Archives of Materials Science and Engineering

Volume 95
Issue 1
January 2019
Pages 31-40

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

**DOI:** 10.5604/01.3001.0013.1015

# Application of polymer impression masses for the obtaining of dental working models for the stereolithographic 3D printing

**L.B. Dobrzański *, A. Achtelik-Franczak, J. Dobrzańska, P. Pietrucha**
Medical and Dental Engineering Centre for Research, Design and Production ASKLEPIOS Ltd, Science Centre, ul. Królowej Bony 13 D, 44-100 Gliwice, Poland
* Corresponding e-mail address: lech.dobrzanski@centrumasklepios.pl

**ABSTRACT**

**Purpose:** The aim of the work is to execute measurements of digital dental models taken by scanning prosthetic impressions using the engineering CAD software and finding dimensional differences and scale factor for precise reproduction of patient tooth dimensions.

**Design/methodology/approach:** Tests were carried out involving the execution of 3 series of impressions for selected impression materials, which were then scanned using two types of prosthetic scanners. Gypsum models based on mentioned impressions were scanned and dimensionally compared with impression-based digital models. Benchmark impressions were also performed in order to verify the obtained results and determine the correction factor for dimensions. The dimensional differences between impression groups were calculated by using Engineering CAD software.

**Findings:** It was found, that compared to the base model, the digital model has a smaller volume than the object being mapped, the digital models based directly on the impression should be 0.09 - 0.12% rescaled to match the dimensions of the base model.

**Research limitations/implications:** It is necessary to perform a practical verification of the results achieved and apply the determined coefficient in practice by creating working models using precise devices such as a 3D SLA printer and verify their results with intraoral scanner based models.

**Practical implications:** This test will allow making precise working models using a 3D printer, allowing finally to perform, for example, implant-based bridges directly from the level of implants, using the masses described in the study.

**Originality/value:** The comparative studies of polyvinyl siloxane and alignate impression materials were carried out in order to measure dimensional differences between working models made directly from the impression and gypsum models and compared with pattern, which allowed to determine the expansion coefficient, which will allow to work in 3D printing technology with close representation of real situation in the patient's oral cavity, which is particularly important when performing full arch bridges and extensive work on implants, including direct implants. The work has practical applications for both dental engineers and dentists performing advanced prosthetic work.

**Keywords:** Polyvinyl siloxane and alignate impression materials, CAD/CAM in dentistry, Digital prosthetic working models

© Copyright by International OCSCO World Press. All rights reserved. 2019

**Reference to this paper should be given in the following way:**
L.B. Dobrzański, A. Achtelik-Franczak, J. Dobrzańska, P. Pietrucha, Application of polymer impression masses for the obtaining of dental working models for the stereolithographic 3D printing, Archives of Materials Science and Engineering 95/1 (2019) 31-40.

BIOMEDICAL AND DENTAL MATERIALS AND ENGINEERING

## 1. Introduction

The use of computer aided design and manufacturing CAD/CAM [1-3] in the production of dental restorations using dental precision industrial manufacturing equipment with high accuracy reaching several micrometres, such as printers and 3D CNC milling machine [4] requires the designer CAD/CAM drawing attention on introduced inaccuracies at every stage of performing prosthetic work, including dimensional changes of the prosthetic impressions and prosthetic gypsum used for the production of working master plaster models. Due to the fact that the use of intraoral scanners dental continues to be difficult in the case of full arch restorations or bridges with more than 6 units it is necessary, to search for the hybrid solutions combining classical methods of models production, with solutions based on computer aided design and manufacturing, which will be able to ensure the highest accuracy of the generated models as well as the final restorations [5-7]. This technique based on procedure of taking the scan directly from the impression tray using an analogue-digital hybrid method. Very important advantage of this solution is possibility of executing the working model using 3D printing at the same time as the prosthetic restoration, which allows to save time necessary to complete the all tasks by the time necessary to obtain gypsum working parameters, creating base, sectioning and finishing the margin line on the model dies. What is important, in the procedure where the CAD/CAM designer is scanning the finished master model, the previously realized stages using gypsum are duplicated in the design software. In the hybrid method, these stages are significantly shorter than in the gypsum-based workflow. Combined with a 3D printer provides the right accuracy.

[8-10] e.g. in the SLA printing technology, a working model can be made to perform the final characterization of the prosthetic restoration at the same time as the prosthetic restoration using a CNC milling machine or a 3D SLS/SLM printer [11-13] for metal ensuring reproducibility the model relative to the patient's teeth at the level of a few or a dozen micrometres. Analysis of the accuracy parameters of commercially available impression materials and dental gypsum demonstrate that the plaster models are undersized in compare with patients teeth [14-17] which require the implementation of the software design parameters such as the tool diameter compensation, space for the cement or a greater one order of magnitude in relation to real differences. In the case of gypsum elimination, there is a risk, that in fact the patient's teeth have a significantly larger volume than the model made on the basis of the impression tray. It is therefore necessary to decide whether this difference is significant and how it is possible to compensate that difference, so that it is possible to make screwed full arch bridges directly from the implant level. For this purpose, the accuracy of hybrid and standard models was tested based on selected types of impression materials and one high-precision prosthetic gypsum. Two types of prosthetic scanners were also used: laser and light.

