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Candidate for the degree

Bachelor of Sciences

Submitted in partial fulfillment of the requirements for

College Honors

Departmental Distinction in Biology

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Title: Tooth Morphology and Comparisons in Traditional and Innovative Methods in Dentistry using CAD/CAM Technology.  
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Abstract

Teeth have very important structures and functions. It is a dentist’s duty to make sure that every tooth is safeguarded and that proper occlusion is maintained or achieved. Though there are several traditional methods in dentistry that have been used to align as well as restore teeth in order to maintain their essence, new technologies have modernized the field. CAD/CAM technology has provided advancements in the field of orthodontia and restorative dentistry. This study reviewed the significance of each tooth and the validity of CAD/CAM methods to provide alternative methods for impressions, study models, restorations, and orthodontia. A compilation of literature was used to thoroughly compare traditional dental methods and CAD/CAM technology in dentistry. It was concluded that CAD/CAM dentistry provides a more efficient method when compared to traditional counterparts. Some of the advantages include faster production of models, the removal of breakage and storage issues, and more accessible communication about a patient’s treatment. CAD/CAM technology allows restorations to be more accurate, made faster, and more economically feasible. It was also concluded that the customization that CAD/CAM technology provides is very advantageous in the field of orthodontia. Though these modern methods have many advantages, the dentists must be proficient in the use of the system and use the system regularly, for the advantages to outweigh the cost of investment.
Introduction

Teeth are invaluable due to their many essential roles and functions. The importance of each tooth is largely linked to their morphology. Each shape, cusp, root, and crown, of a tooth carries out its own specific tasks. Dentists are aware of this and therefore strive to protect each tooth, prevent tooth decay, and provide proper occlusion. There are several traditional methods that have been used to align as well as restore teeth in order to maintain their essence and function. However in the last 20 dentistry has been revolutionized by the use of CAD/CAM technology and has presented modern methods to traditional techniques. Though CAD/CAM automation is currently being used in multiple areas of clinical dentistry all around the world, it has dramatically impacted how the field of orthodontics and restorative dentistry approaches and will approach certain procedures. Understanding the significance of each tooth and assessing the value and efficiency of traditional procedures compared to their CAD/CAM alternatives will provide advancement of the field and provide potential benefits for both the dentist and the patient.

In dentistry CAD/CAM technology is almost analogous to prostheses produced with milling technology, however this is not correct. The term CAD is an abbreviation for, computer aided design. Similarly, the term CAM is an abbreviation for computer aided manufacturing. Therefore the definition alone does not depict the fabrication method. However CAD/CAM technology in its entirety must contain three main components. The first component is the tool, or scanner, that digitizes shapes into digital data into a format that can be manipulated by a computer. Secondly, CAD/CAM must contain software with the ability to process and produce data sets for the fabrication of
the product. Such software includes Rhinoceros, SolidWorks, Auto CAD, PTC Creo, and Materialize Magics. Finally, the third component that CAD/CAM technology must have is the production capability to convert the data into the aspired product (Beuer et al. 2008).

The use of computers to create, modify, or analyze a design is defined as CAD. CAD has a specific set of systems, hardware and software, that are used to carry out these particular functions. The CAD hardware usually consists of a graphic display terminal, the computer, and the keyboard and mouse pad. The CAD the software consists of the computer programs and their corresponding applications. Though there are some generalizations, the use and type of computer program varies largely on the product designed and the field that is designing it. These computer softwares create the product by one of two methods, either a three-dimensional model, point cloud, polygon mesh, or stereolithography (STL). The point cloud method is used in specific 3D modeling programs, such as Rhinoceros, and is used largely in the creation and manipulation of surfaces and solid modeling. The second method, polygon mesh, gets the design ready for printing and constructs the image as mesh or a series, as triangles. STL files are the bridge between the CAD file and the manufacturing process, as it converts or creates a design into a format that is equipped for construction (Live Science 2013).

While CAD focuses on the design, CAM is defined as the management, planning, and controls the manufacturing process, directly or indirectly, through the use of computer systems. The definition of CAM itself is then divided into two categories, computer monitoring and control and manufacturing support applications. Computer monitoring and control is when the computer is used to either monitor or control the
manufacturing process when the computer is connected directly to the manufacturing. This means that the computer can either be overseeing the process, leaving the control of the process in the hands of the operator, or the computer is controlling the manufacturing process completely. However in the category of manufacturing support applications, the computer is only involved to support the operation, and is not directly tied to the manufacturing process (Groover and Zimmers 1984). Computer aided manufacturing encompasses a variety of fabrication methods that can be executed depending on the desired product. Two of the most commonly used computer aided manufacturing methods used, especially in dentistry, include milling and 3D printing.

One manufacturing method of CAM is Milling, or subtractive manufacturing. Milling is a form of subtractive manufacturing because the desired product is developed from a starting material and then fragments are removed to deliver the final product. Most milling variant methods are then group into two classifications, dry processing, usually conducted with regards to zirconium oxide, or wet milling. In wet milling the carbide cutter, or milling diamond, is preserved from overheating by moisture of cool liquid. This method is usually used with metals and glass ceramic materials to avoid heat damage of the material (Beuer et al. 2008). An example of wet milling in dentistry is the CEREC (Chairside Economical Restoration of Esthetic Ceramics) machine. This machine provides restoration is a shortened amount of time with the use of intraoral scanners and subtractive manufacturing.

