The influence of framework design on internal and marginal gap width of anatomic and nonanatomic metal copings fabricated by selective laser sintering

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Abstract: In spite the fact that conventional slip-cast crowns are still largely used in everyday practice, and these techniques had shown their efficiency, selective laser sintering is a new technology which arouse more and more interest in prosthetic dentistry. One of the key factor which determines clinical success is the marginal and internal fit of fixed dental prostheses who influences the long-term survival and clinical outcomes. Selective laser sintering is a rapid prototyping technology used to produce accurate complex-shaped metal objects directly using a three dimensional computer model obtained by computer-aided design. Pieces are automatically fabricated, layer-by-layer by selective superficial melting of metallic powder, these metallic particles fusing together. Being a relatively new technology in this field, it requires further evaluation before embracing it and use it on a large scale as a current procedure. The aim of the study was to evaluate the effect of geometry of tooth preparation and copings design on marginal and internal gap of laser-sintered frameworks. Two maxillary first molars where prepared with two different kind of marginal limits. Two different framework designs were conceived for each: model 1 – a coping with a constant framework thickness of 0.6 mm and model 2 - an anatomically modified shaped cusp supporting framework with a constant veneering thickness. Marginal fit was evaluated with silicone replica technique. Specimens were analyzed by light microscopy at X4 magnification, digital photos were taken and a digital measurement program.The mean marginal gap values were between 37 and 95 µm, the means for the axial region were between 47 and 70 µm and for the occlusal region between 67 and 147 µm. Copings produced by selective laser sintering using CAD/CAM technologies demonstrate acceptable marginal and internal fit in the range of 47 to 120 µm, with better results in case of anatomically-reduced frameworks.

Key-Words: rapid prototyping, selective laser sintering, marginal and internal fit, CAD/CAM system, cobalt-chromium alloy, metal-ceramic crowns

1 Introduction

Even though integral ceramic restorations gained more and more popularity among clinicians and patients, metal-ceramic crowns are still widely used and considered the standard treatment in dentistry, especially in posterior regions of the mouth because of high loading forces. Ceramic fused to metal crowns are used for many decades and proved satisfying long-term performance, and are still the clinician's choice due to their cost, long term results, biocompatibility and ease to produce. [1,2].

Conventional technologies (lost-wax technique) are widely used to obtain metal substructures for dental restorations using different metal alloys for casting. This conventional procedures have many steps were errors can occur, and which are technique sensitive. This is why CAD/CAM technologies arouse more and more interest among practitioners and why we are witnessing a digital revolution in dentistry. However, some clinicians remain reserved to introduce CAD/CAM technologies in their daily-practice, being concerned about the width of marginal gap, problem reported for the early chairside systems. Early CAD/CAM restorations did not shown good results for marginal fit. Modern CAD/CAM systems are using improved scanners, software and manufacturing units, which leads to better restorations, in terms of internal and marginal fitting, which can exceed the ones produced using conventional methods [3].

Most benefits associated with computer generated dental prosthetic restorations include the use of industrial prefabricated and controlled materials, without defects, increased quality and reproducibility, storage emerging data in a standardized chain of production, improved precision and planning, reduced manufacturing time and costs, minimization of human errors, prevention of casting defects and increased efficiency [4,5,6,7].

The beginning of the 1970s started a new era in dentistry by introducing automated manufacturing processes. Until the early 1980s, most CAD/CAM fabrication techniques of dental restorations were based on subtractive manufacturing. A digital model is generated on computer, then this is manufactured in CAM section based on CAD data. Substractive techniques consists in milling the designed object from a solid blank. Recently, the introduction of additive manufacturing provided a completely new concept [8].

Different additive techniques were developed to meet the requirements of rapid manufacturing (RM) and rapid prototyping (RP), such as stereolithography (SLA), fused deposition modeling (FDM), selective electron beam melting (SEBM), selective laser sintering (SLS) or selective laser melting (SLM).

The most used in prosthetic dentistry for fabricating dental restaurations is SLS, which seems to be ideal for producing dental prosthetic restorations. Current studies indicate that Co-Cr alloys restoration can be obtained with similar or better properties than those obtained by the classic casting technique or computerized milling, faster and at a lower cost [9,10,11].

SLS is a process of 3D parts manufacturing, consisting in selectively consolidation and fusing of thin layers of powders, layer-by-layer, of various materials (such as polymers, ceramics, and metals), under the heat of a focused laser beam, directed by the data provided by a CAD file [12]. One of the main advantages is that with SLS can be easily manufactured complicated shapes, with an automatic system in a short time, without the need of wax pattern, investing, burning and casting procedures. Main disadvantage is the high price of equipment [13].

A key factor for long term success of fixed prosthesis is the precise fitting of restaurations [14].