Impression materials are divided into rigid and flexible, the first group includes plaster impression coping, stents weight, weight zinc oxide-eugenol, waxes and impression gutta-percha, is a group of the masses is not used in modern dentistry because of the numerous limitations in their use. Elastic masses include alginate, agar and elastomer masses. The group of elastomeric masses includes silicones, polyether, polysulphide and vinyl siloxane mass. The silicone masses are divided into additional ones, i.e. polyvinylsiloxanes and condensation. Impression materials due to their use in the oral cavity of the patient must meet the following criteria: harmlessness to the tissues of the mouth, a pleasant taste and smell, the precision in projection information anatomical shape stability conferred to the oral cavity, mechanical strength, a suitable setting time, ease and repeatability in mixing. In turn, due to laboratory performance, they should be characterized by the least possible volume change in time of ease of separation from models and the possibility of high reproduction of contours during scanning [18].

Alginate masses are hydrocolloidal that during the curing process in the mouth extend from the sol gel, the sodium alginate connecting with the calcium sulfate forms an insoluble calcium alginate filler is diatomaceous earth masses are used for impression orientation, opposite and impressions under the prosthesis settling partial. An important advantage due to which alginates are commonly used in a dental office is the low price of weight, ease of earning, short time of binding in the mouth, easy release of the impression from the mouth and pleasant taste of the mass. The disadvantages that exclude the use of this mass for precise prosthetic work are low mechanical strength, high flexibility, susceptibility to deformation, the need to immediately cast the impression [19,20].

Agar masses are hydrocolloidal masses reversible, transition of sol into a gel requires its heating to a temperature of 60-65°C. It consists mainly of water in 80% and agar 14%, the rest is borax and potassium sulphate, the use of these masses is practically analogous with alginate masses, and because of the difficulty in preparing the mass for the impression, the harshness of having a device for heating and the risk of burns to the patient, masses are practically not used in everyday dental practice.

Elastomer masses constitute a significant group of impression materials used in making permanent restorations such as crowns, bridges, crown-root inlays, outlays, removable dentures and for taking functional impressions. These masses can be mixed manually or mechanically in special mixers, thanks to which the proportion obtained during the mixing of components is strictly in accordance with the manufacturer's recommendations, these masses are found in different consistencies of putty body, a thick paste (regular body), liquid paste (light body). Thanks to various consistencies, these materials allow for one-layer and two-layer impressions, and in the case of two-layer impressions in one-time and two-time techniques. Single-layer techniques are reserved mainly for polyether masses, although the manufacturers of these masses have also prepared the possibility of using a light body layer, i.e. they gave the possibility of a two-layer technique, but it is not required to obtain the correct reproduction of the prosthetic field. Two-layer techniques are mainly intended for silicone masses, the first mass layer is putty body mass or regular body second, the thin layer complementing the impression has a thinner light body consistency. As demonstrated by Stępień et al. The two-layer technique is less accurate due to the fact that the basic weight is deformed due to the lack of corrective mass flow, and in order to compensate for this deformation, it would be necessary to accurately find 2 mm for the light body mass on the whole impression surface. They also found that the most accurate method that maps the distance between the elements of the prosthetic field is the one-time technique, both single and double-layered [21]. It should also be emphasized that the simultaneous technique saves time of the doctor and shortens the procedure of the procedure which is appreciated by the patient [22].

Among the silicone masses, we distinguish between condensation and additive known as polyvinylsiloxane, the first of which has a silicone polymer with hydroxyl groups and a filler as the base, the catalyst is alkoxyorthosilicates, silicone polymers and tiniccrylate. During the condensation reaction, cross-linked silicone polymer chains are formed and an alcohol molecule is formed, the polymerization proceeds further after removing the spoon from the mouth, therefore this group of silicones requires immediate casting of the model. The disadvantage of this group is also the susceptibility to deformation and hydrophobicity, which ultimately puts condensation silicones in the use grade below the addition silicones. In polyvinylsiloxane silicons during the polymerization there is an addition reaction between the polymeric base with hydrogen silane groups together with the vinyl groups of dimethyl siloxane and the chloroplatinic acid catalyst. The final product is silicone rubber, and the polymerization ends in the Patient's mouth. The lack of side-by-side polymerization products gives minimal polymerization shrinkage of 0.05-0.1%, which makes it possible to cast the model even a few days later. The advantages of these masses also include their hydrophilicity, the possibility of multiple casting of one impression due to high mechanical strength, dimensional stability, the ability to return shape after deformation which is useful in the presence of arcades [23].