CAD/CAM technology is also used in 3D printing. The 3D printing process can only occur when a computer confers a design file or a blueprint to the printer. Therefore, without a computer relaying the information the printing process cannot take place, hence
why it exemplifies CAD/CAM mechanics. Different from milling, which is the process of removing material to achieve a desired product; 3D printing is additive manufacturing (Lipson and Melba 2013). This means that the 3D printed model is literally created by the summation of layer upon layer. After a layer is cured, the tray falls allowing new uncured resin to lie upon the previous layer. This process continues hundreds of times until the final object is printed. Fused Deposition Modeling (FDM) printers often carry out this general printing method (See Fig. 3 in appendix). However, many of the 3D printers being used by dentists are PloyJet Photopolymerization (PPP) printers (See Fig. 4 in appendix). These printers use a similar mechanism as standard inkjet printers, but in a three dimensional way. This process involves liquid resin being jetted out of hundreds of nozzles, which are then cured instantly with an ultraviolet light. The platform in this printer also moves vertically to accommodate the new layers. PPP printers that are of a higher-end also have the ability to print multiple materials on a single model. There are also 3D printers that print on voxels rather than layers, and there are no visible steps. This process is called Digital Light Processing (DLP), and is carried out by a digital micro-mirror device that contain hundreds of mirrors and moves in two directions thousands of times per second (Groth et al. 2014).

However, regardless of the type of printer, every 3D printer uses and requires either support resin or support structure (See Fig. 5 in appendix). The support material prevents refraction due to gravity and also allows creation and formation of overhangs and undercuts. The support resin can then be easily removed with pressurized water, and the model resin can be quickly removed after printing (Groth et al. 2014).
Though 3D printing was presented originally in the 1980s, over the last two decades it has been one of the fastest growing industries and allows for the creation of virtually anything imaginable. Complex shapes, hollow objects, and even interlocked parts can be constructed from the digital world to tangible matter in a variety of materials. Because of the diversity this mechanization provides it is a viable alternative to common manufactured commodities. It is for this reason the book, *The New World of 3D Printing*, dares to assert that 3D printing is superior to any other mode of production in accuracy and versatility. This statement however, is still being scrutinized in various disciplines, one of which is dentistry. 3D printing is an attractive tool in dentistry due to the intricacy, precision, and customization that it provides. 3D printing applications are revolutionizing dentistry by providing modern and faster techniques to traditional methods. For example, today dental labs have the capability to print customized crown, analogous to a natural tooth, from x rays in less than an hour (Lipson and Melba 2013).

### Dental Anatomy and Morphology

It is essential to understand the classification of each tooth, its importance and characteristics to be able to compare traditional methods to their modern counterparts that use CAD/CAM technology. Understanding this is critical since successful methods of restorations and orthodontic apparatuses should not hinder or harm dentition and/or be analogous to the tooth’s function. Therefore the classification and characteristics of human dentition were analyzed in this study.

*Identification of Structures*
The human mouth is composed of two arches, the maxillary arch and the mandibular arch. Each of these arches are then divided in half and are referred to as quadrants, since they encompass a quarter of the dentition. As children, humans have deciduous dentition composed of 5 teeth in each quadrant of the four quadrants. Therefore a child’s mouth can accommodate a total of 20 teeth. Starting from the midline of the quadrants of the deciduous dentition, each quadrant contains two incisors, a central one and a lateral one, a canine, and two molars. However, at the age of 12 or 13 this deciduous dentition is then replaced by permanent dentition. Permanent dentition encompasses a total of 32 teeth, with 8 teeth in each quadrant. The teeth in each quadrant of the permanent dentition, starting from the midline, include 2 incisors, a central incisor and a lateral one, a canine, 2 premolars, and 3 molars (Scheid and Weiss 2012).

There are three main identification systems used to allow comprehensive recognition of a particular tooth or set of teeth. The three systems include the Palmer Tooth Notation System, the World Dental Federation notation, and the Universal Numbering System. This study will be using the Universal Numbering system, which was adopted by the American Dental Association in 1975. The Universal Numbering System numbers the deciduous dentition with the first 20 letter of the alphabet, A through T. The classification begins with the letter A, representing the maxillary right second molar, and continues progressively around the arch to the maxillary left second molar, being letter J. The classification continues on the mandibular left second molar represented by the letter K and then sequentially continues until reaching the right second molar of that arch, represented by the letter T. The Universal Numbering System numbers the permanent dentition similarly to that of the deciduous dentition, except it
uses numbers and not letters. The numbering begins with the right maxillary third molar as number one and continues till reaching the left maxillary third molar, which is then designated number 16. Descending on the left side to the mandibular third molar, designated number 17, and then wraps around to number 32, being the mandibular right third molar (See Fig. 1 in appendix) (Scheid and Weiss 2012).

Each tooth is made up of four main tissues, which are the enamel, dentin, cementum, pulp. The first three mentioned are of a harder consistency due to their calcium and other mineral contents. For this reason, the enamel, dentin, and cementum are referred to as calcified. The enamel and the cementum are the only two tissues that are usually visible. The enamel, the hardest material in the body, is white in color and protects the anatomic crown. Cementum is the opaque yellow tone of the tooth’s root and it decreases in thickness near the cementoenamel junction. This junction, also called the cervical line, separates the anatomic crown from the anatomic root. The third tissue, dentin, is a yellow tissue that resides below the enamel and takes up the majority of the space in the inner tooth. Dentin is not usually visible, however it can be seen when the enamel and the cementum are worn away. Lastly, the last of tissues is the pulp. The pulp is not calcified or mineralized and therefore is the softest of the four tissues. The pulp is located in the center of the crown is called the pulp chamber, while its root section is called the pulp or root canal (Scheid and Weiss 2012).

