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Comparison of an analog and digital quantitative and qualitative analysis for the fit of dental copings

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ABSTRACT

Background: Precision in fit is crucial for dental crowns and bridges. Most analyses of fit are based on analog 2D techniques. Aim of this in-vitro study was to compare an analog and a digital quantitative and qualitative analysis for the fit of CAD/CAM fabricated dental copings.
Methods: A prepared steel canine served as master die. CAD surface models, varying in data density, were purposely enlarged in height (Ez), circumference (Exy) and both of these aspects at once (Exyz). Two titanium copings for each variation were produced. The silicone-replica-technique was applied to analyze the fit by means of a 2D analog light microscope measurement (LMM) and a 3D computer-assisted measurement using an optical digitizing system (ODKM97), respectively.
Results: In most cases, restorations based on the low data density showed a better fit than those based on high data density. Original size low density data showed the lowest marginal and axial values in the quantitative 2D analyses (LMM and ODKM97). The 3D measurements (ODKM97) revealed best fit of the low density original size specimens, whereas the Ez specimens showed the highest values. Noticeable variations in fit were detected marginally and axially depending on the specific measurement point (mesial, distal, oral, or buccal) for both measurement systems.
Discussion: The analog 2D replica technique revealed a loss of information due to the necessary cutting process. By contrast, the digital computer-based method provided 3D quantitative and qualitative results without data loss over the complete surface.

1. Introduction

Precision in fit is crucial for dental crowns and bridges as high marginal discrepancies are correlated with inflammation processes of the gingival tissue [1].

There are plenty of different methods available for the analysis of dental restoration's fit such as non-destructive ones like the direct view technique [2,3], profilometry [4], and the replica technique [5–9]. Destructive methods like the cross-sectioning technique [10,11] will not allow for using the restoration afterwards. In many studies, the marginal and internal gap were evaluated according to the method described by Holmes et al. [12].

Most of the methods mentioned above render only two-dimensional (2D) data. A three-dimensional (3D) non-destructive analysis can give a more complete picture of the size and location of deviations on a free-form surface such as a tooth's surface or a dental restoration's inside [13–17]. Nawafleh et al. [18] suggested to combine two measurement methods in order to verify the results.

A variety of different potential influence factors on restorations' fit have been investigated: the coping material [19], the CAD/CAM fabrication technique [19–21], the convergence angles [11,22], tooth preparation height [22], and the margin configuration [23].

A modification in coping fit in different directions can occur unintentionally both for the conventional as well as the digital manufacturing procedure of restorations. Each step of the respective process chain can be affected. Clinical factors have to be considered the major cause for such unintended modifications in crown fit, e.g. blood or saliva contamination during dental impression making or margin geometry and position [24]. Errors occuring

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in an early step of a process chain may be difficult to alter or to compensate in subsequent steps.

The application of powder on the prepared tooth before digital impressioning or its application on titanium abutments before extraoral digitizing is necessary for most systems in order to achieve a precise 3D surface acquisition. Possible sources of error are irregular powder film thickness [15] or varying accessibility of different tooth areas.

CAD and CAM processes can either compensate or worsen occurring errors. Often, a clear differentiation between these potentially counteracting effects is not possible [25,26].

In this in-vitro study, two measurement methods are used in comparison:

- the conventional 2D analog replica-technique using light microscopy and
- the application of a 3D digital computer-aided technique using an optical digitizing system.

The hypothesis was that the two measurement methods differ concerning their results at different coping locations.

2. Materials and methods

CAD/CAM fabricated dental copings were used, which were purposely modified in fit in order to simulate occurring errors in dental restoration manufacturing. Furthermore, the data sets varied in data density in order to investigate this potentially influencing factor.

The use of two different measurement systems was compared: a light microscope (LMM, Zeiss, Jena, Germany) and an optical three-coordinate measuring system (ODKM 97, Fraunhofer Institute for Applied Optics and Precision Engineering, IOF, Jena, Germany).

A CAD surface model was constructed from which a stainless steel master die was manufactured by high-precision CNC-milling (Fig. 1.1). Modifications of the CAD surface model in data density were performed (high and low) (Fig. 1.2a). In addition, the CAD surface model was modified in fit: the originally sized data (OS) was enlarged in height (z), circumference (x, y) and both of these aspects at once (x, y, z) (Fig. 1.2b). Low viscosity silicone replicas of the cement space, the space between tooth and coping (Fig. 1.3), were made (Fig. 1.4). These silicone replicas were either non-contact optically digitized and analyzed virtually or stabilized with a heavy-body silicone with clear color contrast, cut in segments and measured under a light microscope (Fig. 1.5).

