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The evaluation of the accuracy of shape imaging of prosthetic abutment

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Purpose: The aim of the study was the in vitro evaluation of the accuracy of shape imaging of abutment teeth using different impression compounds. *Methods*: To compare the accuracy of the shape of the numerically imaged real prosthetic abutments with the tested models of abutments obtained with the replica technique, the Geomagic Qualify program was applied. Making use of the licensed program Statistica, statistical analysis of the results obtained was conducted. *Results*: In the research procedures, analyses were conducted for 10 abutment premolars and 10 abutment molars. The tests allowed us to state that the dimensional accuracy of the models of prosthetic abutments obtained with the application of elastic compounds tested ensures comparable shape imaging. *Conclusions*: The objective method developed and applied here is suitable for controlling the imaging of the abutment teeth. The Geomagic Qualify program that was used during the research is a reliable tool of 3D analysis for the estimation of procedure of abutment tooth preparation and indication of an error of shape of prepared occlusal surface, lateral surface of abutment and errors of shaping the chamfer zone.

Key words: *prosthetic abutment, replica technique, numerical models, 3D analysis, shape errors*

1. Introduction

In the process of production of prosthetic crowns it is a very important procedure to carry out the shape imaging of the determined prosthetic abutment on the basis of which the patient's individual permanent construction will be modeled [7]–[10], [12]. The accuracy of imaging is connected with the manner of clinical preparation and preparation of the abutment tooth, the precision of impression as well as the quality of the working models which constitute a model for the technological process. On each stage of these procedures the shape errors may appear and they may determine the conditions of accuracy and tightness of the crown against the abutment, which finally decides on the success of the treatment (Fig. 1). The analysis of the properly produced crown includes the estimation of shaping of the perigingival zone, marginal tightness and fits between the abutment tooth and the crown core [10], [14], [15].

The aim of the tests conducted was to find the answers for the following questions:

1. Which impression material makes the best fit of the crown to the clinically prepared prosthetic abutment.
2. Which elastic impression material is characterized by the best accuracy of imaging due to its rheological parameters.
3. The application of which impression material allows the best tightness of prosthetic crowns to be obtained.

