Methods and Guidelines for Incorporating 3d Printing into Orthodontic Practice: A Literature Review

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Abstract
Three-dimensional (3D) printing is revolutionizing orthodontic practice by enabling the fabrication of customized appliances and improving workflow efficiency. This technology allows for the creation of accurate dental models, clear aligners, surgical guides, and retainers. The most common 3D printing techniques used in orthodontics are stereolithography and digital light processing. Introducing 3D printing into orthodontic practice requires specific hardware, software, and workflow considerations. Digital orthodontics, integrating 3D printing and imaging, has revolutionized orthodontic treatment by enabling precise customization of appliances like clear aligners, bonding trays, and splints. These advancements improve efficiency, adaptability, and patient outcomes, reshaping modern orthodontic practices.

Keywords: 3D printing, aligner technology, in- office aligners, aligner software

1. INTRODUCTION

The idea of align therapy utilised by aligner manufacturers has emerged to be a valuable treatment alternative for patients suffering from moderate to complex malocclusion and this shift has been evolving throughout the first 15 years of CAD/CAM aligner technology[1].

For adult orthodontic practitioners who are motivated to advance through the learning curve of aligner therapy, aligner treatment is an excellent cosmetic alternative.

Furthermore, the success of aligner therapy is increased by improvements in treatment protocols, particularly for patients with complex malocclusions.

A number of factors influence aligner treatment success [2]. The outcome of an aligner therapy depends on a number of factors, including patient compliance, programmed aligner biomechanics, provider clinical abilities, and the effectiveness of an aligner system components.

In recent times, providers have access to a wide range of aligner systems, including Spark from Ormco and ClearCorrect from Strauman.

These systems differ in terms of thermoforming plastic sheets, treatment planning software, aligner features (such as attachments), public marketing positioning, and pricing structure [3].

2. IN-OFFICE ALIGNER SYSTEMS (IOA)

IOA systems represent a significant advancement by enabling orthodontists to manufacture aligners onsite. The workflow includes digital scans, treatment planning via software (e.g., uLab, 3Shape), 3D model printing, thermoforming, trimming, and packaging. These systems offer immediate aligner availability post-debonding, maintaining treatment momentum.

Initially used for minor corrections of malocclusion, aligner therapy has now evolved into a popular treatment choice, widely approved by orthodontists and general dental professionals [1].

Depending on the patient's location, orthodontics may use aligners for 20–80% of the whole treatment [1,4].

- Clear aligner therapy has advanced significantly over the past 20 years since the launch of the first mass-produced aligner system.

Major providers include Invisalign, Spark, ClearCorrect, and SureSmile.

- The rise of 3D printing technology and the accessibility of various teeth alignment software have led to a growing demand for fabrication of clear aligners in-office among dental practitioners [1].
- Thereby, there is an upward interest in an in-office aligner (IOA) system also known as in house aligners (IHA) [1].
- Incorporation of all aspects of manufacturing aligners, digital treatment planning, and orthodontic care delivery constitutes an in-office aligner system [1].

Components of an in-office aligner system

An IOA system includes four main components [1]:

1. data acquisition,
2. digital treatment planning
3. aligner manufacturing,
4. aligner delivery protocol.

When compared to a commercially or mass-produced aligner system, the protocol for treatment delivery of an IOA system is different [1].

The fifth element of an IOA system can possibly be considered as its branding and marketing elements.

3. WORKFLOW INTEGRATION

3.1. Digital Workflow Components

A successful digital workflow incorporates:

- **Data acquisition**: intraoral scanners (e.g., iTero, Medit)
- **Software planning**: segmentation, staging, biomechanics
- **Appliance manufacturing**: printing, thermoforming, finishing

The process of digital treatment planning can be categorised into four main stages beginning from transferring the scanned arches into the software for 3D printing of the planned treatment models [1]:

- tooth segmentation and landmark identification;
- setting up of digital treatment;
- Biomechanical staging of treatment and auxiliaries;
- 3D printing ready model generation.