Not only are teeth and their tissues names, but also their surfaces. The naming of the dentition surface is named based on their natural alignment. The surface of a tooth aligned toward the face, cheeks and lips is designated the facial surface. The facial surface is then designated either labial or buccal if the tooth is anterior or posterior,
respectively. Incisors and canines are considered to be the anterior teeth, while the remaining teeth are then considered the posterior teeth. The title lingual surface is designated to identify the inner surface of the tooth that is aligned towards the tongue. The lingual surface is also called the palatal for a tooth on the maxillary, due to the closeness to the palatal. The chewing surface or cutting surface of a tooth is named differently for the posterior and the anterior teeth. The chewing surface of the posterior teeth is designated the occlusal surface. However, since the anterior teeth are involved in chewing and not cutting, their cutting surface is designated the incisal edge or ridge.

There are also terms that denote and differentiate the approximating surfaces of teeth. The sides of that are aligned towards the adjacent tooth are called the proximal surfaces. The proximal surface is then designating medial, indicating toward the midline, or distal, indicating away from the midline (See Fig. 2 in appendix) (Scheid and Weiss 2012).

In order to describe a particular part or landmark of a tooth, the tooth is divided into thirds. When viewing the tooth facially, lingually, mesially, or distally horizontal lines can be visualized to the divide the tooth’s crown into the following thirds: cervical, middle, and occlusal (or incisal). Furthermore, horizontal lines can also be visualized to divide the root into the following thirds: cervical, middle, and apical. Vertical lines are also used, when viewing the tooth facially or lingually, to divide the crown into the following thirds: medial, middle, and distal. Vertical lines can also be visualized when viewing a tooth from the proximal side to divide the root and/or crown into the following thirds: facial, middle, and lingual. Lastly, mesiodistal lines can be envisioned to divide the crown into facial, middle, and lingual thirds, and faciolingual lines can be envisioned to divide the tooth into mesial, middle, and distal thirds (Scheid and Weiss 2012).
Besides having different sections, teeth also have many ridges, depressions, grooves, and rounded elevations. Some of these specific structures that are predominant have been given specialized names. One of these specific elevations, located on the occlusal surface and on the incisal edges, is called a cusp. The cusps of the tooth are then named according to the surface adjoining the location of the cusp. For example, two-cusped premolar will either be named buccal or lingual. Certain teeth, on the facial or lingual side, also manifest a bulge or ridge. All anterior teeth manifest this bulge, called a cingulum, on the cervical third if you are viewing them lingually. Permanent molars, on the other hand, have a subtle ridge called the cervical ridge located on the facial crown. The cervical ridge runs mesiodistally and is most prominent on the mesiobuccal cusp of the second molars of the lower jaw (Scheid and Weiss 2012).

*Functions of Teeth*

Teeth have very important functions, as they provide support for the face as well as provide aid in the initiation of digestion. Aesthetics play a big role in the function of teeth, and this is one of the reasons why restorative and orthodontic branches of dentistry have grown and are growing so rapidly. However, the most essential function of a tooth is mastication. This is because living organisms, human beings must be able to process energy and this is done through consuming food. The first rule of any dental treatment is to establish or maintain the tooth’s essential functions. These functions however, can slightly vary depending on the tooth. (Vanherele 2001). As previously established permanent dentition is made up of incisors, canines, premolars, and molars and each of these consist of their own particular duty and role. Though a tooth can vary in form from
mouth to mouth, there are certain generalizations that must be made about a particular set (Scheid and Weiss 2012).

Incisors, both maxillary and mandibular, work together articulate speech, particularly “th” sounds in the English language, to cut and tear food, to give structural support to the face, primarily the lips, and to aid in guiding the mandible during occlusion. The next tooth in dentition is the canine. Canines, the third teeth from the midline, are the longest permanent teeth. Though in certain animals canines are involved in defense as well as catching and tearing food, canines in human beings work together with the incisors, and therefore have similar functions. Canines help to cut food, support the lip and face, and protect the premolars and molars from possible harm by causing the posterior teeth separate when the mandible shifts. Because of the long roots that canines have, they also serve and function as secure docking stations for restorations such as dental bridges. Premolars lie between the canines and the molars and share tasks of both sets of teeth. Like canines, premolars aid in cutting and tearing food, however they also help the molars in mastication. Besides these two functions, premolars also provide structural support and help preserve the dimensions of the face and keep the mouth and cheeks from caving in. Permanent molars also serve important roles. Such roles include mastication and grinding of food, preserving vertical dimensions of the face, keeping other teeth in proper alignment by providing cohesion of the dental arches, and providing support to the cheeks and mouth. Loss of one permanent molar can cause increased discomfort and loss of chewing surface area; however, loss of all 6 molars can be detrimental to the patient and can lead to severe pain and/or jaw problems (Scheid and Weiss 2012)
Occlusion and Alignment

In order for teeth to serve their specific functions proper occlusion is necessary. Malocclusions can lead to pain, discomfort, and difficulty speaking and chewing. Occlusion is defined as the interaction of the incisal and the occlusal surfaces of the opposing maxillary and mandibular teeth. All fields of dentistry make proper occlusion a primary concern. While in restorative dentistry, during the process of making a restoration, it is important to keep proper occlusion; in orthodontia proper occlusion is often created through manipulation of the teeth. Ideal occlusion is designated as class I and is characterized by the interaction between the maxillary and mandibular arches at the closest fit, or the maximum intercuspid position. In this position, every tooth has the possibility to interact with two opposing teeth, with the exception of the third maxillary molar. Another characteristic class I occlusal is that the mesiobuccal groove of the mandibular first molar occludes with the mesiobuccal cusp of the maxillary first molar. Class I occlusion is the most advantageous form of occlusion as it allows the teeth the proper alignment to carry out their essential functions. For this reason, this is the occlusion that is promoted during orthodontic treatment, and is preserved when making restorations (Scheid and Weiss 2012).

