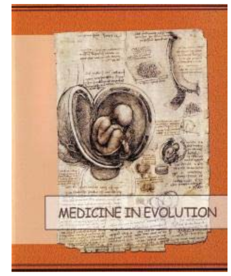
# Comparative technical steps in obtaining implant supported reconstructions using computer aided manufacturing and ceramic layering

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## Abstract

SLS is an additional technique that allows generating a complex three-dimensional structure, by consolidating and successively selecting the layers of metal powder, and bonding layer by layer one above the other, using thermal energy provided by a focused laser beam. Our study presents the technical steps in manufacturing the metallic part of the implant supported over-structures in two different clinical situations, both using SLM for obtaining the frameworks and is highlighting the differences between the followed technological stages in each case. The presented clinical situations have specific features, depending on the type of used materials (alloy and ceramics), on the characteristics of each clinical case, as well as on the habit and custom technical skills developed over time by each technician. Both cases met the targeted aesthetical and functional features and enhanced re-establishing the morphologic and functional integrity of the arches.

**Keywords:** implant, SLM, ceramic layering

## INTRODUCTION

A biomaterial is defined as an engineered material used in a medical device, intended to interact with the biological systems. Biocompatibility has been defined as the ability of a material to perform with an appropriate response in a specific application [1]. The oral implant is an alloplastic biomaterial surgically inserted into the maxillary alveolar bones for functional or aesthetic purposes, serving as a prosthetic support [2]. For a rigorous treatment plan, various factors have to be considered: first of all a decision has to be made regarding the use of endosteal, transosteal, or subperiosteal implants depending on the patient's profile. In regards to the design, screw-retained restorations are mostly used, followed by cylindrical or combined implants [3], whereas the most used material for manufacturing implants is titanium (Ti), titanium alloys and ceramic or ceramic-like calcium phosphate compounds (HAs) as coatings [4]. Different surface modifications or coatings are the methods used to improve biological properties of medical devices using the minimization of protein adhesion onto the surface of medical devices [5].

Another significant consideration relates to the intraoral restorations. The important factors are: the abutments' design, location, and the type of connection between the abutment and the implant body, the prosthodontic aspects of the determined occlusion, the load magnitude and load direction specific to each reconstruction. Regarding the loading, multiunit splinting, especially in irregular angle (unit-to-unit) and cross-arch configuration, tends to dissipate the forces into multiaxial orientations, a combination of bending and torque [6][7][8]. Most critically, the timing of significant intraoral loading plus the prosthodontic occlusal scheme determines the forces which will be transferred and dissipated during the tissue-healing period [4].

Various methods are available nowadays for manufacturing of the frameworks of the over-structures. Classical methods, such as casting, are often replaced in modern treatments with computer aided design and computer aided manufacturing workflows. Some of them are based on subtractive manufacturing or milling [9][10][11], others on additive techniques (SLM- selective laser melting, SLS- selective laser sintering).

### *Aim and objectives*

Selective laser melting (SLM) replaces conventional metal alloy casting and is an additive manufacturing technique that allows generating a complex three-dimensional structure, by successively stacking layers of metal powder, and bonding each layer on top of another, through the use of thermal energy provided by a focused laser beam. It allows manufacturing of complex designs for fixed prosthetic infrastructures and prosthetic structures on implants, by having a high degree of biocompatibility and optimal marginal fit [12], far superior to the metal frameworks manufactured by conventional processes (e.g.: casting)[13].The metallic powder used in our study (Co-Cr Starbond COS Powder) does not contain beryllium and nickel. High density of 8.8 g / $cm^3$ and the CTE (coefficient of thermal expansion) of 14.0 μm /m°C are factors that ensure the perfect compatibility with the ceramic layers used in the PFM (porcelain fused to metal) reconstructions [14].

Our study aims to present the laboratory steps required to manufacture the metallic structure of implant supported over-structures in two different clinical situations, by using the SLM technique.

