Stereoithographic Innovations in Dentistry

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Abstract :

Conventional methods of fabricating prosthesis involves manual procedures and invest lot of laboratory time. The models fabricated with conventional techniques involve unavoidable errors involved at every step. Rapid prototyping is a process that creates model or product by design, electronics, and software programming with minimal errors. Stereolithography is kind of Rapid Prototyping that is created by layer by layer manner. Stereolithography also known as optical fabrication or image and resin printing is one of the several methods for creating 3-D objects, in which a computer controlled moving laser beam is used to build up the required structure, layer by layer, from a liquid polymer that hardens on contact with laser light.

This new technology created from cone beam computed tomography data combined with software driven treatment planning, has tremendous potential in diagnostic and educational models and treatment planning in dentistry.

This paper aims to depict widespread applications of Seterolithography in dentistry including diagnostic study and research models, resin/ wax patterns, crown fabrication, surgical stents for bone remodelling and implant placement and pattern fabrication in maxillofacial prosthesis.

Keywords : Rapid Prototyping, Biomodels, Tissue Engineering

Introduction

Fabricating a successful prosthesis by conventional methods depends upon precision of creating physical model over which the prosthesis is to be fabricated. Lots of errors occur manually operated techniques and is quite time consuming. Also there is no information saved for future retrieval. To avoid laboratory errors the newer technologies are adopted and have become very popular in recent times in the field of dentistry.

Computer modelling has revolutionized almost all areas of medicine. The word prototype is derived from the Greek word prototypon which means "primitive form." Thus prototype is an early sample, model or release of a product built to test a concept or process or to act as a thing to be replicated or learned from. It is a term used in a variety of contexts, including semantics, design, electronics, and software programming. A prototype is designed to test and try a new design to enhance precision by system analysts and users. Prototyping serves to provide specifications for a real, working system rather than a theoretical one. In some workflow models, creating a prototype (a process sometimes called materialization) is the step between the formalization and the evaluation of an idea[1].

Like any other technology, prototyping has also undergone many evolutionary changes since its birth till date.During its primitive phase prototyping evidenced the skill of craftsmen and was done manually since ages.

A revolutionary change in this technique was experienced in around mid 1970s where a soft prototype modelled by 3-D curves and surfaces could be stressed in virtual environment, simulated and tested with exact material and other properties.

The term rapid prototyping refers to a new set of technology which allows fabrication of three dimensional complex physical models based on design data through the aid of a computer using CAD software.In this modern era, the world is advancing in every field be it sports, construction of building, various household products, medicine or even dentistry. One of such recent advancement that has touched the mindsets of medical field is creating 'biomodels' which is a generic name coined to describe the ability to replicate the morphology of biological structures[2]. These biomodels can be virtual or computer based models or can be physical biomodels.

Computer based biomodels are used for surgical panning and performing biomechanical analysis of biological structures.

Physical biomodels originate from Virtual biomodels. These can be built to actual size and can be scaled. These models can be macroscale or microscale depending upon the processing and function it has to perform. Macro scalemedels are used for design and preoperative planning. Microscale models are used for trabecular bone and are used in the field of tissue engineering.

In medical field RP technologies are a new approach to surgical planning and simulation. With the aid of this technique one can have the tactile sensation of his visualization of the outcome of a treatment plan. Thus it favours a new interactive technique of treatment planning based on the idea of "touch to comprehend"; thereby giving more realistic approach towards a treatment with better assured results. Also the doctor can interact and comprehend the whole scenario to his patient in a better and influential way which helps to build a good rapport with the patient[3].

Beyond its known contributions related with the diagnosis, education and surgical planning. This technology is being used in wide areas of dentistry including prosthodontics.

The introduction of RP technologies in prosthodontics has been a boon to this field of dentistry as it has provided us with the advantage of eliminating some tedious and time consuming lab procedures and clinical steps involved in a Prosthodontic treatment. This method has the potential to replace the traditional "impression- taking and waxing" procedures by much modern computer aided mechanical scanning and designing softwares which allow more detailed and realistic reproduction of patient records thereby giving more accurate and promising results. The chief benefit of RP techniques is the production of patient models with exact simulation of undercuts, voids, intricate internal geometrical details and anatomical landmarks such as facial sinuses and neurovascular canals. This technology improves medical diagnosis and provides a precise treatment plan thereby shortening the surgery time and patient risk[4].