Traditional Dental Methods

The two dental methods that are going to be used to compare traditional dental methods to that of their modern counterparts that use CAD/CAM technology are restorative dentistry and orthodontics. These two fields of dentistry were chosen because based on previous literature they are two of the sectors of dentistry most largely
influenced by this new technology. In order to assess if this new technology is indeed superior the traditional methods, it is necessary to first thoroughly understand each of these methods.

*Plaster Models*

Traditionally, both orthodontic and restorative dentistry treatments begin with full-arch maxillary and mandibular anatomically analogous plaster cast models of the patient’s mouth. These models are then used to study, plan, and see the progression of the patient’s treatment. Effective communication, between the lab and the dentist, is critical to ensure that the patient receives the adequate treatment in a time and cost effective manner. Though the process to make a plaster cast is not profoundly complex, it requires careful attention and skill. It is the dentist job to make sure that the person responsible for making the plaster cast is trained and proficient in this procedure (Freedman and Brucia 2001).

A plaster model begins with an alginate impression that was taken from the patient’s mouth. The impressions are then inspected and if the accuracy of the impression is questioned in any way the impression should be retaken (Freedman and Brucia 2001). After the proper impression is obtained it is poured immediately into plaster (Santoro *et al.* 2002). If the model that is going to be made is used just as a study model, then it can be poured into a buff stone. However, if the model is going to be used to make a restoration then it needs to be poured into a high-quality die stone. Once the model is poured, a vacuum mixer is used to guarantee that a bubble-free and dense cast is made. The completed models are then mounted correctly together using the face-bow and the ear-bow. The face-bow and the ear-bow are arranged in such a way that an accurate class
I occlusion is achieved. A polyvinyl or acryl material is then used to keep record of this bite (Freedman and Brucia 2001).

Once the plaster cast is made and endorsed by the dentist and/or lab the next steps of treatment can proceed. If the plaster cast is rejected then the previous steps must be redone in order to ensure the proper cast is made. This is an inconvenience since it requires more material, time, and money. If the plaster cast is no longer needed for the immediate steps of treatment it can be stored for legislative reasons and/or to either be reviewed in the future (Kasparova et al. 2013 and Freedman and Brucia 2001).

RESTORATIVE DENTISTRY

Though there are several procedures that are considered a part of restorative dentistry, this study will observe the methods of conventional crown and fixed-prosthesis fabrication in order to offer comparison with CAD/CAM. A conventional crown is necessary when a tooth is gravely broken or damaged (Scheid and Weiss 2012). The treatment begins with a first appoint that is designated to diagnosing the patient and developing a treatment plan (Christensen 2014). If the damaged tooth is a posterior one a complete cast metal crown is usually the option that is pursued, however if the damaged tooth is an anterior one, and the patient sees esthetics as factor, then a metal ceramic restoration or an all-ceramic crown restoration is considered (Scheid and Weiss 2012). Following this plan, there is a second appointment where impressions are taken and the tooth is prepared. These impressions are used for the Full-arch maxillary and mandibular study plaster cast models, and to make a provisional restoration for the patient (Freedman and Brucia 2001). At this appointment the patient is anesthetized and the tooth is prepped according to the chosen plan and the patient leaves with a temporary restoration. It is
imperative that throughout this appointment the dentist constantly inspects the occlusion and function of the tooth and the phonetics of the patient (Christensen 2014). This second appointment takes approximately half an hour to one hour to complete (Freedman and Brucia 2001). The third and final appointment involves the seating of the restoration. The option of anesthesia is given to the patient; however, anesthesia is not required for this treatment. At this appointment the temporary restoration is removed and the final restoration is established. The last appointment takes approximately half an hour. Therefore the total procedure, without the first appointment, is about one hour to one hour in a half (Christensen 2014).

Orthodontia

The field of orthodontia has also been drastically impacted by the emergence of CAD/CAM technology. However, before the traditional methods are set side by side to their modern counterparts the traditional methods must be understood. Orthodontia is the study of re-positioning and aligning malpositioned teeth and malocclusion. The traditional method of alignment involves the direct placement of small orthodontic devices called brackets on the external surface of the tooth. It is imperative that brackets are placed properly in order to accomplish the desired outcome in a cost effective approach. Orthodontists agree that exact placement of brackets is the most crucial part of for successful orthodontic treatment. Traditional brackets are placed on the tooth directly and are attached through the bonding of composite resins that are either light-cured or chemical-cured. This overall process generally takes anywhere from 1-2 hours, during
this procedure the patient’s mouth is propped open with the use of a mouth prop (Embrace it! 2014) (DentalCare 2015).

CAD/CAM Technology in Dentistry

*Impressions and Models*

Similar to traditional dental methods, both orthodontic and restorative dentistry treatments start with impressions and models of the patient’s mouth, or treatment area. Different from traditional methods however, modern CAD/CAM technology acquires the use computer-aided impression making, CAIM. The process of CAIM is carried out through the uses of intraoral scanners. These scanners use CAD technology and provide digital data of the different tooth surfaces and allow an image that can be manipulated on the computer. Similar to plaster models, these digital models can also be used to study, plan, and see the progression of the patient’s treatment. However, the digital model does not have to be the end product. If the dentist prefers a tangible model the digital model can also be 3D printed. Therefore CAD/CAM technology provides a different process for taking impressions and for making models analogous to the patient’s mouth.

