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Analysis of variability in the manufacture of Cr-Co fixed partial dentures by geometric comparison

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Abstract

This article studies tridimensional adjustment of Cr-Co fixed partial dentures obtained with different manufacturing processes (CNC milling, laser metal sintering and lost-wax), making a special point of the most critical adjustment, the marginal fit. A model was obtained with the impression taken in the oral cavity of a patient. This model was digitalized, and serves as the reference for manufacturing fixed partial dentures using different manufacturing processes. This article proposes a method of comparing the original model with the fixed partial dentures. This comparison was carried out using commercial software, allowing dental technicians to obtain information which can identify errors and geometric discrepancies before the fixed partial denture is implanted in the patient.

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Keywords: fixed partial dentures; marginal fit; three-dimensional analysis; computer-aided analysis.

1. Introduction

One of the main problems that dental technicians face is the fit of fixed dental prostheses or fixed partial dentures with the structures which will support them in the patient's mouth. The structures (abutments) may be natural or artificial (implants). Although a degree of variability in the geometry of fixed partial dentures is acceptable, poor fit can allow acids from food to leak in causing gum inflammation, tooth decay and even the

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failure of the patient's natural abutments and of the fixed partial denture itself , Foster (1990).

One of the areas that has received most attention in literature is the fit of the fixed partial denture to the abutments, measured at the base of the latter and known as marginal fit, since this fit is a good indicator of the durability of the fixed partial denture. Marginal fit can be assessed in two dimensions at the base of the abutment using *in vitro* studies. To do this, a replica of the abutment is created and the fixed partial denture is cemented to it. External fit can be measured using microscopes, Att et al. 2009, or, if one wishes to assess the internal fit, the fixed partial dentures and abutments are sectioned and the internal fit achieved is then measured using a microscope, Kohorst et al. (2011).

Although two-dimensional studies do provide information about marginal fit, a three-dimensional assessment of the fit of the fixed partial denture to the abutment is needed to provide more information about final fit. This approach uses two methods to assess fit. The first of these involves optical devices or computerised tomography, Rungruanganunt et al. (2010). Following the creation of models of the fixed partial denture and abutment, an image of the cement space between the fixed partial denture and the abutment is taken and its thickness is determined. The second is based on the use of CAD software with non-contact 3D scanners, Matta et al (2012).

CAD/CAM techniques originally used for the manufacture of fixed partial dentures are now being used to assess fixed partial denture fit. There are a variety of processes based on scans of fixed partial dentures and abutments which provide information through CAD software on the three-dimensional fit of the fixed partial denture to the abutments, Moldovan et al. (2011). The abutment and the fixed partial denture are scanned, the models are lined up using a CAD system and the fit between them is assessed, Schaefer et al. (2012). Such studies focus on the three-dimensional fit of a single item. However, studies of fixed partial dentures made up of several components are more difficult to carry out. A first point of contact between the fixed partial denture and the abutment must be identified, as this will determine the final position of the fixed partial denture. In addition, the possibility of rotation during cementing of the fixed partial denture must also be considered.

This article assesses three-dimensional geometric variation of fit between three-piece (one pre-molar and two molars) Cr-Co fixed dental prostheses made using three different manufacturing processes: lost wax, CNC milling and selective laser sintering of metal particles (DMLS or direct metal laser sintering). The fit of the various fixed partial dentures differs as a result of the different manufacturing processes, Örtorp et al. (2011).

The fixed partial dentures were made using the three processes mentioned above and a simple comparison between them was then carried out using the equipment and software applications available in a dental laboratory. The comparison was made in three dimensions and data on marginal fit were collected.

In order to carry out the comparison, a digital model of the fixed partial denture was created from the scan of the plaster model of the supporting structures, made using the dental impression taken by a dentist from one of his patients. The various fixed partial dentures were scanned and digitalised once they had been made. Furthermore, assembly tools available in commercial CAD programmes were used, specifically, the SolidWorks assembly module, which permits the detection of points of contact between the fixed partial denture and abutment and the assessment of the positioning of the entire fixed partial denture on the abutments with a view to deciding which seems to offer the best fit (this is a decision taken on the basis of visual evidence).