Apart from stereolithography which is being discussed here, are various other RP technologies available in the field of dentistry.

Literature Review

New developments in computer technologies led to success of CAD-CAM techniques.

Fuster-Torres M.A. in his study used CAD/CAM systems in implant dentistry, especially emphasizing implant abutments and surgical templates manufacturing. He published this in English at Medline and Scopus databases, introducing "dental CAD/ CAM", "implants abutments" and "surgical guide CAD/CAM"[5].

J.P. Kruth in his work explained in detail regarding the Medical and dental applications. He stressed the advantage of the evolution by using Selective Laser Sintering (SLS) / or Selective Laser Melting (SLM), not only for plastic devices like visual anatomical models or one-time surgical guides, but also for functional implants or prostheses with long-term consistency made from a biocompatible metal[6].

Alberti was the first give the idea of producing computer based modes from CT scan for visuization and created true 3D representation that provided both visual and tactile information that is not possible from a screen[3].

The latest revolution which hit this technology stated during early 1980s in which prototype is fabricated by layerwise deposition of material which is tested later on. With this revolution, the accompanied growth in CAD/CAM technology evolved the technique of rapid prototyping[3].

It was exciting that inspite of availability of CT scanners since 1973, it was not until 1987 that this innovative technologies were made available for dental use.

It was in 1987 when Brix and Lambrecht used, for the first time a prototype in health care. They manufactured a three dimensional model using a computer numerical control device, a type of machine that was the predecessor of rapid prototyping. Then later in 1991, stereolithographically produced human anatomy models were first used in a maxillofacial surgery clinic in Viena.

Classification of RP Technologies

To fabricate a physical prototype (model) in industry and/or medicine; two different approaches have been utilized: subtractive and additive (Table 1,2) .

Name	Procedure	Role In Dentistry	Remarks
Milling	It is a numerically controlled (NC)machining process in which the desired shape of the model is milled from a blockof material as guided by the CAD/CAM computer software at the expense of the material being wasted	Fabrication of metallic or ceramic crown from a block of polyurethane or other foam	It has low material costs and the models fabricated can be worked on with surgical instruments. However only surfaces can be milled and the geometric accuracy (±1.5mm) is poor. Also the milling models cannot be used inside the operation theatre because polyurethane cannot be sterilized.(1)

TABLE 1: Subtractive Technologies

Name	Procedure	Role In Dentistry	Remarks
SELECTIVE LASER SINTERING (SLS)	In this technique a computer guided laser beam is used to selectively fuse a thermoplastic powder layer by layer to the desired shape of the object to be fabricated as designed by th e computer software. A roller distributes the powder in every layer after sintering the previous one.	various thermoplastic materials such as nylon composite, investment casting wax, metallic materials, ceramics and thermoplastic composites can be used in this method.(10)	Advantage of this technique is the varierty of thermoplastic powders and a geometric accuracy of ±0.2mm. Disavantage are its high costs and the abrasive surface of sintered models which renders the use of these materials in operation theatre impossible.(1)
FUSED DEPOSITION MODELING (FDM)	in this technique a thermoplastic polymer material is extruded out in molten form from a temperature controlled filament containing nozel layer by layer on a platform where it gets solidified within 0.1 sec to get the desired shape of the object. (1,8)	FDM allows a variety of modelling materials and colours, such as medical grade ABS, polycarbonates and investment casting wax. FDM can produce models as well as surgical guides and templates out of medical grade ABS, which is gamma sterilizable and translucent . Recently polycar bonate and poly \(phenyl) sulfone materials are introduced.(10)	2nd most widely used RP technique after stereoli -thography. It is fast and speedy. The choice in materials and colours allows reproduction of different anatomical structures with different colours. Drawback is that it can be used only with thermoplastic materials and the surface quality and detail reproduction is lower than stereol ithography as it gives a rough surface and is not 100% dense.(1,10)
MULTI JET MODELING OR 3D PRINTING	It works like a normal ink jet printer. Molten thermoplastic material is pressed through a lot of jets onto a surface. This material hardens quickly to build the model layer by layer.	Zirconia based dental prosthesis mainly all ceramic dental restorations.	The most outstanding characteristic is the ability to produce extremely fine resolution and surface finishes, essentially equivalent to CNC machines. The technique is very slow for large objects.

