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Review

In-office Customized Brackets: Aligning with the Future

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Main Points

- 3D technology has been lately introduced in Orthodontics.
- Customized brackets have been used mainly for lingual orthodontics.
- A new Orthodontic CAD software allows the designing and printing of labial and lingual customized brackets in the orthodontic office.
- Hybrid ceramic crown resin and Zirconia slurry have been used to print customized orthodontic brackets. Scientific studies have been published regarding ceramic crown resin and zirconia slurry properties printing outcome.

ABSTRACT

Digital technology introduced many innovations in the field of dentistry and orthodontics in the last years. The most important advancement was the ability to digitize the oral cavity using intraoral scanners. CAD software have been around for decades, but only in the last twenty years started showing up in the field of dentistry and orthodontics. 3D printers are not new in the field of manufacturing. Nevertheless, their inclusion in the orthodontist armamentarium was made possible only the last few years, while new printing materials have been also invented, allowing the manufacturing of many appliances previously made using traditional laboratory procedures. Orthodontic treatment is mainly based on the use of fixed appliances. The vast majority of orthodontists use commercial straight-wire brackets while customized brackets are preferred mostly for lingual orthodontic treatment. New CAD software called Ubrackets allows the in-office designing and printing of customized brackets using hybrid ceramic crown resin or zirconia slurry. Some scientific studies have been conducted to investigate the bracket printing outcome in terms of mechanical properties. More studies must be performed to allow the inclusion of in-office designing and printing of customized brackets in the orthodontic armamentarium.

Keywords: 3D technology, in-office customized brackets, hybrid ceramic resin, zirconia slurry, printed brackets

INTRODUCTION

Orthodontics is a specialty that combines mechanics and biology. It has the unique feature of being the only dental and medical speciality that uses forces to move parts of the human body to correct, malposition of teeth and bones relative to each other. On one hand, there is the medical part that is biology, and on the other hand the mechanical part, engineering. As it is well-known, teeth move continuously in the oral cavity all our life. This characteristic has been used by pioneers in orthodontics such as Angle[1-4] to move teeth using fixed or removable appliances. All these appliances, at least at the beginning of the 20th century were hand-made. When orthodontics was recognized as a speciality, companies started manufacturing brackets, bands, archwires, etc. Fixed appliances were manufactured in one-size fits all manner, while treatment had to be adjusted to each patient by the orthodontist. In the early 70's, Andrews brilliantly thought to create an appliance that could fit most of the patients, taking into account that the labial surfaces of our teeth resembled in a high percentage.[5] Thus, he created the "straight wire" appliance where he incorporated into the brackets all the information needed for correcting malocclusion according to his 6 keys. In reality, Andrews attempted to create customized brackets,

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nevertheless, with the absence of digital technology at that time, that was not possible.

Irrefutably, digital technology has changed many aspects of our life the last 60 years. Dentistry and especially orthodontics have also been a field of great changes in the last years, with the main cause being digital technology. The ability to digitize the oral cavity, import it in orthodontic CAD software, design or edit appliances, and then manufacture them (undigitize) using 3D printers gave a different perspective on the practice of orthodontics. Unavoidably, this digitization-undigitization configuration mode transformed the traditional orthodontic laboratory into a digital one. Moreover, the ability to have a clean, dustless, with fewer machines laboratory, using scanners, computers, and printers allowed its inclusion in the space of an orthodontic office. Thus, a new modality called in-office manufacturing was introduced into the orthodontic society. The core of this digital laboratory is the computer, that handles all the designing, editing, and printing commands.

Due to this technology, dentists and orthodontists can design various appliances such as crowns, occlusal splints, indirect bonding (IDB) trays, dental models, orthodontic bands, rapid palatal expanders, and thermoformed and printed aligners, etc. Printing most of the appliances can be done using VAT technology printers or can be outsourced to powder bed fusion printers for metal appliances.

Due to this immense digital technological advancement, other technologies evolved simultaneously. Resin material for 3D printing was initially only for dental models, while over the course of time, more resins were introduced for occlusal splints, IDB trays, etc. In the last two years, hybrid ceramic permanent crown resin was introduced to the market for the printing of single crowns, inlays, and onlays. On the other hand, compact 3D printers using zirconia slurry that could be installed in the dental office appeared in the market in the last two years.

Another advancement was the introduction of the first orthodontic CAD software for the in-office designing and printing of customized brackets called Ubrackets (Coruo, Limoges, France).[6] Hybrid ceramic permanent crown resin and zirconia slurry were used to test the feasibility of such bracket printing.

