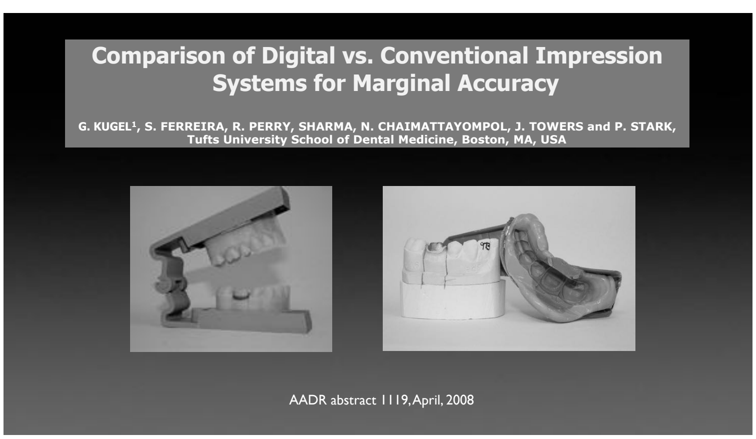


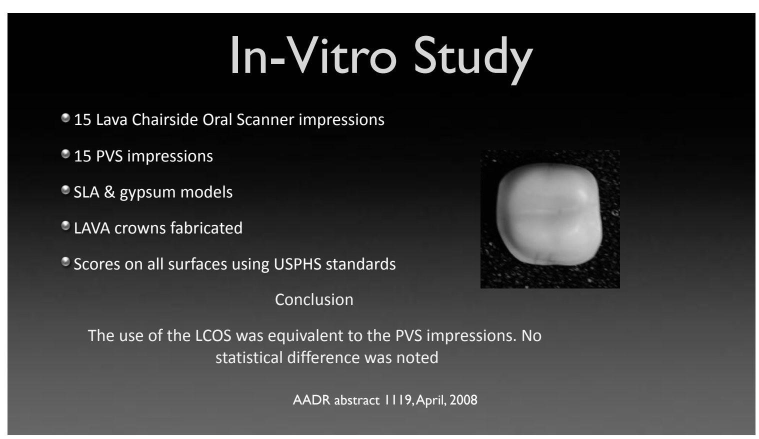

Dentist
Laboratory
Manufacturer
Opposing
Operative
Quad

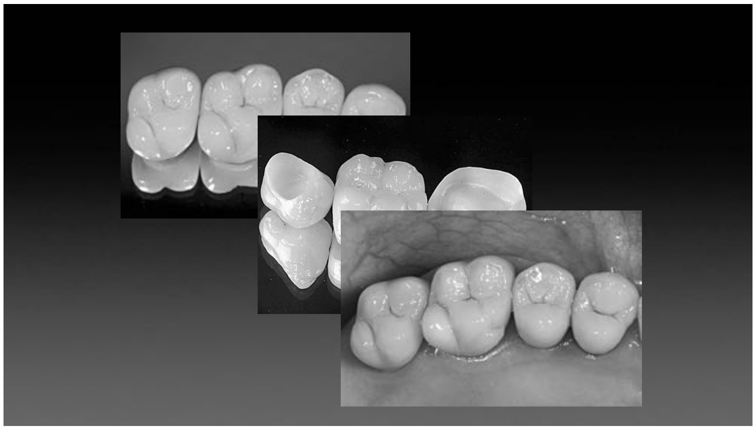

Dentist
Laboratory
Manufacturer
PFM Fabrication
Seat
Finishing

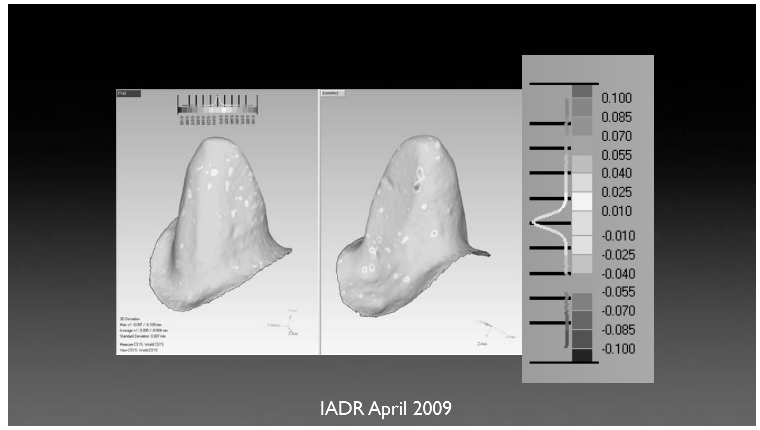

Artex Articulator, Girrbach Dental




Comparison of Digital vs. Conventional Impression Systems for Marginal Accuracy
G. KUGEL[1], S. FERREIRA, R. PERRY, SHARMA, N. CHAIMATTAYOMPOL, J. TOWERS and P. STARK,
Tufts University School of Dental Medicine, Boston, MA, USA
AADR abstract 1119, April, 2008


