Virtual Prosthodontics – A Review Article

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Abstract: In dentistry, CAD CAM was introduced in 1970s. Since then, its use in dentistry has been increasing day by day. Many companies are developing new CAD CAM systems. With CAD CAM, dentists can get high quality inlays, onlays, implant abutments, cast partial dentures, crowns, bridges etc. Maxillo-facial prosthesis and orthodontic clear aligners are also being produced by CAD CAM. Apart from quality and quick production of restorations, cost and difficult usage of CAD CAM are the reasons which are causing hurdles in mass production of these restorations.
This is an attempt to provide an overview for the application of CAD/CAM in the various branches of prosthodontics.

Keywords: CAD CAM, digital impressions, digital imaging, virtual articulators

INTRODUCTION

Recent decades have seen innovation in therapeutic technologies such as the acid etch technique and osseointegrated dental implant. Today, therapeutic interventions involve digital diagnostic, treatment planning, and prosthesis design/manufacturing techniques that are revolutionizing patient care

In the clinical aspect, digitization has revolutionized imaging and diagnostic options.

It was only in the 1980s, that the first intra-oral sensors were developed for use in dentistry.The development of cost-effective intra and extra-oral digital technology coupled with an increase in computerization of practices has made digital imaging a superior alternative in many respects to conventional film imaging. Early 1980s also paved the way for computer aided design/computer-aided manufacturing (CAD/CAM) technology.

The First application of CAD/CAM in dentistry was by Dr. Francois Duret in 1970‘s in his thesis ―Optical Impression. In 1984, Duret invented and patented a CAD/CAM device and illustrated the crown fabrication in 4 hours. At the same time, Dr. Mormann and Dr. Brandestini originated, the first profit oriented digital impression system the CEREC1, in 1985.

Since then, the technology has evolved in two directions—the intraoperatory application for single appointment restoration (using prefabricated ceramic monoblocks) and paralleled by CAD/CAM systems for commercial production centres and dental laboratories.

CEREC 1 combined a 3-dimensional (3D) digital scanner with a milling unit to create dental restorations from commercially available blocks of ceramic material in a single appointment. CEREC 1 was designed for the fabrication of ceramic inlays and Onlays. Cerec 2, cerec 3, cerec 3D were introduced in 1994, 2000 and 2003.

Digital methods used in the fabrication of dental restorations include the computer n

umerical control subtractive methods and the additive methods (AM), which include stereolithography apparatus (SLA) and selective laser sintering (SLS).

To implement the oral condition of a patient virtually, the first step is to create 3D stereoscopic images using a specific scanner which can carry out 3D modeling by using the scanned data to design the tooth shape. When completed, the data are converted to the stereolithography format and transmitted to each device. The shape of the actual restoration is then fabricated using these data.

Dental subtractive manufacturing uses end-milling of a fixed-size solidified block made of a ceramic such as zirconia, wax, resin, or metal.

Digitization and Its Futuristic Approach in Prosthodontics

It is important that advances in technology are accepted and the benefits that they produce utilized in order that clinical practice and patient care continue to improve.

Generations of cad/cam

Dr. Duret- developed the Sopha® System

Dr. Moermann- the developer of the CEREC® system

Dr. Andersson - the developer of the Procera® system

Dr. Duret was the first in the field of dental CAD/CAM development.

Later he developed the Sopha System.

The second is Dr. Moermann, the developer of the CEREC system,who introduced first commercially designed CAD CAM system in the year 1985 and given the name of CEREC.

He attempted to use new technology in a dental office clinically at the chairside of patients. He directly measured the prepared cavity with an intra-oral camera, which was followed by the design and carving of an inlay from a ceramic block using a compact machine set at chair-side. The emergence of this system was really innovative because it allowed same-day ceramic restorations. When this system was announced, it rapidly spread the term CAD/CAM to the dental profession.

Since its introduction to the dental field in 1985 as the CEREC 1, this system has evolved through a series of software and hardware upgrades up to the CEREC 3D.