TABLE 2: Additive Technologies

The subtractive technique is usually accomplished by the conventional NC machining, generally milling. The input data for this method are principally from an optical or contact probe surface digitizer which can only capture the external surface data of the anatomy and not the internal tissue structure of the proposed object. NC machining is used typically in small model making machines and this is the main reason for using them to fabricate metallic and/or ceramic crowns in dentistry.

The additive technologies, on the other hand, can produce arbitrarily complex shapes with cavities; which is usually the case in human anatomy structures. The key idea of this innovative method which is also called "Layered manufacturing" or "solid free form fabrication," is that a solid 3D CAD model of an object decomposed into cross-sectional layer representations and then numerical files in the form of virtual trajectories guiding material additive processes for physically rapid building up of these layers in an automated fabrication machine to form the object called the prototype. In this way, the captured 3D data set, rapidly slice into crosssections, and construct layers from the bottom up, bonding one on top of the other, to produce models for applications. It was demonstrated that by using this method the overall production time will reduce considerably and complex models which are otherwise difficult and/or impossible to make by the conventional NC machining process could be build rather easily.

Principle & Working of Stereolithography Apparatus

Stereolithography is the first commercially available and most widely used RP technology. It was the first RP process, introduced in 1988 by 3D systems, Inc., based on work by inventor Charles Hull. It is an additive RP technique in which a UV laser beam is used to trace and cure the desired shape of model layer by layer from a vat of photosensitive liquid resin acrylate polymer.

Processing

Create CAD Model: for additive process or stereolithographic(STL) model first create Computer Aided Design of the part. For this CT scan of the patient made on cone beam CT Scanner, is obtained.

Convert CAD Mode to STL model: Surfaces of 3D Model is set into set of triangles storing the directions of each triangle.

Slice STL model into Layers: the software then slice the model into layers. Skilled biomodelling specialist differentiates hard and soft tissues via masking process to produce a 3D rendering.

Building parts layer by layer: The stereolithography apparatus then fabricates the model layer by layer as guided by the computer data.This system consists of a bath of photosensitive liquid resin, a model building platform, and an ultraviolet(UV) Helium- cadmium or argon ion laser for curing the resin.

The contour of first layer of the model is scanned on the resin surface and cured by the UV laser. The platform containing the cured layer is then dipped in the vat to coat the part with resin. The platform is again raised to the surface, wiped with blade to remove excess resin and leaving resin enough only for the next layer to be scanned and cured in the same manner. The process is repeated till the desired model is complete. The self adhesive property of the material causes the layers to bond to each other and eventually form a complete 3 D object. The model is then removed from the bath and cured for a further period of time in a UV cabinet.

This process of curing and lowering the platform in resin bath is repeated till the full model is complete. The transparency of the model and recent developments of colour resins allow easy visualization of anatomic structures.

Selective laser sintering is another technique that used laser to fuse together the layers of specific powder.

Applications of Stereolithography in Dentistry

1) **3-D Surgical Models**
   The doctor is able to visualize the model before surgery thereby minimizing the extra oral time and possible injury while doing surgery[6].
2) **Auricular & Nasal Prosthesis**
   To fabricate a prosthetic analogue of same shape, contour and dimension as an opposite normal structure or of a donor with minimal adjustments required at the trial stage[7].
3) **Resin Pattern for Framework**
   With stereolithography, the 1- piece stereolithographic resin structure is used for making the framework evaluation, altered cast impression and maxilla-mandibular relationship record in single appointment[8].
4) **Impressionless Fabrication Of Obturator**
   3-D model of resected site is fabricated via CT scan after healing of tissues on which the obturator is then fabricated in silicone[9].
5) **Lead Shields**
   They can be fabricated to protrct the healthy tissues during radiotherapy treatment.
6) **Implant Guidance Stents**
   Stereolithography can be used to fabricate implant guidance stents which are highly accurate and especially relevant in case of multiple parallel distant implants.
7) **Burn Stents**
   Burnt area can be scanned rather than subjecting delicate, sensitive burn tissue to impression taking procedure[4].
8) **Fabrication of Ceramic Crowns**
   Here the computer design of the dental restoration generates a path much like a cutting tool and instead of cutting, the system sinters

material along the path, building a part from a "bath" of ceramic or metal powder andadding material continually until the complex part is complete. No excess material remains and the dental crown is manufactured in the unit.[10]

9) **Duplication of Existing Maxillary /mandibular Prosthesis**
Especially crucial when an accurate fit to natural teeth or osseointegrated implant is needed[9]

Advantages

1. Highly accurate
2. Gives good surfacefinish and detail reproduction
3. Has good mechanical strength.
4. Processing time is reduced
5. No harmful dust or fumes are created.
6. Skill is easy to master.
7. Can be sterilized for use in the operation theatres.
8. Can be coloured differently to differentiate between anatomic structures.