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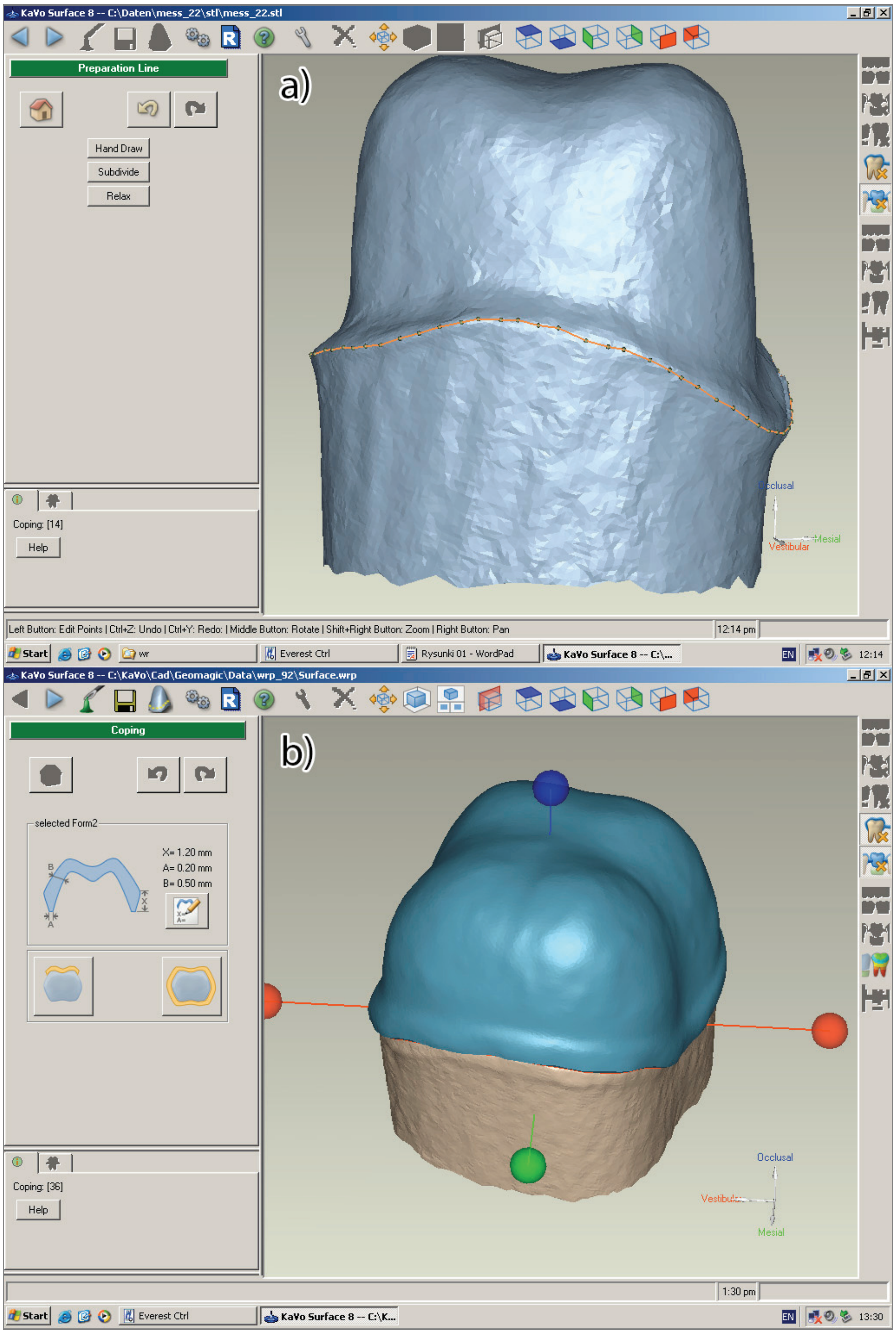

Fig. 1. Modeling of the prosthetic reconstruction in CAD/CAM system (Kavo Everest by KaVo): (a) determination of the preparation on the abutment tooth, (b) designing the core on the working cast

2. Materials and methods

The testing material contained 10 maxillary premolars and 10 mandibular molars, extracted on account of periodontal and orthodontal indications. The teeth were stabilized in acrylic stands and grinded with the circumferential chamfer degree. The chamfer angle equaled 140° ± 4°. The abutments were scanned and then three-dimensional CAD reconstructions were carried out, and thus they became the reference models. The scanning was instrumented with the optical speckle scanner Everest Scan Pro 06 1086 by KaVo.

Next, the impressions of the tooth abutments were collected with the help of the following impression materials:

1. Silicone additive impression material of soft consistency Bisico S1 by Bisico.
2. Silicone additive impression material of soft consistency Bisico S1 and correction impression Bisico Super Hydrophil S4 Suhy by Bisico – dual impression technique in two stages.
3. Alginate class A with chromatic phase indicator Kromopan 100 by Lascot – mechanically mixed.
4. Polyether of average depth Impregum Penta and light correction impression Permadyne Galant by 3M ESPE – dual impression technique in two stages.
5. Sillicone condensing Zeta Plus by Zhermack.
6. Sillicone condensing Zeta Plus by Zhermack and correction impression Oranwash by Zhermack – dual impression technique in two stages.

In the procedures of preparing and working with the impression masses the producers' recommendations were taken into consideration. On the basis of these impressions, after 1 hour, plaster model stumps of abutment teeth were cast using the die stone type IV Fujirock EP Pastel Yellow by Fuji. The obtained plaster models of the abutment teeth imaged with different materials were scanned with the use of the same scanner Everest Scan Pro. In that way 120 virtual, three-dimensional testing models were created.

To compare the shape accuracy of the imaged numerically real prosthetic abutments (reference) with the abutments of the testing models obtained on the basis of the impressions using different impression materials, the Geomagic Qualify program was applied. That program, in the procedure of the best shape fit, sets automatically comparable solids and then identifies positive and negative deviations resulting from the accuracy of shape imaging of the test model of the abutment tooth against the reference model.