CEREC 2 was introduced in 1994 by Siemens. This system was based on two dimensional principles and capable of producing inlay, onlay, veneers, partial & full crowns and copings.

Currently 3rd generation of CEREC is in use, which is capable of producing inlay, onlay, veneers, partial & full crowns, copings as well as virtual automatic occlusal adjustment. This system was introduced by Sirona in 2005.
This system is basically the advanced form of CEREC 3.
Digital Impression
Digital scanners are used to take the image of the prepared teeth which ultimately lead to the removal of conventional impressions. Data acquisition is done with the help of scanners having camera that will collect the images, designing of the restoration is done with the help of software and finally computerized milling device is used for the manufacturing of the restoration.

Types, Propositions and Features of Different Digital Systems

The main digital impression systems those are available on the market include:-

- CEREC
- Lava C.O.S. system
- ITero
- E4D
- TRIOS.

They vary from each other in terms of various features such as working principle, light source, the necessity of powder coat spraying, operative process, and output file format.

CEREC System

The CEREC 1 system (Sirona, Bensheim, Germany) -the first intraoral digital impression and CAD/CAM device.The principle of this system is designed with the concept of ―triangulation of light,where the intersection of three linear light beams is focused on a certain point in 3D space.
CEREC AC Bluecam is the fourth generation product and currently is the most prevalent CEREC system. LED blue diode is the light source which will emit visible blue light for the image capturing. The CEREC AC Bluecam can capture one quadrant of the digital impression within 1 minute and the antagonist in a few seconds.
In 2012, the latest and newest CEREC system, CEREC AC Omnicam, was brought to market. The Bluecam imaging technique involves the single image acquisition while the latest Omnicam takes continuous various images, where a 3D model is generated after data acquisition. .
Lava TM C.O.S. (Lava Chairside Oral Scanner; 3M ESPE, Seefeld, Germany) is an intraoral digital impression device invented in 2006 and brought to market in 2008.
The principle on which it works is active wavefront sampling. Single-lens imaging system is used to obtain the 3D data under active wavefront sampling. Three sensors are used to capture clinical images from different angles simultaneously such as to develop surface patches with in focus and out-of-focus data by proprietary image-processing algorithms.
The Lava C.O.S. has the smallest scanner tip—only 13.2- mm wide. The scanner sends out pulsating visible blue light as light source and they work with a mobile host computer and a touch-screen display. In most cases, supporting CAD software and CAM device are used for desiging and manufacturing of data proprietary files exported by Lava C.O.S.

iTero system

Cadent Inc (Carstadt, NJ) introduced iTero to the market in 2007. They work on the principle of parallel confocal imaging, the iTero system captures intraoral images and contours them by laser and visual scanning.One scan results a total of 100,000 points of laser light at 300 focal depths of the tooth structure. These focal depth images are separated at the level of approximately 50 μm, allowing the camera to acquire precise data of tooth surfaces.
iTero is an open system in the treatment of crowns, FPDs, veneers, implants, aligners, and retainers. Digital image files are send as an STL format, which can be shared by any other lab equipped with a CAD/CAM system

E4D system

The E4D system was developed by D4D Technologies, LLC (Richardson, TX).
It works under the principle of optical coherence tomography and confocal microscopy. Micro mirrors and red laser is used as a light source to vibrate 20,000 cycles per second. E4D‘s are having high-speed laser those formulates a digital impression of the prepared and proximal teeth such as to create an interactive 3Dimage.
The E4D system can work with a chairside-milling device just like CEREC AC Bluecam and Omnicam systems. That means this system can also function as a ―single-visit treatment‖ and provide high-strength ceramic prostheses or composite even for minimally prepared teeth.