## MATERIAL AND METHODS

Two clinical situations have been considered, as follows: case 1- female, age 41 years, with missing teeth 4.6, 3.6, 3.7; case 2- male, age 36 years, male, with missing teeth 2.4, 2.6 and 2.7 in the upper jaw and 4.6 and 4.7 in the lower jaw. The prosthetic solution was -for both cases- implant supported PFM reconstructions, with the metallic frameworks manufactured through the SLM technique and manual layering of ceramic, for the aesthetic reconstruction.

***Impression***

For the first case, standard trays and silicone (Zetapluss, Oranwash) have been used for taking the impressions (Figures 1- A, B), while in the second case, the impression material was Xantopren (Figure 1- C).

For the second case, preliminary casts (Moldano type III plaster) have been poured in order to manufacture the light cured custom trays (Evo Plaque) (Figures2- A,B).

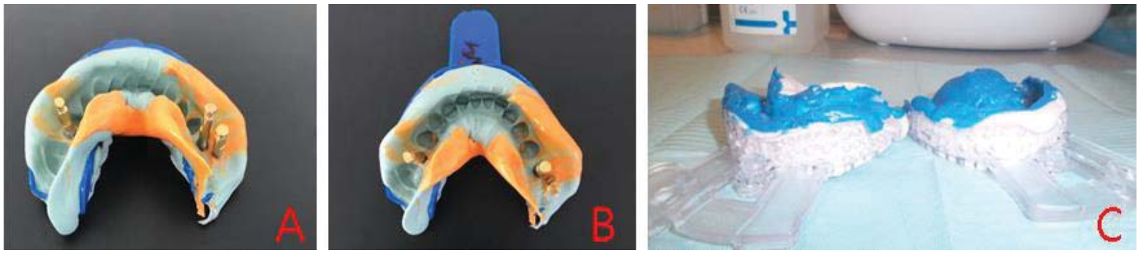


Figure 1. A, B- standard trays, and two consistency silicone material used for the impression in case 1; C- silicone impression in standard trays –case 2

Final impressions were recorded with putty and fluid silicone (Xantopren), by using the custom trays for both jaws.


Figure 2. A- custom tray on the preliminary cast- case 2; B- upper and lower custom tray mucosal side-case 2

***Dental casts***

After positioning the Dentis Global analogs on the transfer abutments in the first case, namely the Osstem analogs for the second case, Gingifast Rigid (Zhermack) silicone was applied around the analogs with a dispencer. This addition silicone suitable for gingival masks, offers precision and dimensional stability. Its role is to render the marginal gingival area and due to accessibility of detachment, it ensures checking of the correct position of the abutment on the analogue and finally of the over-structure, while also giving a satisfactory working space during the technical stages.

The working cast was obtained using the Giroform system and type IV plaster (Alligator, Shera) for the first case (Fig. 3.A) and Convertin Hart type IV plaster for the second case (Figure 3. B).


Figure 3. A- Master cast for case 1 B- master casts for case 2

Mounting on the articulator was achieved by using an Artex CN (Amann Girrbach) in the first case (Fig. 4.A) and respectively an Artex CR (Amann Girrbach) for the second case (Figure 4. B).

