“CAROL DAVILA” UNIVERSITY OF MEDICINE AND PHARMACY BUCHAREST
PhD DEPARTMENT
DENTISTRY

RESEARCH ON THE PREDICTABILITY OF THE WAX-UP STAGE - BETWEEN ANALOG AND VIRTUAL

PhD THESIS ABSTRACT

Scientific coordinator:
PROF. UNIV. DR**.** ***PĂUNA MIHAELA RODICA***

PhD Student**:**
VÂLSAN IOANA MONICA

2024

Contents

List of scientific papers published in the framework of doctoral research

1. **Ioana Monica Vâlsan**, Luminița Oancea, Mihaela Rodica Păuna, Cătălin Gagiu, Alexandru Eugen Petre. "The Influence of Altering the Morphology of the First Mandibular Molar on Functional Mandibular Movements: A Pilot Study". *Dental Oral Biology and Craniofacial Research.* 2021;4(2):2-7. http://dx.doi.org/10.31487/j.DOBCR.2021.02.01. [15]

The article is written starting from the data presented in Study 1 of the Doctoral Thesis (Chapter 4 – pages 36-44).

2. **Ioana Monica Vâlsan**, Mihaela Rodica Păuna, Alexandru Eugen Petre, Luminița Oancea. "Biologic and Esthetic Outcome of CAD/CAM Custom Ceramic Implant Abutment: A Clinical Report". *Maedica (Bucur)*. 2021 Mar;16(1):145-148. https://doi.org/10.26574/maedica.2021.16.1.145. PMID: 34221171; PMCID: PMC8224707 [16].

The article is written starting from the data presented in Study 2 of the Doctoral Thesis (Chapter 5 – pages 45-51).

3. **Ioana Monica Vâlsan**, Mihaela Rodica Păuna, Luminița Oancea, Rareș Buduru. "REPRODUCTION OF OCCLUSAL DESIGN BETWEEN ANALOG AND DIGITAL WAX-UP". *Romanian Journal of Oral Rehabilitation*. 2024;16(3):470-476. DOI : 10.6261/RJOR.2024.3.16.49 [3]

The article is written starting from the data presented in Study 3 of the Doctoral Thesis (Chapter 6 – pages 52-74).

Introduction

The stage of initial diagnosis and planning is of major importance in complex prosthetic rehabilitations of the dento-maxillary system when certain initial parameters have been altered or lost.

The wax-up is a basic tool in the development of complex and sophisticated treatment plans that allows a clinical test of the treatment method thought by the doctor. With its help, a number of parameters are evaluated and tested according to which the prosthetic restorations are built, such as inter-arcade ratios, prosthetic spaces, vertical dimension of occlusion, shape, size and position of the upper front teeth.

Given all this, the aim of this study is to identify the optimal study group size to quantify the extent to which the change in dental morphology influences the amplitude and trajectory of mandibular movements at the condylar and dental level.

The preview of the final result in the fixed prosthetic treatment is mainly used in the case of restorations in the frontal area, where the focus is on restoring the aesthetic aspect. In the lateral area of the dental arches, the main role of using prosthetic restorations is to rebuild the masticatory function and implicit the shape of the occlusal surfaces of the restored teeth. The relief of the occlusal surface of the teeth is a complex one, made of positive shapes (ridges and cusps), as well as negative shapes (grooves and pits), something that complicates the work of the dental technician in the process of manufacturing fixed restorations.

The general part of this PhD thesis, organized in two chapters, aims to prepare and frame the studies carried out in the context of existing data in the specialized literature.

Chapter 1, entitled **"Aesthetic and functional parameters in wax-up"** - presents the aesthetic, facial and dental elements necessary for the realization of prosthetic restorations with the most natural appearance.

Chapter 2, entitled **"Transposing data from Digital Smile Design into analog wax-up and digital wax-up"** - presents in detail the process of Digital Smile Design, as well as the way in which the obtained data can be translated into reality using analog/conventional wax-up, respectively digital wax-up.

Personal contribution

CHAPTER 3 - WORKING HYPOTHESIS AND GENERAL OBJECTIVES

For making this Doctoral Thesis, we started from the idea of checking two methods used in prosthetic treatments to preview the final results, the analog and digital wax-up. For the first method (analog wax-up), the technician makes the shape of restored teeth on the preliminary model, by dripping. The digital wax-up is also made by the dental technician, but this time the operations are carried out on the virtual model assisted by dedicated programs for three-dimensional modeling.

