Additive Manufacturing Technology in Orthodontic Devices Development

W.F.Tang, S.L.Mak, C.H.Li

Abstract*: Traditional wires and brackets has been widely used as orthodontic devices for long time. The metal wires and brackets help to correct the position of teeth as well as fix the cavity. However, metal brace wires have quite a lot limitations. Patients wearing metal brace have many food restrictions and feel not comfortable. Brushing and flossing are required to remove the food debris frequently. Hence, clear plastic aligners have popped up recently. Since the metal brace fabrication process has associated with prolonged process time as a result of a long workflow process starting from brace mold presentation to the prosthesis execution. The growing of additive manufacturing technology make it possible to develop complex structures and shapes of dental brace. By combining 3D oral scanning, it is possible to shorten the lead time of orthodontic treatment process. This review, therefore, investigates the use of Digital Light Processing (DLP) Additive Manufacturing Technology for plastic dental brace development as a remedy to the problems associated with the traditional methods. The study reveals that it is feasible to fabricate these plastic braces utilising the DLP technology. DLP technology is affordable and arguably able to produce dental models with high levels of assurance and accuracy. .

***Keywords* : dental brace, clear aligners, orthodontic device, additive manufacturing, stereolithography, fused deposition modelling**

I. INTRODUCTION

Dental braces are pieces of equipment that are used to strengthen and align teeth. These divides leverage force or pressure to help improve a person's bite or the dental health and hygiene; they can be used to correct underbites, overbites, malocclusions, deep bites, crooked teeth, crossbites, open bites, and various other flows on the jaw and the teeth (Sorooshian and Kamarozaman 2018). According to Benson et al. (2015), braces can either be structural or cosmetics and are used in combination with other orthodontic appliances to aid in widening the jaws, the palate, and otherwise help in dental shaping. There are essential components that traditionally constitute braces including the ligature elastic (O-ring), bonding material, brackets, and the teeth, however, occasionally rubber bands or spring can be applied to put more force in a given direction (Wang et al., 2016).

Millett et al. (2017) add that braces apply constant pressure which loosens the tooth and allows for the growth of a new bone to support the tooth in its new position, a process referred to as bone re-modelling, and with time moves the teeth into the desired positions. According to Kaluđerović, Schreckenbach and Graf (2016), bone deposition also forms a critical factor in the movement of the tooth that happens at the distracted periodontal ligament in order to prevent loosening and occurrence of voids distal to the direction of tooth movement. Some common types of braces include traditional metal wires, gold plate stainless steel, lingual braces, titanium braces, progressive, clear removable aligners, and the customised orthodontic treatment systems (Alkadhimi 2020).

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II. PROBLEM STATEMENT

Even with their universal application, the current studies show several concerns with these metal-based braces as a method of orthodontic correction. First, the process is associated with a more prolonged process time as a result of a long workflow process starting from brace mold presentation to the prosthesis execution. The traditional metal-braces molding methods are associated with accuracy limitations in the final output, causing uneasiness or discomfort among patients after installation (Uno et al., 2019). Further, studies demonstrate that multiple adjustments can extend treatment and reverie time (Kiviat and Fleming 2018). Fourth, using metal braces has a negative social outcome due to the perception of "a mouth full of metal" (Uno et al., 2019). Also, metal braces are associated with diet and food restrictions because sticky or hard foods can dislodge or break the metal wires from the teeth leading to prolonged treatment time as a result of multiple distortions of braces or breakages (Kiviat and Fleming 2018). Lastly, another primary concern is the cleaning of teeth. Lastly, it is quite difficult to brush and floss teeth when metal braces are deployed (Alkadhimi, 2020)

This review, therefore, investigates the use of Digital Light Processing (DLP) Additive Manufacturing Technology for plastic dental brace development as a remedy to the problems associated with the traditional methods. According to Javaid and Haleem (2019), additive manufacturing is growing to make it possible to develop complex structures and shapes, including the dental field, because the fabrication of plastic teeth braces requires complex and precise structures. Therefore, by combining digital scanning and 3D printing, it is possible to design custom clear plastics braces as a replacement of the traditional metal braces for orthodontic correction within short lead time. The primary aim of the review is to assess the current state of dental brace development by using Digital Light Processing (DLP) additive manufacturing technology and the feasibility of using these technologies in creating plastic braces to replace the traditional metal braces and their associated problems.