The definition of additional geometries that can be used to assess the extent to which the desired characteristics are achieved is key to the comparison. These must be transferable to any digital model, whether generated by the dental technician or scanned.

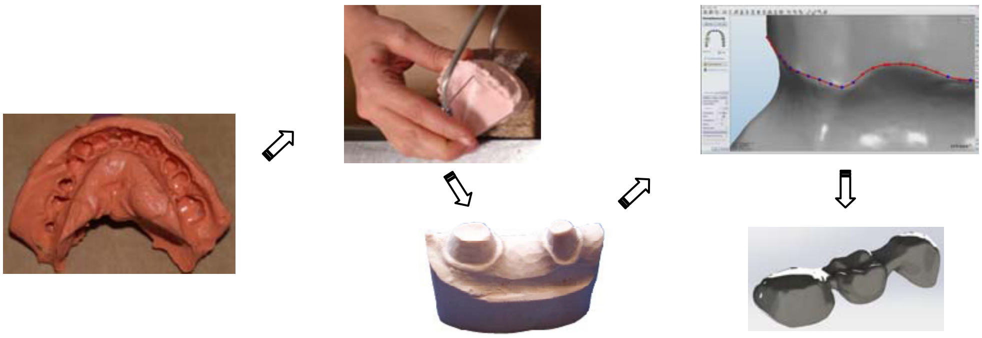
The quantitative results relating to the closeness of the fit and the faithfulness of the geometry to that of the original model can be used to accept or reject a fixed partial denture before it is implanted in the patient. Another important advantage of these results is that they allow changes to be made to the geometry of the fixed partial denture to adjust it to better fit the patient.

2. Experimental procedure

2.1. Development of the original digital model and the rest of the fixed partial dentures

To create the digital model of the Cr-Co fixed partial denture (the original digital model), the dentist took a dental impression, Fig. 1(a), from a real patient and then made a plaster model, Fig. 1(b). The plaster model was scanned using the Ceratomic DS-900 collimated scanner. Using the CAD software that comes with the scanner and is specifically designed for dentistry, the solid model representing the part of the patient's mouth where the fixed partial denture would be implanted was composed.

Based on the solid model obtained and using the options available in the CAD application, the digital model of the Cr-Co fixed partial denture was created and adjusted (Fig 1(c)). This fixed partial denture was to be mounted on the patient's two abutments and used as a base on which to build the three false ceramic teeth. The original digital model, Fig 1(c), was the reference for the physical manufacture of the Cr-Co fixed partial dentures.



(a) (b) (c)

Fig 1. (a) impression of the patient's mouth; (b) preparation of the plaster model of the abutments which would support the fixed partial denture; (c) creation of the original digital model.

The fixed partial dentures were made by machining and selective laser sintering using the original digital model, which was exported in STL format so that it could be used in a CAM application. To make the fixed partial denture using the lost wax method, the plaster model created prior to scanning was used. Fig. 2 shows examples of fixed partial dentures made using each of these processes.

(a) Lost wax (b) Milling (c) Sintering

Fig.2. (a) Cr-Co fixed partial denture made using the lost wax technique; (b) milling; (c) selective laser sintering.

For purposes of comparison, all the fixed partial dentures made were scanned, producing what were called digital models of the sample.

2.2. Method of comparison

Given the variability in fixed partial denture assembly in the mouth of the patient, an assembly method that was as close to reality as possible was chosen. The dentist assembled the dentures manually by touch in order to correct any adjustment defects. Assembly must be carried out in a very short time because the cement hardens quickly and there is only around one minute to get the denture into place. The following are some of the main points to be taken into account during assembly:

- The most important fit for fixed partial dentures is marginal fit
- In aligning the fixed partial denture with the rest of the patient's teeth, marginal fit should be maintained and room should be left for the final coat of ceramic enamel around the whole fixed partial denture, including the adjoining teeth
- The fit of the fixed partial denture to the abutments is somewhat tapered. This draft allows the fixed partial denture to be removed at a later date if necessary without pulling out the supporting structures
- The fixed partial denture is supported on more than one structure. In this case it is supported by two abutments. It is, therefore, not possible to take only one reference. Each interface with an abutment in the patient's mouth has its own errors and, since the fixed partial denture is a rigid structure, correcting an error in one will affect the others
- The cement absorbs certain errors, but should not leave empty areas (trapped air) in the final assembly as this would create weak points
- The fitting process takes several days so slight shifts may occur in the position of the support structures, the abutments, in the mouth of the patient compared to the position that was originally envisaged.