Segmentation is the process of arrangement 3D dental models for movement of maligned teeth [1]. This step involves the removal of teeth from its surrounding tissue along with detection of teeth landmarks. With the availability of various softwares such as uDesign by uLab or OrthoAnalyzer by 3shape, digital planning of a model is done rapidly and efficiently thus reducing time consumption [1].

The next step is the creation of a digital treatment setup to render the movement of tooth and is backed up by automated or semi-automated software setup [1]. This is commonly the rate limiting step.

- The most important advantage of an in-office aligner (IOA) system is the ability to control the development of biomechanics, also known as staging [1].
- 3D model replication based on the replicated treatment plan is the last step and includes creation of digital wax up such as block out, digital pontics and 3D model markings which are considered crucial [1].

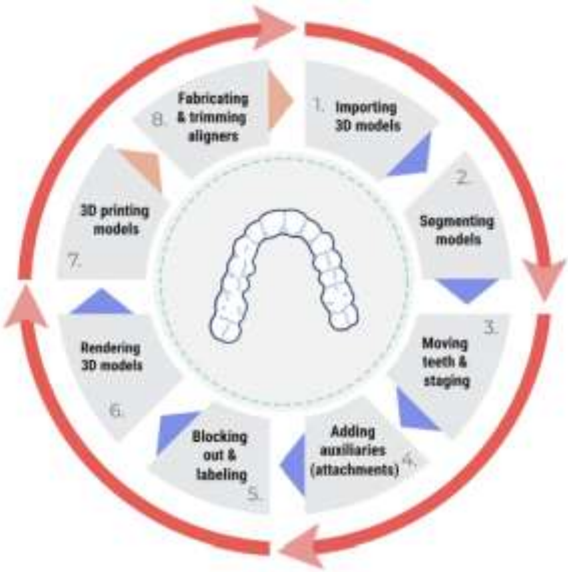

Figure1. Steps Of Digital Treatment Planning And Aligner Manufacturing Cycle [5]

Aligner manufacturing process

- The main steps included in the process of aligner manufacture are replication of 3D printing models, the thermoforming process for aligners fabrication, trimming and polishing the aligners, and lastly packaging [1].
- Manufacturing designs in **CAD/CAM** can be held either with subtractive or additive methods.
- Subtractive fabrication is accomplished by removing material from a block by milling or cutting until a desired shape is created.
- On the other hand, additive manufacturing is referred to a process, in which an object is fabricated by adding a raw material layer-by-layer in a specific manner- **3D printing** / rapid prototyping

Thermoforming plastic sheets

- The key element of an aligner system is the thermoforming plastic sheet and due to its increased demand in the recent years due to its adoption into the in- office aligner system, there has been a boon in the plastic sheet manufacturing industry [1].
- Before 2013, materials like polyurethane (PU) and polyethylene terephthalate glycol (PETG) were used to fabricate a single-layer thermoforming plastic, commonly used for aligner treatment and clear retainers [1].
- In 2013, a multi-layer plastic sheet known as **SmartTrack** was introduced by Align Technology. This new material was designed to maintain consistent force levels for a longer duration and enhance patient comfort.
- The SmartTrack sheet featured a three-layer construction, with a rigid polymer core sandwiched between two softer polymer layers [6] - thus optimizes force delivery and patient comfort.