Regardless of the current state of in-office printing customized brackets, it seems that the river can go back and that the orthodontist will be able to design and manufacture customized brackets in the office in a self-sufficient environment offering more accurate, easy, faster, and trouble less orthodontic treatments.

Clinical and Research Consequences

Customized bracket manufacturing is not something recently developed. More than 20 years ago, Wiechmann et al.[7] introduced the first fully customized lingual appliance called Incognito. Brackets and archwires were customized for each patient designed on a dental arch setup. In the following years, more companies appeared in the market offering customized lingual brackets to orthodontists. Ormco (Orange, Cal, USA) created Insignia customized brackets where customized brackets and archwires are delivered to the orthodontist following a digital setup of the patient's dental scans. Similarly, Light Force customized ceramic brackets (Light Force, Massachusetts, USA) were introduced in the last two years, offering the ability of online setup and design of customized brackets. 3D printing is performed at Light Force premises and the brackets with the IDB tray are then sent to the orthodontist. Despite the obvious advantage of customized brackets, manufacturing is done in a laboratory out of the orthodontic office, which has the disadvantage of considerably higher cost.

Customized brackets have not been extensively investigated due to the lack of customized fixed appliances and their limited use. Nevertheless, most of the studies show controversial results, which range from the finding that customized brackets do not offer something more compared to the straight wire appliance to findings like treatment with customized brackets is faster and has fewer archwire changes.[8-11]

Miethke and Melsen[12] stated that, it is unreasonable to expect that any straight-wire appliance without individual adjustments can be anticipated to lead to an optimal tooth position and that if the straight-wire approach should be followed, the bracket would have to be custom made.

In-office designing and printing, as previously mentioned were made possible due to the manufacturing of various software, machines, and materials such as orthodontic CAD software, 3D printers and printing resins. Various appliances can be designed and printed in an orthodontic office in a clean environment with the center of the digital lab being the computer. Until now, none of the existing orthodontic CAD software included a module for in-office designing customized brackets. The ability to design and print almost everything in the orthodontic office urged the invention of the first orthodontic CAD software for the design of customized orthodontic brackets. The software called Ubrackets (Coruo, Limoges, France) is a software, that allows the import of dental arch scans, which after a certain procedure pass to the setup stage (Figure 1).[6] All the CAD software for the design and manufacturing of thermoformed aligner resemble Ubrackets up to the setup stage. After setup, the orthodontist enters the customized bracket module where there is an option of labial or lingual brackets and an option of full customization or customization by using commercial brackets found in the software library and by adding composite onto their bases. The software library contains several series of brackets for printing. Some bracket series are special for hybrid ceramic resin printing and some for zirconia printing. The different series of brackets have the scope of counteracting the different shrinkage percentages that is observed when hybrid ceramic resin or zirconia slurry is used. By choosing labial brackets and full customization, the software automatically aligns the brackets on 0.018 x 0.025 inches flat archwire exactly opposite to the labial surfaces of the teeth but without getting in contact with them (Figure 2). Each bracket has a manipulator that appears after selecting the bracket to be moved. The manipulator allows the distal or mesial movement of the bracket, the lingual or labial movement, or the rotation of the bracket on the horizontal level (Figure 3). Each time a bracket is moved, the archwire adapts to the new position of the bracket. The whole archwire-brackets system can also be moved (translate or rotate) in any direction to facilitate proper positioning of the system relative to the gingiva and the incisal edges of the teeth (Figure 4). At this point, the base of the brackets is not touching the surface of the teeth. When the brackets are finalized at their proper position, a command tool enables the operator to extrude the surface of the bracket's base toward the tooth surface to create the customized base of the bracket (Figure 5). Thus, the brackets are designed on a flat archwire on the ideal setup, which will be later bonded at the initial malocclusion, hoping that by this procedure, the customized brackets with the customized prototype archwire will bring the teeth to the position that was defined at the setup stage. The whole procedure can be described as "treatment with the end in mind". At the next stage, the software designs a dental model with the brackets attached and the prototype archwire that will serve at all stages

