In Vitro Comparative Study of Different Technologies for Metal Denture Frameworks Fabrication - Direct Metal Laser Sintering, Machine Milling and Hybrid Technology

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Abstract: ***Introduction**: Nowadays the additive manufacturing technologies become more and more popular as they suggest good reproducibly and fast production process. One of the most generally used approach is a fabrication of a pattern, that is later replaced by casting. Modern concept usually utilizes materialized CAD models, that are milled by CAM or 3D printed and later those patterns are invested and casted. It is important for practice to be clarified whether this production method is competitive to the rapid manufacturing and subtractive fabrication methods. **Materials and Methods**: A STL-file with bar framework retained by four implants is used for fabrication of four group of objects. Each group of frameworks is fabricated by different technology as follows: Direct Metal Laser Sintering, Milling and hybrid technology with different investment materials (WiroFine® and Bellavest® SH). All the implant analogs are fixe into a stone plate, scanned and imported in Dental Designer, 3Shape™ software. Once the frameworks are ready, they are used as a matrix for attachment and repositioning of the implant abutments according to their configuration. Then the analogs are fixed into the same stone base, which is scanned, as its image is merged to the one before the realignment procedure. The discrepancies are observed. **Results**: The most accurate reproduction is achieved by DMLS technology, followed milled framework. The hybrid technology shows less accuracy than contemporary methods. Therefore by using an investment material with higher expansion coefficient its accuracy is improved and makes it an alternative method to rest which are observed. **Conclusion**: Nowadays these contemporary technologies still remain expensive. At the same time the suggested modification of conventional casting process allows better accuracy to be achieved at lower price.*

Keywords: prosthetic dentistry, dental materials science, 3D-printing, direct metal laser sintering, machine milling

1. Introduction

In the contemporary prosthetics almost any restoration could be digitally designed, but the final process of materializing still encounters some serious obstacles.[13,14] Nowadays the additive manufacturing technologies become more and more popular as they suggest good reproducibly and fast production process.[1,3,9,15] Unfortunately, some of them require a solid initial investment for still expensive machines that adopt technologies such as Selective Laser Melting, Direct Metal Laser Sintering, Selective Laser Sintering etc. [2,7,11,12]

One of the most generally used approach is a fabrication of a pattern, that is later replaced by casting. [4] Modern concept usually utilizes materialized CAD models, that are milled by machine or 3D printed and later those patterns are invested and casted.[5,6,8] And no matter that the accuracy of the patterns is acceptable, casting could not be considered to be an accurate method of conversion of objects due certain factors such as: temperature changes, physical and mechanical interaction between the materials that are used, the residual ash remnants. [10] It is important for practice to be clarified whether this production method is competitive to the rapid manufacturing and subtractive fabrication methods.

2. Materials and Methods

For the purpose of the study a couple plaster models of fully edentulous patients with four endosteal implants are inspected to analyze the distance between the abutments. A stone plate of low expansion stone (Elite Arti®, Zhermack S.p.A.) is poured. Then four implant analogs (Straumann® RC Bone Level Implant Analog - L 12mm, T) are fixed to the plate in correspondence to the values collected from the studied casts. An additional implant analog (the same as previous four) is fixed at the center of the plate to allow more precise results to be gained. Finally, another portion of low expansion stone is spread over the initial one covering the implant analogs above the retentive zone. **Fig. 1**

Figure 1: All four implant abutments fixed at the stone plate with mounted impression posts.

After the stone is set, five scan bodies (CARES® RC Mono Scanbody) are screwed and the model is scanned by a laboratory scanner (3Shape D850). **Figure 2.**