In order to achieve the most objective evaluation of the two working methods, it is necessary that the same shape of the teeth be reproduced by both methods, and subsequently the two results be analyzed comparatively both with each other and with respect to the initial clinical situation

The role of the prosthetic treatment is to restore the morphology and functionality of the dental arches affected by lesions with loss of substance or even edentations. However, functionality is different in the front area compared to the lateral area. For the frontal area, the main function targeted in the restoration process is the aesthetic one, which is why the comparison in the frontal area is aimed at the shape of the tooth (axial faces but also the incisal edge). In the lateral area, the functional restoration is mainly focused on the mastication, fact that limits comparative studies to the occlusal face of the teeth, areas responsible for mastication.

The hypothesis of the conducted studies was related to the comparative evaluation of the two wax-up methods, in order to establish the degree of accuracy obtained both in the frontal and in the lateral area.

The general objectives of the studies were the following:

- Making the shape of future prosthetic restorations through analog wax-up and digital wax-up;
- Comparative analysis of the obtained results;
- Comparative analysis of the obtained results against the standard reference;
- Establishing the degree of accuracy for the two methods;

CHAPTER 4 - THE INFLUENCE OF CHANGING THE OCCLUSAL MORPHOLOGY ON FUNCTIONAL MOVEMENTS OF THE MANDIBLE

4.1 Introduction. The aim of this study is to identify the optimal study group size to quantify the extent to which the change in dental morphology influences the amplitude and trajectory of mandibular movements at the condylar and dental level.

4.2 Material and methods. For this study 10 participants were selected from an initial group of 54 subjects, who met the inclusion criteria for the study. The study was based on three stages:

1. During the first meeting, a thorough medical history was completed, followed by a precise dento-maxillary examination to establish the existence of the selection or exclusion criteria of the study.

2. In the second session the initial occlusal analysis was done, including the mandibular movements; the virtual facebow, articulator function and function analysis modules from the Zebris JMA System condylograph (Zebris Medical GmbH, Germany) were used (Figure 4.1, 4.2).

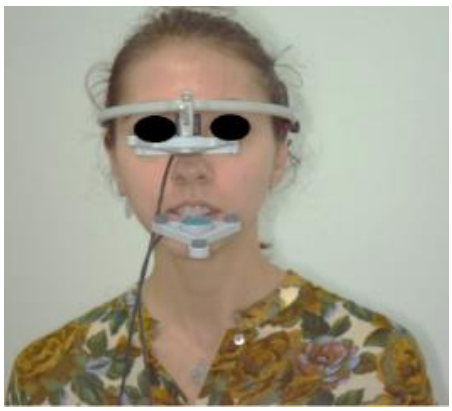

Figure 4.1 – Facebow adjusted to the patient's head.

Figure 4.2 Mandibular movement recording protocol.

3. In the third session, a layer of purple fluid composite was applied to the internal slope of the mesio-buccal cusp of tooth 4.6, creating an interference on the non-functional side in the protrusion movement and also on the non-functional side in the movement of laterality (Figure 4.3). The paraocclusal fork is reconnected. The steps of the condylographic analysis followed the same protocol as in the previous phase. At the end, the flowable composite was removed with red and yellow diamond stones (finest grits), and the surface was polished with polishing gums and toothpaste with 10 micron particles using loupes.

Figura 4.3 –
Interferences on the non-working side
in the protrusion and lateral
movement

The resulting data from the records generated by the condylograph were entered into an Excel file and statistically processed using SPSS2 software.

4.3 Results. In the statistical analysis, the Kolmogorov-Smirnova and Shapiro-Wilk tests were applied to verify the normality of the differences between the pairs of recordings, before and after the interference occurred.

4.4 Discussions. All movement parameters were changed on both sides due to the occurrence of the premature contact in the lateral area of the arch. The results are consistent with those in the literature, where associations were found between interference and premature contacts on the non-functional side.