The basis of polyether materials is a polyester copolymer and the ethyl sulphonate catalyst due to their combination in the polymerization process leads to crosslinking of imino groups, the final product is an elastomer, without by-products, causing the polymerization reaction to be completed in the mouth and possible shrinkage is 0.2%. Polyethers are hydrophilic, the impression is characterized by dimensional stability, thanks to which the impression can be poured up to 7 days, and thanks to the high mechanical strength it is possible to cast the impression several times. In contrast to addition silicones, the polyether mass is characterized by high stiffness which is excellent in the case of implant impressions, whereas in the case of the patient's own teeth or bridges requires blocking large arcades [24,25].

Based on clinical experience and a thorough analysis of parameters, polyvinylsiloxane masses were selected for the work: high accuracy of shape [26,27], the possibility of re-modelling, low mass expansion declared by the manufacturer, simultaneous imprinting with the use of two layers. Two masses of a reputable manufacturer were selected. In the comparison, alginate mass, still commonly used to make models of opposed teeth, was also compared. In clinical practice, such a set of masses is commonly used to reproduce the conditions prevailing in the oral cavity, and thus to eliminate inaccuracies in the relation of upper and lower arches it is necessary to analyse just such a set of masses. The performed work will allow to determine the inaccuracy of mapping the conditions prevailing in the oral cavity in relation to the digital models obtained for various purposes, used to perform precise restorations.

The work involved three series of impressions (Fig. 1) – for each of the selected masses, which were scanned in the form of an impression tray using two scanners. Next, plaster models (Fig. 2) were made, which were also scanned in the same way. Measurements were made using professional engineering CAD software. Then, the analysis of the obtained results was carried out.

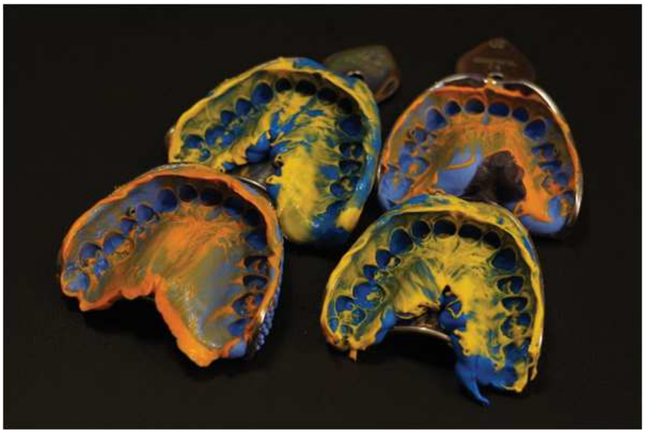

Fig. 1. Photograph showing impressions taken from the patient using selected impression material

Fig. 2. Picture showing one of the plaster models cast from the impressions taken along with the positioning sleeve (between 4 and 5 teeth)

## 2. Materials and methods

The tests were performed using three impression materials:

1. a mass of two-layer polivinylsiloxane mass kneaded with the use of the Honigum Heavy mechanical mixer together with Honigum Light by DMG,
2. mass of a two-layer silivolysiloxane simultaneous hand sanding Silagum Putty Standard together with Silagum Light by DMG,
3. single mass of LASCOD Kromopan Type 1 alginate hand-kneaded.

Their characteristics are presented in Table 1.

Table 1.
Characteristics of selected impression materials [28-30]

| Characteristic | Type of impression material | | |
|---|---|---|---|
| | polyvinyl siloxane single-staged double layered Honigum – impression 1 | polivinylsiloxane single-staged double layered Silagum – impression 2 | single-staged alginate LASCOD – impression 3 |
| Diamentional change during the first 24 hours, % | <0.4 | <0.4 | No data |
| Compensation, % | <0.5 | <0.5 | Do data |
| Preparing time, sec | 135 | 105 | 165 |
| Setting time, sec | 195 | 210 | 30 |
| Shore hardness after setting | 67 | 62 | No data |
| Reproduction accuracy, um | No data | No data | 20 |

In addition, important clinical parameters of selected impression materials include:

- mass 1 – high accuracy of mapping details of the model, ease of application combined with the final hardness after freezing, lack of bubbles, and ease of removal from the teeth after it has set;
- mass 2 – ease of application combined with the possibility of deforming the impression, e.g. when it is necessary to reproduce arcades or impressions of teeth with orthodontic appliances;
- mass 3 – ease of application and a very short time of staying in the patient's mouth, which is especially important for Patients who have great discomfort while making impressions. The biggest advantage of this mass is also its low price and widespread use.

For the performance of master plaster models, the research involved the use of the 4-grade Implant-Rock gypsum plaster from Picodent, characterized by low expansion, creamy consistency and a smooth surface. 20 ml/100 g of water are used to prepare the gypsum working consistency, the mixing time under negative pressure is at least 40 seconds, the working time is about 7 minutes, the hardness after 24 hours is 300 MPa, the compression resistance is 70 MPa and the expansion below 0.08%. In the study, gypsum was mixed in a Renfert vacuum mixer.

