Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/18969
DOI URL: http://dx.doi.org/10.21474/IJAR01/18969

RESEARCH ARTICLE

DIGITAL SPACE MAINTAINERS

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Manuscript Info

Manuscript History
Received: 25 April 2024
Final Accepted: 28 May 2024
Published: June 2024

Key words:-
Space Maintainers, 3D Printing, Digital Scanner, Digital Space Maintainers

Abstract

3D printing is a manufacturing process in which formation of an object is done by building it layer by layer. Many new developments have occurred in paediatric dentistry in recent years. As the world is advancing technologically day by day, 3-D printing technology will be the need of the hour in coming days. The plethora of applications that 3D Printing holds as a technology are more than that can be explained. Technologies like 3D Printing help to have least physical interactions with patients and still provide accurate and best outcomes for our patients taking care of the safety for both doctor and patients.Nowadays, 3D printing is being used to fabricate the space maintainers, to overcome the disadvantages of conventional space maintainers and ribbond and everstick as space maintainers. The space maintainers that use 3D printing technology are called 3D printed space maintainers or digitainers/ digital space maintainers. They offer better results, in terms of impression making, digital impressions make it easy for both the dentist and the patient, less chair- side work, short appointments, better patient's cooperation, improves aesthetics, reduces processing errors, offers high strength, less breakage of the appliance, and also offers good patient's acceptability.

Introduction:-

Dental caries is one of the major concerns in public health. It often leads to premature tooth loss or extraction of the decayed teeth.[1]

When a tooth is lost prematurely, it disturbs the normal physiological process of eruption of permanent teeth,[2] and often leads to malocclusion or loss in arch length discrepancy. Therefore, there is utmost need to maintain the edentulous space created by early exfoliation of primary teeth, to avoid crowding of teeth, impaction of teeth, ectopic eruption of teeth and supra-eruption of unopposed teeth and centre line discrepancies.[3]

As stated by the American Academy of Paediatric Dentistry (AAPD), space maintenance is the preservation of present dentition placement to avoid loss of arch length, width and perimeter.[4] After using the term "Space maintenance", in 1941, JC Brauer went on to explain that it was the process of preserving the space in the mouth that was previously filled by one or more teeth.[5] Space maintainers are the appliances placed in the mouth to prevent drifting of adjacent teeth, thus maintaining the space for the developing permanent teeth. There are different types of space maintainers- fixed or removable, unilateral or bilateral, and functional or non-functional.