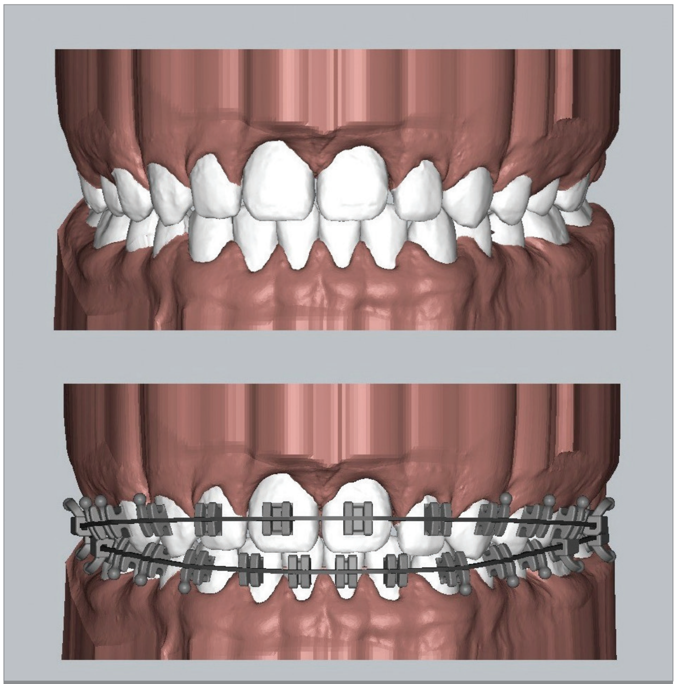

Figure 1. Dental setup in Brackets software and automatic positioning of the brackets

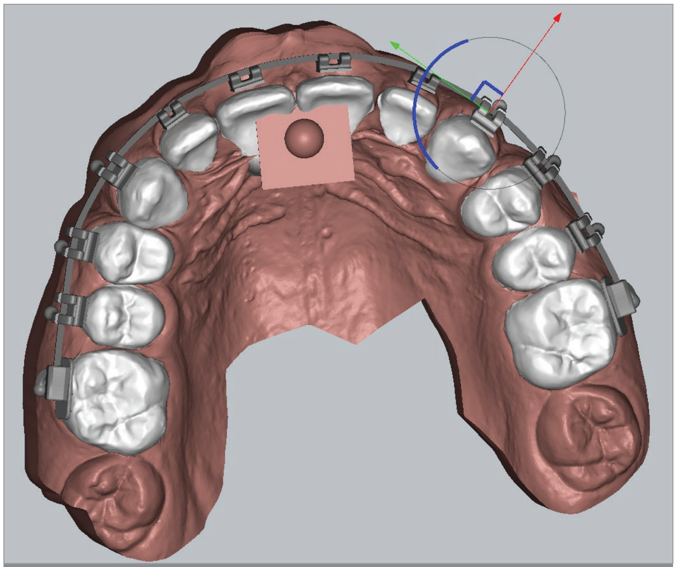

Figure 3. A manipulator can be used to move the bracket in all directions, mesiodistally, labiolingually, and rotationally on the horizontal level. The archwire in each movement adapts accordingly

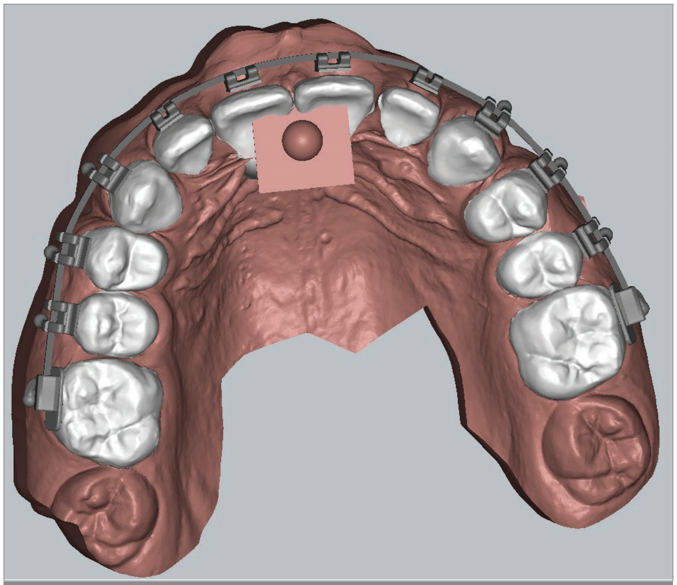

Figure 2. Automatic positioning of the brackets and flat rectangular archwire opposite the teeth' labial surfaces. Note the space between the bracket bases and teeth, which will be later filled by the software to create the customized bracket bases

