Introduction to 3D Printing

Emma McCrory
Specialist Orthodontist

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1

Objectives

- To be able to describe what 3D printing is
- To understand the workflow for 3D printing
- To describe the software and hardware requirements for 3D printing
- Provide an overview of types of 3D printers
- Provide an overview of how a 3D printed model is processed
- Discuss the advantages and disadvantages of digital printing compared to conventional methods for study models
- Discuss orthodontic applications of 3D printing
- Discuss the ROI and future for 3D printing in orthodontics

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2

Introduction

3D printing or *additive manufacturing* is the fabrication of objects from a 3D digital model. 3D printing can be achieved by the successive deposition of photo-sensitive resin material, cured solid with a light source such as a laser. This allows for customisable appliances and improved workflow in practice. 3D printing is a rapidly evolving technology, with many practices beginning to implement it into their digital workflows. Adoption and integration come with many challenges.

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What is 3D Printing?

- Three-dimensional (3D) printing is defined as the process of making a physical object from a three-dimensional digital model.
- Concept introduced by Johannes Gottwald in 1971. Gottwald created a device that used liquified metal, which would then solidify into a shape upon each successive layer.
- In 1984, Charles Hull developed this further – **stereolithography** = using photo-sensitive polymers to build objects using successive layers and lasers to solidify each layer.

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3D Printer Workflow

1. **Scan** – A digital scan is recorded and sent to the lab as an 'STL' file. This file provides the 3D format for image manipulation in CAD programs.
2. **Design** – The digital scan is imported into computer aided design (CAD) software, where the design is simulated.
3. **Print** – The file is then sent to the printing 'slicing' software, where the object is made ready for printing. The slicing software involves setting up model supports, printing speed, determining material options, and printing size.
4. **Prepare** – Post printing, the object must be washed, dried, and post-cured. Prints are washed in 99% isopropyl alcohol (IPA) and cured using heat and ultraviolet light.

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Software Requirements for 3D Printing

- Computer-Aided Design (CAD) programs create digital models in 2D or 3D. This enables the visualisation of a model prior to construction, which can be modified before producing.
- Once designs are finalised, they are sent via a file called an 'STL' file to a slicing software to prepare the digital model for printing.
- Most CAD programs in ortho have automated processes and features that auto-populate functions to improve the design and processing through printing. Slicers are built into the CAD software so the design can be sent straight for printing

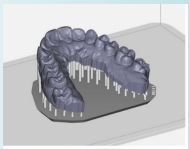

Figure 2: *Rayware Program from SprintRay illustrating model printing. The model is stabalised using 'supports'*

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3D Printer Types and Quality

- Most 3D printing technologies used in orthodontics encompass Stereolithography (SLA) and Digital Light Processing (DLP)
- Although both SLA and DLP technologies have the capacity to achieve the precision and accuracy crucial for orthodontic applications, there can be substantial variation in the quality of outputs from different printer models.
- ***Accuracy*** - how close a measurement is to the true value. The true value represents how closely the 3D-printed design is to the computer-simulated.
- Other measures of printer quality include ***precision*** and ***consistency***

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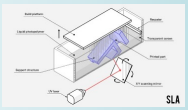
7

Stereolithography (SLA)

1. The build platform is lowered into a resin tank with a distance of one layer height between the build platform and the photosensitive liquid resin or the last completed layer.
2. A UV laser is directed to specific coordinates to cure the resin. Two mirrors help direct the laser to the specified coordinates and light cure sequence.
3. This newly formed solidified layer separates from the bottom of the resin tank, and the platform moves up, allowing for fresh resin to flow into the space.
4. This subsequent layer is then cured and the process repeats until the print is finished.
5. Layer height can be altered, but the smaller the layer height the more accurate the print.
6. After completion, the model can be peeled off the build platform and is then subjected to post-processing.



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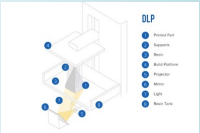
Digital Light Processing (DLP)

1. DLP printers are built around a resin tank. The platform is lowered into the resin tank, and one layer height is left between the platform and the resin.
2. A projector screen is used to flash and cure the resin via mirrors. Curing happens across all points simultaneously.
3. The platform moves up to allow for the fresh resin to fill the layer height and then cured once more. The cycle is repeated until the object is complete.
4. This is faster than SLA printing as the DLP projector instantly cures the entire cross-section of resin rather than following a sequence of coordinates.



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Comparing SLA and DLP

SLA		DLP	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Accurate • Smooth surface • Complex printing patterns • Easy ergonomics • Variety of material choices • Small footprint	• Not environmentally-friendly due to resin usage and wastage • Objects require post-curing • Slower than DLP	• Accurate • Complex printing patterns • Faster than SLA printing • Variety of material choices • Small footprint	• Surface finish not as smooth as SLA • Smaller build volume – due to digital projection (larger the volume, more voxel formation therefore quality reduced) • Objects require post-curing • More expensive than SLA

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10

Processing of 3D Printed Products

After printing, there are three steps required before the appliance/model is ready for use. These include:

1. Washing
The main method of washing involves using a washing station machine featuring a 99% isopropyl alcohol (IPA) tank to clean the appliance. Another method involves using a ultrasonic bath. This uses a tripropylene glycol monomethyl ether (TPM) solution instead of IPA, as the latter is flammable and unsafe for use with an ultrasonic bath.