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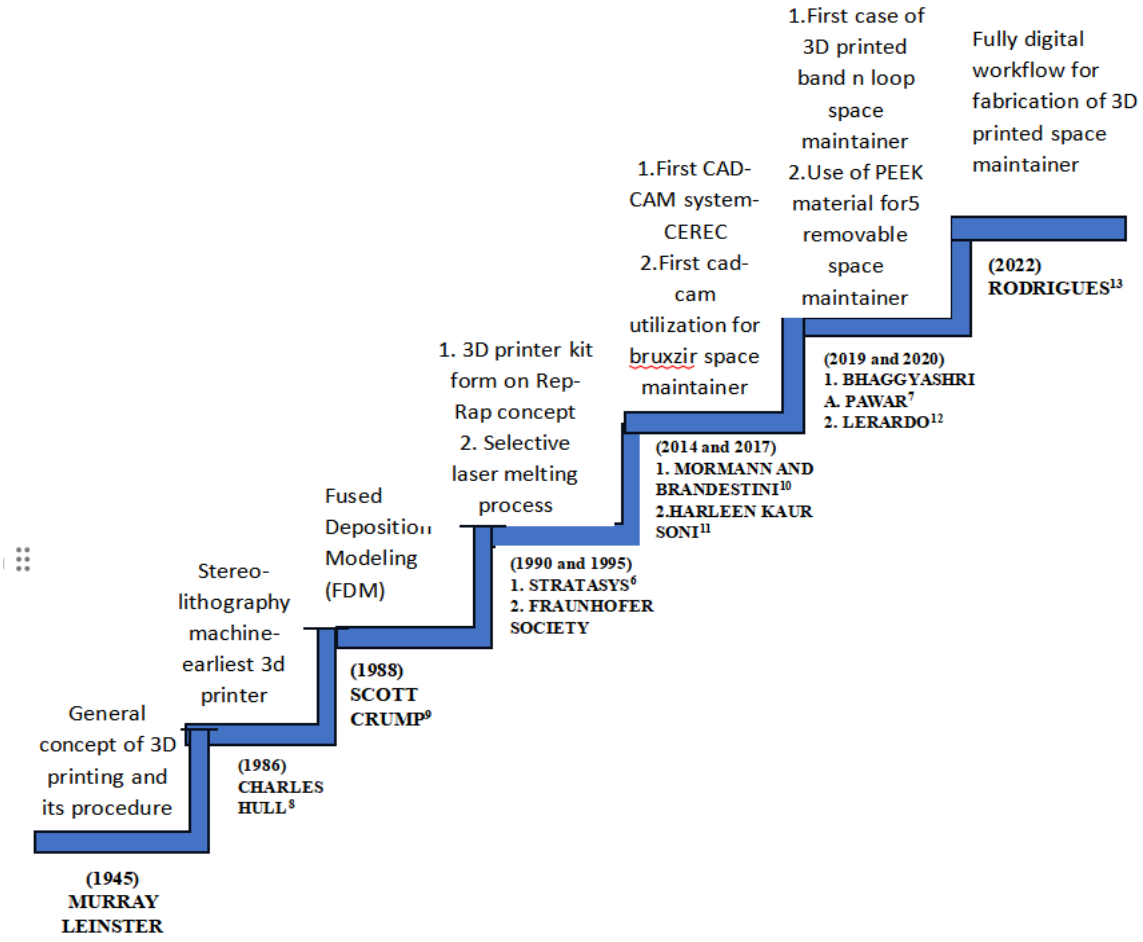
Paediatric dentists have been using conventional space maintainers since long time, but still there are several drawbacks to this approach. Drawbacks such as poor construction quality, expensive and time-consuming laboratory work, processing errors, difficulty in impression making in small children with gag reflexes. These disadvantages of conventional space maintainers led to development of its variants such as fibre- reinforced composite space maintainers and pre-fabricated space maintainers because of ease of fabrication and reduced appointment counts and therefore improved patient's comfort. Though these also showed failures like debonding at the enamel- composite interface and debonding at fibre-composite interface, and the polymerization shrinkage.[5]