4.5 Conclusions. Based on the comparative descriptive analysis of the obtained data, it was observed that by changing the occlusal morphology of the lower first molar and creating an interference, the movement parameters showed variations in terms of the extent and direction of the movement, both in dental and condylar levels. Respecting the initial morphology and its harmonious adaptation to individual functional parameters is a good premise for maintaining the balance between the parts of the dento-maxillary system.

CHAPTER 5 - BIOLOGICAL, AESTHETIC AND OCCLUSAL RESULTS OBTAINED BY USING A CUSTOMIZED CERAMIC ABUTMENT MADE THROUGH CAD/CAM TECHNOLOGY FOR A PROSTHETIC IMPLANT RESTORATION

5.1 Introduction. This study describes the successful use of a custom prosthetic abutment designed using CAD/CAM technology. It has the strength and precise fit of a titanium interface and also the aesthetic advantages of custom-milled zirconia shades with no visible metal elements.

5.2 Material and method (case report). A 28-year-old patient was referred for treatment in our clinic, being unsatisfied with the appearance of the gum next to an implant restoration in the maxillary frontal area (Figure 5.1, 5.2).

Figure 5.1 – Appearance after removal of the prosthetic restoration

Figure 5.2 – Initial radiological appearance.

To improve the condition of the peri-implant tissue, a screw-retained crown design was initially generated, but because of the implant axis, this solution would have required an unacceptable aesthetic compromise: the access hole to the fixation screw would have perforated the vestibular surface, near the incisal edge (Figure 5.3).

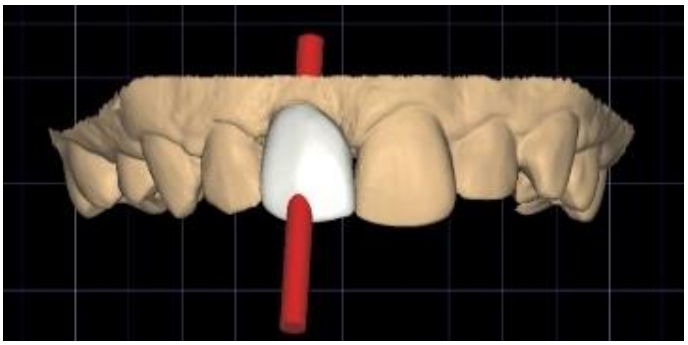

Figure 5.3 – Three-dimensional simulation of a screw-retained prosthetic restoration for the analyzed clinical case.

The zirconia coping was cemented onto a prosthetic abutment compatible with the internal hexagon of the titanium implant (Ti-Base for CAD-CAM, DSI Dental Implant System, Israel). The titanium prosthetic abutment was sandblasted on the surfaces where it comes into contact with the zirconia, using aluminum oxide particles with a diameter of no more than 50μm and an air pressure of 0.2 MPa [1].

The hybrid abutment thus obtained was scanned using an analog abutment. Afterwards, it was fixed on the dental implant using a tightening torque of 32Ncm and an intraoral scan was also performed.

Eight months later, a stable peri-implant soft tissue volume was observed, and also lack of bleeding and a favorable contour. Therefore, the permanent cement retained *e.max* ceramic crown (Ivoclar Vivadent) was made (Figure 5.4).

Figure 5.4 The peri-implant soft tissues appearance after cementing the final *e-max* crown (left) as well as the radiological appearance (right).

5.3 Discussions. The zirconia substructure masks the gray color of the titanium prosthetic abutment both at the coronal and mucosal levels [2]. Fixation of the zirconia coping to the titanium abutment is done on the model, thus achieving a complete removal of excess material and, also, a superior polish of the surface with which the hybrid abutment will come into contact with the peri-implant tissues.

5.5 Conclusions. The possibility of customizing prosthetic implant abutments through CAD-CAM technology allows the creation of more refined prosthetic models that lead to superior implant prosthetic restorations in terms of aesthetics, biocompatibility and durability.

CHAPTER 6: COMPARATIVE ANALYSIS BETWEEN ANALOG AND DIGITAL WAX-UP IN REPRODUCING OCCLUSAL DESIGN

6.1 Introduction. Through this study, we tried to comparatively analyze the degree of accuracy that can be obtained in the reproduction, in similar conditions, of the occlusal design using the analog wax-up, made by the dental technician, but also the digital wax-up, made assisted by a program specialized in three-dimensional modeling for dental technique.