- The ideal aligner material should offer high transparency, flexibility, wear resistance, and biocompatibility.
- Polyurethane-based aligners (e.g., Invisalign) provide better flexibility and force delivery, while PET-G aligners (e.g., Zendura, Biolon) are more resistant to staining and wear.
  The three fundamental factors that control mechanical and physical properties of thermoforming plastics used in aligner therapy are influenced by:
- Type of material used,
- sheet thickness, and
- sheet structure [7].
- Research on fixed appliances suggests that a continuous, low-level force is key to efficient tooth movement [8]. A good plastic for aligners should, therefore, provide a stable, gentle force over time, avoiding excessive force peaks during insertion that can cause discomfort and inefficiency in tooth movement.
- The selection of a plastic sheet is mainly determined by the force levels released from an aligner [1].
- The ideal thermoforming plastic should exert a continuous, low-level force to facilitate efficient tooth movement, without a rapid decline in force over time [1].
- The impact of fixed appliances on tooth movement studied under molecular level states that applying continuous low- level of force leads to effective tooth movement through frontal resorption [1].
- Thus , an ideal thermoforming plastic should create aligners that produce a minimum amount of force at the time of insertion with a gradual low level of steady force maintained over time [1].
  Other vital considerations include **ease of trimming** and **overall usability**. In-office aligner systems often require clinicians to trim the aligners to fit the patient's teeth properly. Therefore, the ease with which the plastic can be trimmed without compromising its structure is important.
- **Packing** of in-office fabricated aligners can range from professionally designed and manufactured to a simple pouch with a zip lock.
- These packages include **identity of the patient, number of aligners included, and patient instructions for wearing and maintenance of aligners [1].**

Clear aligners have sparked a revolution in the field of Orthodontics over the past 20 years owing to the benefits they offer compared to conventional approaches such as reduced chair time and digital assessment of treatment, thus making patients keen on opting this treatment modality [9].

4. LAB SETUP AND SPATIAL DESIGN

A key term currently gaining traction in orthodontics is the **"digital orthodontic workflow" (DOW)** [10]. Efficient lab space is essential. Key areas include:

- **3D printer, wash/rinse units, curing stations**
- **Thermoforming machine**
- **Dedicated counters for trimming, packaging, and model removal**
- **Storage areas for materials and equipment**

The digital orthodontic workflow (DOW) integrates technology into orthodontic practices, enhancing diagnostics, treatment planning, and appliance manufacturing. A well-configured digital lab ensures efficiency, offering flexibility in handling in-house, outsourced, or hybrid manufacturing. Key advancements, such as tooth movement software and affordable 3D printers, have made DOWs more accessible. The manufacturing process includes 3D printing, post-processing, fabrication, trimming, disinfection, and packaging. Common DOW applications include retainers, in-house aligners, digitally-guided bonding trays, splints, bleaching trays, implant-retained restorations, and metal sintered appliances [11]. Emerging technologies continue to simplify and enhance digital workflows, improving efficiency and precision in orthodontic treatment [11].

Figure 2: Analog V/S Digital Lab Processes [11]

ANALOG	DIGITAL
impression - single use only	intra oral scan - infinite uses
alginate, stone, model grinder	3D printer, post-processing unit
physical storage space required	HDD storage only
delayed access to data	immediate access to data
manual processes only for manipulating model	software applications to manipulate scan

Several emerging technologies currently in beta testing are expected to further enhance and simplify digital orthodontic workflows, streamlining processes and improving efficiency even more in the near future [12].

- The workflow is the integration of the linear flow of each individual procedure into an effective and efficient process.
- One of the most critical pieces in the successful implementation of a digital orthodontic work flow is **lab layout, setup, and functionality** [11].
- The flexibility to make independent decisions and customise workflows that can increase the best outcome between orthodontists and their patients is the primary advantage of having a digital lab in a private practice [11].

PLANNING OF SPACE

- The effective utilization and design of the total space required is the first assessment during digital lab installation [11].
- A simple and quick approach for estimation of space required is to make a mental calculation of the digital workflow, by keeping in mind various digital workflows that will take place in a digital lab [11].
- Next step is the creation of **blueprint of the lab** and designing of the physical dimensions, both from top-down view and an eye level perspective [11].

Equipment Space

- **Computer**
- Indicated for practice management, management of workflow, setting up of tooth movement, 3D printing
- Shoto be placed in a user friendly location without interfering with the workflows' manufacture [11].
- **3D Printer**
- ***Powerhouse*** 3D models fabrication of direct printed appliances (night guards/DGB trays) from Stand-

ard Triangle Language (STL) files [11].