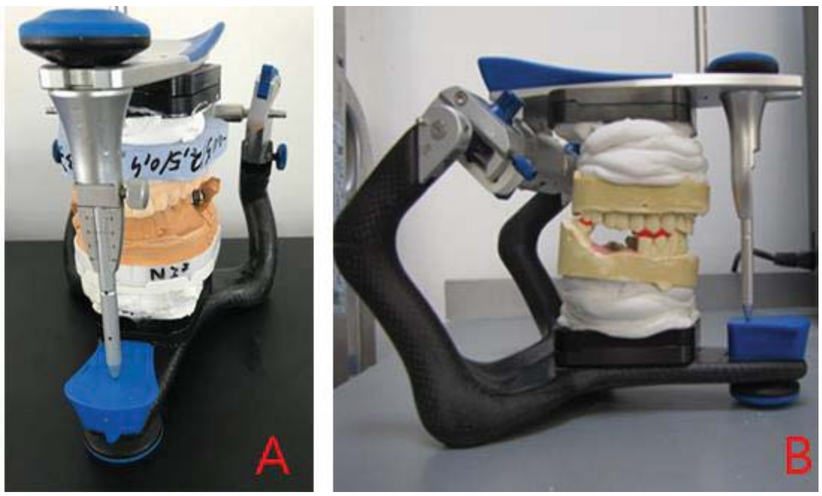


Figure 4. Cast mounted in the Artex CN articulator for case 1 (A) and in the Artex CR for case 2(B).

***Abutment preparation***

Once the casts have been mounted onto the articulator, the correct types of abutments (height, diameter) were inserted, obtaining thus an appropriate finishing line design and position in regard to the gingival margin. For the first case (Figure 5 A), Dentis Implant abutments with 15º angulation were used whilst for the second case Mis standard screwed abutment with a 15 ° angulation were used (Figures 5 B, C). The abutment was positioned so as to correct the implantation axes. The silicone mask (Figure 5 D) was removed to obtain more space along with a clearer image, and all the surfaces were checked by means of a surveyor milling machine. By milling the axial surfaces up to the cervical margins with the surveyor, the parallelization was obtained and a suitable insertion axis of the copings achieved.

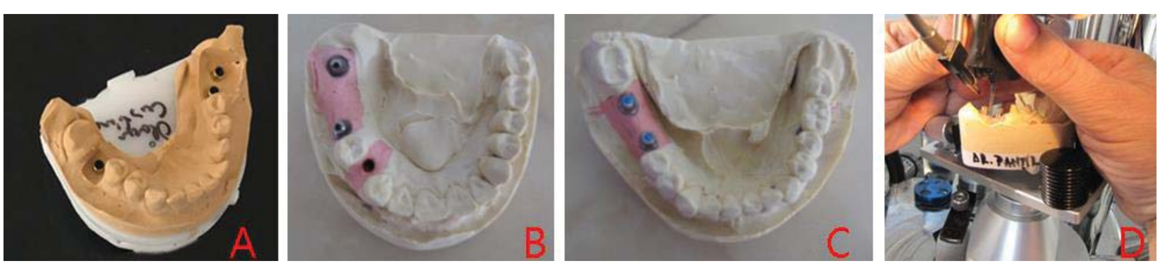


Figure 5. A- Dentis Implant abutments on cast- case 1; B,C- Mis standard abtuments placed on the casts- case 2; D- correction of implantation axis by means of a surveyor milling machine.

*Scanning and design*

Prior to scanning, any excess or impurity was removed and Omega Tech Spray (case1)/Heli Spray (case2) was used to mask the abutments. This avoids glossy surfaces, provides optimum light reflection, facilitating easy scanning of the work area.

Open Technologies Smart Big scanner and the Exocad software was used in case 1 and CORiTEC i3Dscan 2.0 scanner and built-in software for case 2.

For the first case, a new patient record was created, and the virtual chart was completed by selecting the antagonists, neighbours and abutments. The first scan was the one of the casts positioned in MI in the articulator to record the intermaxillary relationship. Next, the antagonists and the master cast were scanned. The last scan was the one of the abutments which was the most detailed (Figures 6 A, B).