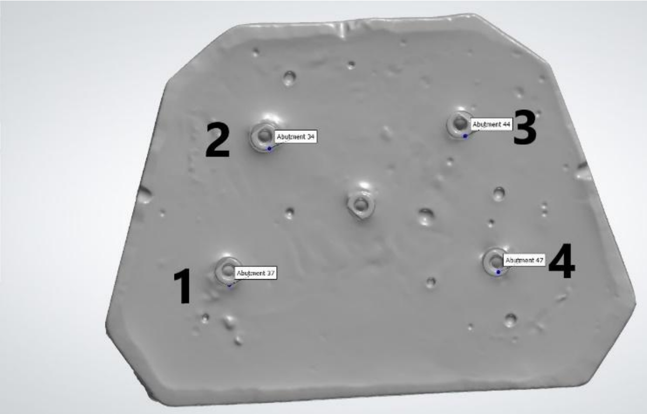

Figure 2: Scanned stone plate and implant analogs marked as follows: №1 – the rightdistal implant analog (1-st quadrant), №2 – the right mesial analog (1-st quadrant), №3 – the left mesial analog (2-nd quadrant) and №4 – the left distal implant analog (2-nd quadrant).

A bar for an implant supported prosthetic construction is created and designed according to available implant supports available. **Fig. 3**

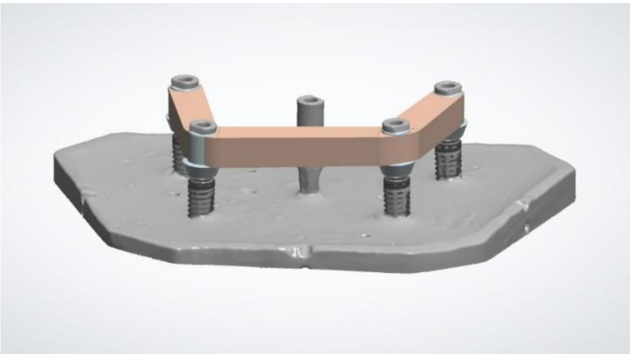

Figure 3: The virtual copy of the bar created

Finally, the generated stl-file is imported in a generic CAD software (Autodesk Meshmixer®) to modify the bar construction as hollow object and also to design another bar (which is round) to connect the very distal edges of the first as a prevention of distortion.

Three groups of at least three object each are created using different production technologies. The first group (which consist of six objects) is fabricated of CstableWax® (Formlabs™) by 3D printer Form2 (Formlabs™) that adopts Selective Laser Polymerization technology. CastbaleWax® is special resin-based material that consists of light curing resin and wax. It doesn't need to be post-cured which eliminates the risk of extra shrinkage, which allow better accuracy to be reached. Once the bar patterns are fabricated the supporting structures are removed and the object are rinsed using isopropyl alcohol. Then the fitting accuracy of the bar pattern is checked. All the available vents are blocked by wax (**Fig. 4**), then a sprue system is fabricated and the patterns of CatsbleWax® are invested. **Figure 5.**

Figure 4: The bar of CastableWax® after the supporting structure removal and obturation of the vents

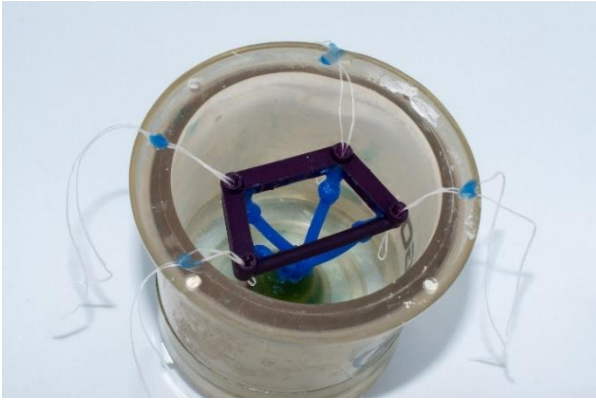

Figure 5: The bar after sprue system fabrication and fixed to the casting cone. Threads are used to remove any bubble that may appear inside the fitting surface of the bar during the investment procedure

Two different investment materials are used for the investment procedure: Bellvest® SH (Bego) for three of them and WiroFine® (Bego) for the rest. Bellavest® SH investment material is prepared by mixing every 160 grams of powder with 40 ml Begosol® HE, in order to gain the maximum possible expansion (according to the information from the manufacturer). WiroFine® investment is prepared by mixing 400g powder with 80ml of Begosol® K. All the investment materials are mixed manually for 30 sec., followed by mixing unit under vacuum for 60 sec. The molds are let to set and are inserted into a furnace, where they are heated up to 1050°C by the shock heating program prescribed by the manufacturer. Then the molds are inserted into a vacuum-pressure casting machine (Nautilus T, Bego) and the invested objects are casted using a Co-Cr alloy Wironit® (Bego). The sprue systems are removed, then all the bars are sandblasted and initially polished by burr.