In this regard, the following constitute the primary study objectives,

1. To investigate the current 3D printing and scanning methods
2. To explore the 3D printing of Digital light processing (DLP) technology.
3. To evaluate the current state of fabrication of clear plastic braces for orthodontic corrections.

Research Questions

The following constitute the primary research questions;

a) How applicable is Additive Manufacturing in Orthodontics?
b) In what ways can clear plastic braces solve the issues associated with metal for orthodontic corrections?
c) What is the feasibility of applying DLP additive manufacturing technology in the fabrication of clear plastic braces?

III. BRACE TECHNOLOGY DEVELOPMENT

- *Metal-based Wired Braces*

The traditional metal-based wired braces are the most commonly studied and applied methods (Millett et al. 2017). According to Kiviat and Fleming (2018), metallic braces entail a stainless-steel that sometimes is combined with titanium. The braces have a metal bracket with elastic rubber band ties straining the wire onto the metal brackets; however, self-ligating braces type do not require elastic ties because the wire goes through the bracket. The second category is associated with shorter treatment time, less pain on the teeth, and fewer adjustment -requirement than the first type. The gold-plated stainless steel is deployed upon patients who are nickel-allergic; however, some chose them for the aesthetic value of gold. The use of titanium is similar to steel braces but achieves the same objective with a lighter material. A novel strategy is the use of progressive, clear removable aligners. This method is used for non-complex orthodontic cases, including palate expansion, extractions, or jaw surgery to move teeth to their final position (Javaid and Haleem 2019).

- *Plastic (Invisalign) Braces*

Invisalign is a clear set of hard plastic aligners fitted for the mouth to help correct crowded or crooked teeth. These items must undergo checking and placing during an initial couple of months to align the teeth correctly in their positions. The choice of braces is popular; clear aligners are practically invisible (Szuhanek et al. 2017). Unlike the metallic braces, these plastic braces provide more comfort when worn (Bowman 2017). These braces are devoid or wires or brackets, therefore, are not associated with painful cuts and nicks in the mouth. Further, Shivapuja et al. (2019) posit that the plastic braces do not irritate the mouth as a result of being smooth and lack sharp edges (Comba et al. 2017). Because the plastic aligners are clear, the feeling and perception of a mouth full of metal do not exist. In the research by Szuhanek, Fleser and Grigore (2015), participants thought that the plastic braces were more attractive to the eye and in many cases go unnoticed by many people. As such, a user of plastic braces can feel free to smile without the need to be overly self-conscious. Further, the cost of clear aligners is comparatively lower compared to the metal based-braces due to material and technology used. Szuhanek et al. (2017) observe that prices of braces have an insignificant dependence on the treatment plan, extent and duration of the issue requiring correction, location, time and age of the treatment or the orthodontist's experience. In a related study by Shivapuja et al. (2019), the researcher observes that since the plastic aligners have become available on a widespread scale in straightening teeth, they are perceived convenient and healthy; therefore, no one may require to deal with metal braces any more. The fact that these braces can be removed when eating, flossing, or brushing teeth, unlike metallic braces. Therefore, a user is able to practice effective oral hygiene and reduces the risk of suffering from gum disease and can also eat the food of choice (Gomez et al. 2015). Bowman (2017) adds that unlike traditional braces, the plastic braces ensure that a user does not worry about food particles getting stuck. Most importantly, plastic braces are easy to maintain. According to Vandenberghe (2018), the braces can get dingy with time, but cleaning freshens them up. The process of cleaning can be done using a toothbrush dipped in a small amount of bleach and water (Szuhanek, Fleser and Grigore 2015). In contrast, Weir (2017) argues that the plastic braces are associated with several adverse outcomes, first, they are expensive to purchase, second, the attachments that go along with the plastic braces make them more noticeable, are expensive, and are required to be worn atlas 22 hours of the day (Jindal et al. 2019). Additionally, plastic prices are also associated with tooth discomfort and inconvenience. Participants of the study by Comba et al. (2017) reported using pain relievers before their teeth adjust to the plastic braces. The user is also required to remove them every time during meals and in order to clean the teeth..