In-Vitro Study
15 Lava Chairside Oral Scanner impressions
15 PVS impressions
SLA & gypsum models
LAVA crowns fabricated
Scores on all surfaces using USPHS standards
Conclusion
The use of the LCOS was equivalent to the PVS impressions. No statistical difference was noted
AADR abstract 1119, April, 2008




0.100
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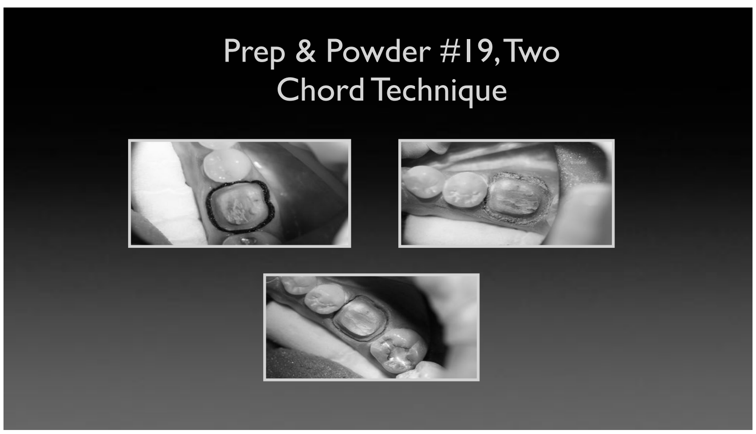
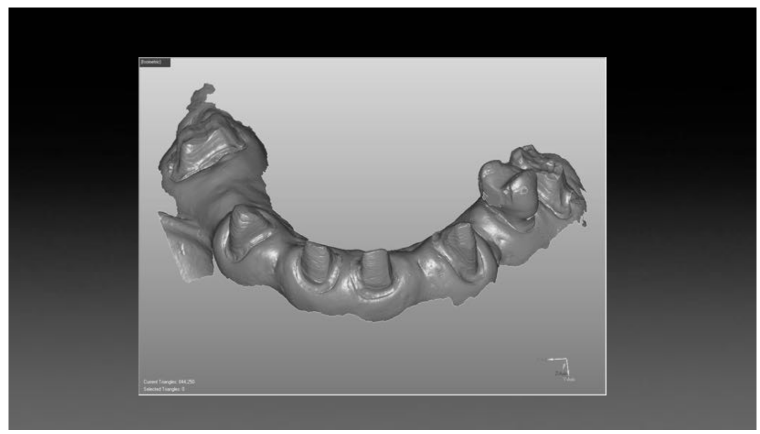
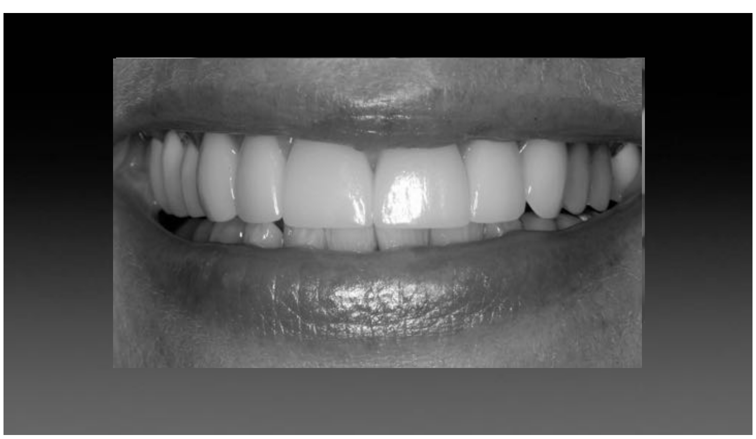
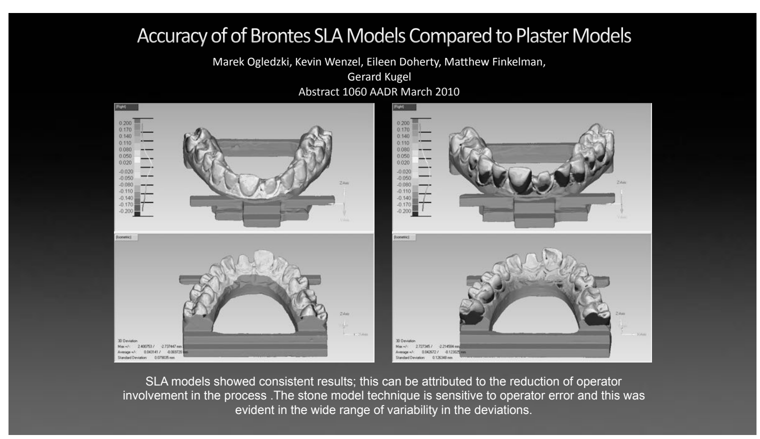
-0.085
-0.100
IADR April 2009