It should be noted that the declared expansion of gypsum is much smaller than the declared expansion of each of the impression materials [31], which means that the expansion of gypsum least affects the dimensional changes of the finished model and does not compensate for the expansion of impression materials.

To make the scans (Fig. 3), two scanners were used that differed in the way of retrieving data from the scanned model. The first of the scanners is a laser scanner of the Dental Wings model series 7 and the second one is a 3shape light scanner model E1.

The first of the Dental Wings scanners has a working field of 140x140x140 mm, works in 5 axes, its declared accuracy is 15 micrometres. The scan time of the entire model is about 120 seconds. It has a red laser source, and a high-resolution camera for setting the model in the scanner (necessary due to the closed working chamber). The digital model is obtained by sweeping the laser beam at different angles of the scanned element, which is reflected back to the source reflected from the imaged element. As a result of calculating the delay between sending the beam and its return, it is possible to create a grid of points in the space that, using the technology of stereolithography, forms the plane of the scanned solid. The places depicted can be interpreted by the software and the resulting holes after calling the appropriate function closed taking into account the tendencies creating a uniform shape.

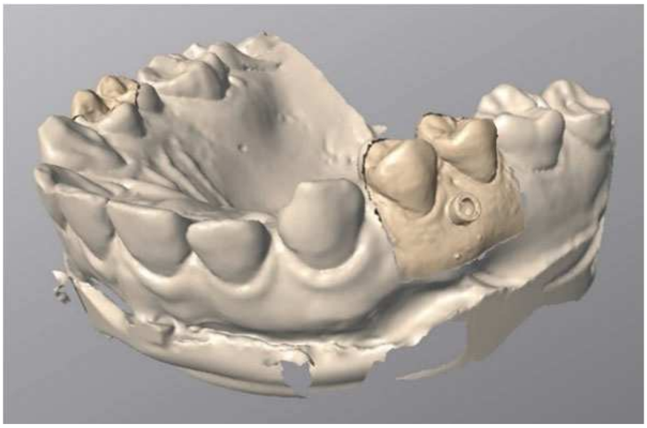

Fig. 3. An example of a plaster model scan made with the use of the Dental Wings scanner together with a positioning element (inserted sleeve between 4 and 5 teeth)

The 3shape light scanner has a larger working area than the Dental Wings scanner due to the open working chamber, which allows for scanning the occlusion relation directly from the articulator. It works in 5 axes, has a source of light LED type and two high resolution 5 MB cameras. The declared accuracy is 10/12 micrometres and the scanning time of the entire model is 40 seconds. The digital model is obtained by scanning with the use of blue LED light of entire lines, which considerably accelerates the whole process. However, this technology is less accurate than laser in the case of mapping holes with a diameter less than 5 mm.

The software of both scanners allows you to perform scans directly from the impression tray. It is worth noting, however, that the impression materials must be matt, because otherwise it is necessary to use additional powder or carbon paper, which affects the accuracy of detail reproduction and dimensional repeatability of the digital model. The scanning was carried out by selecting the option of precise scanning of details in the whole of the examined area. The component used to verify the correctness of the assembly were the sleeves made in SLM/SLS technology from the CoCr alloy introduced between 4 and 5 premolars on both sides of the dental arch after reaching the final dimension of the impression mass (Figs. 2,3). On the basis of impressions with inserted sleeves, digital models were created using a laser and light scanner. Gypsum models were cast in accordance with the procedure recommended by the manufacturer. On the basis of cast impressions, digital models were created using the same scanners as in the case of models made directly from impressions. Before starting the scanning procedure, the metal sleeves were removed leaving the imprint in the impression mass, which allowed for a later stage on the correct combination of models for measurements and verification of the correctness of submission of models made with two analysed methods. A model was also created, which was a 10x25 mm cylinder made in 3D SLS/SLM technology from CoCr alloy, which was imprinted while taking impressions in the tested masses (Fig. 4). In this way, it is possible to verify the declared expansion parameters of individual masses and to compare with the obtained results for dental impressions.

Three series of impressions were collected for each type of impression mass, on the basis of each impression a pair of digital models was created, one of which was based directly on the impression mass, and the other on the plaster model. Using embedded test sleeves using Autodesk PowerShape software, models were made based on an impression tray scan and a plaster impression tray model using the 3-point selection technique and the best fit algorithm (Fig. 5). Then selected by the software was verified by the operator in particular by verifying the penetration of the control sleeves. After finding the parallelism of the sleeves, the measurement was made by selecting a minimum of 12 measuring points for each pair in the tooth area. The measurements were made using the dynamic cross-section function and the measurement points were located on the palatal and buccal sides for the first molar and premolars as well as the labial and palatal for the first incisor. The measuring points were distributed in a uniform manner both in cross-section through the process and in relation to the symmetry axis of the whole model running between teeth 11 and 21.