TRIOS system

A new type of intraoral digital impression system, TRIOS, was introduced in 2010, by 3Shape (Copenhagen, Denmark) and was presented to market in 2011. This system works under the principle of ultrafast optical sectioning and confocal microscopy.
TRIOS include two parts: TRIOSR Cart and TRIOSR Pod. The TRIOSR Pod is having a handheld scanner which offers better flexibility and mobility, so due to its simple construction it is compatible with other computers and iPad.
Digital Workflow :-. The first step is the acquisition of data. Earlier extra oral scanners were primarily used for this purpose. These could either scan the impressions or scan the die sectioned model. Extraoral scanners can be hand-held (Bench Scanner) or full arch scanners
They are either optical scanners or laser assisted optical scanners. In either of the case, a convention impression was necessary. The advent of present generation intraoral scanners will now slowly limit the use of extraoral scanners. If there is an in-house milling machine the dentist could fabricate restoration by themselves. Otherwise, a laboratory integration is essential.
The acquired data is then sent to the laboratory for either manufacturing of CAD CAM restorations or customized restorations with the help of SLA models-3D PRINTING.

CS 3600 (Carestream, United States)
This scanner works on the principle of triangulation with high definition 3D color. The device is a powder-free system and also an open system available in USB version, where the data can be sent to any other milling device.

Digital Imaging

Digital Radiography

Digital radiographic images can be indirect, direct, or semi-direct. Radiographic produced by flatbed scanners with a transparency adapter, slide scanners, and digital cameras are referred to as indirect digital radiographs. Direct digital images are acquired using a solid-state sensor such as CCD or complementary metal–oxide– semiconductor (CMOS)-based chips. Semi-direct images are obtained using a phosphor plate system charge-coupling transfers the number of electrons deposited in each pixel from one well to the next in a sequential manner to a readout amplifier for image display on the monitor.

Area digital sensor array is used for intraoral radiography while linear arrays are used in extraoral imaging. CMOS sensors use an active pixel technology. It reduces required system power by a factor of 100 and eliminates the need for charge transfer. Phosphor plate system consists of a polyester base coated with a crystalline emulsion of europium-activated barium fluorohalide Compound. Incident X-ray photons create a latent image. A scanner reads the image information by scanning the plate with a laser beam of near-red wavelengths to form digital image.

History

Wilhelm Conrad Roentgen in 1895 discovered the "X" rays. Less than two weeks after this important discovery, **Dr. Otto Walkhoff** developed the first original dental roentgenogram from a portion of a glass imaging plate. The image required 25 minutes of exposure. Since the discovery of X-rays, film has been the primary medium for capturing, displaying, and storing radiographic images.

Subtraction methods were introduced by B.G.Zeides des Plantes in the 1920s and the The first digital radiography system called **RadioVisio Graphy** was launched in Europe in 1987 by **Dr. Francis Mouyen.** He invented a way to employ fiber optics to narrow down a large x-ray image onto a smaller size that could be sensed by a Charge Coupled Device (CCD) image sensor chip.

Equipment

I. X-Radiation Source: most systems use conventional dental units as x-radiation source due to its compatibility.

II. Intraoral Sensor: is a small detector that is placed intraorally and used to capture the radiographic image and send to computer for future processing. Sensors are similar in dimensions like conventional films and may be either wired with 8 to 35 feet fiber optic cable for transmission of generated image to computer or wireless.

Intraoral sensor is composed of a silicon chip and a layer that surrounds it. A layer above the sensor chip is the scintillator (material that emits light when particles traverse it), which converts x-ray energy into light and directs it towards the top layer of the chip that is more sensitive to light than x-rays. Top layer of the chip then releases electrons that form the image and send them onto the well in the lower portion of the chip. The energy in each well is then read and digitized with an A/D (analog to digital) converter during the read-out process.

Three types of sensors:

i) **Charge-coupled device (CCD):-** is one of the most common image receptors in digital radiography since 1960‘s and is used in many other devices like fax machines, video cameras, microscopes and telescopes. The CCD is sensitive to x-rays or light & is a solid-state detector that contains a silicon chip with an electronic circuit embedded in.

ii) Complementary metal oxide semiconductor/active pixel sensor (CMOS/APS):- This is less expensive, offers greater durability and 25% greater resolution than CCD sensor.

iii) Charge injection device (CID):- It doesn‘t require computer for image processing and uses same docking platform with intraoral camera & within seconds directly produces digital image on monitor.