Making use of the program Statistica, the analysis of the obtained results was conducted. At the first stage, the obtained results of the accuracy of imaging (deviations between the model premolar and molar teeth and plaster casts taken from the images using six groups of testing impression masses for premolar and molar teeth – no. 6×2×10) were subjected to the analysis using the descriptive statistics. The results were obtained on the ratio scale and there were determined the minimal and maximal values, the average value and the standard deviation.

Distributions of particular variables were also tested and presented in the numerical and graphic forms. The tests included the normal distributions of variables for premolars and molars in each group at the null hypothesis H_0: the distribution of deviations was normally distributed. The value of the level of significance $\alpha = 0.05$. The outcome of the analysis based on the Shapiro–Wilk test was compared with the given level of significance α (if $p < \alpha$ H_0 is rejected taking the alternative hypothesis H_1, if $p > \alpha$ – there are no grounds to reject the hypothesis H_0). Each time the results of the Shapiro–Wilk tests were greater than 0.05. Thus, the hypothesis H_0 could not be rejected and the distributions tested were normally distributed.

In the next stage, the deviations of accuracy of imaging between the premolar and molar teeth and t-test were analysed. For that comparison the level of significance was established as $\alpha = 0.05$ (The null hypothesis H_0: there are no statistically significant differences between the distribution of the group of premolars and molars. The alternative hypothesis H_1: there is a statistically significant difference between the distribution of the groups of premolars and molars). In the analysed procedure $p > \alpha$, that is, in the group of premolars and molars, there are such differences.

The following statistical procedure was based on the measurements of deviations of accuracy of imaging of the tooth shape depending on the applied impression material with one-way analysis of variance ANOVA. To conduct the analyses the following criteria were established: homogeneity of variance, the normality of distribution, equalness-in-number in the test groups (The null hypothesis H_0: there are no differences between groups using different impression materials. The alternative hypothesis H_1: there is a difference between groups). The outcome of the test is $p < 0.05$. The hypothesis H_0 was rejected while the alternative hypothesis H_1 was accepted. That is why it was recommended to conduct post-hoc tests. One applied the Least Significant Difference Test (LSD) and Tuckey's Procedure. Both tests gave similar results. Statistically significant differences ($p < 0.05$) were indicted between the groups of materials of silicone additive type of binding and polyether ones and the rest of the groups of impression materials.

3. Results

The program Geomagic Qualify enabled us to compare the fit of abutment teeth to the plaster copies of these teeth obtained as replicas on the basis of impressions with the application of different impression materials. In the research procedures one conducted analyses for 10 premolars abutments and 10 molars abutments. For each of the abutments plaster copies were prepared with six impression materials. Figures 2 and 3 present selected maps of accuracy of shape imaging of abutment premolars and molars prepared with the help of clinical elastic materials.

Analyses of reports in the form of maps and summary tables indicate that all the histograms and maps are characterized by the symmetric distribution and small values of positive and negative shape deviations (Table 1).

On the basis of the results obtained one can state that all the test compounds ensure proper shape imaging of prosthetic abutments. In the images with the following masses: silicone additive Bisico S1 soft and correction material Bisico Super Hydrophil S4 Suhy, polyether Impregum Penta and correction impression Permadyne Galant as well as silicone condensing Zeta Plus and correction impression Oranwash, it was confirmed that there are distributions of positive and negative deviations of very small values (Figs. 2, 3). Small values of deviations may indicate good rheological properties of the above-mentioned masses. Worse character of imaging of concave and convex areas connected with the rheological parameters of the applied material was

