Robocasting and its resonance with dentistry: A review.

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Abstract
Advancements in the fields of computers and imaging over the last decade, have led to the introduction of generative manufacturing technique also known as Rapid prototyping technique or Additive manufacturing technique such as Robocasting. Additive manufacturing technologies offer a number of advantages over the subtractive technologies: Firstly, the objects with complex geometry can be produced, without need of any complex machinery setup thus reducing cost; Secondly, the method of production is easy and relatively quick. Lastly, the objects can be made of the same or different materials. 3-D printers are becoming more affordable in terms of the cost of running, materials, maintenance, and the need for skilled operators. This article will help us understand the role of robocasting in dental restoration production and how it can evolve to overcome the challenges associated with the production of such restorations

Keyword: Additive manufacturing, robotic material extrusion, 3-D printing, ceramics.

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Email: ishanr3@gmail.com Phone: +91-9831706821. **DOI:** 10.5281/zenodo.5205287
Submitted: 30-Jul-2021 **Revised**: 4-Aug-2021 **Accepted:** 9-Aug-2021 **Published:**15-Aug-2021
Bibliographic details: Journal of Orofacial Rehabilitation Vol. 1(2), Aug 2021, pp. 28-32.

Introduction

Dentistry has had a long association with subtractive manufacturing usually described as ‘milling’. Computer Aided Design/Computer Aided Manufacturing systems earlier relied mostly on cutting a restoration from a pre-fabricated block using diamond burs and diamond disks.[1] Although an effective manufacturing technique, subtractive methods have limitations: Firstly, reduction of internal fit precision or inferior marginal properties occurs due to larger bur diameter than the prepared tooth. Secondly, a considerable amount of wastage of the unused portions of the mono-blocks occurs. Thirdly, excessive abrasion and wear during machining causes shorter running cycles of the milling tools. Fourthly, microscopic cracks onto the surface of the ceramic may be introduced.[2] Last and most importantly, this technique is labor-intensive and time consuming.

Advancements in the fields of computers and imaging over the last decade, have led to the introduction of Generative manufacturing technique also known as Rapid prototyping technique or 3-D printing or more correctly described as Additive manufacturing technique and exhibits the potential to overcome the above described shortcomings. [3,4] This technology is generally used to build objects one layer at a time, thus forming an object through multiple layers.

3-D printing has its earliest application in surgery in the production of an anatomical ‘study model’. This allows complex or unusual anatomy, to be carefully reviewed and a surgical approach planned or practiced before surgery. It also has its role in the manufacture of sterile drilling and cutting guides for use in implant dentistry and in orthopedics for total knee replacement. In fixed and removable prosthodontics, CAD design may be used to mill or print crown or bridge copings, implant abutments, and bridge structures. In implant dentistry, they help in producing batches of complex dental implants with varying geometries which may not be produced by milling alone. Orthodontics makes use of this technology to digitally realign the patient’s teeth by making a series of 3D printed models for the manufacture of ‘aligners’, which progressively reposition the teeth over a period of time.[1]

Additive manufacturing technologies offer a number of advantages over the subtractive technologies: Firstly, the objects with complex geometry can be produced, without need of any complex machinery setup thus reducing cost; Secondly, the method of production is easy and relatively quick. Lastly, the objects can be made of the same or different materials.[5]

The working of the CAD/CAM manufacturing method is simple. The CAD data of the 3-D model are obtained by direct scanning of the patient's mouth or indirectly scanning the impression or the plaster model. With specialised software the scanned data is used to generate the virtual 3-D model, which is then transferred to the CAM unit for manufacturing the prosthesis.

The trend of using ceramic restorations in the de ntal field has been on the rise due to their outstanding aesthetic features as compared to metallic restorations. The methods commonly used for processing dental ceramic restorations such as conventional sintering, heat-pressing and slip casting lack sufficient accuracy and marginal integrity.[6] The newer generative methods of production which overcome these limitations include the following additive manufacturing processes:[7]

1. ***Stereo-lithography*** – uses photosensitive liquid resin bath, a model-building platform, and an ultraviolet (UV) laser for curing the resin.
2. ***Fused Deposition Modeling (FDM)*** – where thermoplastic material is extruded layer by layer from a nozzle, controlled by temperature.
3. ***Selective Electron Beam Melting (SEBM)*** – in which powder is sintered layer by layer by scanning electron beam on a descending build platform.
4. ***Laser powder forming (Selective laser sintering, Selective laser melting)*** - Scanning laser sinters metal powder layer by layer in a cold build chamber as the build platform descend.
5. ***Direct Inkjet printing*** - selectively deposits binding material through a print head to fuse a thin layer of metal or ceramic to a previously fused layer and then fired in a furnace for sintering (Figure 1).

