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ABSTRACT

PERSONAL CONSIDERATIONS REGARDING EVALUATIONS OF METALLIC PROSTHETIC RESTORATIONS FABRICATED BY ADDITIVE CAD/CAM TECHNOLOGIES

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INTRODUCTION

This research theme, which has great relevance, was chosen due to the dynamic evolution of Additive Manufacturing technologies and also to the exponential development of new materials which can be processed through these technologies in comparison with subtractive technologies. The intense evolution of rapid prototyping technologies in industry and their entrance in the dental field led to the necessity of new studies to investigate their behavior, proper applications, and further required improvements.

Digital technologies represented a central topic for the research team of the Discipline of Dental Prostheses Technologies, with numerous research projects previously conducted, and focused on subtractive technologies. The rapid growth of additive technologies aroused great interest among the team, leading to the present study.

Metal-ceramic restorations have long-time been considered the gold standard for dental restorations, and they still represent the landmark for integral ceramic crowns evaluation and preferred especially for posterior teeth (1,2). The conventional lost-wax technique is still widely used to produce fixed dental restorations but is time-consuming and imply many technological steps which can lead to errors. (3,4).

Digital milling represents an alternative to traditional technology but milling alloys is difficult, cause wear of milling instruments and waste of material.

The additive manufacturing (AM) technology represents one of the remarkable recent layer-upon-layer material technologies, which build 3D object products. Few of these found their applicability in dentistry: stereolithography (SLA), fused deposition modeling (FDM), selective electron beam melting (SEBM) or selective laser sintering (SLS), which appears ideal for manufacturing dental restorations. They represent a precise, efficient, fast and cost-effective alternative to subtractive or traditional technologies(5).

The novelty of these technologies requires further in vitro studies to evaluate mechanical, chemical and biological behavior of metal-ceramic restorations with frameworks obtained by modern technologies.

Scientific **objectives** of this research:

1. Comparative assessment of fit and mechanical properties of metal-ceramic crowns obtained by traditional and modern technologies (casting, subtractive technologies-CAD/CAM milling and additive technologies - SLS and SLM).
2. Evaluation of fracture resistance of metal-ceramic crowns with cobalt-chromium frameworks obtained by conventional casting, SLS, SLM, and milling
3. Evaluation of corrosion behavior and biocompatibility of metal frameworks obtained by traditional and CAD/CAM technologies.

This research has a flexible interdisciplinary approach, bringing together perspectives from various scientific fields, such as digital technologies, mechanics, biomechanics, electrochemistry, cell, and molecular biology.

GENERAL PART

CONVENTIONAL TECHNOLOGIES

Metal-ceramic restorations are still among the most frequently used in prosthodontic treatment even though casting method is used for more than 100 years and are considered as standard in the evaluation of integral-ceramic restorations and for new technologies (6).

This procedure is also very technique-sensitive, time-consuming, and wax patterns are fragile, prone to distortions, thermally sensitive, have a high coefficient of thermal expansion and elastic memory (3,4). In order to overcome these limitations, modern CAD/CAM systems were developed.

CAD/CAM TECHNOLOGIES IN DENTAL FIELD

2.1. CAD/CAM HISTORY

Development of CAD/CAM systems in the dental field started in the late 1970s and early 1980s. In 1985 Dr. Duret fabricated a first dental crown with occlusal morphology after intra-oral optical impression, design, and milling with a numerical-controlled milling machine (7,8). In the next two decades, subtractive technologies have been developed by continuous improvement of technologies as well as materials used (9–13,13). Because of the limitations of subtractive technologies, due to the complexity of the piece which can be milled, the lack of internal structure and it also implies a significant waste of material, new additive technologies have been developed (14–17).

2.2. SUBTRACTIVE TECHNOLOGIES

Subtractive technologies have become "traditional" CAD/CAM technologies. After digitization of intra-oral preparation, a digital wax-up is created. The software which produces the design also produces the data for the CNC machine. Using these data milling machine cut down the designed restoration from a prefabricated block (18–21).

2.3 ADDITIVE TECHNOLOGIES

CAD/CAM technologies recently entered in the dental field are generative technologies, also known as Additive technologies (AT). They are based on building an object using a preset thickness layer over layer, from a liquid or powder by polymerization, fusing or melting (7,22,23). The most used in dentistry are:

Stereolithography (SLA) and technologies derived from it (Digital Light Processing (DLP), Masked projection (for MSLA) and Micro-Stereolithography) uses laser or another light source to produce a model from a photo-sensitive polymer contained in a vat, to create models, Provisionals, guards and surgical guides, etc. (24–26).