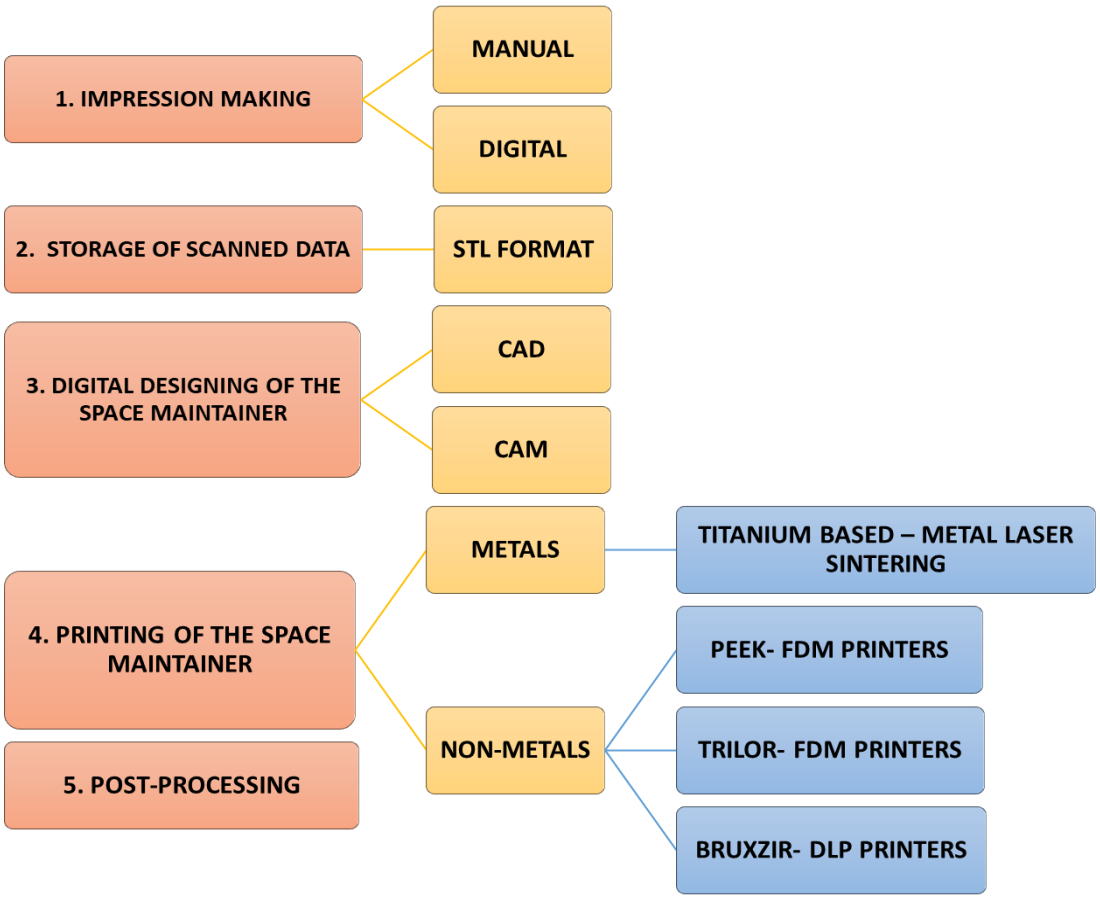
Space maintainers are now being fabricated using Digital workflow instead of traditional analog workflow because of the advantages it offers. A host of new technologies continued to introduce in 1990's and early 2000's.[6] 3D printing is a manufacturing process in which formation of object is done by building single layer at a time. The main idea is to make 3D model which is sliced into many thin layers and the geometric data is used by manufacturing equipment to build each layer subsequently until the desired object is completed. Scanners are used to examine and record the anatomy to deliver the final 3D model. The 3D model is saved in STL format and is sent to 3D printer where layer by layer the design is formed.[7]

3D Printing has become a subject of great interest in paediatric dentistry in specialization of Space Maintainers. Origins of 3D printing are traced back to 1940s. The timeline of the history of 3d printing and Digital space maintainers is shown in flowchart-1.



FLOWCHART-1: TIMELINE OF 3D PRINTING AND 3D PRINTED SPACE MAINTAINERS.

Steps of Fabricating Digital Space Maintainers (flowchart-2)



FLOWCHART-2: STEPS OF FABRICATION OF 3D SPACE MAINTAINER.

Impression Making
Impression making can be done by two methods:

Manual Impression
Manual impression technique uses alginate or polyvinyl siloxane to make the impressions. It is associated with problems such as gags, errors like pulls, tears, bubbles in the impressions, tray-to-tooth contact, temperature sensitivity, less working time, shrinkage of the impression material, inaccurate pouring, over-trimming of the model, and breakage during shipment.[14]

Digital Impression
Digital impression is made with the help of an intra-oral scanner and its advantages include improved diagnosis and treatment planning, increased acceptance by patients, faster records submission to laboratories, fewer errors, reduced storage requirements, improved and more accurate appliance, enhanced workflow. Benefits to the patient include a better experience with more comfort and less anxiety, reduced chair-time, and easier re-fabrication of lost or broken appliances, as well as potentially reduced treatment time. Digital impressions are more child friendly as compared to conventional impression technique.[15]

I**ntra-oral scanner**

Is a portable device which is used to create digital impression directly from the oral cavity. The light source from the scanner is directly scanned onto the object to be scanned, for example dental arches, and then the 3D scan is being displayed onto the screen. In general, the object is exposed with a laser to acquire three-dimensional data, and that data is further converted into polygon data, which is a set of triangular surfaces. The device provides the accurate details of the soft and the hard tissues in the oral cavity. Once the oral cavity is ready to be captured, Intra-oral scanners work by projecting a light source onto an object, which is then analyzed and converted by software to create POI (point of interest). The POIs are then divided into triangles to create a 3D model. These POIs are sent to the computer and converted into an STL-file type.