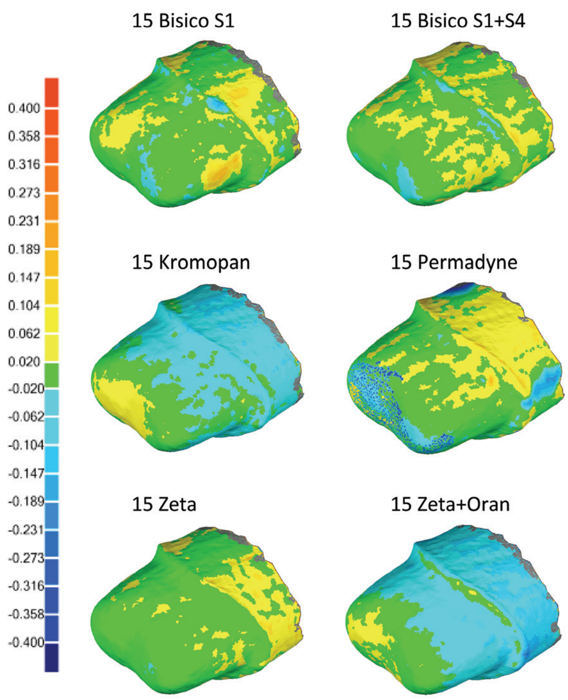

Fig. 2. The map of accuracy of shape imaging of abutment premolars with different impression materials

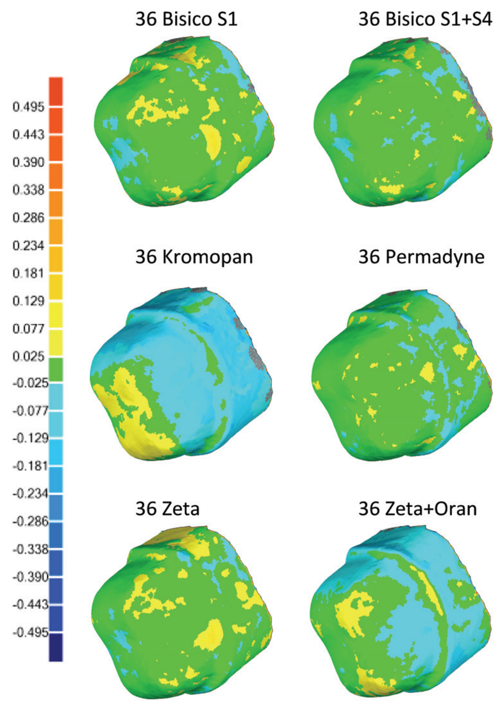

Fig. 3. The map of accuracy of shape imaging of abutment premolars with different impression materials

Table 1. Summary table of maximal and minimal shape deviations of abutment premolars and molars with standard deviation

Abutment	Type of the impression material	Deviations of accuracy of shape imaging of abutment teeth, mm		
		Deviations 3D max	Deviations 3D min	Standard deviation
Premolars (tooth No. 15)	Bisico S1	0.401	–0.399	0.049
	Bisico S1+S4	0.230	–0.230	0.038
	Kromopan	0.400	–0.392	0.051
	Impregum+Permadyne	0.280	–0.280	0.041
	Zeta	0.400	–0.398	0.055
	Zeta + Oranwash	0.340	–0.341	0.048
Molars (tooth No. 36)	Bisico S1	0.496	–0.496	0.062
	Bisico S1+S4	0.240	–0.243	0.042
	Kromopan	0.496	–0.495	0.074
	Impregum+Permadyne	0.265	–0.262	0.045
	Zeta	0.497	–0.497	0.072
	Zeta + Oranwash	0.363	–0.367	0.050

observed for images with the following materials: hydrocolloid Kromopan and double mixing impressions, correction impression with silicone condensing material Zeta Plus and Oranwash (Figs. 2–4).

In both sets one affirmed positive deviations – in the zone of occlusal surface prepared, negative deviations – in the zone of lateral surface. For both of these materials it was noticed that setting of the flowing zone and localization and shape of an imaged area influence the occurrence of positive and negative deviations against the reference model. Furthermore, for the images of tooth abutments, on the basis of Kromopan material, it was stated that there is an unfavorable distribution of deviations on the imaged chamfer – of slight values, indeed, but changing from the positive to negative – which in the conditions of shape fit will cause the occurrence of summation error (Fig. 4).