Prep & Powder #19, Two Chord Technique






Accuracy of of Brontes SLA Models Compared to Plaster Models
Marek Ogledzki, Kevin Wenzel, Eileen Doherty, Matthew Finkelman, Gerard Kugel
Abstract 1060 AADR March 2010
SLA models showed consistent results; this can be attributed to the reduction of operator involvement in the process .The stone model technique is sensitive to operator error and this was evident in the wide range of variability in the deviations.

Dimensional accuracy of dental casts: Digital vs. Conventional impression technique

PG Prosthodontics Thesis

Dr Inna Amirian

Both groups, stone and SLA, when compared to each other against the master model the results were not statistically significant for all four distances. Therefore, it can be concluded that SLA model manufacturing is equal in performance to that of stone.

Summary

- In this accuracy repeatability study the Lava COS showed a precision between 6 μm and 11 μm.

Twenty-five repeated scans over a two week period on a single anterior prep and a single posterior prep gave the following results:

Anterior repeatability ≤5.8 μm, standard deviation 1.3 μm

- Posterior repeatability ≤10.9 μm, standard deviation 3.5 μm

Printing Materials

AM Materials

There are now too many proprietary materials from the many different 3D printer vendors to cover them all here.

Instead, we will look at the most popular types of materials,

Liquid Based | **Powder Based** | **Solid Based**

Additive Manufacturing Materials

Nylon, or Polyamide, is commonly used in powder form with the sintering process or in filament form with the FDM process. It is a strong, flexible and durable plastic material that has proved reliable for 3D printing. It is naturally white in colour but it can be coloured — pre- or post printing.

ABS is another common plastic used for 3D printing, and is widely used on the entry-level FDM 3D printers in filament form. It is a particularly strong plastic and comes in a wide range of colours.

PLA is a bio-degradable plastic material that has gained traction with 3D printing for this very reason. It can be utilized in resin format for DLP/SL processes as well as in filament form for the FDM process. It is offered in a variety of colours, including transparent, which has proven to be a useful option for some some applications of 3D printing. However it is not as durable oras flexible as ABS.

LayWood is a specially developed 3D printing material for entry- level extrusion 3D printers. It comes in filament form and is a wood/polymer composite (also referred to as WPC).

Additive Manufacturing

Titanium is one of the strongest possible metal materials and has been used for 3D printing industrial applications for some time. *Supplied in powder form, it can be used for the sintering/melting/ EBM processes*

Ceramics

Ceramics are a relatively new group of materials that can be used for 3D printing with various levels of success. The particular thing to note with these materials is that, post printing, the ceramic parts need to undergo the same processes as any ceramic part made using traditional methods of production - namely firing and glazing.

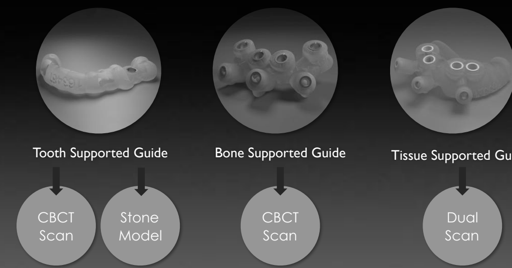
Bio Materials

There is a huge amount of research being conducted into the potential of 3D printing bio materials for a host of medical (and other) applications. Living tissue is being investigated at a number of leading institutions with a view to developing applications that include printing human organs for transplant, as well as external tissues for replacement body parts.