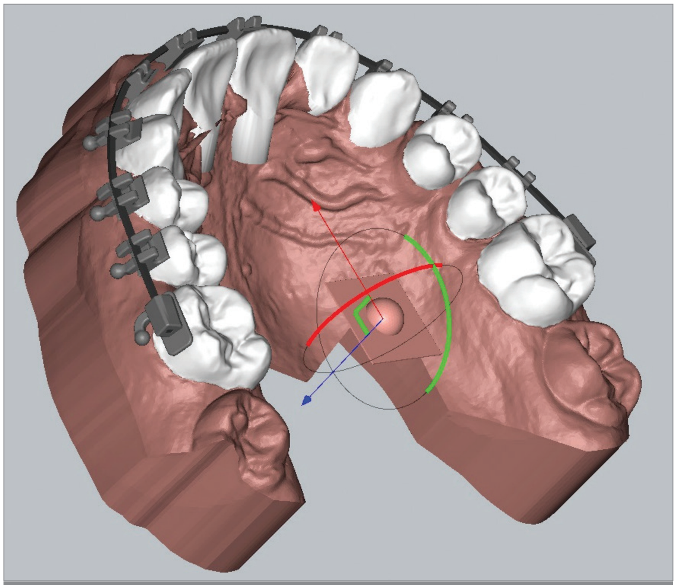

Figure 4. A central manipulator can be used to move the whole archwire-brackets complex in any direction to position them in a proper position away from the gingiva and the incisal edges of the teeth

of the orthodontic treatment. The archwire is exported from the software as a 1:1 ratio PDF drawing to help the orthodontist manually bend the archwires with pliers and as an STL file for the bending of the archwires using an archwire bending robot. The operator is enabled to design IDB trays at this stage that will be later printed in a 3D printer. A unique feature of the software is that it allows the designing of positioning keys for each bracket to facilitate accurate bonding (Figure 6). The positioning key is printed together with the bracket as one unit and removed using a bur after bonding. The positioning key can have a thickness of 0.3 to 1mm or more depending on the material to be used for printing. Usually, when printing zirconia brackets, the key should be thin enough to be easily removed after bonding.

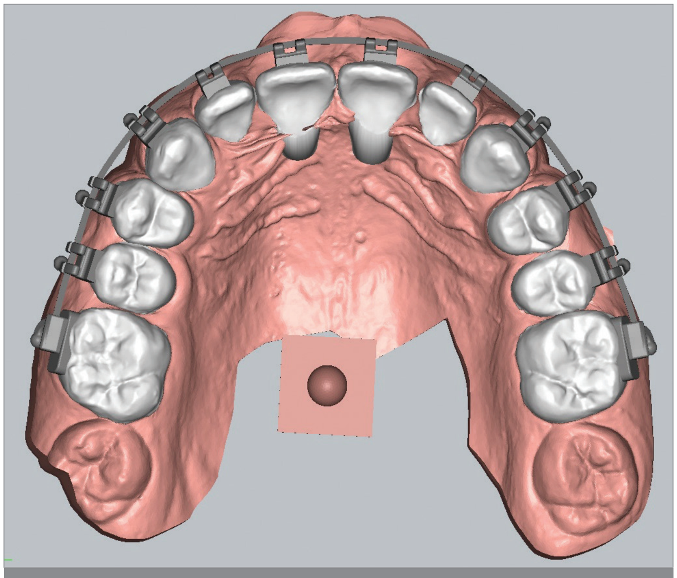

Figure 5. A command tool is used to extrude the bases of the brackets toward the teeth' labial surfaces, thus creating the brackets' customized bases

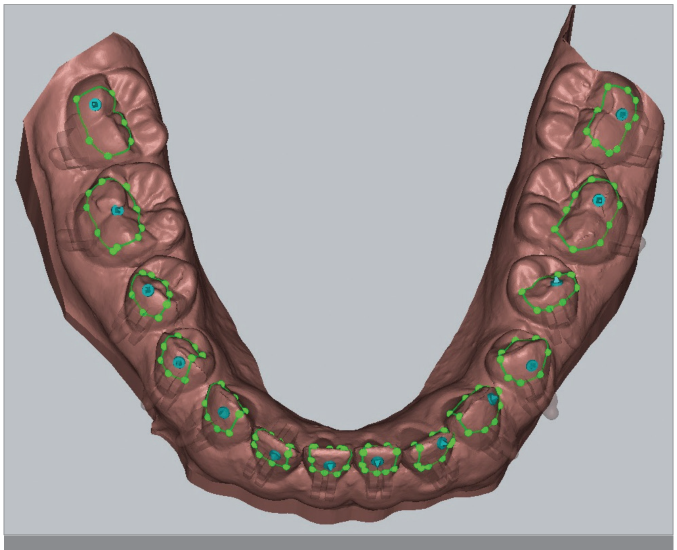

Figure 6. Individual positioning keys can be designed to allow the accurate placement of the brackets upon bonding. The keys were easily removed after bonding

Despite the huge technological advancement of creating software and printers, the real challenge in custom-made bracket manufacturing is the printing material.