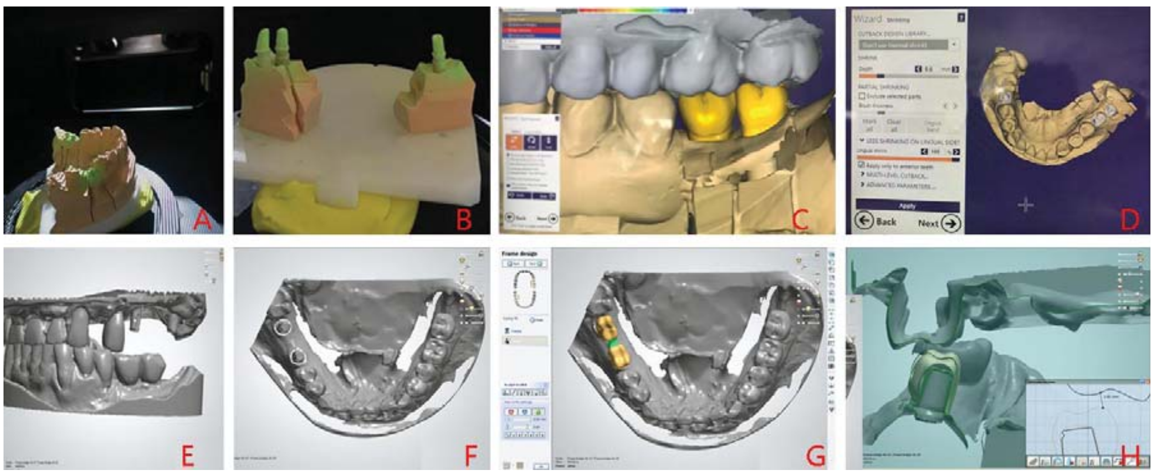


Figure 6. A,B-scanning the dies by using stump profile-case 1; C,D- design stage in Exocad software-case 1; E,F-virtual models for case 2; G,H- proposed design for case 2 in 3Shape design software

After scanning, all components have been aligned to a reference point, which in this case was the master cast. After removing the mouth floor and the palatal area, the remaining virtual model consisted only of neighboring teeth and the marginal periodontium. The base of the removable dies (of prepared teeth) and the gingival margin were also excluded in order to have direct access to the preparation limit.

The data gathered by scanning of the casts was used in the design stage and all original information has been saved and remained in an unmodified form. The mesh-conversion step from point cloud to 3D file followed, employing the same profiles used for scanning.

Once the data has been exported to the Exocad design software, the preparation limit was drawn and the insertion axis established. The virtual reconstruction was placed with the help of the tooth placement function. The Shrink / Reduction stage ensured correction of the copings by designing a proper thickness of the metallic framework, reaching thus the optimum result for providing space for the ceramic layering (Fig.6 C, D). All saved data was exported and sent to the CAM (Computer Aided Manufacturing) software of the SLM machine.

For case 2, a 2D picture of the working cast has been taken, on which the area of the future prosthetic reconstruction was selected. As landmarks, the mesial and distal interproximal contacts of the prepared abutment were selected. After scanning all areas of interest (Fig.6 E, F), the software calculated the position of each element separately. In the end the verification of the virtual cast was done. The next step was to scan the antagonists. The scanning of the occlusion was performed by positioning the antagonists over the working cast, whose base remained fixed on the table of the scanner. Then, data retrieved from the scanner was saved on the hard disk.

In the 3Shape Dental Manager design software, our previously created case was loaded, together with the saved image of the virtual casts. When creating the patient's file, the arch with the prepared teeth was specified, along with the material to be sintered (Co-Cr alloy). The future insertion axis of the reconstructions was established as well as the buccal and oral limit of the cast. The software allows -after the automatic delimitation of the finishing line, a manual correction of the limit of the preparation. Next, the space required for the luting cement was established.

After designing full contour reconstructions, the future framework was reduced to a 0.5 mm thickness and the connectors were designed (Figures 6 G, H). The software detects if these connectors are not of the right size and draws the attention of the operator to areas where there is an increased risk of fracture. The proposed design of the restoration to be sintered had a natural appearance from a morphological point of view, in accordance with the patient's original teeth. Because of the automatically modelled anatomic structures, at the end of all technical steps, after the ceramic layering, physiological contacts, with both adjacent and antagonistic teeth as well as a perfect fit on the abutments was obtained.

