COMPARISON OF MANUFACTURING TECHNOLOGIES OF FIXED STRUCTURES IN PROSTHETIC DENTISTRY

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Abstract: Fixed structures in prosthetic dentistry are highly customized products, individually manufactured for patients that are missing teeth. When choosing the technology for fixed dental structure manufacturing, three viable options are available (precise casting, milling, selective laser melting). Fixed structure performs a holding and positioning function for a tooth prosthetics that have nutrition as well as an aesthetic function. The choice of dental structure’s manufacturing technology is influenced by structures’ material and economical efficiency. The choice of material is influenced by current market trends and knowledge about chemical (non-) compliance of several widely used metal alloys. Results presented in this work, show some technological as well as time-efficiency advantages of selective laser melting (SLM) technology in the field of manufacturing metal dental structures

Key words: Casting, CNC milling, Additive manufacturing, Prosthetic dentistry.

1. INTRODUCTION

Teeth have an important role in mechanical phase of food digestion. Due to various causes (caries, illness, injuries…) losses of teeth can occur. With each missing tooth the capability of proper chewing is significantly reduced. Missing teeth can be replaced by fixed prosthetic replacements that consist of fixed (usually metal) dental structure and ceramic coating (Fig. 1). The oldest and most common manufacturing procedure for fixed dental structures is investment casting. Due to large amounts of manual labour required in this procedure the quality of end product depends largely on skills and experience of dental technician. With development of three-dimensional scanning, computer aided design, CNC machining and additive manufacturing some manual phases of manufacturing can be replaced by dedicated computer software and computer controlled machines. The goal of this paper is to examine different possibilities of manufacturing fixed dental structures. An individual case study is also used for manufacturing time analysis.

2. INVESTMENT CASTING

Manufacturing of dental structures begins by taking a negative mould of patient’s jaw that is later used to produce a plaster model. In investment casting procedure, this model is used by dental technician to manually model the construction’s wax pattern. Also, the casting system with channels and feeders is designed in wax (Fig. 2). This pattern is then removed from the plaster model and poured over by embedding mass to produce a mould that is later used for metal casting. Most often cobalt-chrome or gold-based dental alloys are used.

The quality of design and proper casting depend largely on complexity of individual case and experience and manual skill of dental technician. Therefore, the successful casting and proper product geometry cannot be guaranteed and if any errors occur, all work-time spend from wax pattern design to casting is lost.

Fig. 1. Fixed prosthetic replacement

Fig. 2. Wax structure model with channels on plaster model
3. OPTICAL SCANNING

One of the main advantages of optical scanning is an ability to quickly transform complex physical geometry into accurate three-dimensional computer model [1]. In fixed dental structure production, optical scanning is used to import the geometry of plaster model into dedicated computer software. The plaster model that would otherwise be used for wax modelling can be used, but additional preparation can be required in order to achieve proper feature recognition functionality inside computer software (Fig. 3, Fig. 4, Fig. 5).

Fig. 3. Additional preparation of plaster model for optical scanning

Fig. 4. Results of additional preparation of plaster

Fig. 5. Displayed scanned plaster

Currently, there is also a lot of research into possibilities of intra-oral three-dimensional scanning. This method would make a production of plaster model unnecessary and avoid possible inaccuracies that can occur during this phase.

4. COMPUTER AIDED DESIGN AND MANUFACTURING

Regardless of what kind of scanning method is used, a three dimensional computer model of actual patient’s jaw and teeth configuration is later used to model the dental construction in virtual environment of computer aided design software. This is usually dedicated dental design software, with large standard part library and automatic element and fixture creation. Because this kind of software is usually used by dental technicians some also include design functionality that is similar to manual wax modelling.

Finished dental construction CAD model is later used in manufacturing process. Two main possibilities are CNC milling or selective laser melting.

5. CNC MILLING

Milling is one of the most important manufacturing procedures by material removal. With development of CNC controlled machines complex geometry machining became possible. Writing a NC program that controls the machine is a necessary manufacturing step in CNC machining. This is usually done by computer aided manufacturing software (Fig. 6). In dedicated dental software NC programming phase is usually automatic and hidden from user. This is possible due to a significant shape similarity between customized dental constructions that can always be manufactured by the same milling strategy [2].

Fig. 6. Computer aided NC programing

Milling of dental structures is done by dedicated CNC milling machines. Tools used are often of smaller diameters, therefore the machine’s spindle must enable higher rpm ranges. These machines are also equipped with clamping systems designed for holding standardized dental material blocks. Tool-changes during manufacturing are automatic and predefined in NC program. One of the main advantages of milling dental structures is a possibility of machining ceramic material.

6. SELECTIVE LASER MELTING

Selective laser melting is additive manufacturing technology. It is based on shaping a three-dimensional
object from powder material by laser or electronic beam. Manufacturing is done by layers of less the 0,1 mm thickness. Programming the machine is based on slicing the three-dimensional model in layers and setting the laser parameters for machining (Fig. 7).

Machining is usually done inside an inert gas atmosphere; therefore selective laser melting is very suitable for manufacturing dental constructions from titanium alloys [3].

![Fig. 7. Sliced three-dimensional model in layers positioned on work tray](image)

7. POST-PROCESSING AND CERAMIC COATING

Regardless how a fixed dental construction is manufactured, some form of post-processing before ceramic coating is necessary. When casting is used, the casting channels in feeders have to be cut away (Fig.8). When milling, finished construction has to be removed from the rest of the material blank (Fig. 9). With selective laser melting, a support structure has to be removed (Fig. 10). Also in each case, grinding of the construction surface and sandblasting is necessary [4].

Ceramic coating is usually done in three layers. After each layer a construction has to be heated up and cooled down.

![Fig. 8. Casting made construction with casting channels and feeders](image)

![Fig. 9. Milling made construction with rest of the material blank](image)

![Fig. 10. SLM made construction with support structure](image)

8. COMPARISON

Comparison is based on 3-part case study, already presented on previous figures. This dental construction was made with each presented methodology and time analysis and fitting test was carried out.

9. TIME ANALYSIS

Time analysis is based on measuring the time required for each individual phase of production. Some phases of production are common regardless of methodology selected.

![Fig. 11. The workflow of production and phases required for each methodology](image)
The following chart (Fig. 11) presents the workflow of production and phases required for each methodology. Estimated time requirements for each phase for presented 3-part case study are also presented. Required time estimation is especially problematic for phases that include manual labour, due to being somewhat dependent on experience and skill of the technician.

Fig. 12. Time duration for different methods

Because initial and final phases of dental replacement production are the same for each methodology, the following charts present the time requirements for intermediate phases that differ between methodologies.

Diagrams clearly show the difference between manufacturing times of each methodology. Absolute time differences are valid only for presented case study but the ratios can be generalized for optional case.

10. CONCLUSION

Investment casting is most commonly used technology despite the longer manufacturing times. This is mainly due to the long history of using casting in dentistry and consequentially a large availability of required equipment in dental laboratories.

Milling is also well established technology especially due to a possibility of producing ceramic dental constructions.

Selective laser melting is a rather new technology in the dentistry field. Research presented in this paper clearly shows the advantages of using this technology in terms of manufacturing time consumption. That is why a number of SLM machine variants specially build for dental applications is constantly increasing.

11. REFERENCES


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