Though each of these intraoral scanners have the previously established CAD hardware, CAIM technology differs slightly from scanner to scanner. There are currently three major intraoral scanners on the market, which include the CEREC Acquisition Center (AC) with Bluecam and CEREC 3D Service, iTero and iTero software, and Lava Chairside Oral Scanner C.O.S. and Lava Software Version. Since these are the major intraoral scanners it is important to understand their process.
Before the mouth can be scanned the scanning system must be set up. The scanner systems must first be set up and allowed to be booted. Once the system has booted the scanning software can be set up and the patient’s information can be entered into the system. Prior to scanning, the CEREC AC with Bluecam requires that an antireflective coating, the Lava Chairside Oral Scanner C.O.S. require a light powdering; however, the iTero scanner does not require any antireflective coating. After the necessary coating process, if necessary, the mouth can be scanned. The CEREC AC with Bluecam and the iTero system both use of a foot pedal to capture the data points. The Lava Chairside Oral Scanner C.O.S. does not have a foot pedal to capture the data points, but rather records a continuous stream of data points of the desired area. Once the image is captured the digital impression is created (Patzelt et al. June 2014, Patzelt et al. November 2014).

Once the digital impression is made and validated by the dentist and/or dental lab the next steps of treatment can proceed. If the impression is rejected then the previous steps must be repeated until validation can occur. Many times the planning of the treatment can take place on the computer and the digital data can be manipulated to provide a visual representation of the finished treatment. If the digital impression is no longer needed for the immediate steps of treatment it can be electronically stored for legislative reasons and/or to either be reviewed in the future (Torres et al. 2001).

If a physical representation of the patient’s mouth is needed, as a study model or as a step for another procedure, the digital impression can be printed. Many times digital models have small digital holes that require stitching before printing. There are various softwares, such as Materialize Magics, NetFabb, and Geomagic that allow manipulation of the CAD image to prepare the file for printing. These softwares also allow the imprint
of the patient’s information and the extraction of the desired areas for print. The data sets can also be sent to the manufacturers, of the respective scanner used, and they can print a physical cast (Groth et al. 2014, Patzelt et al. November 2014).

Digital impressions are almost always printed when a physical cast in needed. Few dentists use subtractive technology to fabricate a digital impression. Once reason could be correlated to a study in 2008 that indicated the potential negative effects on accuracy of casts when milling is used (Patzelt et al. November 2014, Schmitz et al. 2008). However, this statement is not clear since there is a lack of literature that indicates the dimensional accuracy of CAD/CAM casts fabricated through milling technology (Patzelt et al. November 2014).

3D Printers in Dentistry

There are several 3D printers that can manufacture models, restorations, and be used for orthodontic treatment based on data points taken by intraoral scanners. Some of the most prominent printers in dentistry include the Object30 OrthoDesk, a new generation of the Stratasys Objet30 printer, the Ultra 3SP Ortho, and FDM printers. Each of these printers has different characteristics and levels of accuracy. The Object30 OrthoDesk is a small PPP printer that is affordable for small-business and home use (See Fig. 6 in appendix). The Object30 OrthoDesk is able to print with a minimum layer thickness of 28 microns and can print at 9mm vertical height per hours. The stage of this printer, 300mm x 200mm x 100mm, allows as many as 12 horseshoe shaped models to be printed in a single job (See Fig. 7 in appendix). This means that in a single job 6 full arch maxillary and mandibular models can be printed. This printer also has three different
available materials that can be used, VeroDentPlus (MED690), MED610, and VeroGlaze (MED620). VeroDentPlus is used for most appliances and is a peach-colored acrylic based polymer. MED610 is biocompatible, clear and can be used for surgical guides. MED610 has also been approved to be used a temporary intraoral application for 24-hour use. Lastly, VeroGlaze (MED620) has also been medically approved to be used in the mouth for temporary use in the mouth for up to 24-hours. VeroGlaze (MED620), however, is not a clear material, but an acrylic used for veneer models or wax-ups in color A2 (Groth et al. 2014).

The Ultra 3SP Ortho is another printer that used in many dental practices, as it was designed specifically for dental use (See Fig. 8,9 in appendix). The 3SP (Scan, Spin, Selectively Photocure) technology, a type of DLP printer, was first introduced by EnvisionTEC in 2013 and uses a orthogonal mirror that spins at 20,000rpm. This technology also provides printing speeds faster than most DLP printers with a maximum rate of 10mm per hour on a 266mm × 178mm × 76mm platform. Not only is this printer fast but it can also provide print up to a minimum layer of 25 microns. The Ultra 3SP Ortho, similar to the Object30 OrthoDesk, has three different available materials E-Denstone, ABS 3SP White, and E-Glass. The only difference is that none of these materials have been approved for intraoral use (Groth et al. 2014).

FDM models are the least costly of the 3D printers and materials. However, this design is mostly for hobbyists and cannot handle the rigor of most dental or orthodontic practices. Because these printers are also made with less expensive parts, they have less resilience to breakage, and produce less-than-ideal surface finish (Groth et al. 2014).

Restorative Dentistry
The process of making a conventional restoration through CAD/CAM technology has evolved throughout the last 20 years. However, with the progress of new technologies, especially intraoral scanners, that deliver high levels of accuracy, the process has become more direct and efficient. This paper will examine the process of using intraoral scans in making a conventional crown restoration, since it is the most efficient way of using the CAD/CAM technology (Miyazaki and Hotta 2011).

The first step of making a full crown restoration occurs during the first appointment when the diagnosis is given and the treatment plan is assigned. The next couple of steps can be done at the first appointment, however some dentists prefer to schedule a second appointment. Regardless of the number of appointments, the next step in the procedure involves the preparation of the tooth (including but not limited to tissue management and anesthesia). The intraoral abutment is then scanned and a virtual model is made. The virtual model can then be used to make a temporary crown, a wax up, and/or a milled restoration. Depending on the placement of the crown it can either be fused to a metal framework, fused to a high strength ceramic framework, or is placed directly in the abutment. Posterior teeth usually require some time of fusion due to the force directed on the tooth’s occlusal surface while chewing. This process can usually be executed in approximately one hour (Christensen 2014, Miyazaki and Hotta 2011).