Restorations adaptability is determined by the marginal and internal gap. After the restoration is placed on the prepared tooth, the gap between the gum and tooth-crown interface acts as a connection with oral environment. Many clinical trials highlighted the important role of marginal adaptation for long term clinical success of fixed restorations. [6]. Large marginal discrepancies expose the cement to the oral conditions leading to dissolution of luting material and microleakage. This percolation allows occurrence of decays and inflammations of the vital pulp. Studies shown that increased marginal gaps are correlated with higher plaque index which leads to gingival bleeding and alveolar bone reaction with reduced periodontal conditions. On the other hand, minimal marginal discrepancies results in less gingival inflammation, cement dissolution, decay and marginal discoloration. The internal gap was defined as the perpendicular distance between the framework and the abutment teeth and it is the misfit of the coping at the occlusal/incisal and axial surfaces. It is not recommended to have an internal perfect fitting, because a space for luting agent is mandatory, as well being necessary for letting the excess of cement to escape, allowing the correct positioning of the restoration. The internal fit should be uniform to provide an ideal space for cement without compromising the retention or the resistance of the crown. If this space is too large the cement will be washed away [15].

For conventional technologies used to obtain metal-ceramic restoration the ideal crown preparation and finishing line is well-known and widely-accepted. Meanwhile, in the matter of tooth preparation design for CAD/CAM restorations confusion still exists among clinicians. Although many studies investigated the longevity and fit of CAD/CAM restorations, few of them were focused on how preparation design and core design impacted the fit of these prosthesis [3].

2 Problem Formulation

Although fabrication of metal-ceramic crowns has a long history and these are still widely used in daily practice, experts have not reached a consensus yet, regarding the optimal tooth preparation and framework design for porcelain fused to metal restorations produced by CAD/CAM technologies.

3 Purpose

The aim of the study was to evaluate the influence of two different abutment and core designs on marginal and internal adaptation of metal frameworks for metal-ceramic crowns, fabricated by selective laser sintering.

4 Materials and method

Two resin first upper molars were prepared: one of them with chamfer finish line, and 6 taper angle of the axial walls (Fig. 1), the other one was prepared with right angle shoulder and also 6 taper angle of the axial walls (Fig. 2).

Fig.1. First upper molar with chamfer finish line

Fig.2. First upper molar with right angle shoulder

The preparations were duplicated with silicone (Fegurasil AD Special, Feguramed, Germania). Than twenty stone-casts of each preparation were poured using Type 4 Dental Stone (GC Fujirock Gc, Leuven, Belgia). These abutments were scanned with D700 3D Scanner (3Shape, Copenhagen Denmark). Ten anatomic and ten non-anatomic metal copings (using Cobalt-Chromium ST2724G powder) of 0.5 mm thickness were designed with PHENIX Dental (Phenix Systems, Riom, France) (Fig. 3) for each tooth preparation and fabricated by selectiv laser sintering with PXS Dental (Phenix Systems, Riom, France), for each, with 0.05 mm space for cement. This is a promising technology for produce precise dental restorations, reducing fabrication steps, waste of materials, because the non-melted powder can be reused, and potential of errors. A high-power laser beam superficially melts metal powder into a mass, layer-by-layer, to reproduce the CAD data, from the occlusal surface to cervical limit. [16].

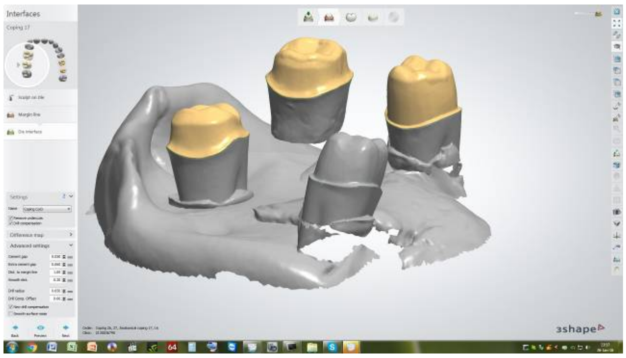

Fig.3. Design of the frameworks.

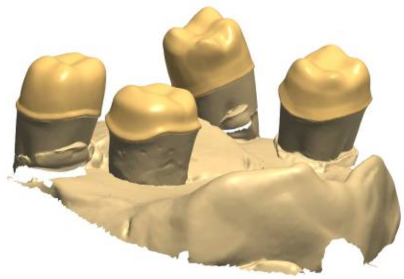

Fig.4. All frameworks designs before laser sintering.

For fit evaluations a very light silicone (Oranwash VL, Zhermack, Badia Polesine, Italy) was placed between sintered copings and stone-cast abutments, and then this thin layer of flowable silicone was embedded in putty silicone (Zetaplus, Zhermack, Badia Polesine, Italy) and covered with light silicone (Oranwash L, Zhermack¸ Badia Polesine, Italy) - silicone replica technique [17].
One millimeter diameter holes were drilled into the occlusal surface of the frameworks to overcome the hydraulic-effect when placing it on stone-cast (Fig. 5).

Fig. 5. Framework prepared for fit tests.

Fig.5. Section through sample prepared for microscope

Then two random sections were made for each sample to obtain a 3-dimensional measure and were analyzed with Leica DM500 microscope (Leica, Wetzlar, Germania) at 4x magnifications with a hundred microns scale (Fig. 5,6).