Another copy of the STL-file is sent to an outsourcing laboratory for fabrication of the second group of objects by Direct Metal Laser Sintering technology (DMLS). The material that is used is Co-Cr alloy withpossible composition:Cobalt (Co) 61.8 – 65.8 %, Chromium (Cr) 23.7 – 25.7 %, Molybdenum (Mo) 4.6 – 5.6 %, Tungsten (W) 4.9 – 5.9 %, Silicon (Si) 0.8 – 1.2 %, Iron (Fe) 0.50 %, Manganese (Mn) 0.10 %. The STL-file that contains a solid bar with same design is sent to the laboratory. After the 3D printing process is completed the supporting structures are remove and procedure of stress releasing heating and firing is done. The objects are heated up to 750°C for 1 hour and afterward up to 880°C for 5 minutes, then the objects are sandblasted and sent back.

The last group of objects are milled of Co-Cr alloy disk by a milling machine. The STL-file that is used was the pure copy of the file that is generated by the dental CAD-software, without any additional processing needed.

After the bars are ready, the fitting accuracy is checked and the restorations are trimmed until tight fit to the abutments if necessary. It is important to notice that the check is done by a single abutment (Straumann®Variobase® for single restorations).

Finally, four abutments (Straumann®Variobase®) for single restorations are screwed to the implant analogs. Three of the analogs are released from the stone plate by trimming all the stone around them (**fig.6**) and the bar is fixed to the only implant analog that rest in the plate (except the one at the center of the plate). Afterwards the three abutments and implant analogs are fixed to the free fitting surfaces in the bar as they are situated around the drilled holes in the stone plate. **Figure 7.**

Figure 6: Three of the implant analogs are released from the stone as the one with the screwed abutment is used as ana index for the framework attachment

Figure 7: A bar screwed to one implant analog just before fixation of the rest by stone

A small portion of low expansion stone is mixed and the spaces between the holes and analogs are filled up. After setting the prosthetic construction is removed, also the abutments and scan bodies are screwed over all five available implant analogs. The new position of the implant analogs is scanned and imported in a CAD software (DentalDesigner, 3Shape™) Then initial image of the plate and the other after reattachment of the implant analogs are merged and the discrepancies are observed.

3. Results

At When the 3D printed (DMLS) bars are observed it remarkable that discrepancies between the implant analogs are not significant. All 3D printed constructions arrange the implant analogs at almost the sameposition as the one in the initial scan. The mean discrepancy values measured between positions of implant analog №2 (according to fig.2) before realignment and analog №2 after that is 0,16 µm. The same parameter is measured for implant analogs №3 and №4, as the mean values obtained are 0,26 µm between analogsmarked as №2 and 0,13 for №3. **Figure 8 and 9.**

Figure 8: The new position of the analogs fixed according to the 3D printed framework

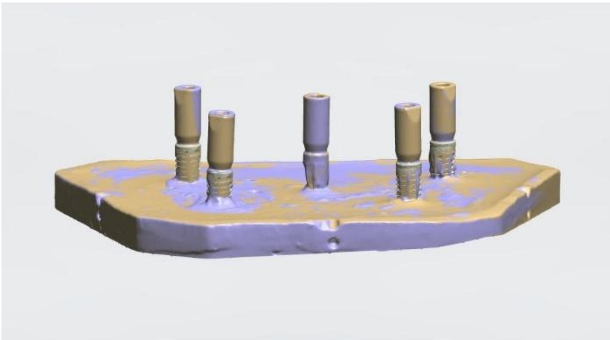

Figure 9: The digital image of the scanned model with the repositioned implant analogs according to the bar fabricated by DMLS. Its image and the initial ones are merged. The purple color represents the discrepancies between two images.