Permanent crown restoration using CAD/CAM technology usually involves subtractive manufacturing and not additive manufacturing. This is because there is currently no resin available that can be permanently placed in the mouth that will maintain the tooth’s necessary function (Miyazaki and Hotta 2011). Therefore when restorations involve 3D printing it is usually only to make a model and traditional
pressing and casting techniques must then be used to make the final crown (Albensi and Cohen 2011). However, this is not the case for subtractive manufacturing since there are wide arrays of materials that can be used. These materials range in strength, aesthetics, and durability (See Fig. 10, 11 in appendix). All of these characteristics should be considered during the planning of the treatment in the first appointment (Miyazaki and Hotta 2011).

The most well-known and used CAD/CAM technology used to provide restorations in a single visit is the CEREC System. The CEREC System was invented in 1986 but various generations have been introduced since then, each one better than the latter (Christensen 2001). The CEREC System is composed of an acquisition center and a water-milling machine. The acquisition center prepares the restoration and makes sure that the lingual, facial, and occlusal surface are designed correctly. The water-milling machine then uses a variety of high-dense quality blocks to produce inlays, veneers, onlays, and crowns. Four main types of blocks are used by the CEREC System involve porcelain based-based glass-ceramics called Vitablocs Mark II, ProCAD, IPS Ivoclar Vivadent, and Vitablocs Trilocs.

Vitablocs Mark II are monochromatic blocks that are constructed in a way that creates a nearly porous free ceramic. This porous free ceramic decreases enamel wear and allows the blocks to withstand forces higher than 160 MPa. These blocks can then be matched to a shade almost exactly that of the tooth’s color using staining. ProCAD is, similar to Vitablocs Mark II, are also monochromatic and can also be stained to match the patient’s tooth in order to provide an ascetically pleasing restoration (Christensen 2014). IPS Ivoclar Vivadent blocks are also monochromatic blocks available in standard Vita A,
B, C, and D shades (Poticny and Klim 2010). Vitablocs Trilocs provides an alternative to staining, as it contains a three-shade variation in color saturation (See Figure 12 in appendix). These three shades are designed in a way to give the appearance of the three different layers of a tooth, enamel, dentin, and pulp. Vitablocs Trilocs provides the color intensity and translucency of a natural tooth for the CEREC restoration (Christensen 2014).

Orthodontia

The field of orthodontia has also been transformed by CAD/CAM methods. As previously mentioned study models are often used to provide and diagnose treatment. Through the methods provided above, orthodontists can create a digital image of the patient’s mouth and view it as needed. This digital file can be stored digitally and shared to other professional to consult treatment. If a physical model is needed these models can then be fabricated by the use of the 3D printer.

CAD/CAM systems have not just provided orthodontist with digital study models, but have also provided patients with alternative methods and customization of treatment. Two of the leading customization appliances modernized by CAD/CAM systems involve indirect bonding and clear alignment treatment options. Customization allows, in regards to indirect bonding, customization of brackets and arch wire based on the patient’s tooth specific morphology. Using CAD/CAM technology, orthodontist can intraorally scan and rearrange the virtual image of the patient’s final occlusion. With this image, specialized software, and reverse engineering, the plan and the mechanics of treatment can be chosen (Weber et al. 2013). The second part of these treatment involves placing the brackets on
the digital image, so slots are present once the model is printed (See Fig. 13 in appendix). This set up is then sent to the orthodontist for approval. Once the orthodontist has approved the positioning of the brackets, the model can be printed and the chosen brackets can be placed (Grauer et al. 2012). With the uses of a vacuum form an indirect bonding tray, that contains the transferred brackets, can be made (See Fig. 13 in appendix). This tray can then be used to place the brackets simultaneously in the patient’s mouth. Once the brackets are positioned, the arch wire can then be placed, and the rest of the orthodontic treatment can proceed (Grauer et al. 2012).

Another customization opportunity is the use of clear removable aligners. Though the first aligners were available as early as 1945, drastic improvements of the aligners due to CAD/CAM have promoted their popularity. Currently, the Invisalign system is the most prominent software technology for the fabrication of clear aligners to correct various types of malocclusions. The process for making these clear aligners begins with an intraoral scan of the mouth. The scan then produces a virtual image of the patient’s occlusion and dental arches that can be adjusted using a CAD software called ClinCheck. The digital file is then sent to the orthodontist to be verified before the aligners are made. Once the scan is made, the treatment is virtually simulated and the aligners are manufactured in a series. The aligners are manufactured in a way that guarantees 0.25mm linear movement per month and 2 degrees of angular movement per month. It is difficult to assign a estimated time of treatment since the length of the treatment varies based on the patients particular problem (Torres et al. 2011).

Comparison of Traditional and CAD/CAM Methods
The two dental approaches, traditional and CAD/CAM equipment, processes were previously explained to provide a basis of comparison. The goal of this section is to present both the advantages and disadvantages of CAD/CAM technology in order to determine their value in dentistry and to determine if the new technology is superior to the traditional methods. Once again it is important to note that this research only looks at two fields of dentistry, restorative dentistry and orthodontia since they have been largely influenced by this new technology.

*Impressions and Models*

As previously stated, dental impressions are a crucial part of treatment and therefore should be made as accurate as possible. Not only is this process crucial, it is also one of the most time-consuming procedures in a dental practice. Various studies have been carried out to assess the advantages and disadvantages of intraoral scanned impressions verses traditional impressions. Some of the major advantages include more time efficiency, the removal or breakage and storage problems, and the ability to share, retrieve, and share the digital information with an equivalency of accuracy as traditional models (Patzelt *et al.* 2014, Santoro *et al.* 2002).