III. Computer: is used to digitize process and store information received from the sensor in 0.5 to 120 seconds and then present the image on the computer monitor where it can be stored or printed.

Techniques :

I. Direct Digital Imaging: - X-ray photons that originate from the conventional radiographic unit come in contact with intraoral sensor and cause electrons to be released from the silicone chip and produce latent image. Electrons travel to computer where are converted into pixel arrangement that can be visually seen on monitor. A pixel is digital equivalent of a silver crystal used in conventional radiography. E.g. CCD sensor can produce 640x480 individual pixels in size. Each pixel is represented numerically in the computer by levels of colour of gray and varies from 0 to 255, which creates 256 shades of gray, referred to as a pixel‘s **gray-scale resolution**.

Zero on this scale means that maximum radiation is measured, which corresponds to black in the radiographic image (radiolucency), and 255 represents no radiation at all, or complete radiopacity (white). The number of possible gray-scale combinations per pixel is known as **bit-depth image**. Digital image with 256 pixel resolution contains 8 bit-depth image.

II. Indirect Digital Imaging

a) Scanning of traditional radiographs:

An existing conventional radiograph is digitized using CCD camera, which scans, converts image from analog to a digital form and then displays it on monitor.

Examples of indirect digital imaging systems; a) DigoraOptime, utilises linear scanning; b) Gendex Den Optix, utilises drum/carousel scanning; c) DürrVistaScan, utilises spinner scanning.

b) Phosphor Imaging or Photostimulable Phosphor Plate (PSP):-

This method employs reusable imaging plate coated with phosphors instead of sensor. After radiation exposure and capture of the image on the plate, a high-speed scanner is used to convert information into electronic image. Time needed for processing the image

from the plate into the computer is between 1.5 and 5.5 minutes. After its transmission into the computer, the radiographic image is cleared from the plate by exposure to view box light for several minutes and is ready for reuse.

Digital Subtraction Radiography:

Digital subtraction radiography is defined as ―the digital or photographic manipulation of a radiograph in which background images are eliminated to highlight areas for pre- and postoperative comparison.

It is used to compare standardized radiographs taken at sequential examination visits. All unchanged structures are subtracted and these areas are displayed in neutral gray shade in the subtraction image; while regions that have changed, are displayed in darker or lighter shades of gray.

Digital subtraction radiography is a technique that allows us to determine quantitative changes in radiographs. These can include measurements of lengths, area or angles. The magnitude of the changes can be measured by evaluating the histogram (graphic depiction of the distribution of gray levels) of the resultant image.

There are two considerable methods in digital fluoroscopy viz. temporal subtraction and energy subtraction :-

Temporal subtraction	**Energy subtraction**
Normal x-ray beam filtrate is adequate	x-ray beam filter switching is preferred
A contrast resolution of 1mm at 1% is achieved .	Higher x-ray intensity is required for comparable contrast resolution
A single KVP is used .	Rapid KVP switching is required
Simple arithmetic image subtraction is Necessary.	Complex image subtraction is necessary
Total subtraction of common structures is achieved.	Some residual bone may survive subtraction
Motion artefacts are a problem	Motion artefacts are greatly reduced
Subtraction possibilities are limited by number of images.	Many more types of subtraction images are possible

When the two techniques are combined, the process is called "Hybrid Subtraction". Image contrast is still enhanced further by hybrid subtraction because of reduced patient motion between taking subtracted images. Temporal subtraction techniques are more often used because of limitation of high voltage generators in the energy subtraction techniques **.**When the two images of the same object are registered and intensities of corresponding pixels are subtracted, a uniform difference image is produced. If there is a change in the radiographic attenuation between the baseline and follow-up examination, this change shows up as a brighter area, when the change represents gain, and as a darker area when, the change represents loss.

Ct scan /MRI:

Computed Tomography (CT & Magnetic Resonance Imaging (MRI) are newer techniques for data acquisition for CAD CAM.By this method, individual images can be taken and then can be transferred to CAD.