Guided Surgery

Case Workflow

What You Need to Provide



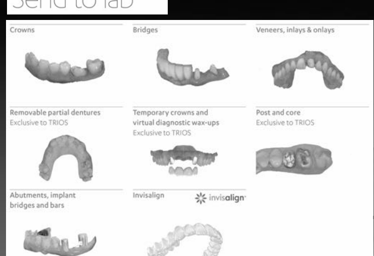
Digital Impression

3Shape TRIOS

Wireless

3Shape TRIOS – Choose Your Workflows

3Shape TRIOS
Send to lab

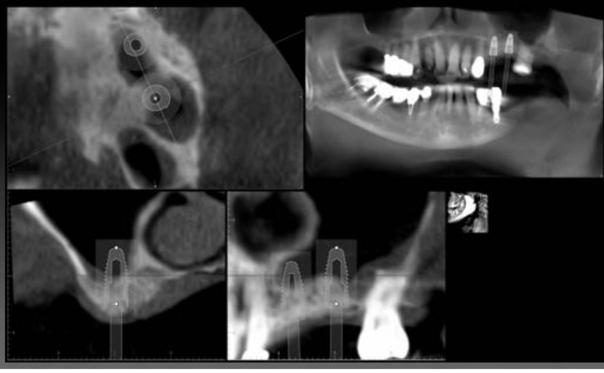


3Shape TRIOS
Design Studio

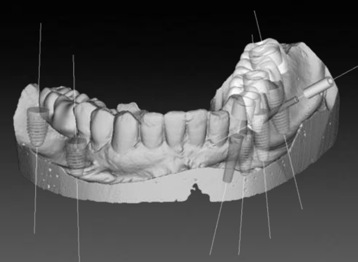
3D Conversions

- High quality manual reconstruction of your CT data with artifact clean-up
- Allow you to visualize your patients' anatomy in beautiful high definition with free 360 degree rotation

CBCT



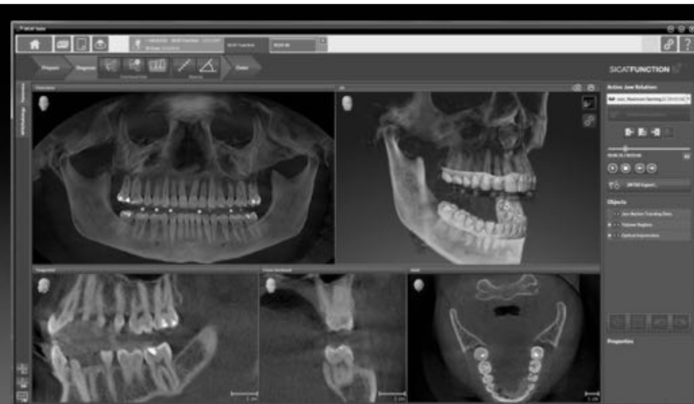
Treatment Plan

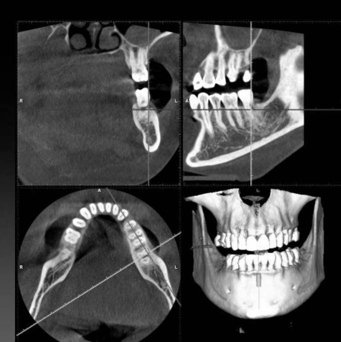


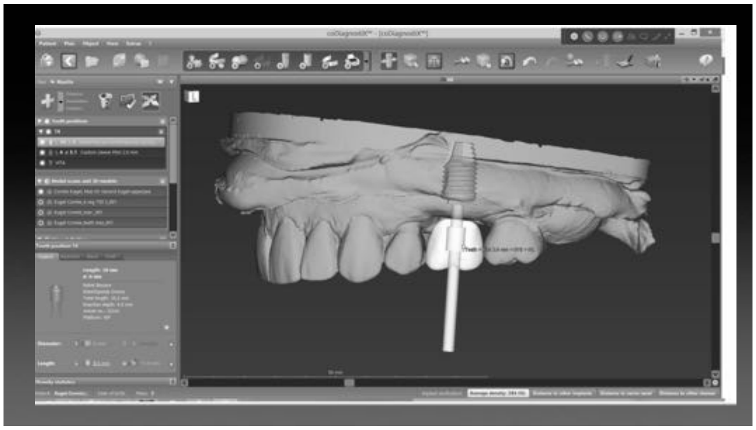
- The lab's dentist works on your patients' CT/CBCT data according to your instructions
- The in-house dentists bring years of experience with computer guided surgery and implant planning software