Various studies have demonstrated the accuracy of intraoral scans and their respective 3D models when compared to traditional impression taking methods. A study carried out in 2002 concluded CAIM methods did not show any clinical difference in accuracy compared to the traditional methods and therefore provide an alternative to such methods (Santoro *et al.*). Another study in 2013 agreed with the results since they stated that digital study models are indeed an acceptable alternative to traditional. However, this statement could not be made, if the scan the models are made from are not also accurate
A more recent study, carried out in November 2014, compared the accuracy of the three intraoral scanners mentioned previously to traditional impressions and also concluded that they all provided an acceptable level of accuracy (Patzelt et al.). My own personal research also agreed with these findings. When comparing a traditional plaster model to the 3D printed model, made by the iTero scanner and the Object 30 3D printer, there was no significant difference in accuracy between the two (Mendez-Ceballos 2014). Therefore based on these studies, it can be concludes that intraoral scanning is a valid alternative to the traditional method of taking impressions.

Intraoral scans and 3D printed models are not only equivalent to traditional methods; they also provide greater time efficacy. All of the scanners mentioned previously were used in a study to determine the time efficacy of intraoral scans. It was determined that intraoral scanners were up to 22 times faster for a single tooth scan and up to 13 minutes faster for a full arch scan. Therefore this study concluded that digital impression making is more efficient than traditional impression methods (Patzelt et al. June 2014). Not only is process of scanning faster using CAIM technology, but overall process time is reduced due to less appointment times, less rejections of impressions, and the ability for one person to carry out the whole process (Benefits for Dentists).

Another advantage to intraoral scans is the removal of breakage and storage problems. Because the data files are digital, storage is more compact and convenient. Plaster models are very fragile and can be easily broken, while digital files can be stored and only printed if that step is necessary for the patient’s treatment. These digital files also make it possible for dentists and orthodontist to share information and inquire consultation about a diagnosis. Plaster models, again due to their fragility, are very
inconvenient to send through mail. Digital models completely eliminate this inconvenience (Santoro et al. 2002).

Lastly, digital impressions are also eliminating the mess and discomfort of traditional impressions. Most patients, especially children, find discomfort in the process of taking an impression. Some even feel a claustrophobic feeling that causes a gagging sensation when biting into an alginate impression. This process is completely eliminated by using intraoral scanners, thus granting the patient superior comfort during an essential part of treatment (Christensen 2014).

Though there are a lot of advantages to these CAD/CAM methods, there are a few disadvantages. The first is that some dentists worry that since intraoral scanners provide a digital impression the data could be misused and/or prone to technical errors. However, these issues can be addressed and do not reduce the value the technology provides (Kasparova et al. 2013). The second issue that is often raised is the learning curve in understanding these new CAIM methods. Dentists and orthodontists have to be proficient with the scanner and the software to have the advantages described above. Therefore dentists and orthodontist must determine whether familiarity with the traditional methods outweigh the advantages of the CAIM techniques (Christensen 2009).

**Restorative Dentistry**

Crown restorations consist of more than 80% of fixed restoration done at dental offices (Christensen 2001). Therefore making a crown accurately and efficiently is a critical process in a dental practice. CAD/CAM methods provide many advantages compared to traditional crown restorations. Some of the major advantages include accuracy, reduced turn around time, the delegation of procedures, a one-appointment
procedure, removal of lab charges, and stronger restorations (Knight 2013, Christen 2001, Christensen 2014, Christensen 2001). The accuracy in the restoration is virtually exact because of the intraoral scan of the patient’s mouth (Knight 2013, Giordano 2006). The precision in the digital impression also allows the restoration to be fabricated quicker, due to a less probable chance of a failed restoration (Trest, Stines, and Burt 2006). A study that was done in 2014 took two-crowns restoration, one made traditional and one made using CAD/CAM technology, and asked 117 dentists which restoration they would prefer. In more than 68% of the time the dentists chose the crown used with CAD/CAM technology. This exemplifies the accuracy of the restoration and its superiority to traditional ones (Rifkin 2014).

Crowns made using CAD/CAM technology are also done much quicker due to less chair time, and a faster turn around time (Knight 2013, Christensen 2001, Trest, Stines, and Burt 2006, Giordano 2006, Christensen 2006, Rifkin 2014). “Turn around time” refers to the time it takes for a dentist to receive a crown from a lab after the impression has been sent. CAD/CAM equipment allows the whole restoration to be done in the dental practice in one appointment thus reducing the turn around time drastically (Knight 2013). Not only this but CAD/CAM technology allows the dentist to be in full control of treatment, while being able to delegate certain parts of the process, thus increasing efficiency (Christensen 2006, Once the dentists are proficient with the equipment the design process can take approximately 5 minutes and the milling process averages 10-12 minutes per crown restoration (Trest, Stines, and Burt 2006).

The decrease in required times and appointments for CAD/CAM crowns restorations also cutbacks on expenses. One appointment decreases the administration of
anesthesia, and the use of material and staff, and the removal of laboratory fees
(Christensen 2001, Trest, Stines, and Burt 2006). The highest quality CEREC model is
about $139,995, and though the initial investment is significant there is a high return on
the investment. Traditional crowns are made for approximately $120, while crowns made
with the CEREC machine are made for approximately $26 (Trest, Stines, and Burt 2006).
Therefore not only is money saved due to a decrease in time, but the overall the process is
eventually cheaper.