Virtual Facebow

DEFINITION

An instrument used to record the spatial relationship of the maxillary arch to some anatomic reference point or points and then transfer this relationship to an articulator, it orients the dental cast in the same relationship to the opening axis of the articulator, customarily the anatomic references are the mandibular transverse horizontal axis and one other selected anterior reference point4. - GPT 9

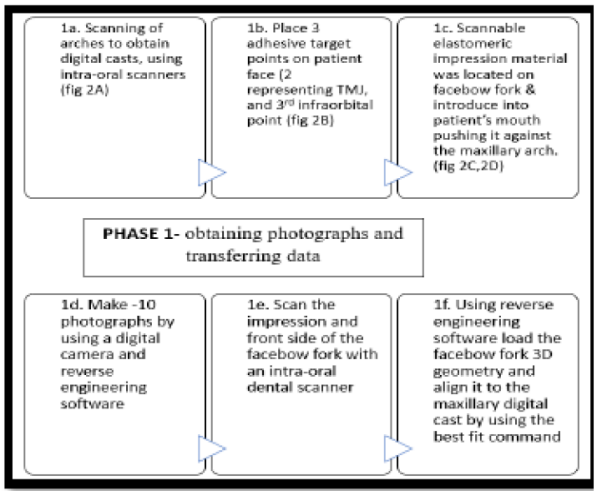
To assist the process, the mounting of a patient‘s diagnostic casts remains an important step, as it allows the assessment of critical factors such as occlusion, implant position,forces direction and angled abutments.

To support proper mounting of patient casts, a facebow, which aligns the maxilla to relative facial planes, can be utilized

The Virtual Facebow has been developed as a digital substitute to the analogue facebow to address the shortcomings.

The main advantage of using the virtual facebows and articulators is they provide six degrees of freedom.

TECHNIQUE OF USING THE VIRTUAL FACEBOW:



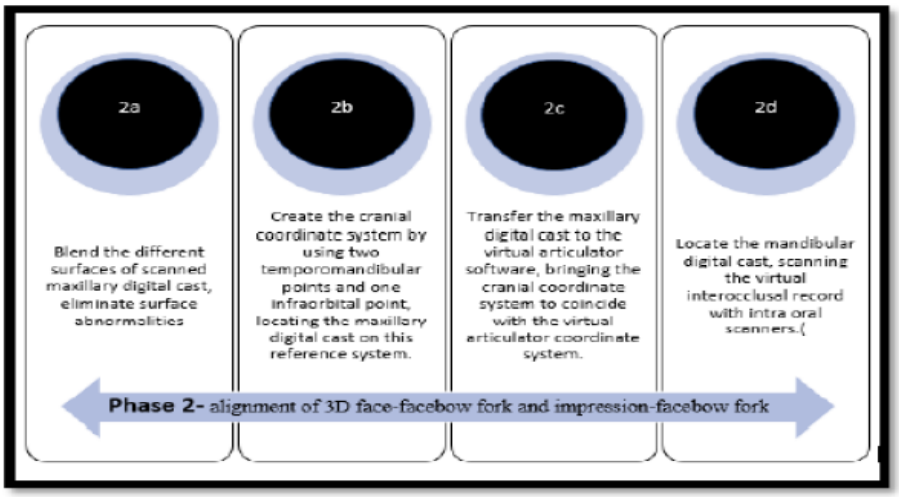
[Y. Satya Sai Sruthi et al /J. Pharm. Sci. & Res. Vol. 13(3), 2021, 149-154]

Figure 2. Three-dimensional (3D) geometry of patient's face and facebow fork. A, Left lateral view. B, Frontal view. C, Right lateral view. D, 3D geometry on Agisoft software.

[Solaberrieta, E., Garmendia, A., Minguez, R., Brizuela, A., &Pradies, G. Virtual facebow technique. The Journal of prosthetic dentistry, 2015, 114.6: 751-755.]

Figure 2. (*continued*). Three-dimensional (3D) geometry of patient's face and facebow fork. A, Left lateral view. B, Frontal view. C, Right lateral view. D, 3D geometry on Agisoft software.

