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ADVANCED PROCEDURE FOR FABRICATION OF SUBSTRUCTURE IN DENTISTRY

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The paper presents some aspects of the novel integrated system, procedure for fabrication of metal substructure of metal-ceramic crowns. The results been shown that the CAD/CAE/RP technology integration presented in this paper can be fully applied to casting metal substructures. The substructure fabricated in this way, confirm the reduction of the total manufacturing time, with an increase in the percentage of high quality castings that use integrated system.

Key words: casting, metal, ceramic, dental, fabrication

INTRODUCTION

Investment casting (IC) is the most acceptable technology for metal substructure fabrication. Additive manufacturing (AM) technologies are advancing rapidly in dentistry. These technologies are making manufacturing of dental devices easier, faster, cheaper and more predictable [1-6]. The application of the AM in dentistry is due to its ability to fabricate a variety of complex shapes. The most applied rapid prototyping (RP) technologies in the dentistry are stereolithography, selective laser sintering, selective laser melting, and 3D printing [7]. Fused deposition modeling, laminated object manufacturing, three-dimensional printing, laser engineered net shaping, rapid freeze prototyping and multi-materials laser-assisted densification are also popular RP.Selective laser melting (SLM) is the only additive technology that is available to fabricate metal crowns, metal fixed dental prostheses or removable partial denture metal frameworks [8]. Rapid investment casting (RIC) is a combination of IC process with RP technologies [9-11]. The objective goal of integration with RP technology was to increase the quality of metal substructure of metal-ceramic crowns manufacturing and the reduction of lead-time and certainly total manufacturing time. The RP in conjunction with IC has become the leading technology for fabrication precision castings quickly and inexpensively [12]. Currently, dental substructures are mainly performed through IC using the lost wax process, which is highly labour intensive. The contour and fit of wax patterns used in this process is created manually, using dental special instruments and magnification devices [12]. Therefore, more attention should be paid to additional combination of the medical imagining, IC and RP technologies. Martinez-Hernandez et al. have developed the RIC method for manufacturing the shells from patterns made of polymer [13]. Design and fabricate of metal substructure could be divided into three steps: data capture, substructure design and fabrication. First, the data capturing of the patients mouth was obtained by means of 3D laser scanning. Then, design and manufacturing phases were carried out through CAD/CAM procedures and RP technologies to obtain the impression of mould cavity [14]. Wu et al. used widespread method for fabricating titanium dental crowns using laser measuring, numerical simulation, RP pattern and IC. Software package MAGMAsoft was used to simulate shrinkage porosity in the crown castings using the feeding criterion [15]. Jevremovic et al. combined reverse engineering (RE) as a modelling technique and SLM, as the AM technology for fabrication of removable partial denture [16].

The IC and RIC are still dominant technologies for dental cast fabrication. Currently, RP for dental model manufacture is used mainly for improved, cost-effective medical diagnosis and surgical operation planning. It has a significant impact on the reduction in time spent, and consequently, the cost of before and after operative procedures. The paper presents application of the CAD/CAE/RP integrated system for casting metal substructure of metal-ceramic crowns.

METHODS OF METAL PRODUCTS FABRICATION

State-of-the-art formation of the simulation model required a wide variety of special small devices and automated processing equipment to be integrated and linked together through a manufacturing network. The

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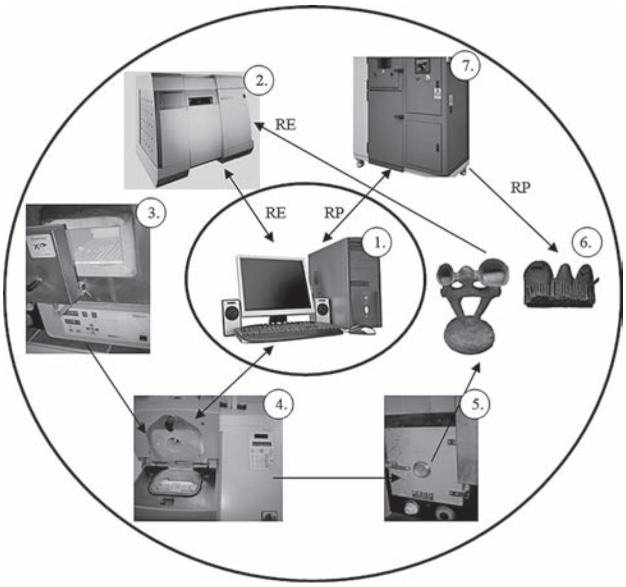