The first attempt to design and print customized brackets in the office was done using Formlab's hybrid ceramic permanent crown resin.[13] The brackets were designed in Ubrackets software together with positioning keys for accurate bonding and printed in Formlabs 3B, while isopropyl alcohol 91% was used to clean the uncured resin excess followed by UV curing using a Cure M curing machine (Graphy, Seoul, Korea) (Figure 7). To investigate the mechanical properties of this resin, a study was conducted where the permanent crown resin was compared to temporary crown resin made by Formlab's.[14] The results showed a low value of hardness and elastic modulus (low stiffness) while fracture toughness was adequate. Nevertheless, hardness was almost double compared to commercial plastic brackets that were studied in a similar research article.[15] Hardness is an important property for brackets. Low hardness causes wear off of the brackets upon steel ligation or archwire insertion. Fracture toughness is also important as a property that is defined as the ability of a material to absorb energy when a force is applied to it without breaking. These findings encourage the invention of a hybrid ceramic resin with better properties to serve as a material for bracket printing.

Another material that the author used to print customized brackets was zirconia. Currently, there is a desktop zirconia 3D printer (AON, ZiproD, Seoul, Korea) that can be used for in-office printing of crowns, bridges, etc. Zirconia slurry comes in an A1 color and it is used as a material to print crowns.[16] As a proof of concept, brackets for a patient were designed and printed using Zirconia slurry (Figure 8). The procedure for zirconia bracket printing is longer and more complex as it requires the use of a debinding-sintering oven after the printing process. Printing is accurately performed using a 50 μm Z-axis resolution and

Figure 7. Customized brackets with their positioning keys were printed using hybrid ceramic permanent crown resin. After bonding, the keys were removed

it takes approximately two to three hours depending on the height of the brackets and supports that will be printed (Figure 9). Zirconia slurry contains, except zirconia, a polymer that helps bind zirconia particles at the printing time. Zirconia brackets pass a procedure of debinding after printing to remove the polymer, which is not needed anymore. The Zirconia slurry that is currently used is supplied by AON Company and it is called Inni-Cera. Brackets after printing are soft due to the presence of the polymer and the zirconia particles which are not firmly connected. After debinding, spaces remain between zirconia particles where the binding polymer used to be.[17] The next procedure is sintering, which brings the zirconia particle in touch with each other, creating a hard, strong zirconia bracket that will be later polished and colored to be bonded in the patient's mouth. Debinding and sintering take up to 13 hours depending on the kind of furnace and debinding-sintering furnace program. Coloring can be performed using special zirconia colorings in all shades of white according to the patient's teeth color. After debinding, the brackets are immersed in the zirconia painting for some seconds and then left to dry for some time.

Figure 8. Customized brackets were printed using zirconia slurry and bonded to a patient. The color is the standard slurry A1 color, which can be painted using zirconia painting. Here, no zirconia paint was used

Figure 9. Zirconia bracket after printing. The uncured excess slurry will be moved back into the printing tray to be used for other printings. Brackets can be easily removed and cleaned from the excess resin using isopropyl alcohol 91%

Later, the brackets are reinserted in the furnace for the last stage of sintering. Polishing is the last stage of the workflow using special brushes and zirconia polishing paste. To counteract the shrinkage of the bracket upon sintering, the virtual files of the brackets are enlarged by the printer's software before printing (Figure 10). This compensation enlargement is different for the x, y, and Z axis. Hybrid ceramic resin printing does not need any major virtual bracket compensation.

In an attempt to investigate the mechanical properties of zirconia-printed brackets, a study was undertaken where, zirconia, Clarity (3M, Monrovia, Cal, USA), and Light Force (Light Force, Massachusetts, USA) customized brackets were compared.[18] The main finding was that fracture toughness was significantly higher compared to the Clarity bracket and much higher compared to the Light force bracket. As it is well-known, ceramic brackets suffer from low fracture toughness, which causes them to be fragile. This finding proves that zirconia could be a better material concerning fracture resistance compared to alumina. Hardness was higher for the Clarity brackets followed by the Light Force and Zirconia brackets. Nevertheless, the difference in hardness between the three kinds of brackets is not found clinically significant as the amount of hardness for the brackets was very high and adequate for their clinical use. Ideally, a bracket should have high hardness, elastic modulus, and fracture toughness.