Phase 2: alignment of 3D face-facebow fork and impression-facebow fork



Flow chart2 : functioning of virtual facebow- Phase 2

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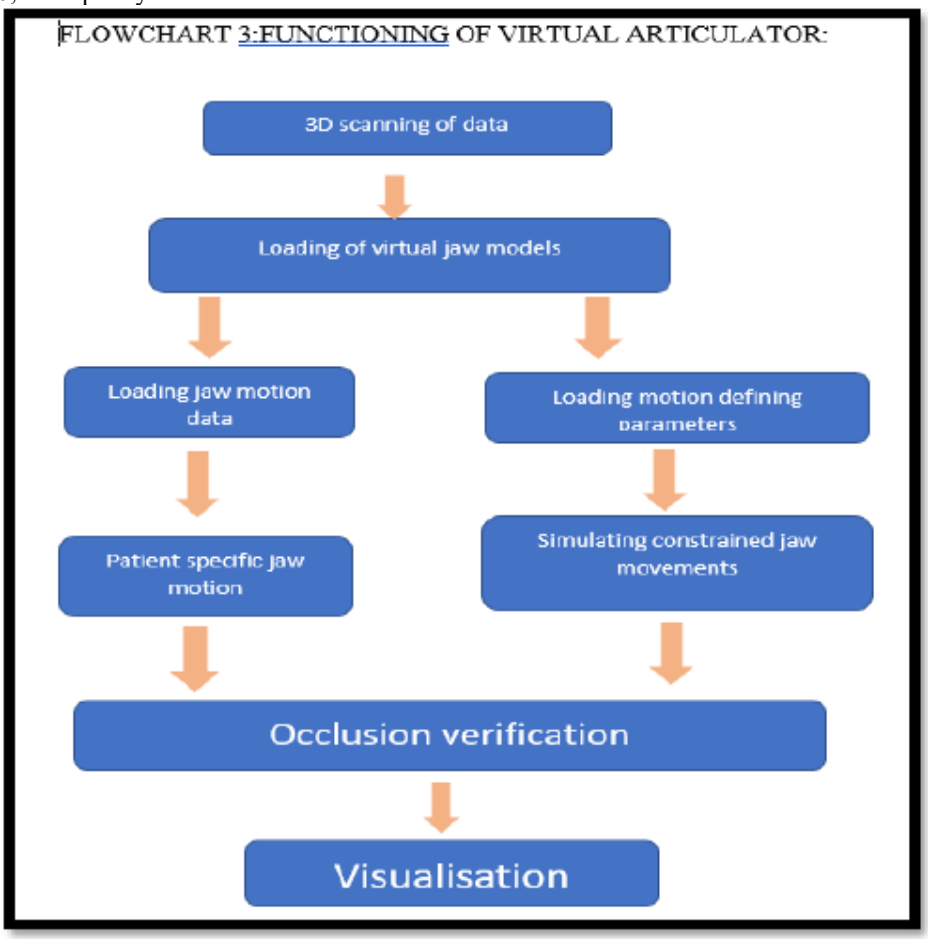
Virtual Articulator

Based on the advancing science there is a need for revisiting the classification by adding the virtual articulators as class V.
Class V : articulators based on virtual reality [Fig 4]
Class V a: records exact movement paths of mandible by using jaw motion analyzer (jma)
Examples: Koidass and Gartner virtual articulators, Dent CAM virtual articulator
Class V b: It records / reproduces movements of the articulator based on mathematical simulation of articulator movements. Allow additional settings such as curved Bennett movement or other movements for adjustment in ideal settings.
Examples: Stratos 200, Szentpetery‘s virtual articulators



Flowchart 3: Functioning of Virtual Articulator.

The programming and adjustment methods of the virtual articulator were described by Kordass and Gärtner in 1999.

Fabrication Process

All CAD/CAM systems have three functional components:
1. A digitalization tool/scanner converts the surface geometry into digital data which is then processed by the computer.
2. The processing software which processes scanner data and a data set in readable format is produced.
3. A manufacturing technology transforms the data set into the desired product and fabricates the restoration.

To fabricate a physical prototype in, two different approaches have been utilized: Subtractive (conventional CAD/CAM) and additive (rapid prototyping).