There has also been a lot of progress in CAD/CAM technology and in the
materials that are provided for crown fabrications (Trest, Stines, and Burt 2006). A study
in 2006 demonstrated that CEREC blocks have less enamel loss then traditional crown
materials (See Fig. 14 in appendix). This is because the blocks are made continuously and
densely with fine grain powders. This method of fabrication makes for a nearly pore-free
crown restoration (See Fig. 15 in appendix) (Giordano 2006). However, these blocks do
present the disadvantage of being monochromatic and sometimes not ascetically
appealing. The monochromatic nature of the blocks can be camouflaged by proper
staining (Christensen 2001). Though these stains are tricky to master, once they are
mastered the monochromatic nature of the block is no longer an issue (Trest, Stines, and
Burt 2006). Though there are also other issues that have been raised about CAD/CAM
restorations such as a need for upgrades, the initial financial investment, and the learning
curve, most studies agree that CAD/CAM has revolutionized the crown fabrication
process (Christensen 2001).

*Orthodontia*
Various studies have also examined the advantages and disadvantages of CAD/CAM technology in orthodontia. CAD/CAM systems have provided patients and orthodontist’s alternative modern methods and customization of treatment. Two of these methods are indirect bonding and the option of clear alignment trays. Customization, in indirect bonding, allows more accurate placement of the brackets. This customization directly correlates to reduced treatment time. This positive outcome is not only due to customization of slot orientation but also the ability to preview the final occlusion at the beginning of treatment. Indirect bonding also provides greater comfort for the patient and an easier placement of the orthodontic treatment on the patient (Weber et al. 2013). The patient and the orthodontist also both benefit from decrease chair time. For the orthodontist reducing chair time provides more time to see other patients and therefore increases revenues. Patient’s also receive increase comfort due to the shorten chair time (DentalCare).

Indirect bonding does have a couple disadvantages. Because CAD/CAM technology is so advanced the professional staff must be trained on this new equipment. There is a also potential for error in bracket positioning if the process is not executed correctly (Grauer et al. 2012). Not only this, but CAD/CAM technology is very expensive thus the product is only cost effective if it is used adeptly and frequently (DentalCare). However, as the performance of indirect bonding continues to be validated, the procedure will become more common and the price of this treatment will be reduced (Breuning 2011). Therefore as long as professional knows how to use the equipment and is skilled at it, the advantages of this new method outweigh the traditional methods.
Clear alignment trays also have many advantages. The first advantage has to do with aesthetics of the treatments. Because of the clear nature of these appliances many patients, that previously were reluctant to wear traditional appliances, have been given orthodontic treatment. The use of clear alignment trays provides high levels of accuracy in movement for various types of malocclusions with a single mold. This treatment is especially advantageous for patients with mild crossbites, deep bites, and patient’s bruxism. Bruxism can be avoided because the trays help protect against occlusal deterioration of the tooth and thus reduced pain facial muscles and joints. The clear alignment trays also help reduce the plaque buildup and promote oral hygiene. Also, because of CAD/CAM technology in the development of these trays, patients can see what their results would look like before their treatment begins. Therefore with this technology disappointment in the outcome of treatment is rarely an issue. Once again, the only drawback to this treatment is cost and a possible lack of familiarity with the new technology. However, similarly to indirect bonding, once these issues are addressed the advantages of this new method outweigh the traditional methods (Torres et al. 2012).

Conclusion

Teeth have very particular structures and functions. It is a dentist’s duty to make sure that every tooth is safeguarded and that proper occlusion in maintained or achieved. Orthodontia and restorative density methods have been revolutionized by the use of modern methods using CAD/CAM technology as a way achieving these goals. This study reviewed the significance of each tooth, and the validity of CAD/CAM methods to provide alternative methods for impressions, study models, restorations, and orthodontia. CAD/CAM dentistry provides a more efficient method to its traditional counterparts.
With the use of CAD/CAM technology impressions and study models are more time efficient, there is no issue of breakage or storage, and the ability to retrieve and share the digital information is more accessible. CAD/CAM technology also has made restorations more accurate, faster, more economically feasible, and provides customization in orthodontia. Though these modern methods have many advantages, the dentists must be proficient in the use of the system and use the system regularly, for the method to be cost effective. The dentist must decide if they consider CAD/CAM technology is a priority based on the needs of their patients and practice. However, upon pursuing and learning the use of this new technology, CAD/CAM alternatives provide advancement and innovation of the field and many provide benefits for both the dentist and the patient compared to the traditional approaches. As the advantages CAD/CAM technology continue to be researched and more dentists begin to use these methods the technology will be economically feasible and the innovation will increase.

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how they are using 3D printing to provide accurate dental appliances at a faster pace than
the traditional method.
### Permanent Teeth

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<td>9 10 11 12 13 14 15 16</td>
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<td>24 23 22 21 20 19 18 17</td>
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### Primary teeth

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<td>T S R Q P</td>
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**Figure 1.** The numbering of permanent and primary teeth using the Universal Numbering System (Google/Images).

**Figure 2.** The different sides and viewpoints of a tooth (Google/Images)
Figure 3. The traditional method of additive manufacturing (Miyazaki and Hotta 2011).

Figure 4. (Miyazaki and Hotta 2011).
**Figure 5.** Support and structure resin necessary for the 3D printing of a model (Miyazaki and Hotta 2011).

**Figure 6.** (Miyazaki and Hotta 2011).
Figure 7. (Miyazaki and Hotta 2011).

Figure 8. (Miyazaki and Hotta 2011)
**Figure 9.** (Miyazaki and Hotta 2011).

**Figure 10.** (Miyazaki and Hotta 2011).
Figure 11. (Miyazaki and Hotta 2011).

Figure 12. (Christensen 2014)
Figure 13.
(Grauer et al. 2012).

Figure 14.
(Christensen 2014)
Figure 15.
(Christensen 2014)
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