- Commonly used in orthodontics: faster **Digital Light Processing (DLP) and Masked SLA (MSLA) printers** as well as the slower **Stereolithography (SLA)** printer [11].
- **Wash/ Rinse Unit**
- Incorporates **95-99% isopropyl alcohol (IPA)** for uncured resin removal from the outer surface of the printed models [11]
- **Compressed Air Gun**
- For drying of the models after water rinse and to remove any fragment left on appliances or after trimming/polishing [11]
- **3D Curing Unit**
- Consists of a light equipped box that emits light of wavelength between 385 and for **final curing of the outer surface of the model** or appliance to guarantee highest strength and stability [11].
- **Dental Curing Light**
- For curing block-out material on models with significant undercuts and for curing composite used during other lab procedures [11]
- **Thermoforming Machine**
- For fabrication of aligners or Essix-type retainers on orthodontic models [11]
- It consists of a heating element and positive pressure for aligner forming
- **Vent System/ Voc Monitoring**
- For escape of 3D resin fumes.
- **Lab Handpiece**
- Used for finishing aligners
- **Heat Sealer**
- For sealing after **quality control and disinfection.**
- **Appliance Storage System**
- After final packaging is complete the entire case is stored until the delivery appointment.

Counter Space

- **Removal Of Model**
- Counter space is required to remove the models from the 3D printer build plate [11].
- **Aligner Trimming/ Polishing**
- Done after removal of aligners from the circular thermoforming blank with scissors [11]
- **Attachment Template Loading**
- Loading of attachment templates are done
- **Aligner Packaging**
- Involves disinfection of aligners followed by quality control checking [11]

Storage Space

- **3D Printing Supplies-** are commonly stored in extra resin tanks and resin [11] and are used when required
- **Thermoforming Material-** to be placed close to the thermoforming machine [11]

Movement Space

- Space facilitated for optimal lab workflow.
- For instance, adequate space is required for easy movement of individuals while working in the lab.

Ventilation systems and VOC monitors ensure safety during resin handling.

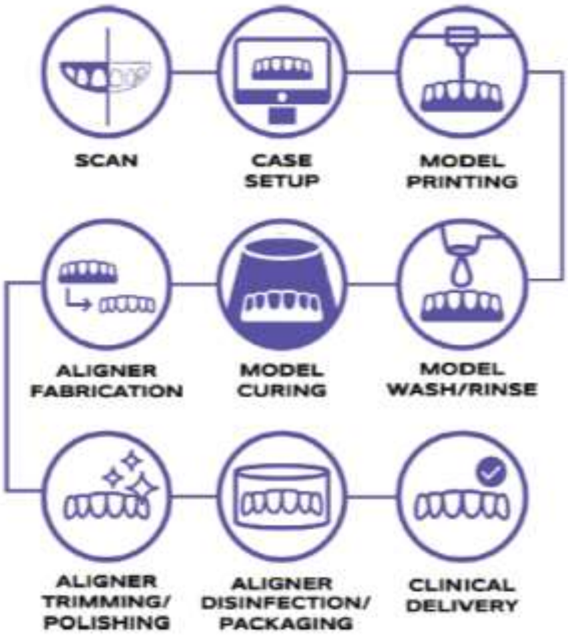

Figure 3: In-House Aligner Workflow [11]

5. 3D Printing Technologies In Orthodontics

The most prevalent technologies in clinical orthodontics include **stereolithography (SLA)**, **digital light processing (DLP)**, and **masked SLA (MSLA)**. These technologies are favored for their accuracy and surface resolution. **Selective Laser Melting (SLM)** and **Selective Laser Sintering (SLS)** enable the fabrication of metal appliances such as RPEs and space maintainers. Material selection—including biocompatibility, mechanical properties, and transparency—is critical for clinical success.