IV. ADDITIVE MANUFACTURING PROCESSES DEVELOPMENT

The primary processes involved in the 3D printing process include the acquisition of data, data processing, additive fabrication, and post-processing procedures. According to Francois et al. (2017), the data acquisition sequence can be achieved by leveraging the contact or non-contact scanning devices. The original equipment includes cone beam computerised tomography (CBCT), computerised tomography (CT), lacer digitising (intraoral or extraoral scanning devices) and magnetic resonance imaging (MRI) (Gokuldoss, Kolla and Eckert, 2017). The sequence then shifts to data processing that involves the use of specific computer-aided design (CAD) software to create a virtual design of the object (Harun et al. 2018). Upon the design completion, the STL file generated is imported on the printer software which controls the process of slicing and addition of support structures based on the parameters and the build variable information it generates to control the operation on the 3D printer (Ziemian, Sharma and Ziemian 2012). The next phase of the sequence, additive fabrication is responsible for building the object utilising a Slice file in the 3D printer.

Lastly, during the post-processing phase post-curing to help complete the polymerisation process and the cleaning of the object is undertaken. However, the post-processing procedures are printer or technology-specific, and therefore depends on the recommendations of the manufacturer (Francois et al. 2017).

- *Digital Light Processing (DLP)*

The DLP additive manufacturing technology is considered similar to SLA (Mu et al. 2017), with a primary difference in the source of light. In the DLP, image creation is by the digital mirror device (DMD); this is a microscopic mirror in a matrix within the semiconductor chip or an arch lamp (Thrasher, Schwartz and Boydston 2017). According to Zuzak et al. (2013), each microscopic mirror represents a unit or multiple pixels in the projected images; thus, the number of mirrors is directly proportional to projected image resolution (Nayar and Boult 2014). A projector under safelight conditions projects light to a vat composed of liquid polymer, and the projector displays the image of the desired object onto the liquid polymer. In the DLP additive manufacturing technology, the desired object is pulled out from the liquified resin and not down, further into the liquid photographic system. The radiation passes the rug; the ultraviolet transparent window, the process is then repeated until the desired object is fully built (Mu et al. 2017).

In a study to assess the performance of DLP AM technology in terms of effectiveness and adequate accuracy for clinical applications under a variety of orientations as well as settings, the researchers collected oral impressions from 15 patients to make 3-dimensional printed models (Sherman et al., 2020). The researchers tested for the following variable of the printing method; hollow vs solid shell, placement on the build plate (corner vs build), and thickness in the z-axis (50 vs 100) microns. The researcher then printed the impressions using the different orientations and printing techniques on the same printer; the researcher then measured a total of 240 mandibular and maxillary arches. The printer yielded a total of eight combinations of print. The researcher then measured and compared the arch and tooth from individual models. Further, the researcher used the intraclass correlation coefficient to assess the intra observer reliability of the repeated measurement error (Sherman et al., 2020).

Sherman et al. (2020) established highly reproducible results as a result of the high intraclass correlation coefficient for all the record measures. All the mean differences retrieved from the protected combinations were statistically significant. Further, there was an observably high degree of agreement among all the sets of models and printing variations as verified by the Bland-Altman plots. As such, the experiment proved that the DLP printer produced clinically acceptable models in all build-plate areas with solid and hollow model shells and at its high-speed setting of 100 microns. Therefore, the DLP AM printer should be a viable option for orthodontics within a clinical environment at a high-speed mode; however, the build plate should be filled with less resin while filling the build plate. Similar results are replicated in the study by Oliveira (2019), the study showed better trueness value for DLP, the researcher however obtained a discrepancy ranging between 20-50µm, which is insignificant for a clinical trial.