Fig. 4. Metal sleeve (pattern) made in SLS technology and its cast gypsum model

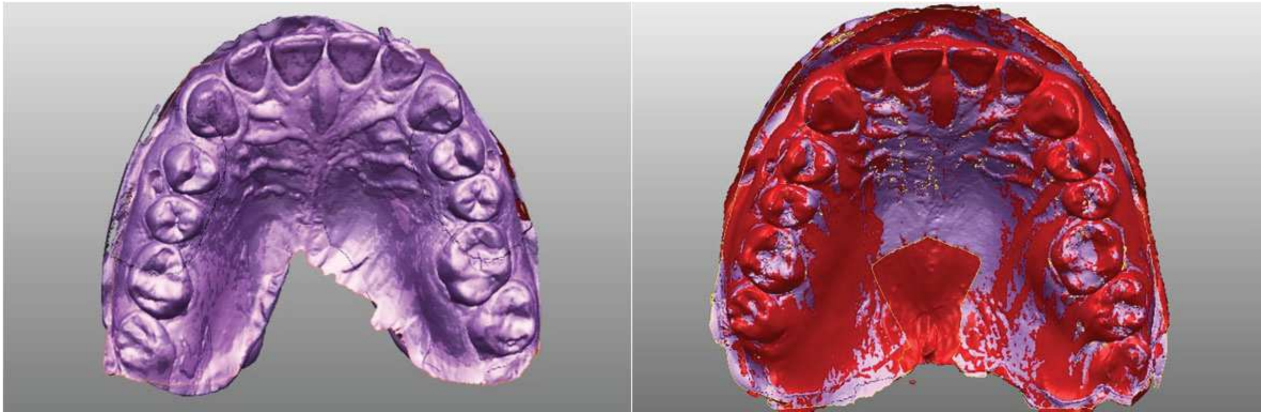

Fig. 5. The method of submitting scans coming directly from the extrusion bucket and plaster model scans made in the Autodesk Power Shape software

## 3. Results

The results of the obtained measurements were collected in diagrams of Figs. 6-9, where the differences between dimensions: standard (metal sleeve with fixed and unchanged dimension), plaster models and digital models made on the basis of plaster models and digital models made directly from the impression tray were presented using selected impression materials.

In Figure 6, using a metal standard, the dimensions of the standard in the form of a plaster model and digital models were compared to it. The measurement results

contain information on the average dimension of plaster models and digital models of the standard, taking into account the standard deviation in a certain confidence interval. The individual markings on the x-axis of the graph refer to:
PK – a model of a metal pattern,
GA – a model of a plaster cast made of alginate mass measured by a vernier caliper,
CGA – a digital plaster cast model made of alginate mass sized in CAD software,
CWA – a model of a digital standard scanned directly from alginate mass, dimensioned in CAD software,
GS – a plaster cast model made of Silagum mass measured with a vernier caliper,
CGS – a model of a digital plaster cast model made of Silagum material sized in CAD software,
CWS – a model of a digital standard scanned directly from the mass of Silagum, dimensioned in CAD software,
GH – a plaster cast model made of Honigum mass measured by vernier caliper,
CGH – a digital plaster cast model made of Honigum mass sized in CAD software
CWH – a digital master model scanned directly from the Honigum mass, dimensioned in CAD software.

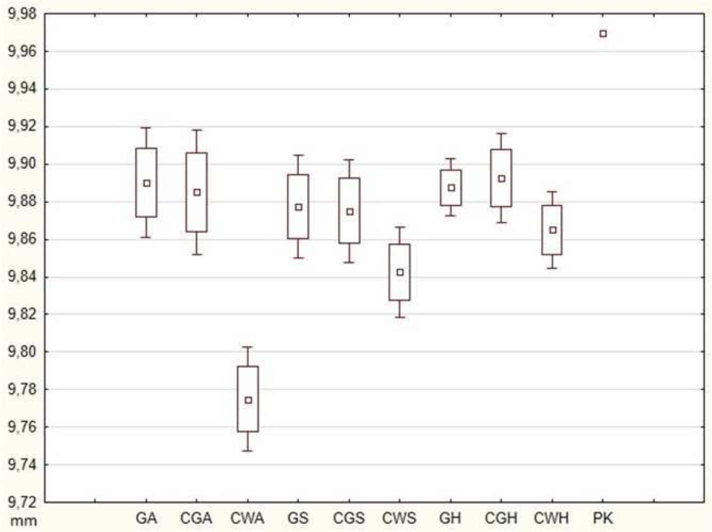


Fig. 6. Diagram showing the dimensional difference between the reference roller measured using a measuring calliper with a measurement tolerance of 0.02 mm and the dimensions of the gypsum model of a pattern cast from various impression materials and standard scans made directly from the impression tray