The Techniques of scanning includes passive and active techniques.[16] Passive techniques use only ambient lighting to provide light to the intra-oral tissues and they rely on certain level of texture of an object whereas Active techniques use white, red, or blue structured lights projected from the camera onto the object and relies less on the real texture and colour of the tissues for reconstruction. In active techniques, a luminous point is pointed onto an object and the distance to the object is calculated by triangulation. An alternative to this is, light pattern projection, for example line or mesh projections.[17]

Intra-oral scanners fall under two systems- open and closed system[18]. In open system, the digital file created by the intra-oral scanner can be transferred to any CAD-CAM software, mill and printer. These files are most commonly saved in STL format (standard triangulation language). whereas in closed system, the digital file created by the intra-oral scanner are in a proprietary format that only works with the software and mills or printers of same format or company. Therefore, they offer only specific set of clinical applications.

EveryIntra-oral scanner has 3 components- A software to back information entry.Acomputer-monitor to enter prescriptions, approve scans and review digital files.And a hand-held camera wand to scan the intraoral tissues.[19]

There is plethora of intra-oral scanners since its inception. Some of the commonly used products regarding the same are Lava C.O.S, iTero Element, TRIOS 3, True Definition, CEREC Bluecam, CEREC Omnicam etc.[20]

Regardless of brand, intraoral digital scanner systems can be divided into three parts: image capture, data processing, and onscreen scan results. The major factor that influences the performance of different scanners is the first part (i.e., the imaging technology).

The three imaging principles most commonly used throughout the development of an IOS are as follows-

According to Henry Hann-Min Hwang et al (2018),[21] there are three imaging principles

Confocal laser scanning

The emitting laser is projected to the target through a filter with tiny pinhole. The confocal imaging plane captures only the light reflected from the object in focus. Out-of-focus data are not recorded. Thus, the whole 3D structure is reconstructed by retrieving 2D images at different confocal planes. This imaging process is also known as "point-and-stitch reconstruction." iTero and TRIOS are the two scanners that use this technique.

Triangulation technique

The triangulation method is composed of three points: the laser emitter, sensor, and object surface. With the known distance and angulation, using the Pythagorean theorem (the sum of the squares of the two legs of a right triangle is equal to the square of its hypotenuse),the object surface information can be acquired. However, to obtain more detail and predictable light dispersion, the tooth surface may need to be covered with a thin layer of radiopaque powder. (e.g., Optispray® by CEREC, primarily comprising titanium oxide).

Active wave-front sampling (3d-in-motion video recording)

This optical sampling method refers to 3D information gathered using a single-lens imaging system for measuring the depth on the basis of the de-focus of the primary optics. Lava Chairside Oral Scanner (COS) and True Definition both use this technique in their 3D-in-motion video recording technology. Three internal complementary metal–oxide–semiconductor (CMOS) sensors capture 3D information from different perspectives (i.e., image triplets). In addition to the high accuracy it can provide, high data redundancy is one of the unique characteristics.

Saloni Kachhara et al (2019)[22], Mounika pulluru et al (2017)[19] and Raphaël Richert et al (2017)[23], added the 4th principle-

Stereophotogrammetry – Estimates all coordinates (x, y, and z) only through an algorithmic analysis of images, it relies on software and passive light projection.[24]

1. Storage Of Scanned Data

The scanned data is stored in **STL file format[25].**STL is an acronym of the word stereolithography, a 3D printing process created by Chuck Hull in the 1980s. There are backronyms attached to the STL file type, including "Standard Triangle Language," "Standard Tessellation Language," and "Surface Tessellation Language." The main purpose of the STL file format is to encrypt the surface geometry of a 3D object. The information is encoded using a simple concept called tessellation.