In a related study by Jasiul et al. (2018) to compare the accuracy of dental models printed by the DLP compared to other technologies including SLA and UDP technologies, twelve 3D digital surface models were selected, exported as stereolithographic surface models and then printed at 50µm and 100µm. The researchers then created a digital STL file out of the scans and then superimposed to the original scan. The research study outcome revealed no statistical significance in the difference in the layer of thickness between DLP, SLA and UDP. As such, these technologies could be utilised to obtain a desired level of accuracy. However, Lee et al. (2017) in their study also observed that the DLP AM technology is not valid when printing multiple models simultaneously, spread out entirely around the build platform to produce results of desired quality because the technology has the tendency of object quality degradation when spread towards the edge of the build platform.

- *Stereolithography (SLA)*

The SLA is an additive manufacturing process that primarily constitutes the following steps; first, the SLA building platform is submerged in a liquified resin polymerised by ultraviolet laser (Partolo 2011). Second, a pre-programmed design of the object is drawn using UV laser for layer formation; because the photopolymer is UV-light sensitive, the photochemical solidification of the resin occurs to form a unit layer of the desired 3D object. Third, upon complete polymerisation of the layer, the process of descending the building platform is initiated; the platform descends at a distance equivalent to the thickness of the layer allowing for coverage of the previous layer by incurred resin (Choi et al. 2011). This process is repeated several times until the building of the printed object is complete. According to Melchels, Feijen and Grijpma (2010), the completed parts require washing using UV light to clean wet resin from the surface. The SLA utilises laser technology to trace out the object cross-section. A set of lenses is used to focus the laser, which is then reflected off the galvanometer, which constitutes double motorised scanning mirrors. Melchels, Feijen and Grijpma (2010) posit that the z-axis resolution is determined by the depth of cure controlled by the irradiant exposure conditions and the photoinitiator, including velocity, wavelength, and power, pigments, dyes, or added UV absorbers. The layer thickness of the SLA process, in general, is dependent on the standard of the printer model, which ranges between 5-150 µm having a surface roughness of about (35-40) µm Ra. Further, the UV light wavelength useful during the material polymerisation depends on the printer. It ranges between (200-500) nm. According to Partolo (2011), SLA technology is associated with the freedom of printing complex geometries besides being temperature resistant. The ability of the SLA technology to allow for bottom-to-up printing makes it possible to ensure that the build volume is significantly more prominent than the vat and that only a sufficient photopolymer is utilised to sustain the bottom of the build with a continuous supply of photopolymer (Kiviat and Fleming 2018).

However, the success of the process is significantly dependent on the support structures which consume additional material leading to extended post-processing and production time (Melchels, Feijen and Grijpma 2010). The supporting structures attach to the elevator platform and help resist lateral pressure from the resin-filled blade, mitigate the deflection due to gravity, and retain the freshly created sections during button-to-up printing. The supports are automatically created during CAD models preparations; however, they can also be manually generated, but are removed mechanically upon completion of the printing process (Partolo 2011).

- *Polyjet Printing (PP)*

This process involves the selective jetting of liquid resin out of hundreds of nozzles and the polymerisation with ultraviolet light (Sood, Ohdar and Mahapatra 2010). According to Choi et al. (2011), the curing using the UV is done upon a desire for the virtual design, and because the process utilises multiple print nozzles, the co-deposition of supporting material occurs. Singh (2011) posits that the distinct variations in colour or building materials possessing a variety of properties can be designated, including structures having spatially graded properties (Castiaux e al. 2019).