***CAM file preparation***

For both cases, the STL (Standard Triangle Language) files of the generated frameworks were imported into CAM (Computer Aided Manufacturing) software of the SLM machine (3Shape Cambridge). The role of this software is to position the virtual designs on the working surface of the sintering machine, with the occlusal/incisal surface towards the working surface and at a level that is as close as possible to this plane. Also, the objects will be placed in a position as flat and low as the plane, to have a smaller number of layers as possible. Between the working surface and the restorations there will be a space of at least 3mm - space which will be occupied by the supports and that allows the technician to remove the restorations from the working surface after printing, with a disc or saw. The supports that will be attached to the restoration have the role of keeping the occlusal surface away from the working surface and are assisting in the construction and support of the object during the printing process. The supports dissipate the internal tension which forms in the printed object during the manufacturing process. After this preparation phase, the CAM file is generated by the software.

***SLM machine preparation and post-processing***

Before each manufacturing cycle, the SLM machine (MySint100, Sisma, Italy) (Figure 7A) is prepared by the technician. For this purpose, the build plate is placed inside the machine and fixed by means of a screw, the reservoir is filled with Co-Cr powder (Starbond COS 30), the coater which spreads small quantities of metallic powder over onto the build plate is calibrated and the laser lens is cleaned with a microfiber pad. The working chamber is now closed and the inertisation of this chamber is performed with nitrogen, until the oxygen content in the chamber drops below 0,5%. The CAM file is then loaded and the sintering process begins (Figure 7B).

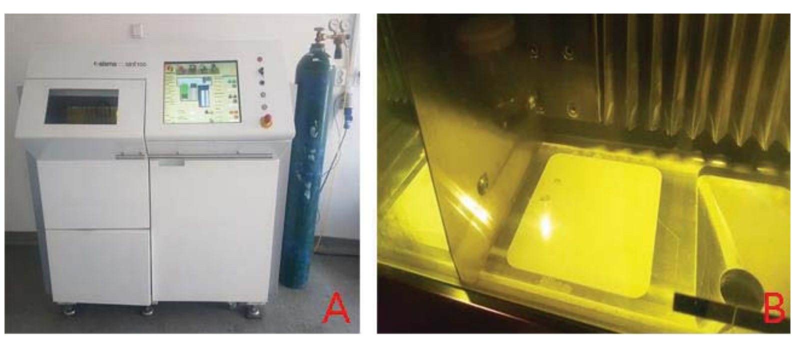


Figure 7. A- Sisma MySint 100 SLM machine; B- Sintering process

After the completion of the loaded work cycle, the chamber is opened and the excess metal powder is wiped away into the excess reservoir by means of a brush, in order for it to be re-used. The build plate is removed and placed inside of a conventional furnace to perform the heat treatment. A heat treatment at 850 $^{0}$C of the completed framework was done to reduce internal tensions, porosities and micro-fissures. After sintering, the restorations are cut away from the build plate by means of a vertical electric saw. Only a minimal mechanical finishing of the frameworks (Figure 8A, B) with extra-hard burs was required before sending the frameworks to the dental office for try-in.

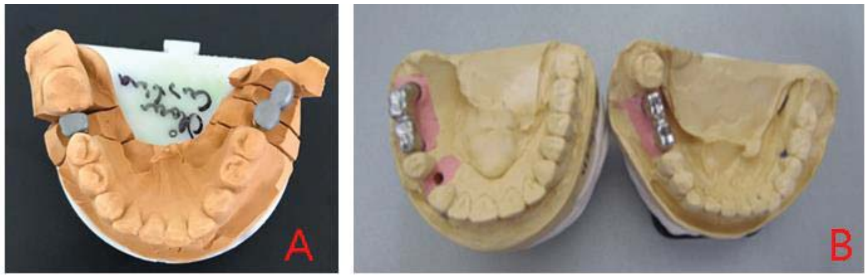

Figure 8. Metallic framework for case 1(A) and case 2(B)

***Ceramic build-up***

After receiving the metallic frameworks from the try-in session, the necessary adjustments are performed and the framework is sandblasted with $Al_2O_3$ (25 µm), at a pressure of 5 bars. The frameworks are steamed cleaned afterwards.