The best accuracy of shape imaging of real prosthetic abutment is a distinguishing feature of copies of plaster abutments obtained on the basis of double mixing impressions, correction impression of silicone additive material Bisico S1 soft as well as silicone additive liquid Bisico Super Hydrophil S4 Suhy (Fig. 5). Moreover, when using these double mixing impressions, correction impressions Bisico S1 soft and Bisico Super Hydrophil S4 Suhy one gained the best sharp contours in the chamfer zone. The comparable feature of sharp contours is characteristic of the chamfer imaging with Bisico S1 soft material (Figs. 5, 6).

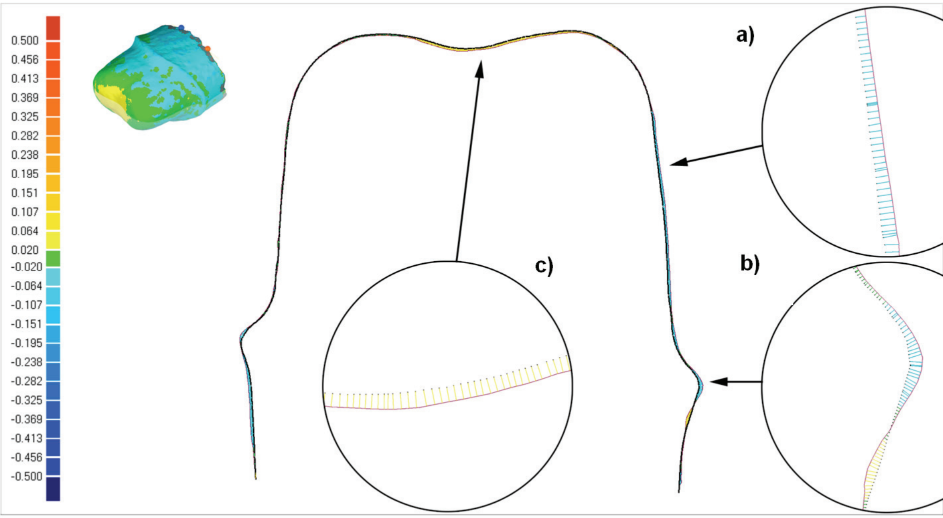

Fig. 4. The distribution of deviations of accuracy of shape imaging of abutment premolar with Kromopan material in cross-section by frontal plane: (a) zone of lateral surface, (b) chamfer zone, (c) zone of prepared occlusal surface

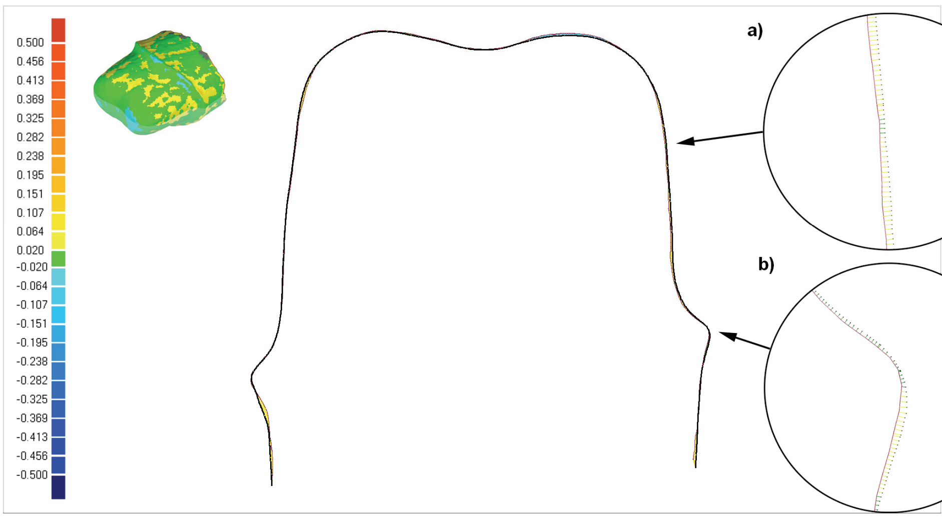

Fig. 5. The distribution of deviations of accuracy of shape imaging of abutment premolar with materials Bisico S1 soft and Bisico Super Hydrophil S4 Suhy in cross-section of frontal plane: (a) zone of lateral surface, (b) chamfer zone