2. Removing Supports
Some intricate appliances require supports to stabilise the appliance during printing, which can be broken off by hand or removed with a flush cutter. After which sandpaper can be used to improve the final surface texture.

3. Curing
Curing the appliance under ultraviolet (UV) light is crucial to allow for the final material properties to be achieved. The curing time varies depending on the manufacturer and the material used. A specific curing station is used and is often available from the printer manufacturer.

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Digital Vs Conventional Methods

Advantages	Disadvantages
• Accurate (more?) • Quickly identifies scan defects • Time saving • Reduced lab fees • One machine = multiple products • High degree of customisability of treatment • Improved material properties • Space saving due to reduced need for storage of models • Improved patient experience	• Print quality • High upfront cost • Staff training • Implementation • Ecological effects • Health and safety • Insufficient expertise • Space requirements • Hardware company longevity

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Orthodontic Applications of 3D Printing

1. Models
2. Occlusal splints and retainers
3. Aligner staging
4. Bracket printing
5. Virtual bracket removal
6. Transfer brackets/Digital indirect bonding
7. Direct aligner printing - Graphy was the first to develop a photocurable resin that would allow for direct aligner printing. CAD programmes (i.e. uLab, Delta Face) work by creating a 'shell' design for aligner construction. It will significantly reduce environmental waste and speed up manufacturing.
8. Orthognathic surgery - orthognathic wafers, cutting guides and models for treatment
9. Band and loops - personalised space maintainers
10. Metal printing - Recent developments in the use of Selective Laser Melting (SLM) and Selective Laser Sintering (SLS) are being used to create metal appliances such as rapid palatal expanders (RPEs) and other metal-based appliances such as brackets/springs and screws. The printers are costly, and the current return on investment for practices favours the buying decision. This will change once cost and print time decrease.

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13

Return on Investment

There are two options when considering an item: purchase externally or produce internally.

Cost and quality are important factors - Cost is essential to working out the viability of 3D-printer investment, but also ensuring prints are of comparable quality to the purchased products (eg stone models from external lab)

Purchasing can be viewed as a fixed cost, whereas when producing an item, labour costs, material and running costs are combined to give a combined value.

For fabrication, costs are associated with printer purchase, washer/curer, software and scanner required for the digital process. Maintenance costs must be considered along with materials such as consumables, resin, and post-processing solutions. Costs associated with the possible recruitment of an in-house technician and the potential need for plumbing and re-wiring of the printer room need consideration.

Different objects will require individual calculation, due to the different sizes and volumes of prints. Smaller items, like brackets, will incur smaller 'per print' cost than larger items, such as models.

Ortho-CAD software have features that can quantify the resin used and time for each print, allowing a cost per print to be calculated. These costs must be combined to determine a 'break even' figure. This number signifies the minimum number of prints required to break even, which will help determine the purchase or produce debate.

Upfront Costs	In-House 3D Printing	Purchasing/ Outsourcing
Printer And Software Cost	£3000	£0
Training (Optional)	£500	£0
Material Costs	£100	£0
Cost Per Print	£10	£30
10 Prints	£3600 + £100 = £3700	£300
50 Prints	£3600 + £500 = £4100	£1500
100 Prints	£3600 + £1000 = £4600	£3000
200 Prints	£3600 + £2000 = £5600	£6000

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14

Future of 3D Printing

Printer hardware
- print at greater speeds with increased accuracy and volume
- refined materials will have better properties (biocompatibility, environmentally friendly and less shrinkage)
- greater level of personalised treatment will be achieved
- even shade-matching brackets to teeth for patients who do not want clear aligners or lingual appliances

Materials and the environment
- biocompatibility, mechanical strength and an increased printing range
- new materials are being developed to ensure the technology becomes more sustainable
- Nylon in manufacturing orthodontic appliances - does not create chemical bonds during curing and can, therefore, be recycled into pellets. These pellets can then be used in the non-cosmetic part of cars and other machinery.

Brand monopolies
- specialist orthodontists can challenge big brands with monopolies on clear aligner systems.
- printing aligners in house – reduced costs for the practice which can be reflected in the reduced cost to the patient.

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Conclusions

- 3D printing is part of the 'fourth industrial revolution' - continuous advancements in technology due to substantial investment driven by corporate commercial interests and expanding research
- 3D printing yields precise and durable dental models, circumventing the inaccuracies inherent in conventional dental impressions and plaster models. This transition from traditional fabrication methods to a fully digital workflow has been shown to yield cost savings and enhance overall operational efficiencies.
- Accessible across a range of price points, 3D printing offers orthodontists flexibility in selecting comprehensive ecosystems or individual components and software.
- With a discernible shift from analog to scanning and digital workflows, 3D printing emerges as the logical next step in this evolutionary trajectory. Its increasing accessibility and affordability, coupled with improved hardware and user-friendliness, position 3D printing as an integral component of many orthodontic practices in the near future.

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16

References

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17

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Thank You.

Any questions?

Contact: emma@lisburnorthodontics.co.uk

18