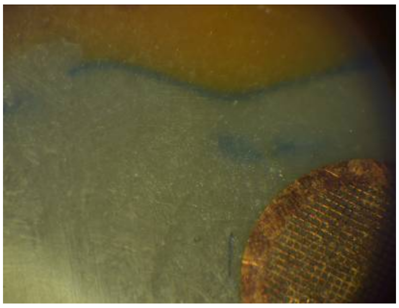

Fig. 6. Specimen with 100 µm scale.

Seven mesiodistal and vestibulolingual positions were measured, and each of these were divided into the following categories: marginal gap (MG), cervical gap (CG), axial wall at internal gap (AG), and oclusal wall at internal gap (OG), using this silicone key for measuring the gap between coping and abutment. Measurements were made with ImageJ software (Fig. 7).

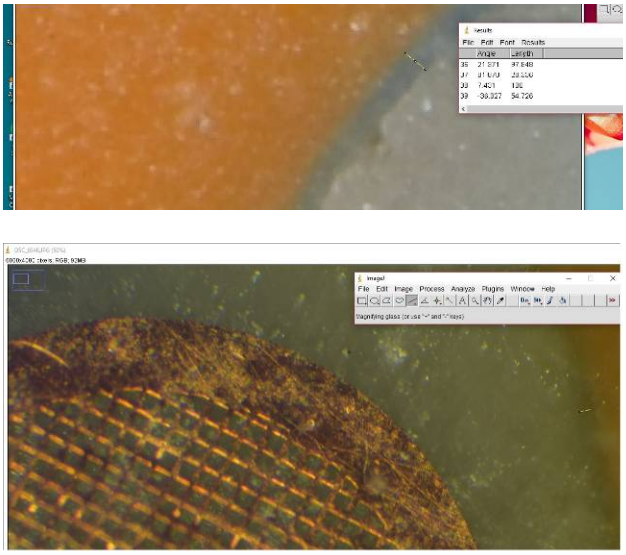

Fig. 7. Measurements made with ImageJ software.

5 Results and discussions

Descriptive data for mean marginal gap was significantly smaller for the fourth group- anatomical coping on shoulder preparations. The highest values for marginal discrepancy were found in first group - uniform thickness on chamfer preparation. The mean occlusal gap width of anatomically reduced framework on chamfer preparation was sensible smaller than in case of anatomically reduced framework on shoulder finishing line. Best adaptability results were found in anatomic copings both on chamfer and shoulder marginal preparations, the best being found in the group with the shoulder preparation, except occlusal level, where this group recorded the biggest discrepancies (Table 1).

Table 1. The mean values measured (in µm) for all four groups. Group 1: chamfer preparation, uniform thickness framework; Group 2: chamfer preparation, anatomic coping; Group 3: shoulder preparation, uniform thickness framework; Group 4: shoulder preparation, anatomic coping.

Group	MG	CG	AG	OG
1	95.01	91.623	70.709	98.68
2	55.34	55.12	50.059	67.28
3	78.87	83.33	67.078	85.89
4	37.787	47.37	47.457	146.5

The mean marginal and internal discrepancy measured on the sintered Co-Cr copings were within the range considered clinically acceptable by most studies. The results for better adaptability are not longer expected with specific preparations margins. The better results from literature for chamfer margin design compared with shoulder finishing line can be explained as a consequence of scanning, software and milling difficulties for accessing strong angles, using subtractive CAD/CAM technologies due to limitations caused by the shape and size of drills used. With performing scanners and additive techniques, these limitations no longer exist [18].

A study like this one can be limited by sources of variability such as manual pressure applied to restorations for four minutes while the very light silicon had to set. There were taken all measures to ensure replicability. to avoid variations in precision only one trained person performed silicone-replicas, sections and examinations. Although this is a non-destructive with specimens, abutment teeth and casts, simple method of measuring, with accuracy and reliability confirmed by a large number of studies, new measurements methods are needed to overcome the disadvantages of this one, and to fulfill the requirements proposed by Groten et al of measuring the gap at a minimum of 50 points for evaluating the fit for a crown [19].

Most studies conducted in this field are focused to marginal and internal fit comparing laser sintered crowns with conventionally fabricated crowns and with ones obtained by alternative technologies (different casting methods, milling, etc), without considering the framework design [20]. Most of them established that SLS, SLM, and other CAD/CAM technologies provide more accurate and appropriate for clinical use restorations than traditional ones. Also, these new computer assisted manufacturing procedures allows greater design flexibility: the cement space can be modified both as thickness and surface, the framework design can be controlled in every aspect, for example: constant thickness of the framework, anatomic reduction for uniform thickness of the veneering, full-anatomic contour with space for ceramic veneering on buccal aspect of the tooth, etc. to fulfill many different exigencies [6]. Therefore further studies will be necessary.

6 Conclusion

Within the limitations of this in vitro study, the sintered Co-Cr copings produced with PHENIX Dental Systems show clinically acceptable marginal fit within 15-120 µm, before ceramic veneering, except occlusal gap in case of anatomical copings on shoulder preparations, which goes up to 304 µm. The largest gap were occlusally in all specimens. It can be concluded that not only the technology used to obtain dental copings can affect clinical outcome, but also the preparations and framework design can have a major influence on adaptability of restorations obtained by selective laser sintering.

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