6.2 Material and method. From an initial group of 10 subjects, 3 subjects were selected based on the study inclusion criteria. The study was approved by the Ethics Committee of Scientific Research of UMF "Carol Davila" Bucharest, through Opinion No. 11579/30.04.2024.

On the maxillary model, tooth 1.6 was removed using a laboratory spatula. The neighboring teeth, 1.5 and 1.7, were prepared on the model using the same principles as for metal-ceramic crowns. The model thus prepared was scanned using the same machine, the data was updated in the modeling software (Figure 6.1).

Figure 6.1 – Working model scanned after removal of tooth 1.6 and preparation of teeth 1.5 and 1.7.

On the prepared model, the dental technician made a wax pattern for the 1.5-1.7 bridge (analog wax-up), and at the end of the modeling process, the pattern and the model were scanned. A virtual model was thus obtained that will allow measurements in digital format, for better accuracy. In the virtual modeling program (Exocad), a virtual pattern was made for the same clinical case (digital wax-up) using the analysis given by the program, but also the necessary adjustments made by the dental technician. The model thus obtained was saved separately for making digital measurements.

The comparative analysis of the two wax-up methods was carried out by comparing the degree of precision in the reproduction of the occlusal surfaces of the three processed teeth (1.5, 1.6 and 1.7) compared to the initial situation, using the Medit Design program (version 2.1.4) , part of the Medit Link program [3], specially created to compare and analyze 3D data. The program allows automatic or manual alignment of the models subjected to

comparative analysis. In our case, the initial model was set as a reference model against which the analysis of the models on which the two types of wax-up were performed was carried out. The deviation display mode (Deviation Display Mode) allows the tolerance level to be set in a range from -2 mm to +2 mm from the reference model. For research accuracy, the tolerance level was set to the range (-0.05 mm; +0.05 mm).

The analyses were made for each individual patient, comparing the models on which the analog and digital wax-up was performed against the original model by overlapping. To carry out the analysis, strictly on the occlusal surface, several landmarks were established, targeting both positive and negative elements.

The positive landmarks analyzed were (15 elements):

- The cusps of the upper 2nd premolar: buccal (B) and lingual (L);
- The cusps of the upper 1st molar: mesiobuccal (MB), distobuccal (DB), mesiolingual (ML) and distolingual (DL);
- The cusps of the upper 2nd molar: mesiobuccal, distobuccal, mesiolingual, (because the distolingual cusp has a variable shape it was excluded from the measurements for the study group);
- Mesial marginal ridge of the three teeth near the mesial fossa;
- Distal marginal ridge of the three teeth near the distal fossa (Figure 6.2);

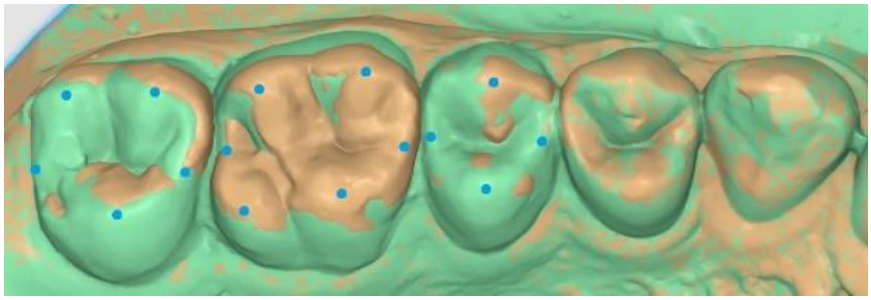

Figure 6.2 – The positive landmarks taken into analysis.

The negative landmarks analyzed were (11 elements):

- Mesial fossa (all analyzed teeth);
- Distal fossa (all analyzed teeth);
- Central fossa (on the molars);
- The buccal groove, the place of passage from the occlusal to the vestibular surface (on the molars);
- The lingual groove, the place of passage from the occlusal to the lingual surface (on the upper 1st molar) (Figure 6.3);