- *Fused Deposition Modelling (FDM)*

This is an additive manufacturing technology based on the thermoplastic material extrusion. In this approach, the material is drawn via a nozzle, heated, and deposited in layers (Anitha, Arunachalam and Radhakrishnan 2001). The nozzle movement is horizontal, but the platform movement is vertically downward or upward. According to Sood, Ohdar and Mahapatra (2010), the final model quality depends on several factors; however, the technology shows excellent potential upon successful control of the factors. While this technology demonstrates more significant similarity with other AM methods, it is unique because of material added in a continuous stream and under constant pressure. Ziemian, Sharma and Ziemian (2012) posit that this pressure must be kept steady for an accurate outcome. Chemical agents or temperature control strategies can be deployed to bond material layers.

Figure 1. **Dental mold produced by Fused Deposition Modelling method**

Making a perfect square nozzle is currently impossible; therefore, the nozzle responsible for material deposition is designed with a radius impacting on the quality of the outcome of the printed object (Anitha, Arunachalam and Radhakrishnan 2001). According to Dul, Fambri and Pegoretti (2016), the quality of the final model depends entirely on the nozzle's material thickness. The speed and accuracy are also considerably low compared to other processes. Based on the study by Singamneni et al. (2010), it is critical to consider the tension and gravity in the event the process is being used for components where achieving high tolerance is a primary requirement (Sood, Ohdar and Mahapatra 2010). In this technology the layer thickness ranges from (0.178-0.356) mm

- *The current 3D Printing Equipment for Orthodontics*

The field of orthodontics is currently benefiting from a more efficient and cost-effective workflow utilising state-of-the-art technology due to the evolution of the 3D imaging and modelling industry. Several dental fields demonstrate the practicability of 3D imaging and modelling techniques, including oral maxillofacial surgery and prosthesis, prosthodontics, physical models, and or surgical guides in dental implant treatment. According to Vandenberghe (2018), orthodontic appliances can be fabricated using three-dimension printed models as a result of the workflow shift to a digital format. Therefore, these technologies are more affordable and are able to produce dental models with high levels of assurance, precision, and accuracy. Recent advances in 3D scanning technologies have led to the invention of intraoral scanners that help eliminate unpleasant impressions while ensuring reduced treatment time and accuracy of appliances for patients setting the ground for the development of 3D printing to work in conjunction with scanners.

Moser, Santander and Quast (2018) posit that every 3D print equipment requires a separate computer workstation to initiate any printing task. Some printers, however, are integrated with the workstation itself; the printer also requires a build tray for model fabrication, and a print medium including, sand, plastic, metal, human cells, clay which is in many cases printer-specific. Some of the commonly used 3D printers include objet30 OrthoDesk, Ultra 3SP Ortho, MakerBot and other FDM printers.

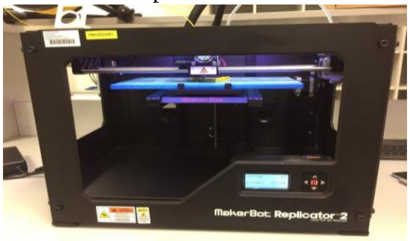

Figure 2. **Markerbot 3D printer**

V. RESULTS AND DISCUSSIONS

- *Applicability of DPL Additive Manufacturing*

The study has established that in order to make the process of manufacturing plastic aligners sustainable, the braces have to be considerably cheaper compared to the metal braces. Therefore it is necessary to establish a cost model by identifying the key components that contribute to the cost per part of the equipment, develop a mathematical relationship associating the parameters of the process and also the need to allocate the overhead costs (Jiang 2019; Partolo 2011). The study also shows that with the cost model in place, it is possible to quickly adopt the DLP for the fabrication of plastic aligners (Castiaux e al. 2019; Dawood et al. 2015). Further, cost modelling is suggested to have a positive come on the advancement of AM advancement.

The study has also established the capability of DLP technology to print different features with various aspect ratios and sizes. The study, however, points out that this possibility is dependent on exposure time, geometry, film thickness, and printing layer thickness (Davoudnejad et al. 2017; Castiaux e al. 2019).