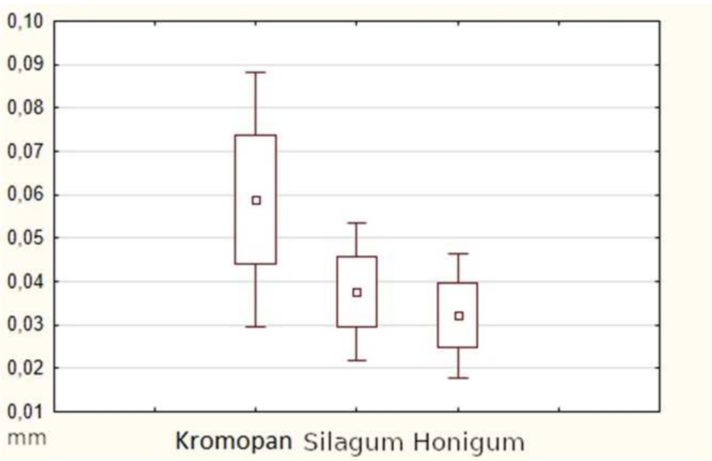


Fig. 7. A graph showing the dimensional differences between digital models made directly on the basis of an impression tray and based on the plaster model of selected impression masses

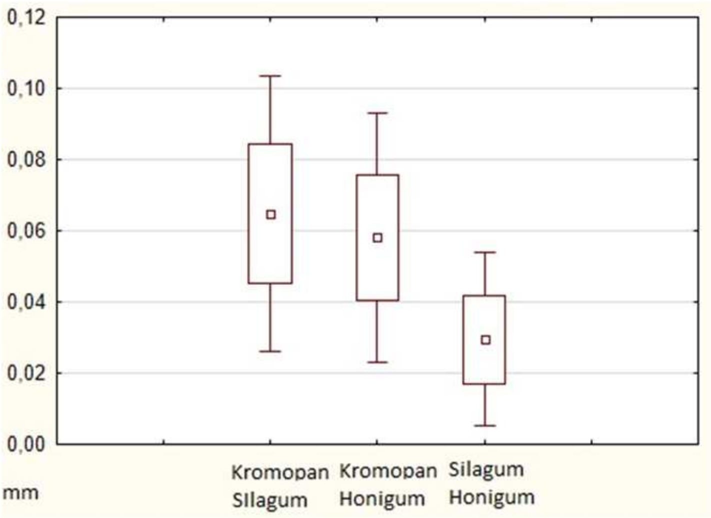


Fig. 8. Diagram containing information on dimensional differences between individual pairs of digital models based on scans made directly from impressions made from selected impression masses

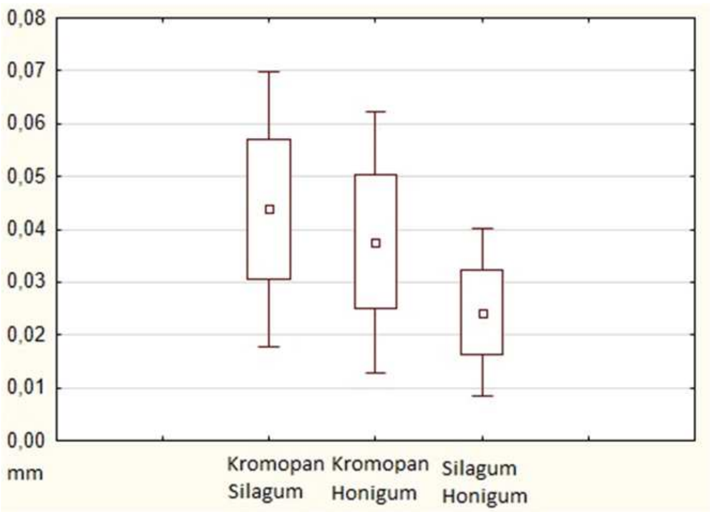


Fig. 9. Diagram showing dimensional differences between individual pairs of digital models based on scans of plaster models made using selected impression materials