Other technologies that can be used in the dental field are Selective laser melting (SLM), Selective laser sintering (SLS). It uses a source of thermal energy which scans the surface to fuse specific areas of the powder bed, layer upon layer (27–29).

Most AT requires post-processing phases which are influencing the properties of final restoration along with processing parameters (30–33).

2.4. MATERIALS USED FOR ALTERNATIVE TECHNOLOGIES

The list of materials which can be processed by the CAD/CAM system is in continuous expansion, new materials being developed, both for subtractive and additive technologies (34).

Metals processed by CAD/CAM milling are used to produce frameworks, mesostructures and abutments for dental restorations: cobalt-chromium alloys, titanium, and titanium alloys. These metals can be also processed from powder using SLS or SLM (34,35).

Digital technologies are also able to process a wide variety of ceramics, such as Glass-ceramics, Infiltration ceramics, Oxide high-performance ceramics, as well as resins and hybrid materials (36–38).

2.5. EVALUATION OF DENTAL RESTORATIONS

2.5.1. STRUCTURAL EVALUATIONS

There are several methods to evaluate metallic structures obtained by different technologies. Some methods involve microscopic examination of the crystal structure made after polishing small material samples and submerging them in diluted acids. Others are contact techniques (39). Mechanical properties and surface characteristics vary according to material and also fabrication technology, surface processing, and post-processing treatment. Because of heterogeneous structure of pieces obtained by AT, rough surfaces, surface and internal pores some evaluations such as Atomic Force Microscopy (AFM) and Scanning Electron Microscopy (SEM) are hard to perform (38). Other non-destructive investigation methods are represented by Ultrasonic and Computerized Tomography.

2.5.2 CORROSION BEHAVIOR AND CYTO-COMPATIBILITY EVALUATION

The oral environment is particular due to its complex biological and electrochemical behavior. The oral fluid is an excellent electrolyte. Different dental alloys “interact” via saliva which is acting as an electrolyte, and produce a galvanic cell. The corrosion behavior is analyzed in artificial saliva, at 37°C, simulating the oral environment, using an electrochemical potentiostat. *Linear polarization* (LV), *cyclic voltammetry* (CV), *electrochemical impedance spectroscopy* (EIS) and chronoelectrochemical studies (chronoamperometry - CA and chronopotentiometry - CP) have been successfully used to investigate corrosion processes in dentistry (40).

Cell cultures are usually used to evaluate the cytotoxic effect of released ions by direct or indirect exposure to the investigated material (41–44).

2.5.3. MECHANICAL EVALUATION

Dental restorations are usually composed of a number of various materials with different chemical and mechanical properties, with complex morphology. Besides material strength, a number of other material characteristics, such as microstructure, processing methods, testing environment and methodology, failure mechanism should be considered as well. During material processing, different sizes and distribution flows can be induced to the material. The shape of the final restoration has an influence on stress distribution. This is why the mechanical evaluation of dental crowns shows some particularities(45,46). The most utilized methods are the static load until fracture and fracture toughness under cyclic loading. For metallic frameworks, non-destructive methods may be used as well, such as SEM in conjunction with EDAX (Energy Dispersive X-Ray Analysis) analysis, AFM (47).

2.5.4. ADAPTABILITY

Because restorations adaptability, determined by the marginal and internal fit, is a key factor for long term success of metal-ceramic crowns numerous investigations methods have been developed (1). The most accurate technique to evaluate adaptation involves direct microscopy measurements of the sectioned tooth-restoration complex, embedded in resin, in a precision cutting machine, and polished surface. This is a destructive technique, but it allows both internal and marginal fit evaluation. One of the most used is a silicone replica technique. This is a popular method because is a non-destructive method, which can be easily applied in clinical use. It consists of placing a light-body silicon material (fit-checker) between coping and abutment, which is afterward removed and embedded in a heavy-body material. This complex is sectioned and analyzed (48). Other methods are using a digital camera associated with an optical microscope, Micro-CT scanning or Superimposing the scanned abutment with the abutment covered with silicone that simulates the luting agent.

EXPERIMENTAL PART

3. FIT EVALUATION OF CERAMIC FUSED TO METAL CROWNS

AIM OF THE STUDY

The purpose of this in vitro study was to evaluate the adaptability of ceramic-fused to metal crowns with frameworks fabricated using modern computer-assisted technologies. Adaptability was measured before and after ceramic veneering, to evaluate how porcelain firing is influencing ceramic fit.

