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EVALUATION OF INNOVATIVE TECHNIQUES FOR DENTAL CROWNS MANUFACTURING

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Abstract: *A structured procedure for evaluating the accuracy at each step of the crown restoration manufacturing sequence is proposed. This procedure includes the definition of an innovative benchmark and it is applied to evaluate the accuracy of both digitization and cap production phases. Three different up-to-date manufacturing processes are analysed.*
Key words: *crown restoration; benchmark; CrCo alloy; Zirconia; dimensional evaluation*

1. INTRODUCTION

Recently, Reverse Engineering (RE) and Additive Manufacturing (AM) have proven to be interesting techniques alternative to traditional procedures in dental applications, such as crown manufacturing. The geometry of a stone replica can be digitized by a three-dimensional scanner. From the points clouds a Virtual Model (VM) is generated and tooth caps could be designed on it and manufactured by Computer Aided Manufacturing (CAM) or employing AM techniques.

The sequence from replica digitization (VM) to cap fabrication involves many production steps, each one inevitably inducing dimensional errors. However, the information given by systems suppliers or present in literature is lacking and does not allow comparison among different manufacturing systems. Therefore, it becomes important to investigate new technologies to quantify their accuracy and precision. Currently, there is not a standard methodology for evaluating the error introduced by each step of the manufacturing cycle, from the scanning of the replica to the final dental device. Moreover, to have comparable data, a suitable benchmark must be defined (Atzeni *et al*., 2009). In literature a few benchmarks based on standard geometries were proposed for dental applications (Brosky *et al.*, 2002; DeLong *et al.*, 2003), but they appear lacking because differences from posterior and anterior teeth shapes, tooth position along the dental arch, and three dimensional arrangement of teeth are disregarded.

In this work a standard procedure for evaluating the accuracy at each step of the manufacturing sequence for dental caps is proposed. This analysis is based on the definition of an innovative benchmark. Deviations introduced by benchmark manufacturing, scanning operation, cap design, and fabrication are studied.

2. MATERIALS AND METHODS

The innovative benchmark, illustrated in Figure 1, is specifically designed through classical features resembling real prepared teeth. By this way shapes inspection and reproduction is made easier, thus allowing the comparison among different techniques. The benchmark includes tooth orientation and provides oblique surfaces similar to those of a real prepared tooth: this is a significant innovation. The starting point for benchmark geometry definition is the analysis of physical artificial teeth used for partial (or complete) denture fabrication. Three different teeth are selected as reference: lateral incisor (32 and 42), second premolar (35 and 45), and second molar (37 and 47). Prepared teeth shapes and dimensions are identified by simulating the preparation of the corresponding artificial tooth by considering the following rules related to prosthodontics (Goodacre *et al.*, 2001):

- the tooth reduction is set to 1 mm, common average value for metal-ceramic restorations;
- a tapering of 5 degrees is made around the circumference of the prepared tooth, appropriate to allow crown fitting while providing enough grip;
- the tooth is prepared with a chamfer finish line.

The first step of the manufacturing sequence of crown restorations consists in the achievement of the virtual model from the stone replica and errors in this phase will highly affect next prosthesis design and fabrication. Thus, the benchmark is first produced by selective laser sintering (SLS) of polyamide and then inspected and digitized to obtain its virtual model. The inspection of the physical benchmark with a coordinate measuring machine (CMM) is required to evaluate the deviation contribute of the scanning operation. In fact, it is not possible to compare the point-cloud directly to the original 3D CAD model, because results will include errors from the benchmark fabrication. In this way, a Reference Model (ReM), consisting of actual dimensions of the benchmark, is yielded for next comparisons. The point-cloud from digitization process is inspected as well by using a specific software to evaluate the same dimensions. The comparison of results from both inspections allows to identify the accuracy of the digitization step. From the VM, caps are designed disregarding the manufacturing process and installation (i.e. gap for cement is set to zero, while actually it is variable as a function as the fabrication technique). By this way, caps cannot fit the original studs, but the use of a unique geometry makes possible to compare different processes. Compared techniques are milling of Zirconia, selective laser sintering (SLS) of a dental CrCo-alloy, and investment casting of CrCo-alloy from Drop-on-Demand (DoD) wax patterns. The coupling surface of each manufactured cap is inspected and compared with its CAD model to give information about fabrication processes accuracy.

3. RESULTS AND DISCUSSION

The results of the CMM inspection of the physical benchmark are listed in Table 1, where the average error (Av.) and standard deviation (SD) are detailed for dimensions grouped into basic sizes (0÷3, 3÷6, and 6÷10 mm) accordingly to ISO 286-1 (1988).