Given all of the above, the method of comparison proposed is made up of the following steps:

1. The scanned base (made from the dental impression), which was used to create the original digital model, is used as the point of reference.

2. The digital model established by the dental technician (original digital model) is mounted on the base. The fit will be optimal since this model is created directly from this base.

3. The original digital model is hidden and the digital model from the scan of the physical fixed partial denture (the digital model of the sample) is mounted. For this phase, the CAD application's collision detection function is activated and the drag and turn tools are used. Position and orientation are adjusted visually on screen. The distances between the digital model of the sample and the base are determined by measurements carried out on the planes, layout and elevation, see Fig. 3.

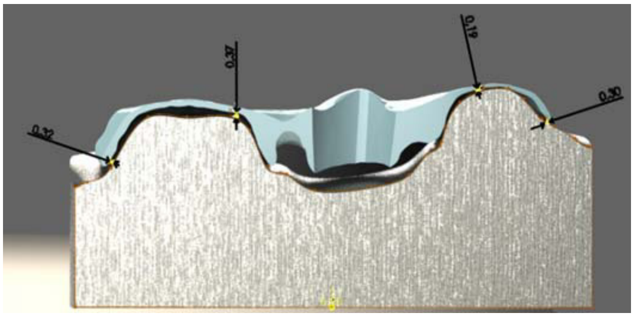


Fig.3. Measurements from the digital model of the sample to the base.

4. The following planes (views) of the molar and pre-molar from the original digital model were generated. They are separate from one another. A plane (view) turned according to the three outermost points of the original model's best-fit line, which will determine marginal fit, containing a closed continuous profile. These three points would be the first to come into contact with the base. Points were chosen at angles to one another in order to avoid incorrect orientation. A plane (view) taken from the same angle as the one above but outside the digital models, see Fig. 4, "view of molar" and "view of pre-molar".

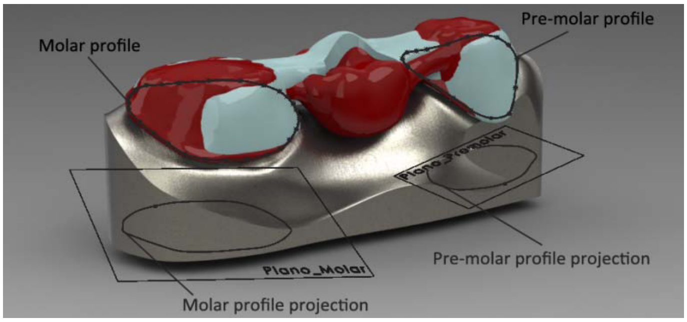


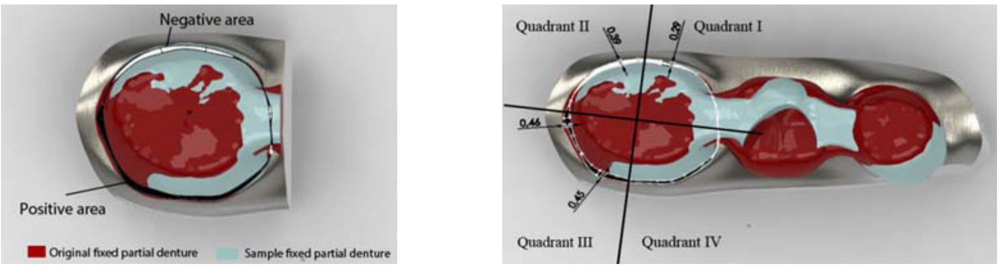
Fig.4. Views of the profile projections for checking marginal fit of the molar and pre-molar.

5. For the comparison, both the original digital model and the digital model of the sample were left visible. The intersection curves between the models and the planes described in point 4 were then created. These curves can be used to compare the closed profile of the original digital model with that of the digital model of the sample. This comparison determines the deviation between the models measured at a given height in relation to marginal fit where the model material completely surrounds the abutment.