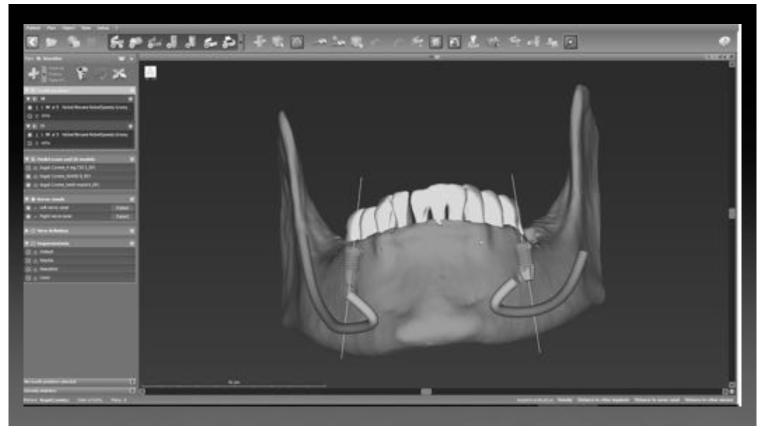
Fine Tuning Session

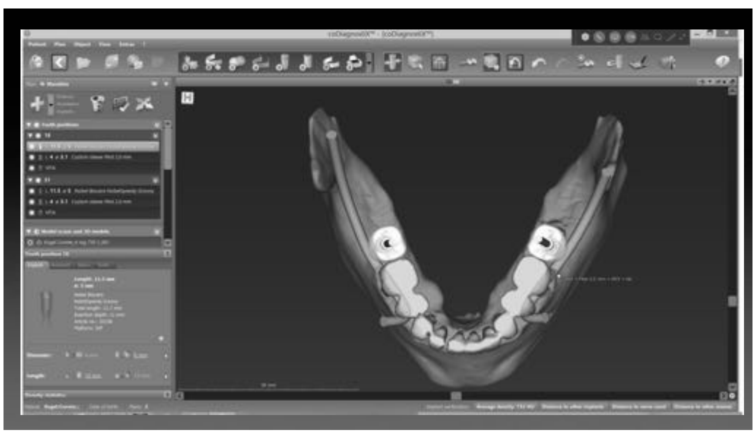
- You can review your treatment plan during the online fine-tuning session
- Unlimited one-on-one fine-tuning sessions ensure that you remain the final decision maker for your cases.