The STL specification has some special rules for tessellation and storing information. These are as follows-

The Vertex Rule

The vertex rule states that each triangle must share two vertices with its neighboring triangles.

The Orientation Rule

The orientation rule says that the orientation of the facet (i.e which way is "in" the 3D object and which way is "out") must be specified in two ways. First, the direction of the normal should point outwards. Second, when looking at the object from the outside, the vertices are placed in counterclockwise order (right-hand rule). This redundancy exists for a reason as it helps in ensuring mesh consistency and also spot corrupt data. The software calculates the orientation from the normal and subsequently from the vertices also and verify whether they match. If they don't, it can declare the STL file corrupted.

The All-Positive Octant Rule

This rule says that the coordinates of the triangle vertices must all be positive. This implies that the 3D object lives in the all-positive octant of the 3D Cartesian coordinate system (and hence the name). The idea behind this rule is to save the space. If the 3D object were allowed to live anywhere in the coordinate space, we would have to deal with negative coordinates.

The Triangle Sorting Rule

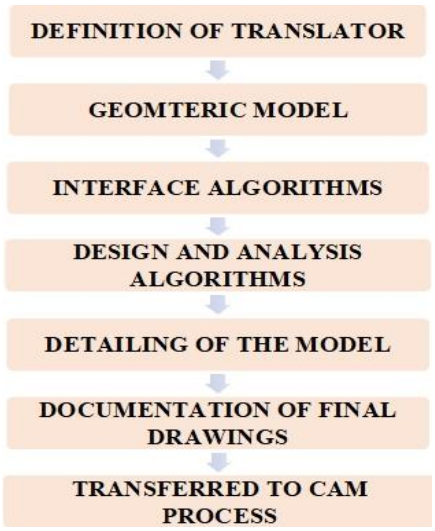
It states, that the triangles appear in increasing z-value order. This helps the software to slice the 3D models faster, but the rule is not strictly enforced.

2. Digital Designing of the Appliance

CAD stands for Computer-Aided Design and CAM stands for Computer-Aided Manufacturing, both of which are used to make things. CAD/CAM software is used to design and manufacture prototypes, and finished products.[26]

CAD process (Flowchart-3)

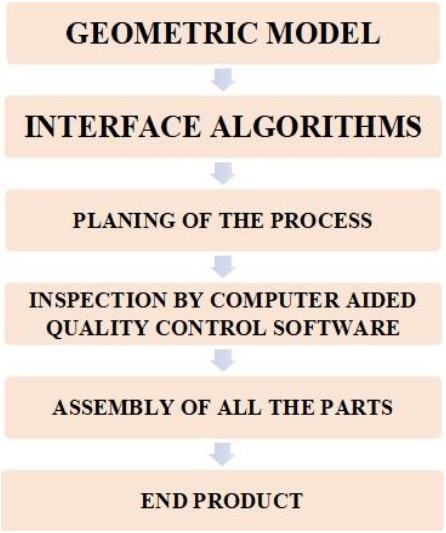
Computer Aided Design (CAD) is the use of sophisticated computer graphics techniques for designing the models of physical products, which means computers are used to aid in creating the design, modifying the design, and analyzing the designing activities, its development, costing and ergonomic problems associated with it. Computer Aided Design is also known as computer aided drafting.



FLOWCHART-3: CAD PROCESS

CAM process (Flowchart-4)

Computer Aided Manufacturing (CAM) is the use of computer software to plan, manage and control machine tools in the manufacturing of modules. CAM transforms engineering designs into end products through either direct or indirect computer interface. Computer Aided Manufacturing is also known as Computer-Aided Modelling or Machining. The purpose of CAM is to use 3D models to design machining processes i.e. CAM converts the geometry to the machine tool.