The comparison of planes located off the models was repeated for the molar and pre-molar. In this case spline-type curves were projected tracing the marginal line in both the original digital model and the digital model of the sample. This enables the final marginal fit to be calculated.

When performing comparisons, the CAD application calculates the size of the area resulting from the cuts between the profiles. A "positive area" is when the profile of the original digital model appears first when moving from the centre of the abutment outwards on the plane of the cut. A "negative area" is when the profile of the digital model of the sample appears first, figure 5 (a).

6. Using the cutting planes referred to in point 4, the largest and smallest deviations between the profiles of the original digital model and the digital model of the sample were calculated. In the following examples, the two largest and the two smallest deviations for the molar and pre-molar areas of each sample were used. The centre of gravity of each abutment was used as a reference point. In addition, a note was made of which quadrant the points in question were located in so as to get an idea of how far and in which direction the digital model of the sample had moved in relation to the original digital model, figure 5 (b).



(a) (b)

Fig.5. Deviations between the profile of the original digital model (red) and the sample (blue).

Below are some of the results from the comparison of the original digital model with two fixed partial dentures made using lost wax, two machined fixed partial dentures and two made using laser sintering.

Table 1 shows the results for positive and negative areas for the six sample fixed partial dentures when compared with the original digital model.

Table 1. Size of deviations, mm^2, between original digital model and digital models of the samples.

	Molar		Pre-molar	
	Positive area	Negative area	Positive area	Negative area
Lost wax_1	4.01	-4.57	2.32	-2.50
Lost wax _2	1.18	-6.71	0.52	-2.74
Milled_1	2.10	-3.94	1.07	-1.30
Milled_2	2.70	-3.89	1.38	-1.78
Sintered_1	3.30	-4.07	0.97	-2.27
Sintered_2	1.90	-4.07	1.45	-1.51

Table 2 contains the results for the molar, where two maximum and two minimum points were taken per sample and the quadrant where the points were located was included. Table 3 shows the results for the pre-molar.

Table 2. Molar. Maximum and minimum linear deviations between the original digital model and the digital models of the samples. Figures in mm.

	Molar							
	Maximum				Minimum			
	1st		2nd		1st		2nd	
	Max.	Quadrant	Max.	Quadrant	Min.	Quadrant	Min.	Quadrant
Lost wax_1	0.63	III	0.36	III	0.43	IV	0.31	I
Lost wax _2	0.71	III	0.59	III	0.33	IV	0.22	I
Milled_1	0.39	III	0.29	III	0.30	I	0.28	II
Milled _2	0.46	III	0.45	III	0.39	II	0.29	I
Sintered_1	0.48	III	0.41	III	0.41	I	0.31	I
Sintered_2	0.39	III	0.37	III	0.21	IV	0.19	I

Table 3. Pre-molar. Maximum and minimum linear deviations between the original digital model and the digital models of the samples. Figures in mm.

	Pre-molar							
	Maximum				Minimum			
	1st		2nd		1st		2nd	
	Max.	Quadrant	Max.	Quadrant	Min.	Quadrant	Min.	Quadrant
Lost wax_1	0.39	II	0.28	II	0.44	IV	0.32	IV
Lost wax _2	0.25	II	0.21	IV	0.31	IV	0.31	IV
Milled_1	0.22	I	0.11	I	0.30	IV	0.22	IV
Milled _2	0.29	II	0.23	III	0.28	IV	0.19	IV
Sintered_1	0.33	III	0.21	III	0.23	I	0.15	IV
Sintered_2	0.15	III	0.10	III	0.31	I	0.23	IV

The most important conclusions that can be drawn from the data shown include the following. Taking into account that the positive or negative area refers to a discrepancy between the original digital model and the samples (Table 1), it is clear that the samples with the largest discrepancies are the lost wax fixed partial dentures, followed by the sintered fixed partial dentures and that the milled fixed partial dentures are the closest fit. Then, by looking at the values for the positive and negative areas, we can classify the fixed partial dentures by how loosely or tightly they fit the abutment for the molar and the pre-molar. Table 1 shows that both the positive and negative areas for the molar are always larger than the areas for the pre-molar, whatever the manufacturing process (remembering that the minus sign simply indicates the position of the digital model in relation to the sample). This means that it would be advisable to change the molar part of the original digital model. Since the fixed partial denture links a molar and a pre-molar, very low values for the positive and negative areas of one of these causes the area values for the other to rise. The pre-molar of Sintering_1 has low values for positive and negative area, meaning that a very good fit has been sought there. In order to achieve that fit, the fit to the molar (the structure joining the two is rigid) has been sacrificed and its areas are larger.