(a) (b)

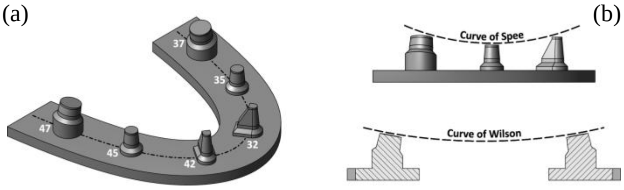
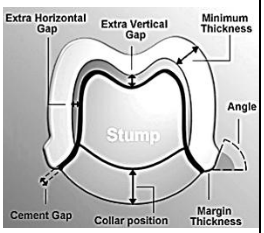


Fig. 1. Benchmark design (a) and teeth three-dimensional arrangement (b), overall dimensions 70 × 57 × 12 mm^3

	Fabrication *(Physical Model)*			**Digitization** *(Virtual Model)*	
Basic sizes	**Dimensional deviation** (mm)				
(mm)	**Av.**	**SD**		**Av.**	**SD**
0 ÷ 3	-0.19	0.04		0.07	0.03
3 ÷ 6	-0.20	0.07		0.01	0.03
6 ÷ 10	-0.12	0.04		-0.02	0.01

Tab. 1. Benchmark: dimensional deviations for basic sizes

Angle	65 deg
Cement gap	0 mm
Collar position	1.5 mm
Extra horizontal gap	0 mm
Extra vertical gap	0 mm
Margin thickness	0.2 mm
Minimum thickness	0.6 mm



Tab. 2. Cap design parameters

Results confirm that the discrepancies of the physical benchmark with respect to its original three-dimensional CAD model meet common SLS tolerances for plastic parts (Silva *et al.*, 2008). In fact, the obtained deviation of about 0.2 mm is in agreement with the declared laser spot size of about 0.4 mm and the accuracy of laser positioning of about 50 µm. The average error of 0.12 mm obtained for basic sizes 6÷10 mm, that is smaller than the error for basic sizes 0÷3 mm and 3÷6 mm, is justified by the fact that the measured dimensions belonging to this group are along the building direction (Z-axis) of the SLS machine. The precision of the SLS system along Z direction is very high because it depends on the (high) precision of the building platform elevator that is an electro-mechanical device, while the influence of the laser system is very low.

The outputs of the digitization are imported into Rapidform software to inspect the same entities previously analyzed. The comparison between scan data and CMM measurements in terms of dimensional deviations (Table 1) shows that the point-cloud is an accurate description of the real benchmark, with errors ranging from minus 0.02 to 0.07 mm. The accuracy of the digitization accomplished on the benchmark is good and adequate for medical purposes. Bigger deviations are found on the smaller dimensions (basic size 0÷3 mm), among which there are the dimensions of the incisor. The deviations range is consistent with the declared accuracy of the scanning device (DentalWings). The rough aspect of the benchmark surface, amplified by the digitization (noise), leads on the Virtual Model to standard deviations (SD) of the same order of magnitude of the error. After this validation, the Virtual Model is proven to be a valid replica and consequently it becomes the base for techniques evaluation.

Caps are designed using a DentalWings proprietary application that full integrates the scanning environment and the “Crown & Bridge” design module, by setting parameters as listed in Table 2. Caps produced by the three selected techniques are shown in Figure 2. Results of the inspection of the inner surfaces of the caps are listed in Table 3, where the deviations are clustered for dimension groups with respect to the Virtual Model. In fact, because of the null gap, the inner surface of the cap copies exacltly the outer surface of the stud of the virtual model. By this way, the measured deviation, only due to the manufacturing process, give information on the ability of the process to reproduct the designed geometry. This indication is of paramount impontance for the definition of the ideal gap as a function of the process.

Results show that the accuracy of caps of CrCo-alloy, produced by SLS and by investment casting from DoD wax pattern, is comparable, the absolute deviation ranging from 0.02 mm to 0.19 mm. Analysing data, a scale effect could be appreciated. Moreover, most deviations are positive in sign,

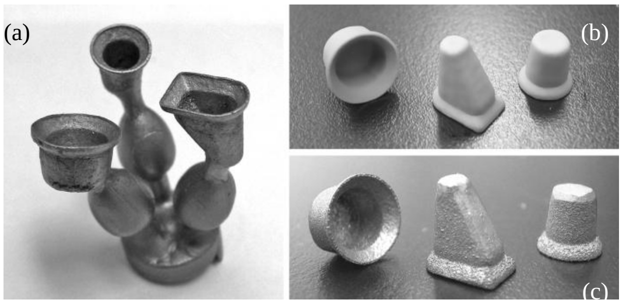


Fig. 2. Caps manufactured by investment casting of CoCr alloy (a), milling of Zirconia (b), and Selective Laser Sintering (SLS) of CoCr alloy (c)

	CrCo *(laser sintered)*		**CrCo** *(investment cast)*		**Zirconia** *(milled)*	
Basic sizes	**Dimensional deviation** (mm)					
(mm)	**Av.**	**SD**	**Av.**	**SD**	**Av.**	**SD**
0 ÷ 3	-0.02	0.01	0.02	0.01	0.05	0.06
3 ÷ 6	0.02	0.09	0.07	0.13	0.16	0.08
6 ÷ 10	0.19	0.04	0.14	0.10	0.33	0.06

Tab. 3. Caps: dimensional deviations for basic sizes

meaning that the produced cap is larger than the corresponding stud. This is an interesting result that could allow the installation of the cap instead of the null gap. Worst results are obtained for zirconia milled caps. It could be observed that among the studied techniques, the sintered caps could be preferred in terms of lead time.

4. CONCLUSIONS

An evaluation procedure based on an innovative benchmark is defined to assess errors introduced by each step of up-to-date dental restorations production methods. Two main outcomes are obtained: the availability of a validated virtual model of the benchmark, and accuracy information about the three most widely used cap fabrication techniques.

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