MATERIALS AND METHOD

A resin first upper molar was prepared for a full coverage metal-ceramic crown and ninety-six resin models have been obtained divided into four groups, for conventional lost wax technology (T), digital milling (F), SLS and SLM. The patterns for the casted group was obtained from a photo-cured resin using DLP (Digital Light Processing) technology. SLS and SLM group suffered post-processing thermal treatment. All frameworks were veneered with over-pressed ceramics. Silicone replicas were made before and after veneering. They were sectioned and photographed under a microscope using a hundred microns scale. The gap was measured in nine points.

RESULTS AND DISCUSSIONS

The best values were obtained for the milled group followed closely by SLM and SLS group, and a significantly higher gap for the casted group. For all groups were found small differences for measurements conducted before and after veneering.

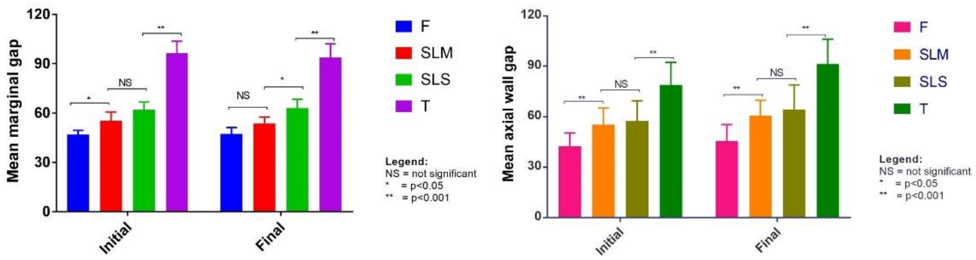

Figure 1 Obtained results - initial and final measurement: Mean Marginal Gap, Mean Axial Wall Gap

The present study promotes AT as a fast, efficient and cost-effective alternative to traditional technology. Using digital technologies there are fewer steps in which errors can occur and the risk of distortion is diminished (33,49).

4. COMPARATIVE EVALUATION OF FRACTURE RESISTANCE OF METAL-CERAMIC CROWNS WITH FRAMEWORKS MANUFACTURED BY DIFFERENT TECHNOLOGIES AND MICROSTRUCTURE CHARACTERIZATION AND HARDNESS DETERMINATION

AIM OF THE STUDY

This in vitro study investigates mechanical behavior and fracture load of different metal-ceramic crowns with frameworks obtained by alternative methods SLS, SLM, and CAD/CAM milling compared to conventional casted ones, as well as surface texture, microstructure characterization and hardness of these structures

MATERIALS AND METHOD

In order to assess the study's objectives, 32 metal-ceramic crowns were produced. The applied techniques varied and tried to include the most popular technologies from this specific area: CST, MIL, SLS and SLM, four groups being obtained. These were cemented on resin abutments and subjected to static loading test in a universal testing machine.

Samples were made for micro-hardness and microstructure analysis. They were polished and one side was sandblasted after. Microhardness was measured on each side, and EDAX, AFM, and X-ray diffraction analysis were conducted.

On other samples, different thickness of ceramic veneering was applied and the metal-ceramic interface was observed using SEM.

RESULTS AND DISCUSSIONS

All the evaluated specimens suffered fractures, initiated especially at the indenter contact point or in the proximity of it, mainly on a negative occlusal surface. There were noticed cracks starting from loading point and propagated radiant through veneering material in surface and in depth. The number of fragments resulted after the fracture was directly influenced by the loading force.

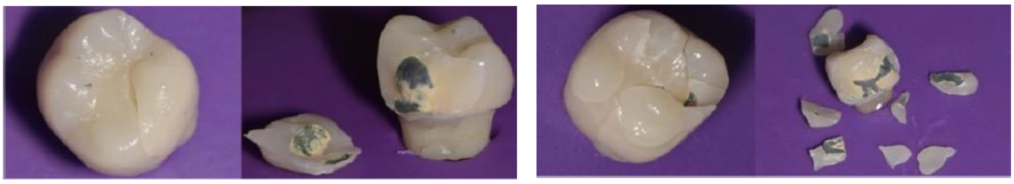

Figure 1 Adhesive fractures sample 2 milled, sample 8 SLS

Best results were observed for MIL and SLM, with very few defects. MIL samples presented traces from milling instruments and few small voids with dimensions up to 20 μm and 25 μm for SLM. The biggest defects and inclusions were observed for casted samples. These results were observed in optic microscopy, sustained by SEM and AFM analysis. Samples produced by AT before thermal treatment presented the most irregularities, because of the technological process. This implies superficial melting and solidification of the alloy, leading to variable compositions between layers and granular structure.