This gives rise to further conclusions. The best fit will obviously have been achieved when the area values are minimal. Positive values are preferable since negative values mean altering the abutment. High values for both positive and negative areas indicate that the sample digital model is poor, particularly if an examination of the quadrants where the maximum and minimum points for the molar and pre-molar are located shows there is no possibility of adjusting the fixed partial denture by moving it over the abutments. An initial classification of the fixed partial dentures can be made on the basis of the sum total of the area modules. The digital models of the samples with the lowest scores will be preferred as such scores indicate that the corresponding physical fixed partial denture fits better.

Although an initial classification can be carried out using the areas, the breakdown of the values contained in tables 2 and 3 is needed to quantify the deviations and draw conclusions such as the following. Table 2 shows that for all the digital models of the samples, the maximum distances are found in quadrant III. It would, therefore, be advisable to correct the original digital model. The part of the model which should be changed is the part in that quadrant. In table 3, from the data on the pre-molar it is clear that the fixed partial dentures made using laser sintering have lower maximum and minimum values. Sintering_2 has the lowest values for maximum distances with 0.15 and 0.10. However, the lowest values for minimum distances are those for Sintering_1. These two distinct sets of figures mean that it would be advisable to consider fixed partial dentures made using sintering better than those made by milling. The maximum and minimum values for a single fixed partial denture should not be in the same quadrant as this would indicate a very pronounced local change of geometry.

By using the quadrants it is possible to distinguish errors caused by the manufacturing process from errors arising from the digital model. For example, if, for all the digital models of the samples, whether produced using the lost wax, milling or sintering technique, the maximums for the molar are in quadrants II and III, and the minimums for the pre-molar are in quadrants I and IV, this would indicate general displacement and the original digital model should be revised. However, if the digital models belonging to only one manufacturing technique are affected, milling, for example, then the cause is likely to be the manufacturing process, in this case the milling.

With a more detailed analysis of the data, the deviations associated with the models can be identified and described and fed back in at the fixed partial denture design stage. Another interesting application for these comparisons is the setting of limit values, which would allow pieces to be accepted or rejected on a reasoned basis almost automatically.

3. Conclusions

The proposed method allows the original model to be compared to any manufactured fixed partial denture. Furthermore, if more than one fixed partial denture is made, comparisons can be made between fixed partial dentures.

It allows the level or degree of fit between the fixed partial denture and the base (the abutments) to be quantified for the fixed partial denture as a whole and for all its pieces at the same time. Assembly is done in the same way it would be done in reality since the user has full and free manual control, ensuring there is a close link between simulation in a CAD environment and fitting a real patient.

The reference points and variables used for the comparison can be adapted and added to by the dental technician to take into account other aspects of the fit, making this a powerful open tool for detecting fixed partial denture defects.

At the same time, equipment and applications which are available in dental laboratories are used, allowing dentists to make decisions based on data which they themselves can easily extract from the simulation.

4. Further works

Since the proposed method has been shown to be feasible, a detailed study of the accuracy of the results obtained is needed. This would analyse all the elements involved and the contribution of each element to the final error (the chain of uncertainty), from errors linked to the process of taking an impression to those linked to the collimated scanner, the CAD software used, the peripheral used for modifying the 3D models, the manufacturing process used or thesilicone primer used in the part to be scanned, etc.

Once the orders of magnitude and their accuracy are known, the comparison method will be used to describe and classify the main defects for each manufacturing method and make suggestions on how to correct errors at the design stage. Furthermore, another important feature of the proposed method is the possibility of automating it using the development modules included in commercial CAD software packages (‘Software Development Kit’).

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