The milled bars show a little more discrepancy than those that are 3D printed by DMLS technology. It is important to be noted that the construction should be adjusted until proper adaptation is reached. This cause a slight rotational movement of the bar around the axis of the implant analog that is left fixed during the realignment procedure. When the position between implant analogs №2, №3 and №4 before the reattachment procedure and afterwards are observed the following mean values are collected: The highest discrepancy between analogs marked as №2 is 0,26 µm, between analogs marked as №3 – 0,36 µm and №4 – 0,30µm. **Figure 10 and 11**.

Figure 10: The new position of the analogs fixed according to the milled framework

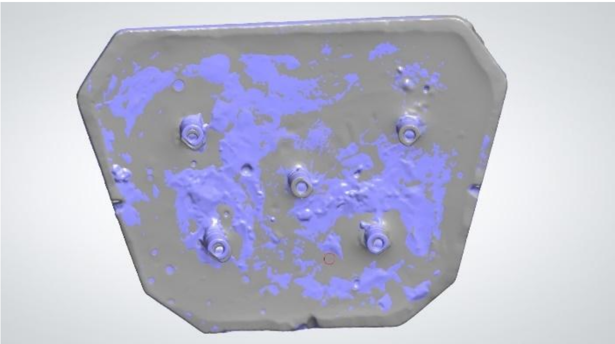

Figure 11: The digital image of the scanned model with the repositioned implant analogs according to the bar fabricated by milling. Its image and the initial ones are merged. The purple color represents the discrepancies between two images

The next group of bars observed (these invested by using WiroFine®) shows the highest discrepancy values compared to the previously examined groups. The mean discrepancy value between the pairs of analogs marked as №2 is 0,54 µm, between №3 is 0,79 µm. and between these marked as №4 is 0,67 µm. At the same time the fitting surface of the bar must be trimmeda lot to fit to the abutment surface. **Figure 12 and 13.**

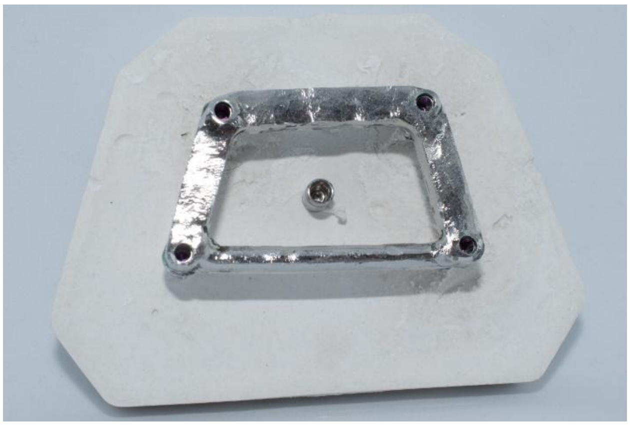

Figure 12: The new position of the analogs fixed according to the cast framework.

Figure 13: The digital image of the scanned model with the repositioned implant analogs according to the cast bar (invested with WiroFine®). Its image and the initial ones are merged. The purple color represents the discrepancies between two images.

When the objects that was invested by using Bellavest® SH areexamined, the different variations in implant analogs positions are evident. It is obvious that explored discrepancy values are higher than the first two of presented groups, but smaller than those to the bars invested with WiroFine®. The mean values between the pair of implant analogs №2 is 0,31µm., between the pair marked as №3 – 0,42µm. and for pair №4 – 0,39µm. In this case the fitting surface of the bar should also be trimmed to fit to the abutment surface, but the procedure is a little less short and easy compared to those objects invested with WiroFine®. **Figure 14 and 15.**

Figure 14: The new position of the analogs fixed according to the cast framework

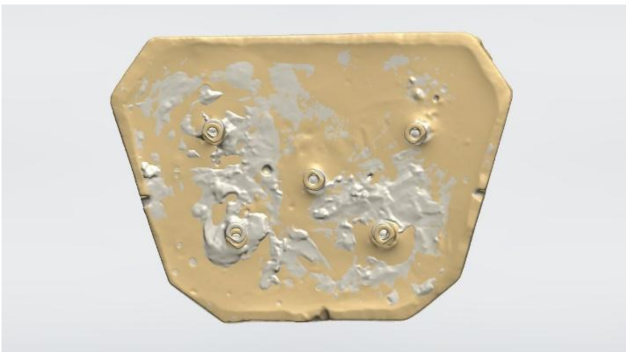

Figure 15: The digital image of the scanned model with the repositioned implant analogs according to the cast bar (invested with Bellavest® SH). Its image and the initial ones are merged. The purple color represents the discrepancies between two images.