FLOWCHART-4: CAM PROCESS

So, in simple words CAD represents your part geometry to the computer, whereas CAM converts the geometry to machine tool. CAD software is used by an engineer, and CAM software is used by a machinist. So, the proper design and model is created using the CAD-CAM software.

3. Printing of the Designed Appliance

Considering the requirements for a non-toxic, biocompatible, and inert material, the current 3D printers developed for dental applications are limited in their use of metals and ceramic materials to produce provisional dental restorations and are variable in the effect of print direction and accuracy.

The various materials used in 3D printing according to different printing technology are-[27]

1. Poly-jet printing – Photopolymers
2. Multi-jet printing - Plastics, ceramics and metals
3. Fused deposition modelling (FDM) – Acrylonitrile Buta-diene styrene (ABS), polycarbonates (PC), polyester, PEEK
4. Selective laser sintering (SLS) - Plastics, ceramics and metals
5. Selective laser melting (SLM) – Metals
6. SLA / DLP - Photopolymers, plastics and ceramics

Metal Space Maintainers

A material frequently used in dentistry is metal, which is widespread for the use in strengthening restorations or incorporation into frameworks of space maintainers. This has led to these materials to be studied and industrialized for additive manufacture, mainly by selective laser sintering (SLS). Due to favourable levels of strength,[28] most widely used metals are **cobalt-chromium, stainless-steel,nickel alloy and titanium metals** have gotten the most progresses.[29]

Fabrication of Titanium-based metal space maintainer by micro laser sintering

After designing the appliance in CAD-CAM software, the titanium-based powder is dispersed in a thin layer on top of a platform inside of the build chamber of the printer. The printer preheats the powder to a temperature somewhat below the melting point of the raw material, which makes it easier for the laser to raise the temperature of specific regions of the powder bed as it traces the model to solidify a part. The laser scans a cross-section of the 3D model, heating the powder to just below or right at the melting point of the material. This fuses the particles together mechanically to create one solid part. This process is repeated for each layer until the desired appliance is formed. The finished parts need to be removed from the build chamber, separated, and cleaned of excess powder. The powder can be recycled and the printed parts can be further post-processed by media blasting or media tumbling. Parts may be spray painted, lacquered, electroplated, and coated to achieve different colours, finishes, and properties.

Advantages

a) It is non-esthetic because of its colour.
b) It may cause allergies in some patients.

Disadvantages

a) It is radio-opaque in x-rays.
b) It offers greater strength.

Metal Free Space Maintainers

This includes plastics, polymers and zirconia-based materials which are used for the fabrication of the 3D printed space maintainers.

PEEK Polymer (polyetheretherketone)

Digital technologies and new materials are becoming popular, getting better and changing the way to do diagnosis and therapy. Polyaryletherketone (PAEK) is a family of high-performance thermoplastic polymers, consisting of an aromatic backbone molecular chain, interconnected by ketone and ether functional groups. Thus, PEEK belongs to a larger family of PAEK polymers, sometimes referred to as polyetherketones (PEKs) or more simply as "polyketones.[30]

Polyetheretherketone (PEEK) is a semi-crystalline polymer commercialized from 1978 and composed by repeating units of three phenyl rings, two ester groups and one keto group.[31]The chemical structure of PEEK, similar to its PAEK cousins, confers stability at high temperatures (exceeding 300^0C), resistance to chemical and radiation damage, compatibility with many reinforcing agents (such as glass and carbon fibres), and greater strength than many metals.

Advantages
a) It is bio-compatible hence used in patients with metal allergy.
b) It shows superior mechanical qualities.
c) It is aesthetically pleasing.
d) Used in both fixed and removable appliances.

Disadvantages
a) It is radiolucent in x-rays.
b) It is weaker in strength as compared to metal space maintainers.