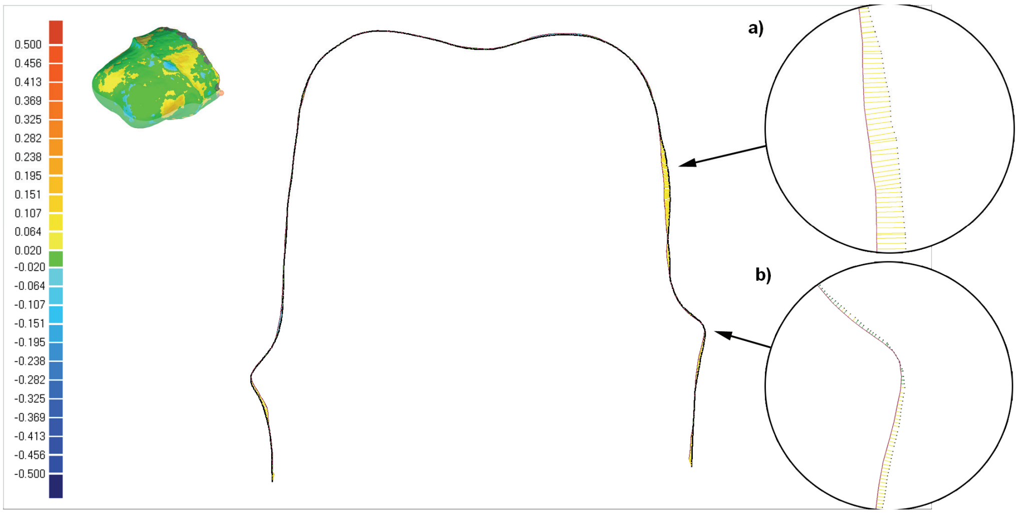

Fig. 6. The distribution of deviations of accuracy of shape imaging of the abutment premolar with Bisico S1 soft materials in cross-section of frontal plane: (a) zone of lateral surface, (b) chamfer zone

Images of abutment teeth with the application of impressions of the following elastic materials: silicone additive and condensing used in double mixing impressions, correction impressions as well as polyether impressions applied in double mixing impressions, correction impressions provided optimal accuracy based on the best fit to clinically prepared prosthetic abutment and the best sharp contours in the zone of the imaged chamfer.

4. Discussion

The program used in the study is a reliable tool to conduct a geometrical analysis of clinically prepared prosthetic abutment teeth. Due to the very good visualisations of analyzed shapes, it can verify the prosthetic's work – tooth preparation for the crown, which is executed freehand in the patient's mouth. The procedure requires that in the surgery saving tissues and in the proper preparation of perigingival zone one should create the chamfer with permanent chamfer angle on the periphery of the tooth. The aim of that tooth preparation is creation of conditions to set the formed crown which will have proper tightness and retention and zones of stress concentrations will not occur in occlusion and chewing. The zones of stress concentrations which may result from the faulty grinding of the abutment and its incorrect imaging, especially in the zone of degree, may cause the loss of retention of the crown to the abutment and unsealing of the marginal zone and penetration of pathogenic bacteria.

The accuracy of imaging can be estimated by fit or tightness of the construction. For long-term effective therapy with the use of permanent restorations, the tightness of the construction is necessary [3], [11]. Clinically unacceptable marginal tightness may cause cementum leaching with biological complications such as secondary caries, problems with periodontium and pulp inflammation [11], [12]. Non-parallel internal fissure may cause cementum crumbling because of the irregularity of contact pressures in the conditions of chewing and also result in unsealing of the crown and loosening. The definition of the term tightness is different in different studies. What is more, various techniques of measurement of marginal and internal fissures are applied [7], [10], [11], [14]. Together with increasing number of techniques of designing in CAD/CAM systems in reconstructive dentistry, a significant meaning is attached to numerical methods of accuracy estimation of shape imaging.