6. The Application Of In-Office Aligners In The Combination Treatment Protocol

Orthodontists have the option of choosing either braces or clear aligners for treating their cases [12]. However, one can use the advantage of incorporating both fixed and removable appliances as combination treatment, thereby enhancing the aesthetic outcome effectively in a shorter treatment time. Combining clear aligner therapy with fixed lingual appliances is also an esthetic means of treating malocclusions in a shorter treatment time with low cost and high efficiency [12,13].

- Beginning treatment with fixed appliances allows for initial tooth movement, which can then be more effectively continued with clear aligners compared to starting treatment with aligners alone [12].
- Numerous modifications in clear aligners are required while dealing with complex tooth movements such as extrusions, rotations, or overjet expansion, to obtain the final outcome result [12,14]. Fixed appliances effectively handle these movements that are challenging for clear aligners, thus, the limitations of aligners in these areas are reduced or eliminated.
- With the availability of in-house aligner production, clear aligners can be fabricated and delivered to patients almost immediately once debonding of fixed appliance is done thus eliminating delivery delay [12].
- Usually combo treatment is initiated in those patients who began with fixed treatment but had to discontinue and switch to clear aligners due to a life event.

- Combination treatment is often initiated for patients who began with fixed appliances but had to pause their treatment and switch to clear aligners due to a certain life change [12].

7. Applications Of 3D Printing In Orthodontics

The prevalence of 3d printing in industry is ever increasing, perhaps no more evident than in dentistry and, in particular, orthodontics [15].

1. **Fabrication of Orthodontic Appliances:**
   - **Resin Polymerization:**
     - SLA/DLP printers produce models for vacuum forming thermoplastic aligners.
     - Stereolithography, or SLA printing is a method that uses a light source to cure a photo-sensitive resin [18].
   - **FDM Printing:**
     - Creates dental models for Hawley-type retainers.
   - **Metal Appliances:**
     - Technologies like Selective Laser Melting (SLM) and Selective Laser Sintering (SLS) fabricate custom metal appliances such as rapid palatal expanders.

These processes are leading to better fitting, more individualized appliances due to better dimensional accuracy as compared to the traditional alginate and stone dental models [16, 17].

2. **Fabrication of Dental Models**
   - **Diagnostic models**: 3D-printed models replace traditional plaster casts.
   - **Treatment planning**: Digital scans allow orthodontists to simulate treatment progress.
   - **Storage efficiency**: Digital files reduce the need for physical model storage.
3. **Clear Aligner Production**
   - 3D printing enables **in-house aligner production**, reducing reliance on third-party manufacturers.
   - Workflow:
     - Intraoral scanning (iTero, Medit, etc.).
     - Digital tooth movement planning
     - Printing of dental models.
     - Thermoforming clear aligners over printed models.
4. **Retainers and Splints**
   - Hawley retainers and occlusal splints can be fabricated using **3D-printed models**.
   - Faster production compared to conventional impression-based methods.
5. **Temporary Anchorage Devices (TADs) Guides**
   - 3D-printed **surgical guides** improve the precision of **TAD placement**.
6. **Digitally-Guided Bonding (DGB™) Trays** [17]: Custom trays used to assist with precise bonding of brackets.

8. Challenges And Considerations

- Lack of standardization in IOA systems leads to variability in outcomes.
- A steep learning curve exists for software and printer operation.
- Clinicians must balance automation with manual oversight.
- Regulatory compliance and patient safety protocols must be strictly followed.

9. Future Directions

AI-enhanced treatment planning, new printable materials (including biodegradable and functional materials), and increasing affordability of high-resolution printers promise to further revolutionize orthodontic practice.

10. Conclusion

- The advent of 3D printing technology has transformed the potential of in- house aligner manufacture [11].
- Introduction of 3D printing has also boosted the work environment and expertise of orthodontists [11].
- By combining conventional fixed orthodontic appliance treatment with clear aligner therapy the possibilities of excellent results are immense [11].
- By combining both systems, practitioners can achieve best outcomes for most orthodontic cases while balancing the costs compared to using a single system alone [11].

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