Trilor[33]
Trilor®, developed by BiolorenSrl, is a new techno-polymer consisting of thermosetting resin and a multidirectional reinforcement of fibreglass. Trilor® is made of woven fiber structure in a multi-directional configuration. It shows enormous strength while offering natural flex and natural load distribution. Trilor® is compatible with all CAD and CAM software and is available in the forms suitable for all milling machines present in the dental market (grinding and milling).

Advantages
a) Provides natural load distribution
b) Light weight
c) Aesthetic and durable
d) Easy to clean

Disadvantages
a) Dislodgement and breakage of the appliance is more.

BruxZir
Bruxzir is a solid monolithic zirconia material that uses Cad-Cam for its fabrication[11]. The space maintainers fabrication using bruxzir is done via DLP printers. The DLP 3D printing is what is known as a vat polymerization technique. These printers accept STL files, or CAD files that can be cut into layers in preparation for printing using a so-called "slicing" software. The printer's build platform is submerged in a vat of liquid resin, and a digital light source projects each layer onto it. The light causes the material to cure onto the platform, creating a solid sliver of the part. Layers are built on top of each other until each layer has completed, where the part is then removed from the build platform for post-processing.

Advantages
a) High flexural strength
b) Offers greater resistance to masticatory forces
c) Exhibit 3-5 times the fracture toughness of typical zirconia
d) Aesthetic and durable

Disadvantages
a) Breakage and dislodgement of appliance is more.

4. Post-Processing Finishing and Polishing
Parts that are manufactured by 3D printing requires some degree of post processing finishing and polishing. This is required to give a finished touch to the parts to further enhance the object. The 3D printed space maintainer is further finished and coloring is done if required. The powder removal is done in powder bed fusion and SLS technique to remove the excess powder.

Advantages of 3d Printed Space Maintainers Are-
1. Better acceptance of the procedure by the patient with strong gag reflex due to the absence of the impression material.[34]
2. Less time consuming.[35]
3. Decreased no. of appointments.[36]
4. High esthetics.[35]

5. No need to pour the casts as the digital file recorded allows to make the digital model using the CAD-CAM software.
6. The appliance formed using the 3D printing technology is a highly finished appliance therefore reduces the chances of plaque accumulation.
7. The final appliance which is printed is a single unit appliance with no solder joint, hence, less chances of plaque accumulation and less gingival problems are seen.
8. The strength of the 3D printed space maintainers is more as compared to conventional space maintainers.
9. No solder joint offers less breakage of the appliance making it more child-friendly.
10. No gingival lacerations and trauma as no band pinching required.[11]
11. High precision and reduced deformation and errors with reduced de-cementation.[37]
12. Patients with special needs can easily be given 3D space maintainers because it requires less chair-side time and the final fit of the appliance is more accurate.
13. Digital process keeps all records for as long as needed, there is no need to store bulky models of the patients.
14. Environment friendly as patient's records are kept digitally.

Disadvantages Of 3d Printed Space Maintainers[11]

1. The digital devices and machines are expensive.
2. Lab assistance is required for 3D printing.
3. Requires skilled workers to perform digital workflow (requires special training).
4. Cost effectiveness of the appliance is less than that of conventional space maintainers.

Conclusion:-

Delivering the dental care to child patient in stress free and more friendly manner is the most desirable need of the hour for any formulated dental treatment plan. 3D printed space maintainers are the boon for the paediatric dentists in cases where taking impressions is a difficult task. Digital impressions have the potential to increase efficiency along with the enhanced comfort for the patient, and also reduces the long-term costs/expenses of dental procedure. The chairside time reduces with the help of digital scanners and the cumbersome task of pouring the casts is now eliminated with the help of CAD-CAM technology. Furthermore, the Intra oral scanners are environment-friendly because no disposal of wastage of impression material is needed as in the case of conventional impression materials. 3D printers can print out models in a relatively short period of time but the high cost of the equipment makes the popularization of 3D printing a challenge. The cost of running the laboratories, maintenance, and the need for skilled operators, as well as the need for post-processing must also be carefully considered. Despite all the concerns, 3D printing will have an increasingly important role to play in paediatric dentistry.[38]

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