A disadvantage of this technology compared to the traditional manufacturing of commercial brackets (i.e. molding) is that it entails many steps that are prone to errors and could affect the final result. Designing the brackets is an important part while the STL file resolution is important to creating high-resolution brackets that will be printed accurately and that will be smooth. Different printers use different technology in printing, which could lead to different printing results. Under the same conditions, a printer could print the same brackets at successively printing sessions with different properties. The homogeneity of the resin or slurry is of great importance and they should be adequately stirred before printing. Positioning

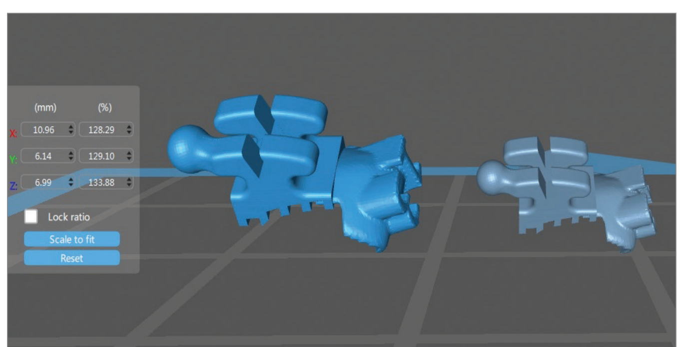

Figure 10. Zirconia brackets pass a different procedure to be printed. Debinding and sintering, which follow printing, decrease the size of the brackets due to material shrinkage. For this reason at the process of virtual bracket placement in the printing software, there must be compensation in dimensions. The right bracket is exactly as was exported from the software. The left bracket is enlarged in all three dimensions (x, y, z) according to the guidelines of the AON company providing ZiproD zirconia printers. The software that was used is Chitubox (CBD-Tech, Shenzhen City, China)

the brackets on the virtual printer platform is also an important aspect. The most important part of the bracket is known to be the slot, and it is the one that must be accurately printed. For this reason, brackets should be oriented properly to ensure accurate printing results. In the case of permanent hybrid ceramic crown resin, the use of a UV curing unit is essential. It is well known that oxygen prevents the full polymerization of oligomers and monomers.[19] An ideal condition would be to use UV curing units with a nitrogen generator that removes oxygen from the curing process in its chamber. All these stages should be investigated through *in vitro* research, while *in vivo* research should be carried out to check for example, material aging, leaching, etc.

It is obvious that the inclusion of a small digital lab in our orthodontic offices is not anymore a figment of our imagination. Moreover, the ability to design customized brackets and easy access to affordable 3D printers enables the orthodontist to create a self-sufficient orthodontic office offering personalized orthodontic treatment to the patients.

CONCLUSION

The time has come that the orthodontist should take the manufacturing of the appliances into his/her hands. 3D technology offers this ability to the orthodontist in a relatively low-cost, easy way. A self-sufficient office would be independent of most of the external companies creating tailor-made appliances that would target the patient's specific orthodontic problems. The software can design customized brackets in an easy and fast way based on the setup that the orthodontist will perform, which will be the imaginary orthodontic treatment result. Orthodontic associations should try linking all the orthodontic offices through a central server where all data will be gathered, and with the use of artificial intelligence software, there will be given feedback to the orthodontic offices for better and more efficient orthodontic treatments. Nevertheless, before this technology is fully used in the office, extensive research should be undertaken regarding new material for bracket printing and the material behavior in the oral aging. Additionally, there should be research proving the advantages of bracket customization over straight-wire appliances. Last but not least, protocols should be created to ensure the safety of the patients and personnel in the orthodontic office regarding the proper installation of the machines for bracket manufacturing.[20] It is obvious that the centralization of orthodontic appliances manufacturing in an orthodontic office is not a fantasy. The orthodontist could guide the production of the appliances according to the needs of every orthodontic case performing personalized treatments for each patient.

Ethics

Peer-review: Externally peer-reviewed.

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Competing interests: Dr. Nearchos Panayi declares that he is the inventor of Ubrackets orthodontic CAD software.

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