Microhardness test showed double values for AT compared with traditional casting and milling, these values can be induced by post-processing thermal treatment. This treatment increases the hardness but makes the alloy less ductile.

5. BIOCOMPATIBILITY AND CORROSION RESISTANCE OF COBALT-CHROMIUM ALLOYS PROCESSED BY TRADITIONAL AND DIGITAL TECHNOLOGIES

AIM OF THE STUDY

The study assesses the cytotoxicity and corrosion behavior of cobalt-chromium alloys processed by CAD/CAM technologies such as additive manufacturing (SLS, SLM) and CAD/CAM milling (MIL) compared to traditional casting technologies (CAS) using human fibroblast cells.

MATERIALS AND METHODS

Samples were manufactured by casting, digital milling, SLS, SLM, prepared for veneering and ceramic was over-pressed. The metallic surface was polished, sterilized and submerged in culture environment for seven days. Human skin fibroblasts were cultured in Dulbecco's Modified Eagle's Medium. To compare the cell proliferation rates, the cells were exposed indirectly to the alloys. After 2,4 and 7 days, they were evaluated using Muse Count & Viability Assay, Muse Annexin V & Dead Cell Assay, and Muse Cell Cycle Kit.

To evaluate the corrosion process in Co-Cr alloys relevant techniques were applied: linear polarization (LV), electrochemical impedance spectroscopy (EIS), cyclic voltammetry (CV), chronoamperometry (CA), chronopotentiometry (CP).

RESULTS AND DISCUSSIONS

After 2 days in culture, the alloys treated cells had a higher number of cells and indicate a more advanced proliferation process than control. In MIL treated environment number of apoptotic cells is increased when compared to control. After 4 days in culture, alloy treated cells are more numerous than control, suggesting a proliferative tendency. The number of viable cells is greater in SLM and SLS groups compared to CAS and control. The number of dead cells is lower in MIL compared to control. Apoptotic cells number in CAS is the highest. After 7 days in culture both total cells number and viable cells decreased in all samples, probably because of a long time in culture. The decrease is higher for CAS and SLS.

The open circuit potential (OCP) variation for the evaluated materials- CAS, MIL, SLM, SLS shows the formation of a protective film on the surface formed on all samples. The strongest behavior in this direction was observed for CAS probes.

Tafel plots show similar behavior for all samples.

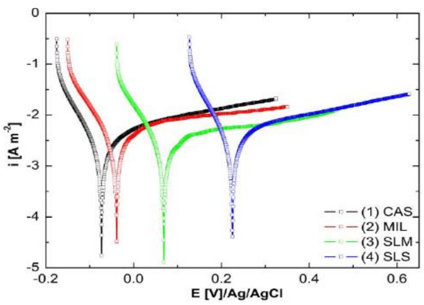

Figure 3 Tafel polarization plots for evaluated probes in specific conditions (artificial saliva, similar temperature like the body 37 degrees)

Potentiodynamic measurements found similar results for CAS, MIL, and SLM, while SLS samples had greater stability. Linear polarization plots recorded CAS samples as most corrosion-resistant with similar results with SLM and MIL.

CONCLUSIONS

1. 3D printing of resin patterns represents a viable alternative for traditional manufacturing of wax patterns, being cost-effective, less time-consuming and precise, having the potential to completely replace in a few years the conventional technique.

   Modern additive and subtractive technologies represent a very good alternative to produce rapidly and economically precise and resistant patterns for conventional casting of dental alloys and ceramic pressing, compared to conventional wax-patterns.

   New additive manufacturing technologies can provide pieces with excellent adaptation.

   Ceramic over pressing did not influence significantly marginal and internal gap of restorations, regardless of the manufacturing method used to produce a framework.
2. In this study, we did not identify a significant difference between specimens obtained using laser-based additive technology and conventional casting or computerized milling concerning the fracture behavior, mean values for the maximal compressive force being situated between 1955.02 and 2432.92 N. AT produce restorations with good quality structures when processing parameters are strictly controlled and the post-processing treatments are performed.

Metal-ceramic interphase characteristics are dependent on fabrication technology and post-processing treatment.

3. Digital technologies can produce high biocompatible frameworks, comparable with traditional technologies.
   We obtained very similar corrosion resistance in Co-Cr frameworks processed by both technologies computerized and conventional.

Further studies:

Because teeth preparation optimal design for AT restorations is not yet established further research are required for improvement, with clinical implications.

In vitro studies represent the first step in biocompatibility evaluation, new test on tissues and in vivo studies are necessary.

New studies are needed to improve corrosion resistance by varying production and post-processing parameters.

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