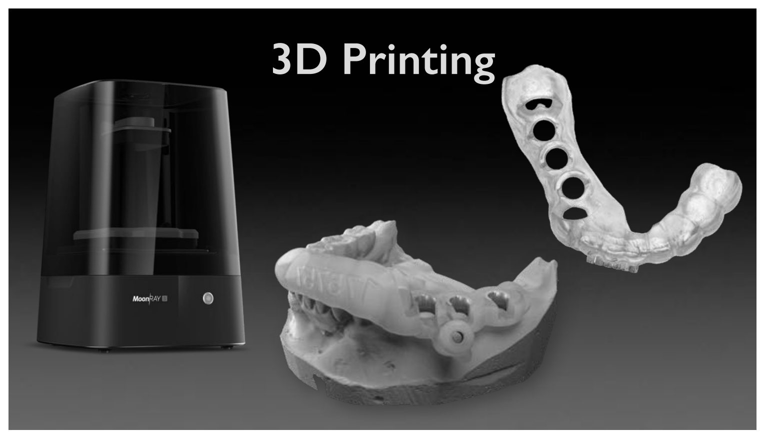


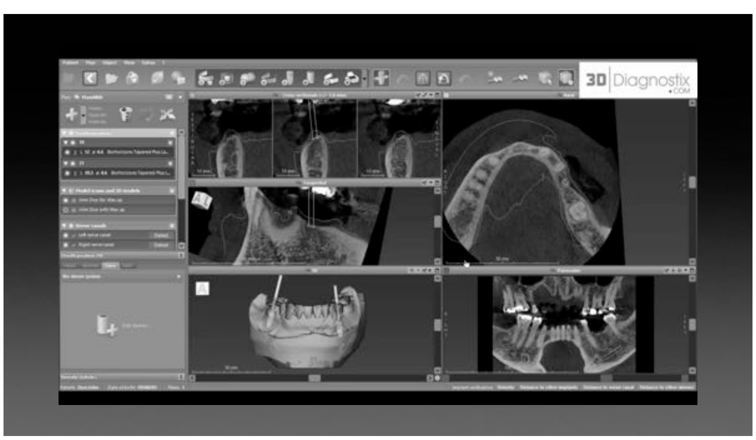


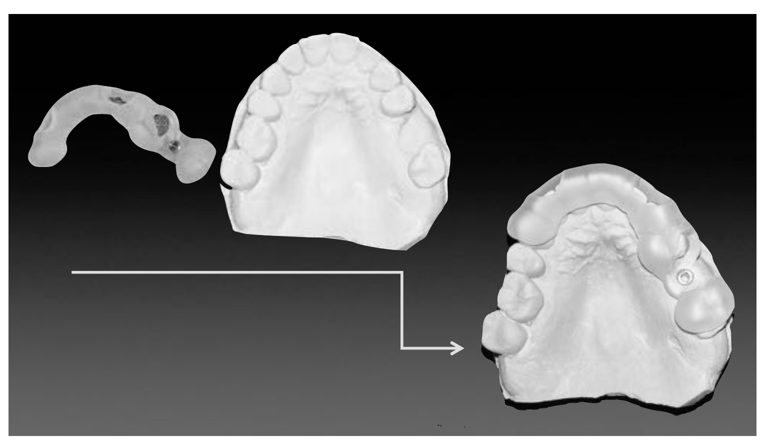


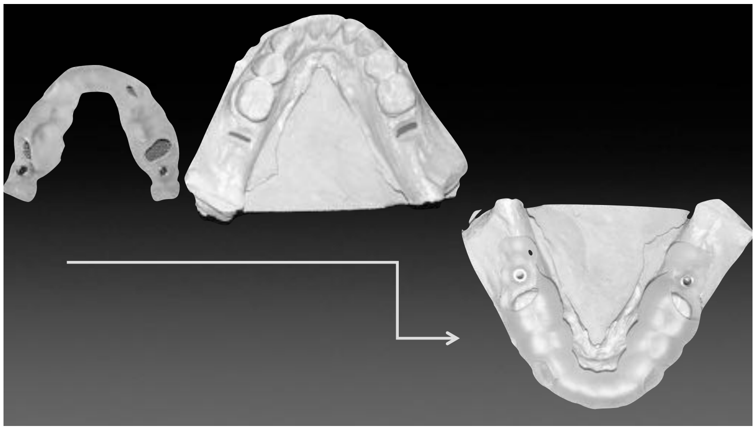


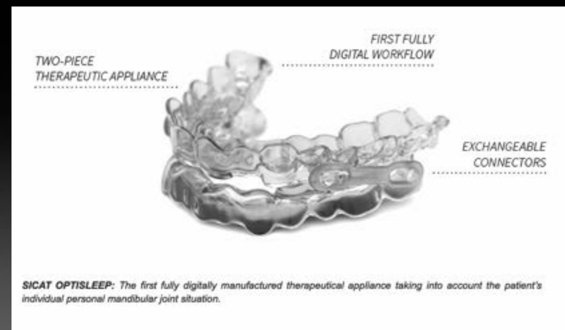



3D Printing
MoonRAY


3D Diagnostix .COM







Virtual Articulation

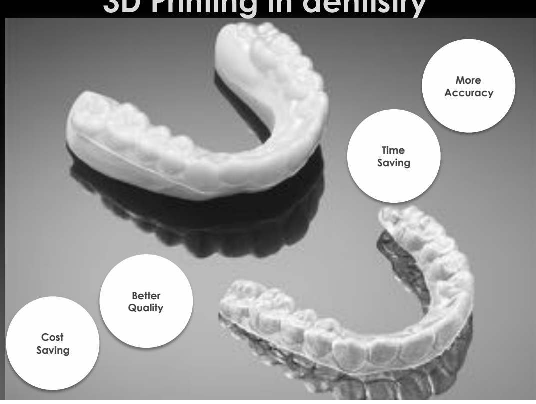
Virtual Articulation is turned on or off during the setup phase. If turned on it will take the in to consideration the jaw movements of the patient to render a better initial proposal.