Disadvantages

1. It requires post curing.
2. High cost of material and equipment.

Discussion

The term additive manufacturing is used as the umbrella term for additive technologies. Direct manufacturing, rapid tooling and rapid prototyping refer to the application of Additive Manufacturing.

The term rapid is used because additiveprocess is performed much faster than conventional methods. Subtractive fabrication may take sometimes much longer. So additive processes were rapid as compared to subtractive process. Additive technologies sometimes can be called Rapid prototyping by some of the authors. Recent collaboration between the Society of Manufacturing Engineers and International American Society for Testing and Materials has finay decided to name it 'Rapid Technology'.These standards 'allow manufacturer to compare and contrast the performances of additive processes, and 'enable researchers and developers to provide repeatable results.

Accuracy of different RP Technologies needs further researchcompared to milling of polyurethane with poor accuracy 1.5mm, additive technologies offer accuracy of .2-.1mm.

Santler reported systematically deviation upto 3.15mm in comparison to additive techniques which have evenly distributed deviation of 2mm[12].

Current resolution of STL model and SLS model is for macroscalemodel ,microscale mode need high resolution[13].

D'Usro believed the use of biomodels had reduced operating time by a mean of 16% and were cost effective.

Though the use of models created by this advancing technology has improved the prerequisites for planning and simulation of complex procedures.the technology lacks its preference of being used on daily cases because of its cost. Just as picture is worth a thousand words.Stereolithography based on saying 'one real prototype is worth a thousand pictures'provides tactile planning of surgery of complex anatomical objects even before surgery. It also provides an aid to perform mock surgery and evaluate its outcome via digital softwares thereby allowing the selection of best technical approach.

Using a model clearly improves the communication between operator and patient before a complicated treatment intervention. It is also possible to use medical models to build individual implants, which fit more precisely and can be prepared before surgery. It offers high reproduction precision.

Osteotomies can be planned and simulated precisely. The extent of skeletal transposition can be assessed with high accuracy and above all the simulation allows to judge the selected surgical approach critically allowing it to be optimise well in advance. Finally after autoclaving it can be used intraoperatively as to nature template.

In nutshell the clinical use of medical RP models improves the quality of the preoperative planning and simulation process. Higher quality and faster patient acceptance are to be expected.

Future Trends

Tissue Engineering

For the microscale model high resolution microCT is required. Microscale models help a tissue cuture grow in a predetermined 3D manner since they represent exact biological structures. The generation of bone and cartilage by autogenous and allogenous grafts is very useful in biomedical engineering. Biomodels help in designing and generating the scaffold unit cells[13].

Patient Specific Implants

Traditional Implants are produced in number of sizes and shape. With these biomodels patient specific implants can be selected for better treatment plan with required structural Properties.

Scaffold design/graft at micro/macro levels

Tissue engineered bone graft and scaffold devices offer great potential for biological Implant development. At present these technologies are not used because of the limitations of using and developing biomodels but with better materials availability it can be used in practice much often.

Material combinations

Biodegradable scaffold design can be an exciting expect of biomodels in Implant practice. Sometimes material combinations can be used for tailored drug release that can predict long term mechanical performance of the Implant. However of work is needed to be done to achieve this goal.

Conclusion

Stereolithography which is a type of rapid prototyping has proved to be a boon to the medical and dental field as it has revolutionized the way of providing health care in great way in every step of treatment be it surgical planning, complex lab and clinical procedures or evaluating the treatment outcome thereby giving confidence regarding results both to the doctor as well as the patient.A part from the above mentioned applications, this technique is still in its experimental stage for various other uses which needs to be explored. The main shortcoming of this technology is its high cost which if we succeed to overcome can make its use common in day to day practice.

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