At **Fig.16** all the mean values achieved for the observed technologies and each reattached pairs of implant analogs are presented.

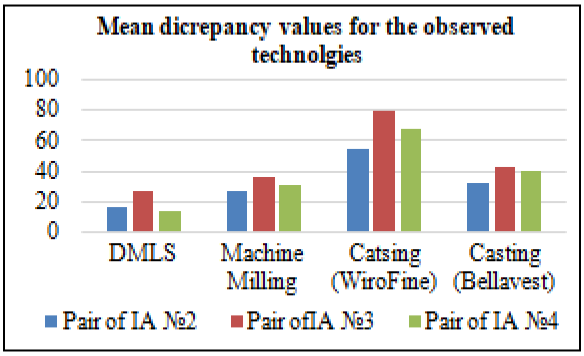

Figure 16: The mean discrepancy values (μm) between each pair of implant analogs (IA) for all the observed technologies. It is apparent that the greatest accuracy is achieved by the DMLS and less - by the casting method using WiroFine® as investment material.

4. Discussion

The objects fabricated by DMLS technology show unique accuracy during initial adjustment to a single abutment and great dimensional stability. Along with the other process characteristics, the perfect fitting accuracy of the objects confirms that the technology is extremely time-saving and allows unique optimization of the working process in the laboratory. The main disadvantage is that it is expensive method for fabrication (having in mind the huge initial investment for DMLS machine) and is compatible only with metals and alloys.

The milling machines also allow precise fabrication of objects as they eliminate the high temperature as possible cause for distortion. In this manner the achieved results are somehow controversial, as the higher accuracy is achieved by DMLS. There may be many possible reasons for these results. A reasonable explanation of this may be the fact that the milling machines should be equipped with relatively wide range consumables to produce complex objects of the suggested materials. This may be the reason that most of the laboratories do not equip their milling machines enough, which may result in some fine discrepancies to the final product. Another reason may be the machine calibration or just a need of some software setting to be changed. Nevertheless, this method can be defined as reliable and accurate.

The casting process can be defined as inaccurate method for conversion of restoration patterns made of wax or resins to a definitive construction made of alloys. It is also a time-consuming method that occupy technician's attention during the whole process. It requires various equipment and procedures to be accomplished. At the same time, it is relatively cheap method that allows acceptable results to be achieved. By some modifications this conventional method become more optimized and generates better results.

Based on previous researches it is proven that the material CastableWax® allows fabrication of very accurate patterns with less than 15μm. discrepancy in every dimension. It is also proven that it is compatible with more friable (with low compressive strength) investment materials (e.g. Sherafina Rapid®, Bellavest®). The achieved results with WiroFine® are not satisfying due to the poor accuracy, so another investment material with more suitable properties was examined. As a result the bars that are invested by using Bellavest® SH show less inaccuracies than those invested with WiroFine®. The reason for this result is that the Bellavest® SH investment material has bigger coefficient of thermal expansion (around 3,5% according to the manufacturer) than the WiroFine® has (around 3% according to the manufacturer). Having in mind that the 3D printed bar pattern is adjusted for perfect fit to the abutments and its stable and stiff structure, the only reason for the observed discrepancies that left is the thermal contraction of the alloy or respectively the insufficient thermal expansion of the investment material. Nevertheless, the suggested method (hybrid technology) and the modification by using Bellavest® allow achieving almost similar results with the contemporary technologies at lower price and faster than the conventional casting process.

5. Conclusion

All the observed technologies allow acceptable results to be achieved. Restoration fabricated by DMLS and machine milling surpass the conventional technologies almost at all, except the cost. Nowadays these contemporary technologies still remain expensive. At the same time the suggested modification of conventional casting process allows better accuracy to be achieved at lower price.

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