The articulator is an averaged based adjustable articulator, ranges may be changed if you have know values for the patient. Proper setting of the initial model axis is critical.

3D X-ray scan with a CT or Conebeam system. The patient wears the SICAT Fusion Bite during the scan.

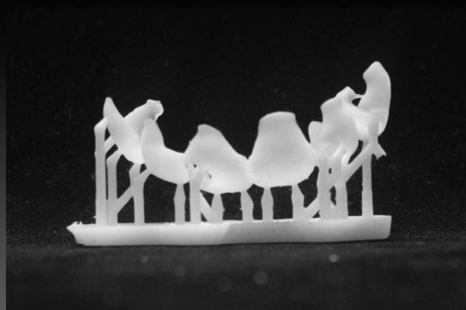
Movement data is recorded with SICAT JMT + and exported to SICAT Function.

3D Printing in dentistry



3D Printed Night Guards

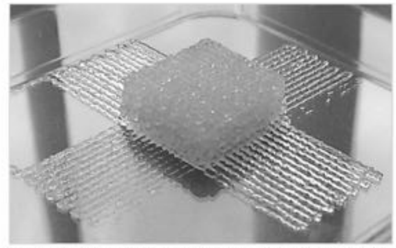
Printed Surgical Guide



Silk bio-ink could help advance tissue engineering using 3-D printers

Could allow for printing tissues loaded with pharmaceuticals or for use in biomedical implants and tissue engineering

September 3, 2015



Scientists have developed a silk-based, 3-D printer ink for use in biomedical implants or tissue engineering (credit: American Chemical Society)

Tufts University scientists have developed a silk-based bio-ink that could allow for printing tissues that could be loaded with pharmaceuticals, cytokines (for directing stem cell functions), and antibiotics (for controlling infections), for example, or used in biomedical implants and tissue engineering.

New Bioink Can 3D Print Tissue At Room Temperature

By Suzanne Hodsden

Advances in 3D-printed biomaterials have been limited by the chemical processes and high printing temperatures required by their bio-inks. Researchers at Tufts University, longtime proponents of the biomedical potential of silk, have introduced a silk-based bio-ink that they say can be printed at room temperature without any harsh chemical treatments. The unique properties of the silk, they told the American Chemical Society (ACS), will pave the way for a host of more complex 3D-printed tissues loaded with biologic drugs or stem cells.

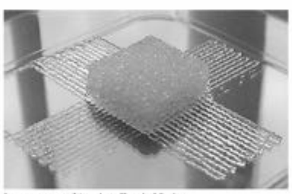
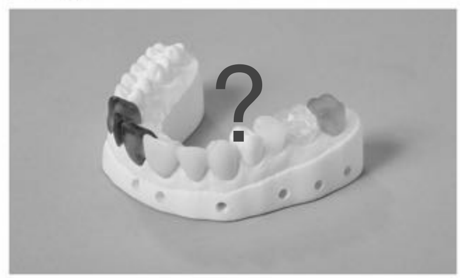


Image courtesy of American Chemical Society.

3D printing has thus far made liberal use of materials like silicone, thermoplastics, collagen, gelatin, or alginate, but all these materials require high temperatures to set up and to retain their structures. Their curing process often involves chemicals or a change in PH balance, which can break down biologic components infused in their ink. Scientists have long-believed that they could create a 3D-printed replica of a human organ suitable for transplant by using 3D printing methods and stem cells, but they've lacked a suitable ink.

What the future holds for 3D Printing

Predicting what's to come for this game-changing dental technology.