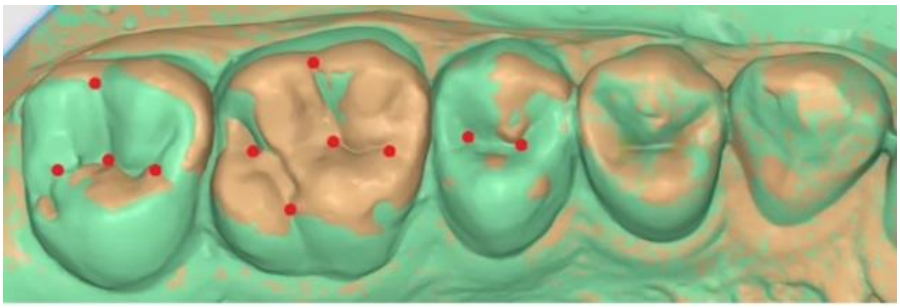

Figure 6.3 – The negative landmarks taken into analysis.

Thus, 26 landmarks were selected for each patient, with a total of 156 comparative analyses. For each model, the average and the general standard deviation were calculated, as well as individual for each separate tooth. The presence of statistically significant differences was assessed using the Kruskal-Wallis test (p=0.01) [4] [5]. Further analysis for the identified significant differences was performed using Wilcoxon Mann-Whitney and independent samples t-tests [6] [7] [8]. The starting null hypothesis is that analog and digital wax-up similarly restore the occlusal morphology of the analyzed teeth.

6.3 Results. For each analyzed model, measurements were made for the positive and negative relief elements specified in the organization of the study (Figures 6.4 and 6.5.).

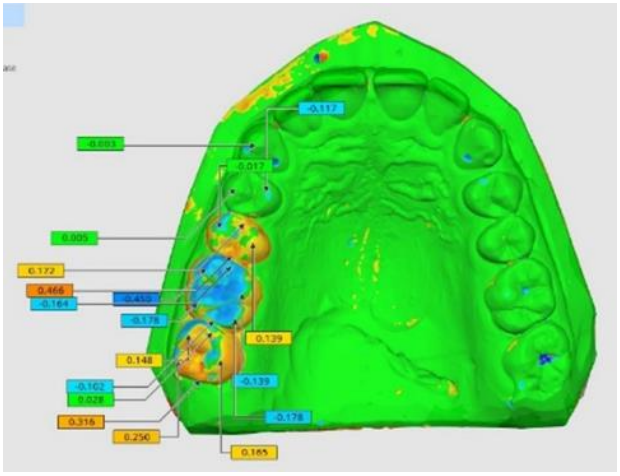

Figure 6.4 – – Measurements of variation in positive landmarks on the analog wax up model.

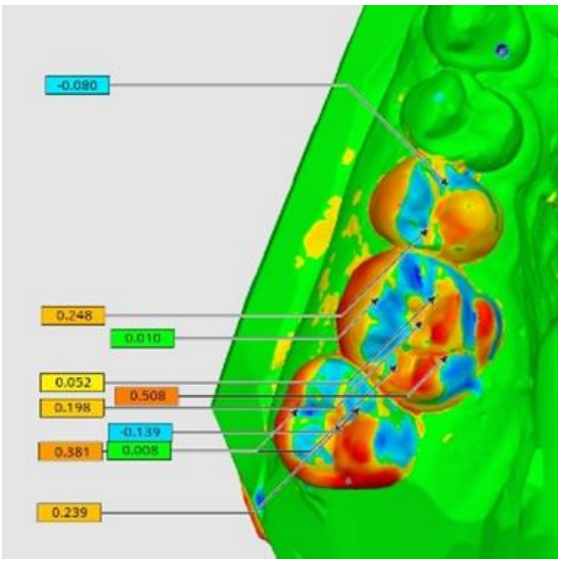

Figure 6.5 – Measurements of variation in negative landmarks on the analog wax up model.

The primary analysis of the values refers to the differences that appear by using the two wax-up variants compared to the initial situation considered as a reference element. For this, the values for positive and negative relief elements were analyzed separately.

Figures 6.6 and 6.7 analyze the variations of the positive relief elements for the three teeth considered. The dotted line, marking the value of 0, represents the level at which the landmarks are located on the original model. Variations appearing in the positive direction of the vertical axis mark areas where the objects compared to the original situation show over contouring, while variations appearing in the negative direction of the vertical axis mark areas where the models are undersized compared to the original teeth.

