Review Article

Comparative evaluation of rapid prototyping and computer-aided milling in prosthodontics – A review

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ABSTRACT

The evolution of computer-aided design/computer-aided manufacture and rapid m-shift prototyping technologies has led to a dramatic paradigm shift in all disciplines of dentistry, especially in the fields of prosthodontics and restorative dentistry. The integration of these systems with advances in biomaterials, such as zirconia high strength ceramics, has led to an overhaul in prosthodontic patient education and health care. This article aims at reviewing the advantages, disadvantages of the use of rapid prototyping and computer-aided milling in prosthodontics.

KEY WORDS: Computer aided milling, manufacturing, prosthodontics

BACKGROUND

The evolution of computer-aided design/computer-aided manufacture (CAD/CAM) and rapid shift prototyping has led to a dramatic shift in dentistry, especially in prosthodontics and restorative dentistry. The advances in these systems in biomaterials, such as zirconia high strength ceramics, have improved the prosthodontic patient education and health care. The first attempts on CAD/CAM commenced >20 years ago. Later, CAD/CAM was introduced in dentistry in the early 1980s.[1]

All CAD/CAM systems have three functional components:[2]

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).[3]

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KEY DIFFERENCES IN THE MANUFACTURING PROCESS CAD/CAM VERSUS 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.[4] The accuracy of tool positioning was reported to be within 10 µm.[4] 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.[5,6] 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.[7] 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.[6]

Torabi *et al.*[1] in their studies concluded at the CAD/CAM system were better than the conventional systems for the reduction of clinical fit and fracture resistance.

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Additive Manufacturing

In additive fabrication, the final desired part is manufactured layers which are added on top of the other step by step.[8] 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."[9]

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.[10]

The additive systems used in dentistry are stereolithography, selective laser sintering or melting, and 3D printing. The features differing them from subtractive methodology are as follows:

I. There is step by step vertical object build-up
II. No material wastage
III. Large objects produced
IV. Passive production
V. Finer details.

Additive technology (Selective Laser Melting [SLM]) is used to produce crowns, fixed dental prostheses, or removable partial denture frameworks. In 3D printing, the material is removed from a nozzle which solidifies as it is deposited. 3D printing has the ability to print multiple materials at 1 time.[11]

The precise fit of the intaglio surface depends on the size of the smallest tool for each material and the use of a larger tool will result in a reduction of internal fit precision.

1. A large amount of raw material is wasted since the unused monoblocks are discarded and cannot be reused.
2. Increased abrasion and wearing of the milling tools occur, thus can withstand only short running cycles.
3. Microscopic cracks can be introduced due to machining of brittle ceramic.
4. It is not easy or economic to produce complex prosthetic designs.

KEY DIFFERENCES IN THE MATERIALS USED IN CAD/CAM VERSUS RAPID PROTOTYPING

Materials used in Subtractive Manufacturing

Subtractive milling processes metals, ceramics, resins, and waxes. Workpiece durability is ensured since it is milled from an industrial grade blank. The fabrication flaws are reduced, by relying more on the tighter quality control processing.[12]

For dental prostheses such as fixed dental prostheses and implant abutments and frameworks, zirconia can be used as the material of choice since a high occlusal load is expected.[13] For this, the material should be heat treated to its melting temperature and then controlled cooling.[14] Such a set-up is not available in commercial dental laboratories.

Two milling forms are available: Hard machining and soft machining.

The hard machining is for metal, sintered zirconia, and composite resin. The soft machining is specifically used for pre-sintered zirconia. Therefore, the majority of the cutting power will turn into thermal energy; this reduces the life of the milling tool. Thus, constant cooling is required to prevent overheating of the milled material.[15]

Soft machining is the milling of a large piece of a pre-sintered zirconia followed by sintering. The composition of pre-sintered zirconia differs from the hard machined zirconia. This reduces the hardness which enhances the machinability. 25–30% shrinkage is caused.[16] The tool like is increased due to quicker milling and better cutting efficiency, potentially better surface quality, and moisture absorption of the zirconia blanks. This removes the need for drying the milled zirconia before sintering.[16]

Materials used in Additive Manufacturing

The selection of the material depends on the purpose of the prosthesis and the manufacturing procedure. The additive technique is more economical since there is no material wastage and the unused material is used for future processing.[17] There is a minimal restriction on the ability to fabricate facial prosthesis, etc., which cannot be achieved by subtractive methods which are more suitable for smaller workpieces.

Microporosities are seen in the additive method in the range of 30–45%[18] porosities proved advantages in case of implant fabrication as it produces implants with similar elasticity to bone.[19] This facilitates ingrowth of bone that can promote osseointegration. Mechanical durability is necessary for intraoral prosthesis.

Short-term clinical study was done recently reported good outcomes for the fabrication of posterior crowns.[20] Greater tensile forces are seen in the multiunit prosthesis. Thus, more clinical studies are required to validate this technique. Wu *et al.* suggested the use of additive manufacturing to produce a wax pattern that then cast using conventional techniques.[21]

Production of high-strength zirconia frameworks by 3D printing has been done recently. The zirconia framework was printed from nanoscale zirconia particles with an inkjet printer.[22] The strength reported was 764 MPa and the fracture toughness was 6.7 MPam.[22] Scanning electron microscope imaging showed a homogeneous microstructure; due to the clogging of nozzles during the injection of zirconia paste. Sub-micropores were detected. These were found to reduce the strength of zirconia frameworks.[22]

KEY DIFFERENCES IN THE ACCURACY OF CAD/CAM VERSUS RAPID PROTOTYPING

Accuracy in Subtractive Manufacturing

Milling eliminates waxing, investing, and casting of prostheses which would improve the precision. However, there is a lack of evidence in relation to tooth-supported restorations.

Tan *et al.* reported milled titanium crowns with a vertical gap of 79.4 µm, and cast noble metal crowns with a vertical opening of 23.9 µm.[23] Similarly, Han *et al.* compared the marginal accuracy of milled titanium and cast titanium crowns.[24] This difference was significant enough to be associated with more microleakage.

Factors explain the limited accuracy of the CAD/CAM protocols. The first factor was the learning curve in fabrication following the CAD/CAM protocols compared with the well-established conventional protocol. The second factor is although multiple steps are omitted, steps such as scanning, locating the margin digitally, software modeling, and milling will also introduce a source of inaccuracy if done improperly.

Ortorp *et al.* a drill compensation feature had to be incorporated for the production of accurate internal fit.[25] However, this feature was found to produce negative fit errors and it increased the space between the restoration and the prepared tooth. Excessive cement space has been attributed to a compromise in the mechanical durability of a restoration.[26]

Accuracy in Additive Manufacturing

No drilling required; thus, no compensation feature is required. Further, the production is passive without force application. It involves sequential layering, and coarse morphology representing each fabrication layer along the construction direction.[10] Such stepping adversely affects the surface texture and the overall dimensional accuracy of the workpiece.[10,27]

Layer thickness and the width of the curing beam determine the accuracy. Limited number of studies that have evaluated the accuracy of prostheses fabricated by additive manufacturing. In relation to SLM, the dimensional accuracy of metal workpieces has been reported to be in the range of 3–82 µm, which is clinically suitable for the intraoral prosthesis.

The smaller the dimensions, the greater the accuracy and the density of the final product.

CONCLUSION

Subtractive milling widely implemented computer-aided protocol in dentistry and it is suitable for tooth supported restorations. Additive manufacturing aim proving method would be used more frequently in dentistry in the future since the accuracy and applicability has a wide range.

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