## 4. Discussion and conclusions

The use of industrial equipment with high precision in the production of prosthetic elements requires the CAD/CAM designer to take into account even the minimum inaccuracies at each stage of designing and manufacturing of these elements. The dimensional inaccessibility of models made with impression materials is an extremely important issue. These masses are characterized by an expansion of about 0.4%. For a plaster model, it is partially offset by the expansion of plaster, which in the case of research is below 0.08%. As a result, the obtained digital model has a smaller volume than the object being mapped. This correlation should be balanced in the software by taking into account the parameter of the tool width compensation or by entering the parameters of the space for cement, in order to obtain the proper fitment of the prosthetic elements to the actual stubs of the teeth. This dependence is particularly burdensome for performing prosthetic restorations embedded directly on implants because the tolerance of the implant sockets is about 10-20 microns, which can not compensate for the dimensional differences of the mass-gypsum set. In the traditional methods of manufacturing the master working model, additional layers are considered, such as the spacing, which increases the volume of the plaster model, approaching the dimensions of the pattern. What is extremely important, the results of the standard measurements do not completely coincide with the results of measurements of the dentition models. This is due to the fact that using a simple pattern body we can not verify the way of mapping details such as the anatomy of bumps. For this reason, the performance of tests reflecting the patient's teeth is justified. The conducted research has also shown that it is important to conduct the entire model making process strictly with the recommendations of the manufacturer of impression materials and gypsums, as non-compliance with these recommendations results in additional introduced uncertainties. The conducted research has shown that the use of polyvinylsiloxane masses introduces measurement uncertainty at the level of 25-40 micrometres. At the same time, these masses are characterized by high repeatability of shape, especially in the field of small-sized elements, in particular precisely reflecting the shape of occlusal planes.

Conducted tests for patterns and impressions taken from the oral cavity allow to state that the parameters obtained by making impressions using the standard at room temperature while maintaining the confidence interval coincide with the results obtained for the models obtained when scanning impressions taken in the oral cavity. The analysis of the graphs, however, shows that the alginate masses have significantly lower accuracy in detail mapping, because the standard deviation is 0.0149, which means that locally this mass is much less accurate without mapping anatomical details. At the same time, the measurements for polyvinylsiloxane masses are characterized by a standard deviation of 0.007, which means that these masses reproduce anatomic details well. Their average inaccuracy is 0.032 for the Honigum weight and 0.037 for the Silagum mass, except that the standard deviation for Honigum is 0.007 and for Silagum 0.008 which confirms the manufacturer's declaration that this mass is dedicated to extensive work requiring high precision contour mapping.

The comparison of the results of the model models and models of the performed impression in the oral cavity allows to conclude that the exact reproduction of the conditions prevailing in the oral cavity requires rescaling the digital model immediately after its execution before the commencement of the design works. Based on the measurements carried out, it can be determined that this coefficient must be between 0.09-0.12%. It is the sum of the uncertainty of the impression mass and the prosthetic scanner. It should be verified in the further course of work whether the application of such a scale-up will allow to perform extensive prosthetic work, including implants, directly from the level of implants. In the case of a statistical patient, the distance of implant analogues for such cases can be changed.

## Bibliography


[1] P. Malara, L.B. Dobrzański, Computer aided manufacturing and design of fixed bridges restoring the lost dentition, soft tissue and the bone, Archives of Materials Science and Engineering 81/2 (2016) 68-75.

[2] P. Malara, L.B. Dobrzański, Screw-retained full arch restorations – methodology of computer aided design and manufacturing, Archives of Materials Science and Engineering 83/1 (2017) 23-29, DOI: 10.5604/01.3001.0009.7538.

[3] L.B. Dobrzański, P. Malara, Methodology of computer-aided design and manufacturing of dental restorations from solid engineering materials, in: L.A. Dobrzański, A.D. Dobrzańska-Danikiewicz (Eds.), Metallic microporous and solid materials for medical and dental applications, Open Access Library Annal Vol. 1(VII) (2017) 500-534 (in Polish).

[4] L.B. Dobrzański, Comparison of incremental and decremental methods for the manufacture of prosthetic dental restorations, in: L.A. Dobrzański, A.D. Dobrzańska-Danikiewicz (Eds.), Metallic microporous and solid materials for medical and dental applications, Open Access Library Annal Vol. 1(VII) (2017) 434-499 (in Polish).

[5] P. Ahlholm, K. Sipilä, P. Vallittu, M. Jakonen, U. Kotiranta, Digital Versus Conventional Impressions in Fixed Prosthodontics: A Review, Journal of Prosthodontics 27 (2018) 35-41.

[6] S.J. Lee, R.X. Macarthur 4th, G.O. Gallucci: An evaluation of student and clinician perception of digital and conventional implant impressions, The Journal of Prosthetic Dentistry 110/22 (2013) 420-423.

[7] B. Gjelvold, B.R. Chrcanovic, E.K. Korduner, I. Collin-Bagewitz, J.J. Kisch, Intraoral digital impression technique compared to conventional impression technique. A randomized clinical trial, Journal of Prosthodontics: official journal of the American College of Prosthodontists 25 (2016) 282-287.