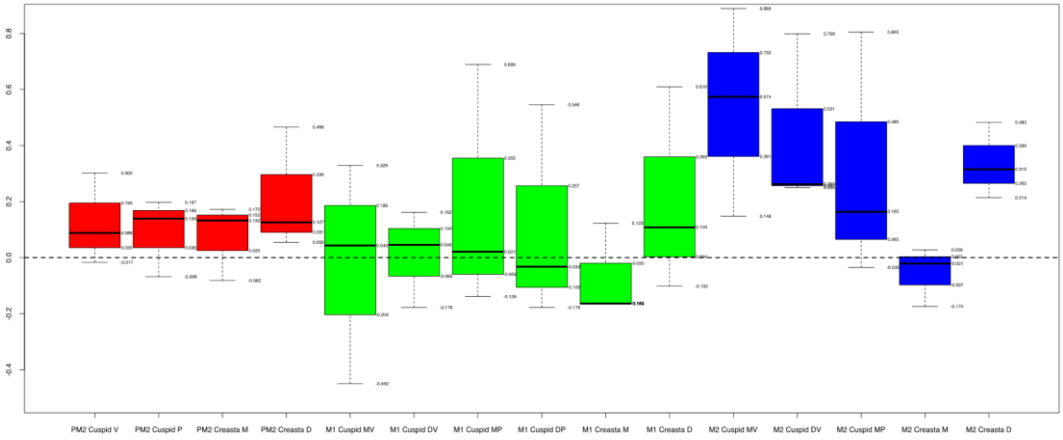

Figure 6.6 - Comparison of positive landmarks between analog wax-up and the original situation.

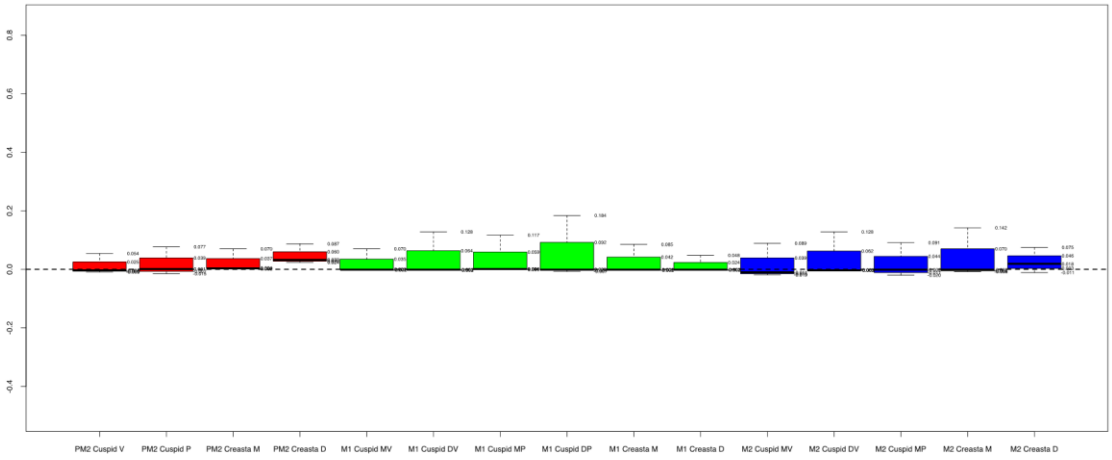

Figure 6.7 - Comparison of positive landmarks between the digital wax-up and the original situation.

The analysis of the values recorded for the positive relief forms shows very small dimensional variations for the digital wax-up compared to those for the analog wax-up (Figure 6.8).

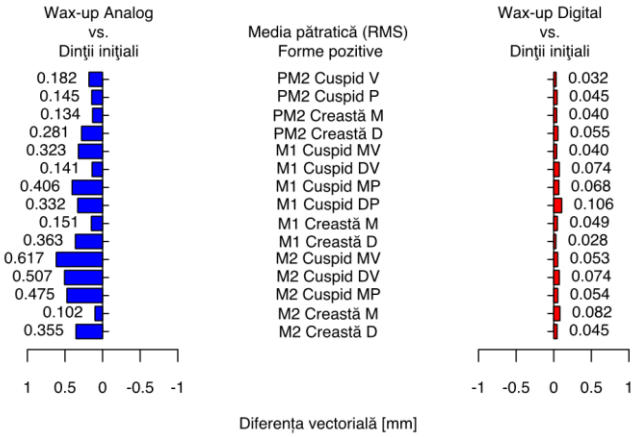

Figure 6.8 – Root mean square analysis for the positive relief landmarks restored by the two types of wax-up.