Figure 1 Hardware support for the design and fabrication of metal substructures of metal-ceramic crowns
1 PC configuration Fujitsu P400;
2 3D scanner Zeiss Metrotom 1500;
3 Furnace BEGO Miditherm;
4 Casting machine BEGO Nautilus CC+;
5 Cooling machine by Reco;
6 Metal substructure of metal-ceramic crown;
7 Machine for SLM Concept laser MLAB

equipment for the design and manufacturing of metal substructure of metal-ceramic crowns are presented in Figure 1. PC (1) was used for distribution and direct control of computer tomography (CT) scanner (2), casting machine (4) and RP machine (7). Furnace (3) and air cooling machine (5) are not connected with PC. Operating parameters needed for cooling and heating processes were estimated using MAGMAsoft and CASTCONTROL software packages. CASTCONTROL is the operating software for manage and control casting parameters of machine (4).

Procedures for metal substructures fabrication are presented in Figure 2. The manufacturing of dental structures begins with taking an impression of patient's jaw that is used to make a plaster model. In IC procedure, dental technician manually models the wax pattern. In addition, the gate subsystem with channels and feeders is designed in wax. This pattern is then removed from the plaster model and poured over the embedding mass to produce a mould that is later used for metal casting. The successful casting and proper product geometry is uncertain and if any errors occur, all the worktime spend from wax pattern design to casting has been lost. In metal substructure fabrication, optical scanning is used to import the geometry of plaster model into dedicated computer software. The plaster model used for wax modelling can be used, but additional preparation can be required in order to achieve proper feature recognition of functionality inside Creo Parametric software. Intraoral 3D scanning method makes a production of plaster model unnecessary and avoids possi-

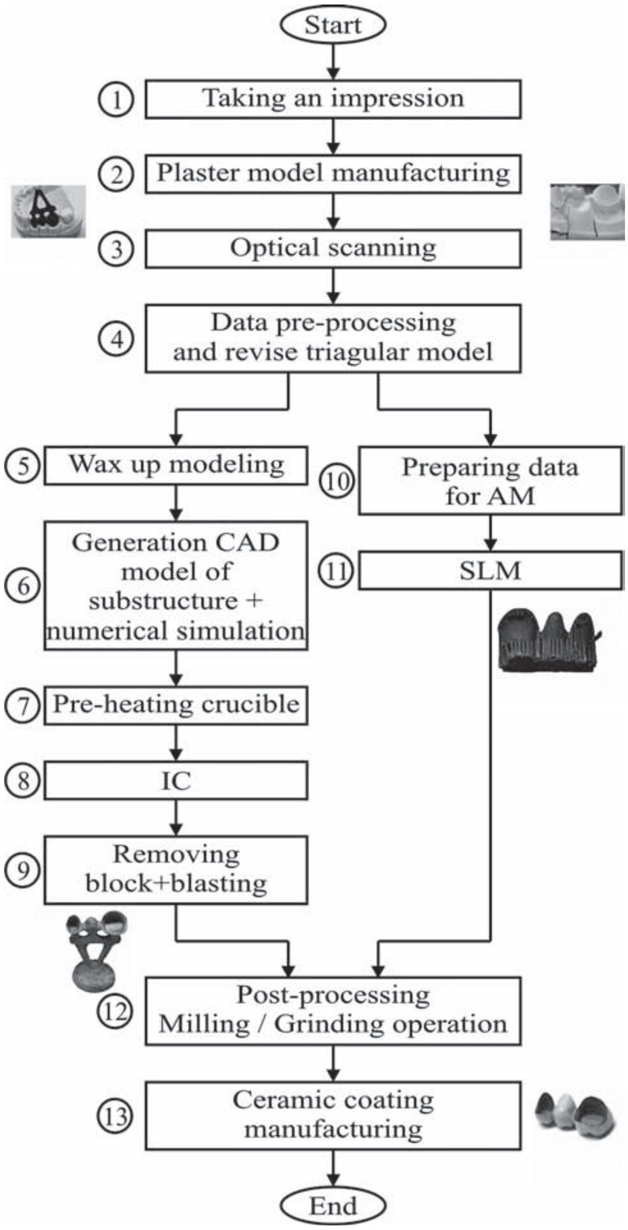

Figure 2 Phases required for metal substructure of metal-ceramic crowns manufacture

ble inaccuracies that can appear during this phase. Scanning with CT scanner provides the model assembled from cloud of points. Complete triangular model is generated based on the integration of its multiple partial views in software package My VGL.