Ceramic layering started with the oxidation cycle of the frameworks, which is performed at 950°C for 1 minute. Afterwards, another sandblasting with $Al_2O_3$, at a pressure of 5 bars and steam cleaning was performed.

The opaque foundation was the placed onto the frameworks. For case 1, Vita VM 13 ceramic was used, and the color for the opaque layer was OP2 (chosen with Vita 3D Master). The first opaque layer, the wash opaque was sintered in the Ivoclar Vivadent Programat EP 3010 oven, at 890$^{O}$C. The second, more consistent opaque layer enabled the complete masquing of the greyish color of the framework (Figure 9A).

The layering of the dentine began in the cervical area by placing 3M3, 2M3 and 2M2 base dentine, offering good coverage and shade for the limited space of the present case. Transpa dentine 3M3, 2M3 and 2M2 was used for rebuilding the complete tooth shape followed cut back of the occlusal 1/3 for the enamel layers (Figure 9B)

To complete the morphology, small amounts of enamel were applied in the occlusal third, slightly oversized to compensate the contraction during sintering. Window effect was used in the end to enhance the required translucency to the occlusal third (Figures 6c, 6d, 6e). The pre-drying time was 6 minutes, during which time all water molecules present in the ceramic paste evaporated. Starting temperature V1 was 500$^{0}$ C, rising 55$^{0}$ per minute until it reached 879$^{0}$ C, when the vacuum pump stopped and V2 reaches 880$^{0}$C. After the cycle was completed, the oven lid opened gradually within 1 minute to prevent sudden cooling of the restorations.

Due to the contraction, corrections with dentine base in the cervical and the middle third, transpa dentine, enamel and window in the middle third and the occlusal third were necessary (Figure 9C). Second firing implied 6 minutes drying time, at 500$^{0}$ C, followed by increasing the temperature with 55$^{0}$C per minute of until reaching 869$^{0}$C, when vacuum pump is switched off and the firing is carried out at 870$^{O}$C. after sintering, opening of the oven lasted 1 minute for gradual cooling. For individualization Vita Akkzent Plus kit was used (Figure 9D). Glazing, carried out in the Vita Vacumat 40T oven in atmosphere, prevents the absorption of oral fluids and renders the restorations a natural gloss.

Figure 9. Case 1: A- Layering of Base Dentine; B- Application of Transpa Dentine; C- Completed morphology before 2nd firing; D-External individualization

Drying the glaze paste for 1 minute, was followed by a temperature rising with a pace of $80^0$C per minute up to $500^0$C and afterwards to $866^0$C, were actual sintering took place. Gradually lowering of the temperature, like in previous firing cycles was followed by complete cooling at room temperature (Figures 11 A, B).

For case 2, the framework was sandblasted with $Al_2O_3$ (25 µm), at a pressure of 5 bars, cleaned and degreased with a hot water-steamer jet. Because of the poor quality of the oxide layer of Cr-Co alloys, bonding (Chrom-Kobalt Bonding, Bredent) was applied to enhance the metal-ceramic bond. Before the layering of the ceramic, the cast was cleaned by means of a steamer, and insulated to avoid drying of the ceramic paste by moisture absorption into de gypsum of the cast. Absorbing the excess of distilled water is accomplished by using blotting paper.