[8] G. Rossini, S. Parrini, T. Castroflorio, A. Deregibus, C.L. Debernardid, Diagnostic accuracy and measurement sensitivity of digital models for orthodontic

purposes: A systematic review, American Journal of Orthodontics and Dentofacial Orthopedics 149/2 (2016) 161-170.
[9] S. Akyalcin, B.E. Cozad, J.D. English, C.D. Coville, S. Laman, Diagnostic accuracy of impression-free digital models, American Journal of Orthodontics and Dentofacial Orthopedics 144/6 (2013) 916-922.
[10] S. Marck, T. Bonilla, J.D. English, B.E. Cozad, S. Akyalcin, Accuracy of 3-dimensional curvilinear measurements on digital models with intraoral scanners, American Journal of Orthodontics and Dentofacial Orthopedics 152/3 (2017) 420-425.
[11] L.A. Dobrzański, A. Achtelik-Franczak, M. Król, Computer aided design in Selective Laser Sintering (SLS) – application in medicine, Journal of Achievements in Materials and Manufacturing Engineering 60/2 (2013) 66-75.
[12] L.A. Dobrzański, A.D. Dobrzańska-Danikiewicz, T.G. Gaweł, A. Achtelik-Franczak, Selective laser sintering and melting of pristine titanium and titanium Ti6Al4V alloy powders and selection of chemical environment for etching of such materials, Archives of Metallurgy and Materials 60/3 (2015) 2039-2045.
[13] M. Klimek, The use of SLS technology in the manufacture of permanent prosthetic restorations, Your Dental Review 12 (2012) 47-55 (in Polish).
[14] C.A. Freitas, T.S. Zanotti, F.A. Rizzante, A.Y. Furuse, M.F. Antunes de Freitas, Linear setting expansion of different gypsum products, RSBO 12/1 (2015) 61-68.
[15] K.X. Michalakis, N.V. Asar, V. Kapsampeli, P. Magkavali-Trikka, A.L. Pissiotis, H. Hirayama, Delayed linear dimensional changes of fivehigh strength gypsum products used for the fabrication of definitive casts, Journal of Prosthetic Dentistry 108/3 (2012) 189-95.
[16] K.X. Michalakis, A. Stratos, H. Hirayama, A.L. Pissiotis, F. Touloumi, Delayed setting and hygroscopic linear expansion of three gypsum products used for cast articulation, Journal of Prosthetic Dentistry 102/5 (2009) 313-318.
[17] P.K. Pal, S.S. Kamble, R.R. Chaurasia, V.R. Chaurasia, S. Tiwari, D. Bansal, Evaluation of different disinfactants on dimensional accuracy and surface quality of type IV gypsum casts retrieved from elastomeric impression materials, Journal of International Oral Health 6/3 (2014) 77-81.
[18] Z. Raszewski, W. Zabojszcz, Impression materials and gypsum, Elamed, Katowice, 2010 (in Polish).
[19] K. Żelezińska, M. Nowak, J. Żmudzki, C. Krawczyk, G. Chladek, The influence of storage conditions on the physicochemical properties and dimensional accuracy of the alginate impressions, Journal of Achievements in Materials and Manufacturing Engineering 87/2 (2018) 69-73.
[20] Z. Raszewski, M. Jałbrzykowski, Alginate stability during a time, Scholars Journal of Applied Medical Sciences 5/10E (2017) 4128-4139.
[21] J. Stępień, B. Dejak Evaluation of the accuracy of the prosthetic field mapping depending on the impression technique, Prosthetics LXV/3 (2015) 2014-224 (in Polish).
[22] S. Caputi, G. Varvara, Dimensional accuracy of resultant casts made by a monophase, one-step and two-step, and a novel two-step putty/light-body impression technique: an in vitro study, Journal of Prosthetic Dentistry 99/4 (2008) 274-281.
[23] W. Chee, T. Donovan, Polyvinyl siloxane impression materials: A review of properties and techniques, Journal of Prosthetic Dentistry 68 (1992) 728-732.
[24] J. Stępień, B. Dejak, Elastomer masses – review of the literature, Modern Dentistry 18 (2011) 35-39 (in Polish).
[25] R. Hariharan, C. Shankar, M. Rajan, M.R. Baig, N.S. Azhagarasan, Evaluation of accuracy of multiple dental implant impressions techniques, The International Journal of Oral & Maxillofacial Implants 25 (2019) 38-44.
[26] A. Schmidt, T. Ahussling, P. Rehmann, H. Schaaf, B. Wostmann, Accuracy of various impression materials and methods for two implant systems: An effect size study, Journal of Prosthodontic Research 62/2 (2018) 245-251.
[27] V.J. Hoods-Moonsammy, P. Owen, D.G. Howes, A comparison of the accuracy of polyether, polyvinyl siloxane, and plaster impressions for long-span implant-supported prostheses, The International Journal of Prosthodontics 27/5 (2014) 433-438.
[28] https://pl.dmg-dental.com/pl/produkty/product/honigum-light/
[29] https://pl.dmg-dental.com/pl/produkty/product/silagum-light/
[30] https://tech-dent.pl/kromopan-450g.html
[31] H.A. Reza, M. Mohammad, S. Hakimeh, H. Habib, A. Marzieh, The effect of conventional, half-digital, and full-digital fabrication techniques on the retention and apical gap of post and core restorations, The Journal of Prosthetic Dentistry 121/2 (2019) 364e1-364e6.