The first four techniques can only produce porous structures. Direct inkjet printing on the other hand can generate restorations at a higher resolution having complex shapes.[2]

Solid free-form modelling based direct inkjet printing or robocasting

Direct inkjet printing ejects small drops of ink propelled with pressure, heat and vibration towards a substrate which change phase almost immediately on deposition.[7] It requires minimum tooling and gives great design and fabrication flexibility. Robocasting is a unique technique developed by the Sandia National Laboratories[8] and received its patent on October 18th, 2005 (Patent number - US 6,955,776 B1)[9] and is the newest among the additive manufacturing processes. It involves the computer-controlled robotic extrusion and deposition of highly concentrated colloidal suspensions of slurries, gels or inks that assembles geometries in a layer-by-layer process.[10]

The printing process is much like writing with a pen only automated and takes close to 24 hours for a complete prototyping process. The advantages over a conventional CAD/CAM system include –

1. Capability to spatially grade composition and/or microstructure (e.g., porosity) to meet specific designs or needs, without requiring a previous mold.

2. A more precise control over internal morphology, shape, distribution, and connectivity.

3. The ability to 'print' with multiple materials at one time as well as create graded structures [10]

The greatest disadvantage of robocasting is the formation of a 'stair stepped' surface. For printing, the step size is a function of the nozzle diameter. This requires some post-processing prior to final sintering. Occasionally, drying issues, such as cracks, can also occur. Margins do not have less than < 25 μm tolerance (Figure 2).[10]

Colloidal inks used in robocasting

One of the keys to successful printing of ceramic crowns by the robocasting technique is the development of suitable materials for printing for assembly of the complex geometry required for a dental restoration.

Inks which are generally used in Direct write techniques are incapable of fully supporting their own weight during assembly. But those used in robocasting are designed to solidify via a drying-induced pseudoplastic to dilatent transition and are thus capable of supporting their weight.[11]

They must also satisfy two criteria –

- A well-controlled viscoelastic response and should set immediately to facilitate shape retention of the deposited features even as gaps span in the underlying layer,
- A high colloid volume fraction to minimize drying- induced shrinkage after assembly. [12]

The composition of the ink is usually of 50 - 65 vol.% ceramic powder, < 1 vol.% organic additives, and 35 - 50 vol.% volatile solvent (usually water). A recent innovation in the ink formulation by *Smay et al* uses ink that contains 45 to 47% solids. For dental crowns he used aluminum oxide because of their high strength. For the photonic band gap structures and sensors, he used barium titanate and lead zirconate titanate.[13]

The paste is extruded as a continuous filament at a controlled rate through a nozzle ranging from a couple of millimeters to tenths of millimeters attached to a syringe. Proper robocasting requires a synergistic control of the:

1) Percent solids in the ceramic powder slurry,

2) Viscosity of the slurry,

3) Dispensing rate of the slurry through the orifice, and

4) Drying kinetics of the slurry of the beads dispensed.

The current list of materials systems used with robocasting include -[12]

Alumina (dense and porous) PZT

A120 3 / TiCuSil composites ZnO

A120 3 / Al composites Kaolin

A120 3 / Mo Stabilized Zirconia Mullite

In Development: Silicon Nitride, PMN

Recent developments in robocasting

In bone tissue engineering applications, the process of direct-write assembly (Robocasting) techniques has been used to fabricate β-tricalcium phosphate (β-TCP) scaffolds which have designed three-dimensional (3-D) geometry and mesoscale porosity. For developing bone scaffolds that can be implanted in the body so bone cells will grow into pore space and make new bones, a biocompatible ceramic – Hydroxyapatite, which is widely being processed through robocasting. For the fabrication, CT and MRI data can be used. [14,15]

Conclusion -

3-D imaging and modelling, and CAD technologies are hugely impacting on all aspects of dentistry. 3-D printers are becoming more affordable in terms of the cost of running, materials, maintenance, and the need for skilled operators. As with any new invention in the process for the ever challenging job of dental restoration production, robocasting has room for improvement. An accompanying effort involves the calculation of optimal support structures to yield the best geometric results and minimal material usage.