Ivoclar IPS Classic Ceramic has been used. The application of the opaquer layers to cover the metallic component was achieved by the two-step method, the first layer being applied thinner, while the second layer which covers the first was uniform as thickness and more consistent, ensuring an even masking effect of the metallic framework (Fig. 10A). Sintering took place at $960^0$ C for 6 minutes under vacuum conditions. Base dentine, dentine, transparent and enamel were used to reproduce shape and morphological elements, of the axial walls and occlusal surface (Fig. 10B-D). Drying time was 5 minutes followed by the raising of the temperature at 750 $^0$ C for creating the vacuum and again rising during 6-7 minutes, up to 960 $^0$ C were sintering took place.

Finishing was performed with diamond burs which aided in achieving the required form as well as the right texture of the ceramic surface. During the try-in, both static and dynamic contacts were checked. A creamy consistency of glaze paste was prepared and was used to cover all faces, excess being removed so that in the end an even, thin film of glaze covered the entire surface. In order to perform the individualization, a brown pigment was used for the occlusal surface, and pink hue in the cervical area. Sintering was accomplished in atmosphere at 930ºC, for 2-3 minutes (Figure 11 C,D)

Figure 10. A- aspect of the restorations after the opaque firing; B-. Application of base dentine, dentine and C-Enamel; D. aspect of the restoration before sintering

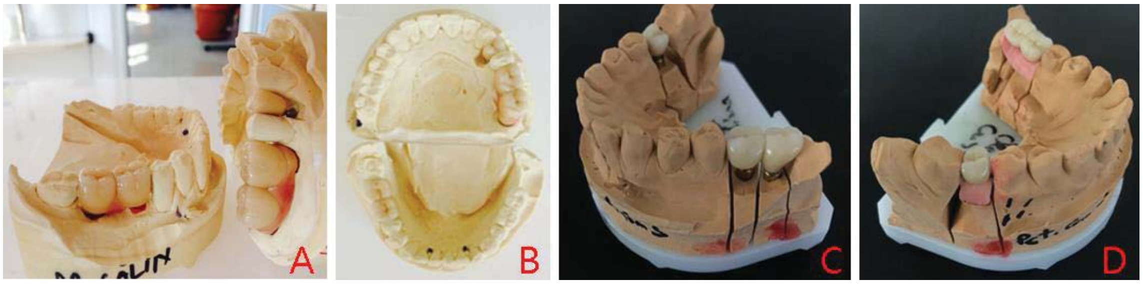


Figure 11. A- Final aspect of the restorations-case 1; B- occlusal aspect of restoration-case 1; C- Final aspect of restorations-case 2; Aspect of restoration with the applied silicone mask-case 2

## DISCUSSIONS

It is a well known fact that selective laser melting technology has reported numerous instabilities that increase the surface roughness and volumetric porosity of the manufactured parts. Identifying the optimal parameters of the energy intensity and the phenomenon of heat transfer allows stabilization of the thermal processes and avoiding the misfitting of the manufactured restorations [15]. Selective laser melting is a process developed to manufacture objects with dense structures and homogeneous distribution of the material, a process in which no significant changes of the physical and chemical properties of the materials occur [16]. Among the benefits of selective laser melting are the ability to create complex geometries, which by conventional methods would be very difficult to manufacture and the ability to use a wide range of metals and alloys. The most noticeable benefit of selective laser melting is the principle on which SLM operates - complete metal powder melting, which offers the possibility to manufacture objects with the same thermal conductivity as the material from which they are made [17].

## CONCLUSIONS

Altough we used the same technology in order to obtain the final restorations, the 2 presented situations have specific features, depending on the type of used ceramics, on the characteristics of each clinical case, as well as on the habit and custom technical skills developed over time by each technician. Both cases met the targeted aesthetical and functional features, and were perfectly integrated by the patients, because of the perfect fit and marginal adaptation.

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All 4 authors have the same contribution in this study.

The reconstructions were manufactured by the technicians Belgiu Patricia, Damian Camelia (Imprint Scan Dent).

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