Flagship Printers:

A Comparative Analysis

Monoprice Select Mini

Entry Level FDM printer
Build Plate: 120 mm x 120 mm x 120 mm

Best Layer Height: 0.0875 mm

Best XY Resolution: based on nozzle (0.4 mm stock)

Pros

- ~$200
- Can use many types of filament, more with mods
- Easy to modify and upgrade due to large user community
- Small desktop footprint
- Wifi, USB, and SD card printing available

Cons

- Small build plate limits quantity or size of models
- Wiring flaws with the bed shorten lifespan, multiple ways to modify however
- Z axis movement speed: 1.5 mm/s
- Single material, no dissolvable support
- Extruder max temp: 250°C Bed max temp: 60°C limits material selection

Prusa MK3

Kit or Preassembled FDM printer ($200 difference)
Build Plate: 250 mm x 210 mm x 200 mm

Best Layer Height: 0.05 mm

Best XY Resolution: based on nozzle (0.4 mm stock)

Pros

- Open source hardware and software
- Kit is able to compensate for errors while assembling
- Automatic bed leveling
- Can be upgraded for multiple materials

Cons

- Large footprint
- Bearing and rod tolerances raises noise level
- Lacks enclosure

Ultimaker 3 Extended

Multi Material FDM Printer
Build Plate: 215 mm x 215 mm x 300 mm

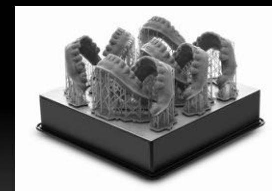
Best Layer Height: 0.020 mm

Best XY Resolution: based on nozzle

Pros

- Built in webcam
- Second nozzle can quickly be raised when only using one material
- Dissolvable support
- Auto bed leveling
- Open source hardware and software

Cons



- $4,300
- As with any FDM printer, speed
- Not much else, 100% of Ultimaker 3 Extended (and Ultimaker 2+) reviewers said that they would recommend their 3D printer to somebody else - beginners through to experts, as per 3dhubs.com

Moonray S 100

DLP Printer
Build Plate: 124 mm x 81 mm x 229 mm

Best Layer Height: 0.02 mm

Best XY Resolution: 0.1 mm

Pros

- Small footprint
- Clear and castable materials
- Longer lasting resin tank
- Dental material in development
- DLP, print speed only affected by Z axis
- Will print surgical guides

Cons

- Closed source
- Software lacks manual support
- DLP printers traditionally have "dead zones" in the corners due to the technology
- Resin material needs models with holes to drain
- ~$4000

Form 2

SLA Printer
Build Plate: 145 mm x 145 mm x 175 mm

Best Layer Height: 0.025 mm

Best XY Resolution: 0.14 mm

Pros

- Small footprint
- Clear and castable materials
- Dental material in development
- Easy to setup and start producing quality prints
- Will print surgical guides with a broken wiper

Cons

- Closed source
- Software lacks manual support
- Wiper system between layers creates print failures
- Resin material needs models with holes to drain
- Replacing resin and resin tanks becomes very costly
- ~$3500

cara Print 4.0

DLP Printer
Build Plate: 103 mm x 58 mm x 130 mm

Best Layer Height: 0.03 mm

Best XY Resolution: 0.05 mm

Pros

- Unmatched accuracy
- Continuous print makes it one of the fastest DLP printers (50mm/h@50mic
- Ortho, guide, & castable materials, with denture base on the way
- Resin trays are not prone to clouding and becoming a consumable
- Can add material without pausing print, no cartridge
- Standard 405 DLP materials

Cons

- Closed source software
- ~$12,000
- Resin material needs models with holes to drain
- Possible to break the build plate when homing axes if user positions it incorrectly

Resin Post Processing

- Both DLP and SLA models need to be soaked in isopropyl alcohol to remove residual print material
- Once clean, UV light curing is used, you may already have a light box
- 3D printing UV lights will strobe to prevent hot spots
- Protip: you can starve your model of oxygen while in UV to speed up the process, fill half of a clear thermoformed denture case with clean water and submerge the model

Melting Methods

SLM- Selective Laser Melting

- Fuses plastic beads, can fill the entire print area without using support
- Limited materials (for now)

SLM- Selective Laser Melting

- Fuses metallic powders, generally in a pressurized chamber
- High cost

DLP/Injection Hybrid

- DLP prints a dissolvable part mold
- Then injects the mold with a variety of materials including plastic, silicone, metal, and rubber

Repetier Server

- Almost any FDM printer can become wifi-enabled for $5
- Raspberry Pi Zero W runs a software called Repetier
- Once you configure your computer and network, you can access your printer from ANY device with a web browser
- Recommended for the tech-savvy only
- Resin and filament printers think differently, but development to make this software universal is in progress
- Collect "royalties" on your prints?!

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