2.1. Manufacturing of restorations

A CAD surface model was constructed using a free form spline surface and curve (3D construction tools in Surfacer® 9.0, Ann Arbor, Michigan, USA) to create the ideal shape of a prepared maxillary canine (FDI: 13) [17]. From this CAD surface model the stainless steel master die was manufactured by high-precision CNC-milling (Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Jena, Germany). Its height was 7.8 mm, the cone angle 4° and the bucco-oral diameter 10 mm at the margin. The CAD surface model (Fig. 1.1) was purposely modified. First, the alteration of the data density was performed (Fig. 1.2a). The Sample-Surface-tool was used for creating separate point clouds from the CAD surface model (Surfacer 10.6, Menu: Point | Create From Surfaces | Sample Surface). The sampling was performed uniformly in the surface's parameter space. Each point in the resultant point cloud got its normal from the corresponding point on the surface. For high density data, 400 points in U and V were chosen as sampling parameter and for low density data, 100 points in U and V were used (Fig. 2). The two resulting point clouds consisted of either 8513 points (low data quantity, LDQ) or 123,029 points (high data quantity, HDQ, thus representing the range of digital data density commonly used in dental CAD/CAM. They were then purposely enlarged in different directions by 5% in relation to the original size using the basic tool Scale (Sufacer 10.6) (Fig. 1.2b). The original size (OS) copings served as control for the either in circumference (Exy, Basic | Scale | X Scale Factor 1.05, Y Scale Factor 1.05, Z Scale Factor 1, Scale Center 0, 0, 0), height (Ez, Basic | Scale | X Scale Factor 1, Y Scale Factor 1, Z Scale Factor 1.05, Scale Center 0,0,0) or all directions (Exyz, Basic | Scale | Scale Uniform with Scale Factor 1.05, Scale Center 0, 0, 0) enlarged point clouds for the titanium copings.

For each of the resulting 8 data sets, two titanium copings were CAD/CAM-made (DiGident®-system, Girrbach Dental GmbH, Pforzheim, Germany) (Fig. 1.3). The thickness of the framework was set to 0.5 mm and the cement space was set to 70 μm. Standard milling parameters were used.

2.2. Manufacturing of replicas

Five replicas consisting of light-body addition-curing silicone (Dimension® Garant L, 3MESPE AG, Seefeld, Germany) were produced for each titanium coping, resulting in 80 replicas for each measurement system (Fig. 1.4).

The replicas for the LMM were made on the master die. An individual marker ring with grooves for orientation was fabricated from training alloy (Degussa Dental GmbH & Co., Hanau-Wolfgang, Germany). The LMM replicas could thus be reproducibly segmented (Fig. 3). After isolating the copings on the inside with silicone oil (Type 350, Caesar & Loretz, Hilden, Germany), which was spread carefully by compressed air to achieve a minimal isolating film, the restoration was half filled with light-body silicone (pink color) and seated manually on the master die with a force of 20 N, which was controlled using a digital scale (Leifheit AG, Nassau/Lahn, Germany). The manufacturer's recommended setting time was extended to 10 min to guarantee complete setting of the silicone material at room temperature.

The copings were removed in axial direction with pliers. A heavy-body addition-curing silicone with a clear color contrast (green color) was used for stabilizing the thin silicone-replica before cutting.

The gypsum duplicate dies (Type IV gypsum, esthetic rock 285, apricot, dentona, Dortmund, Germany) of the steel canine were made with dental high-precision impression materials (Dimension® Penta H and Garant L, 3MESPE AG, Seefeld, Germany), as the reflecting steel surface was inappropriate for digitizing with the white-light fringe projection digitizing system (ODKM 97). The one-stage, two phase impression technique and an extended setting time of 10 min (manufacturer's recommended setting time plus an extra 4.5 min) was used in order to compensate the lack of body temperature. Only flawless gypsum duplicates were used. For the replica making, the titanium copings were seated on the gypsum dies in the same way as described above for the LMM.

2.3. Quantitative 2D analysis (LMM)

The stabilized replicas were cut crosswise according to the markings of the marker ring. Marginal gap and internal gap were evaluated according to the method described by Holmes et al. [12]. The replica thicknesses was orthogonally measured with a light microscope (40 × magnification) at defined points, which resulted in 24 measurement values (8 marginal, 8 axial, 8 incisal) per specimen due to two measurements at both sides of each sectional cut (Fig. 3). The mean values for each location were calculated, resulting in 4 marginal, 4 axial and 1 incisal value.

A hair cross in the microscope eyepiece was positioned at the starting and end point of the measurement section (marginal gap and internal gap).