Subtractive Manufacturing

Subtractive manufacturing means the milling of the workpiece from a larger blank by a computer numeric controlled (CNC) machine. The software translates the computer designed model into the tool path for the CNC machine. The computation of the commands series that dictates the CNC milling. The accuracy of tool positioning was reported to be within 10 µm. Compensation steps are incorporated for the cutter tool diameter ensuring that the milling bur reaches the desired surface without sacrificing necessary segment of the workpiece.

Since the movement is restricted to the milling tool, it is difficult to produce large prosthesis by 3-axis milling. In dentistry, 5-axis machines are suitable for producing complex shapes. For dental applications, the quality of the restoration is independent of the number of axes; instead, it reflects the method of processing the workpieces and CAD path of milling

Additive Manufacturing

In additive fabrication, the final desired part is manufactured layers which are added on top of the other step by step.

The key idea is that the three-dimensional-CAD (3D-CAD) model is sliced into many thin layers and equipment uses data based on geometrics to build each layer sequentially until the part is completed. Thus, it is referred to as ―layered manufacturing,―3D printing or ―solid freeform fabrication.

Once the CAD is finalized, it is segmented into multislice images. There are 5–20 layers for each millimeter laid down by the machine. Then, the workpiece is refined.
The additive systems used in dentistry are stereolithography, selective laser sintering or melting, and 3D printing.

SLATECHNIQUE

This type of 3d printing was presented by Hull in year 1984, for the production of 3d models from photopolymers resins. This system consists of both of photosensitive liquid resin, a model building platform and an ultraviolet (UV) laser for curing the resin. The layers are cured sequentially and bond together to form a solid object beginning from the bottom of the models and building up.As the resin is exposed to the UV light, a thin well defined layer thickness becomes hardened. After a layer of resin is cured , the resin platform is lower within the bat by a small known distance. A new layer of resin is wipped across small known distance. A new layer of resin is wipped across the surface of the previous layer using a wiper blade, and this second layer is subsequently exposed and cured.
The process of curing and lowering the platform into the resin bath is repeated until the full model is complete. The self adhesive property of the material causes the layers to bond to each other and eventually form a complete en bloc 3D object. The model is then removed from the bath and cured for a further period of time in a UV cabinet.

Laminate object manufacturing (LOM) :

It is a rapid prototyping system developed by Helisys. It layers of adhesive-coated paper, plastic, or metal laminates are successively glued together and cut to shape with a knife or laser cutter. Objects printed with this technique may be additionally modified by machining or drilling after printing. Typical layer resolution for this process is defined by the material feedstock and usually ranges in thickness from one to a few sheets of copy paper.
Laminated Object Manufacture (LOM) cuts the component slices from thin layers of material using a CO2 laser mounted on a 2D plotter.

Digital smile designing :

It is a digital mode that helps to create and project new smile design by attaining a simulation and pre visualization of the ultimate result of proposed treatment.
Coachman and calamita described DSD as multi use conceptual tool that can support diagnostic vision,improve communication andenhance treatment predictability by permitting careful analysis of the patient facial and dental characterstics that may have gone unnoticed by clinical,photographic or diagnostic cast based evaluation procedures.
Christian Coachman in 2017 has proposed this evolution in generations as:
Generation 1. Analogue drawings over photos and no connection to the analogue model
Generation 2. Digital 2D drawings and visual connection to the analogue model.
Generation 3. Digital 2D drawings and analogue connection to the model.
Generation 4. Digital 2D drawings and digital connection to the 3D model.
Generation 5. Complete 3D workflow.
Generation 6.The 4D concept-Adding motion to the smile design process.

Conclusion:

CAD CAM has no doubt changed the concept of modern world dentistry. Different specialties of dentistry are being successfully benefited by CAD CAM. Either orthodontics or prosthodontics, quality treatment is possible with accuracy and effectiveness. But cost of these treatments is still a problem for the patients and the dentists, esp. of the developing countries. We are hopeful that in the near future, CAD CAM will be started using widely in the developing countries as well

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