The study has also shown the possibility of improving the AM technology in terms of material consumption, building time, and surface quality. The study shows that by adopting segmentation designs, it is possible to reduce material consumption by reducing the support structures (Hilliard 2008; Uno et al. 2019). Building time can also be reducing segment height. These aspects help reduce surface roughness. In terms of DLP performance, the current study shows that the DLP printed is faster. They can print builds with multipart that take much part of the build platform. The study also demonstrates that it is also faster in printing large, fully dense prints. The study suggests a fart of ideas in order to improve the precision and accuracy of DLP AD, for instance, ensuring the right temperature for the nozzle, treating the filament with care and the application of different builds with respect to the different effects (Davoudnejad et al. 2017; Kiviat and Fleming 2018).

The study has also demonstrated that the integration of digital solutions has revolutionised treatment planning and diagnosis from traditional approaches like 2D to the current 3D roaches, which have been rapidly integrated into orthodontics. The AD processes including facial and intraoral scanners, cone-beam computed tomography, digital radiology and additive manufacturing processes can, therefore, be used to create an equipped office for orthodontic reality (Dawood et al. 2015; Kiviat and Fleming 2018). Unlike the traditional computer-aided design and computer-aided manufacturing, 3D technology allows for the capture of high-resolution 3D virtual models. With 3D technology, it is possible to leverage the non-contact optical technologies and principles without causing discomfort to the patient, or any other negative outcome regarding lab work or imprecision (Marotti et al. 2013; Kazemi and Rahimi 2019).

- *Effectiveness Plastic Aligners*

Plastic aligned are made out of flexible plastic. Using plastic aligners is observed by the study outcome as widespread (Gomez et al. 2015; Vandenberghe 2018). The widespread acceptance of plastic aligners is attributed to their transparent colour. Therefore the users can use the plastic brakes without the worry of the negative social outcome (Hilliard 2008; Szuhanek et al. 2017; Alkadhimi, 2020). The study also shows that these braces are relatively cheaper to produce compared to metallic aligners (Charalambis et al. 2017; Comba et al. 2017). The relatively affordable prices make them ideal for use in orthodontics. Further, the study results show that plastic aligners do not irritate the mouth and are associated with convenience. The user can remove the braces when eating, cleaning the teeth, unlike the metallic braces. Another aspect that is widely discussed by the reviewed sources is the aspect of the easy maintenance associated with the plastic braces. The researcher suggests the use of a toothbrush dipped in a small amount of bleach and water(Kazemi and Rahimi 2019; Haleem 2019). However, care should be taken to follow the orthodontist's directions appropriately to prevent adverse health outcomes.

VI. Conclusion and Recommendation

The purpose of this review was to establish the current state of AM technology application in orthodontics and the possibility of applying this technology to fabricate plastic braces leveraging the DLP AM technology. The review has revealed that AM technology has become of age and is already being applied in dentistry. The review also shows that the manufacture and use of plastic braces is happening widely and with significant acceptance mainly due to considerably low prices, clearer look, the convenience of use and the comfort associated with their use. These pieces of equipment can, therefore, be used to replace the traditional metal braces that are perceived by users to be lacking discomfort and the perception of having "a mouth full of metal."

The study also reveals that it is feasible to fabricate these plastic braces utilising the DLP technology, the reviewed studies demonstrate that the DLP technology is affordable and arguably able to produce dental models with high levels of assurance, precision, and accuracy within a short period. However, the associated processes and requirements have to be fulfilled. Further, the fact that the plastic braces are widely accepted, it is possible to produce them in mass due to the availability of the market. As a result of the more reasonable price of the DLP printers, the availability of software to help align and produce sequential models based on the teeth movement, and the acceptance of the clear plastic braces, the project is not only viable by feasible. Since companies are developing resins that allow for the direct printing of clear aligners makes the whole process more cost-effective and efficient. As a recommendation, this study proposes that current manufacturers of transparent plastic braces should ensure to minimise the cost of production to keep the product price low and the demand high, proper marketing should also be encouraged for the products and to encourage investment as only a few companies can manufacture plastic braces. Future research should also be undertaken to investigate the best way to counter the social concerns associated with the use of clear plastic braces.

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