The issue of accuracy of imaging of prosthetic abutments, which is the basis of final creation of optimal crown, especially in CAD/CAM systems, is analyzed by many researchers [1], [4], [5], [7], [9], [10], [18]. It concerns the production of different constructional solutions of crowns. It is analyzed in crowns of metal core faced with ceramics [8], [9], [17], ceramic crowns [2], [13], [16], ceramic crowns of zircon oxide stabilized by yttrium [5], [7]. The methods of estimation of imaging accuracy of abutments are based on physical measurements of prosthetic abutment and measurements of imaging of the centre of core using light impression compound [8], [10], with the technique of scanning of referential models and replicas [6], [7], [10], analysis of crown fit with micro CT [11] and the analysis of shape with the help of structured light [12]. None of these methods, however, uses an impartial tool – fit estimation in authomatic numerical procedure free from errors related to the person conducting the measurement.

The applied volumetric procedure of accuracy of imaging of prosthetic abutments is originally developed by the authors. It allowed to estimate the quality of materials and is clinically used in Prosthodontic Department in Jagiellonian University Medical College.

Impression masses differ in rheological properties which results, far and foremost, from the molecular structure and the character and time of bounding. The phenomenon of creeping of the mass depends on the structural viscosity in the working temperature as well as under influence of shear stress they can, better or worse, overflow in the details of the prosthetic field.

When working with materials and taking impressions it has been found that the shear force influences the structural viscosity in both aforementioned sets of impression materials. That phenomenon was observed both while increasing the oppression of the mass during the abutment imaging as well as while the material was being squeezed from the syringe at syringing the abutment. The viscosity of unbound material decreased when the internally working forces increased. The moment they ceased, the viscosity increased. In both materials the phenomenon of shear tinning occurred and it was based on the decrease of viscosity together with the increase of the internal pressure which caused the increase of the shear rate. The mechanism of that phenomenon results from the molecular structure and is based on the layer arranging of the structure of the material in accordance with the direction of the tangential force and induced tangential speed – that is why the structural viscosity decreases. After cessation of the force, the viscosity increases with the randomization molecules network. It is believed that this phenomenon has decided on more precise abutments imaging.

Applied in the tests the impression elastic materials undergo contraction during the process of polymerization. Some of them may release by-products and also contract. The main factor which is responsible for the contracting of the material during the process of bounding is crosslinking of the chain and change of the bindings within and between the polymer chains. That is why, to obtain greater accuracy the plaster models were cast when the time of 1 hour elapsed after the impression was taken – it was applied to all sets of impression materials.

To conduct the tests, 4 groups of materials were chosen: alginate, silicone of additive and condensed way of bounding as well as polyether ones. It should be mentioned that the accuracy of imaging of shape of prosthetic abutments will be dependent on wettability and hydrophilicising of the impression materials. In the materials tested the hydrophilic property was characteristic of alginate material only, and indirectly polyether material. The silicone material of additive way of bounding is not as wettable as the polyether one.

5. Conclusions

The objective method developed and applied here is suitable for controlling the imaging of the prosthetic field.

The Geomagic Qualify program that was used during the research is a reliable tool of 3D analysis for estimating the procedure of abutment tooth preparation and indication of an error of shape of prepared occlusal surface, lateral surface of abutment and errors of shaping the chamfer zone.

The tests conducted allowed us to state that the measurement accuracy of plaster models of prosthetic abutments in premolars and molars obtained using all elastic materials tested with the observation of rules of their preparation and impressions collecting, ensures sufficient shape imaging for further procedures of crown modeling and production.

The best accuracy of imaging of prosthetic abutments was obtained when applying the double-mixing correction impressions. The initial impression was taken with the silicone material of additive way of bounding of thick consistency, with the space left for the final impression with the help of the hydrophilic materials of thin consistency and when the polyether material of average density and the filling impression with the polyether material of thin consistency were used.

The accuracy of imaging of tooth abutment is influenced by the technique of impression taking, the structural viscosity of the material, time of bounding and changing of the dimensions during the bounding, the time of return to the original shape after the deformation as well as the susceptibility to creep and hydrophilic.

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