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FIGURES

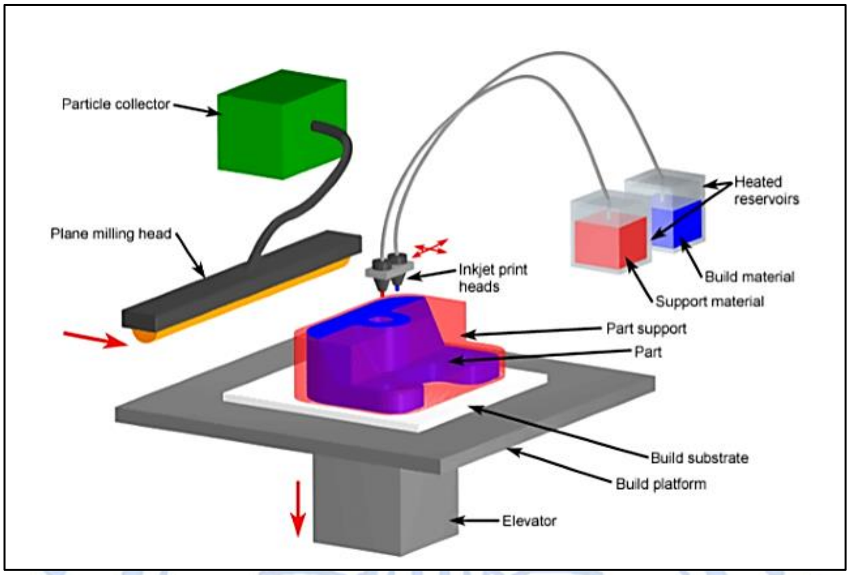

Figure 1: Schematic depiction of the direct inkjet printing machinery

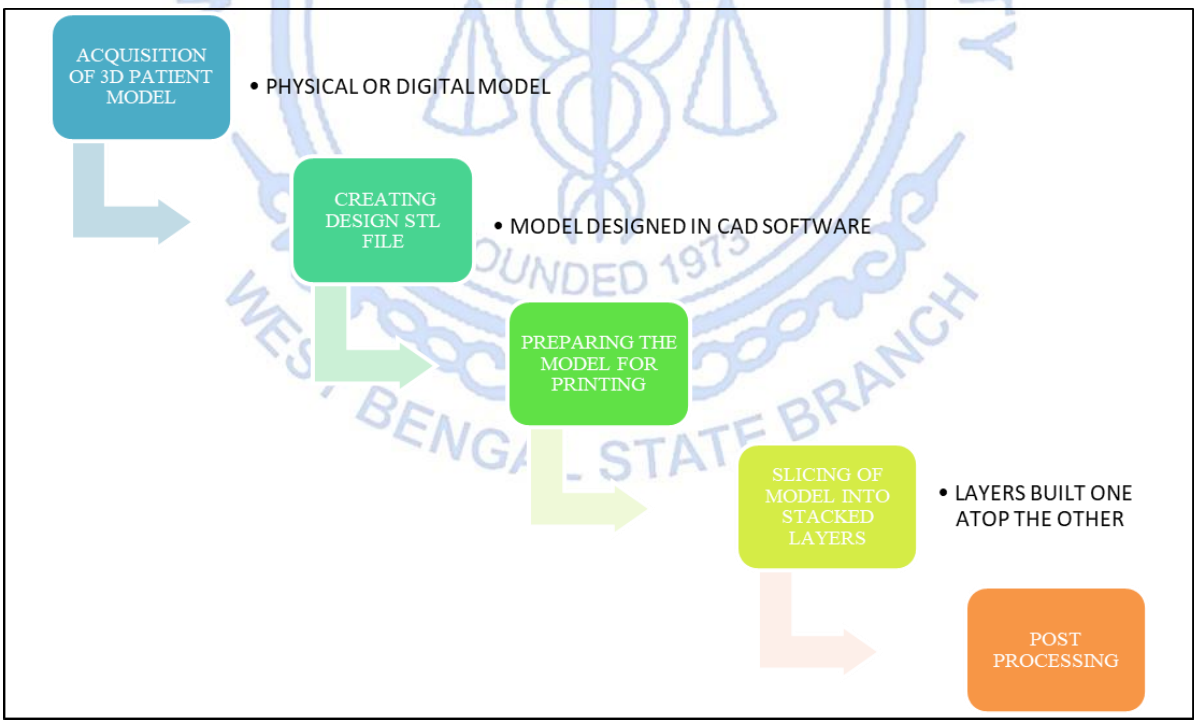

Figure 2: Flowchart showing the robocasting process