After data pre-processing into CREO Parametric and GOM Inspect, this triangular model is revised into solid, although it is possible to use the STL format as neutral format for triangular model. The solid is then assembled with the model of gate subsystem imported from developed data base. Assembly of the simulation model is exported to numerical simulation into MAGMAsoft for determination of casting parameters using iterative redesign and trial-and-error method. Numerical simulation provides an insight into the pouring, solidification and cooling process. On the other hand, after data processing, the user converts the file of the metal crown in STL file format required for RP. The physical object is fabricated using RP machine. SLM is AM technology, which is based on shaping a three-dimensional object from powder material by laser or electronic beam. Programming of the RP machine is based on slicing the three-dimensional model in layers and setting the laser parameters for machining. Fabrication is done inside an inert gas atmosphere; therefore, SLM is suitable for manufacturing dental substructures from titanium alloys. It is very important because casting machine is not designed for casting some of the biocompatible titanium alloys. Heating, pouring and one of the two cooling sub-phases were fully performed by CAST-CONTROL software. The first part of the two cooling sub-phase is performed on the casting machine and the other on the cooling machine. Next procedures are removing the block and blasting.

The simulation model can be sliced and transferred to an RP machine to fabricate the pattern. The CAD model is cast to a metal substructure. Through this process, the feedback on the design of the dental crown from the patient can be taken into consideration before the dental crown is fabricated.

Regardless how a metal substructure is manufactured, post-processing before ceramic coating manufacturing is necessary. When casting is used, the gate channels should be removed. With SLM, a support substructure has to be removed. Furthermore, milling/grinding operation is applied. Accordingly, ceramic coating is done in three layers. A substructure has to be heated up and cooled down after each layer.

THE RESULTS OF THE APPLICATION

Total fabricated time for metal substructure that contains three metal products is reduced using developed integrated system. Duration time of certain manufacturing phases is shown in Figure 3.

Fabrication time of ceramic coatings is 250 min. Total fabricated time for metal substructure using SLM is 194 min.

Total fabrication time using the integrated system equals t_1 while the conventional system takes t_2. Some examples are given in Table 1 for three metal substructures.

Table 1 **Total fabrication time for metal substructure**

No. of metal products	Model of metal substucture	t_1 / min	t_2 / min
3		373	467
4		378	501
11		412	512

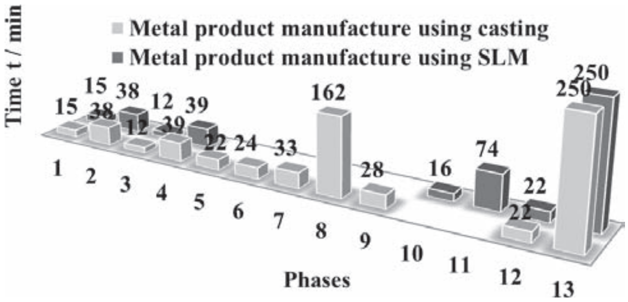

Figure 3 Duration of phase time for manufacturing products /min
1 Taking an impression;
2 Plaster model manufacturing;
3 Optical scanning;
4 Data pre-processing and revise triangular model;
5 Wax up modeling;
6 Generation of CAD model of substructure and numerical simulation;
7. Pre-heating crucible, measured on the Miditherm BEGO furnace (3);
8 IC (self-test + heating + pouring + cooling);
9 IC post-processing (removing block + blasting);
10 Preparing data for AM;
11 SLM;
12 Post-processing (milling/grinding);
13 Ceramic coatings manufacturing.

CONCLUSION

IC is the most commonly used technology despite the longer manufacturing time. This is mainly due to the long history of using casting in dentistry and consequentially a large availability of required equipment in dental laboratories. RIC and SLM are rather novel technologies in dentistry field.

The presented substructure confirm reduction of the total fabrication time using integrated system. It has been shown that the CAD/CAE/RP system can be fully applied to casting metal substructures.

The research also shows the advantages of using SLM in terms of manufacturing time consumption. Furthermore, an increasing number of SLM machine variants specially built for dental applications is appearing.

Future progress considers building novel modules for CAI and CAM. The module for CAI will be integrated into Zeiss Calypso software for the CMM called Zeiss Contura G2. The module for CAM will be integrated into dental software CEREC, and software 3D Doctor for generating surface model of the scan object. The future improvement can be related to the Case Based Reasonning method for model of the gate selection. Further research will refer to the development of collaborative system using web technology, if it is required.

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