The analysis of the number of standard deviations (Figure 6.9) for the positive relief landmarks shows, in the case of digital wax-up, the maximum number of standard deviations with a value of 2.12 in the case of the DL cusp of the 1st molar, the differences being thus statistically insignificant. For the analog wax-up, out of the 15 landmarks, 9 have a number of standard deviations greater than 5, the most significant landmark being the MB cusp of the 2nd molar for which 12.34 standard deviations are recorded.

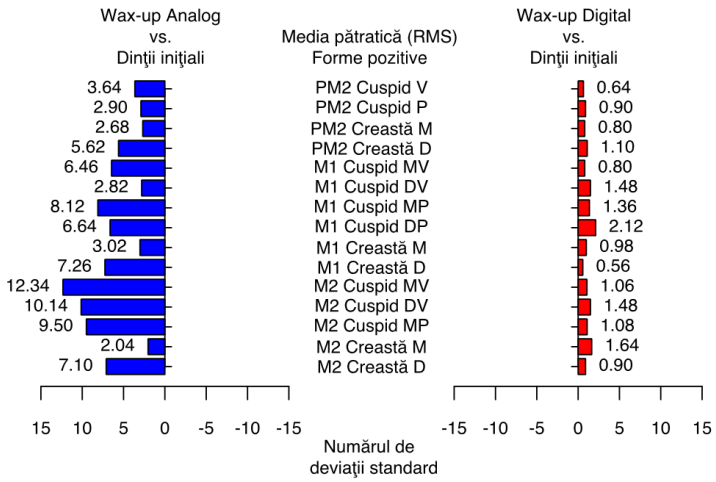

Figure 6.9 – Analysis of standard deviations for the positive relief landmarks restored by the two types of wax-up.

The final analysis was performed using the Kruskal-Wallis test in general mode, for all teeth, but also individually for each separate tooth, to detect statistically significant differences. Where differences were reported, the values were also analyzed using the Wilcoxon Mann-Whitney and t-tests, to emphasize statistical significance. For each measured value, the square mean of the measured values for the three patients was calculated, the results obtained being those analyzed by the three previously mentioned tests.

For the 2nd upper premolar, the analyzed values showed statistically significant changes between the two methods, the p value being below the established reference value (p=0.01), as it can be noted from Table VI.1.

Table VI.1 – Statistical significance of dimensional differences in the case of PM2 for the used tests

Statistical test	***Statistical significance p-value***	***Statistical significance the exact value***
Kruskal-Wallis	$p<0,01$	$p = 0.006485$
Wilcoxon Mann-Whitney	$p<0,01$	$p = 0.004329$
Two Sample t-test	$p<0,01$	$p = 0.004932$

In the case of 1st molar, the analysis of the measurements led to the results shown in Table VI.2. In this case also, the differences between analog wax-up and digital wax-up are statistically significant.

Table VI.2 – Statistical significance of dimensional differences in the case of M1 for the used tests

Statistical test	***Statistical significance p-value***	***Statistical significance the exact value***
Kruskal-Wallis	$p<0,01$	$p = 7.105e-05$
Wilcoxon Mann-Whitney	$p<0,01$	$p = 2.835e-06$
Two Sample t-test	$p<0,01$	$p = 5.536e-07$

The results of the statistical analysis for the 2nd molar also show statistically significant differences between the analog wax-up and the digital wax-up, as it can be seen in Table VI.3.

Table VI.3 – Statistical significance of dimensional differences in the case of M2 for the tests used

Statistical test	***Statistical significance p-value***	***Statistical significance the exact value***
Kruskal-Wallis	$p<0,01$	$p = 0.0006748$
Wilcoxon Mann-Whitney	$p<0,01$	$p = 0.0001645$
Two Sample t-test	$p<0,01$	$p = 4.307e-05$

The general values for the evaluated group of teeth were also analyzed statistically, the results are presented in Table VI.4.

Table VI.4 – Statistical significance of dimensional differences in the case of M2 for the tests used

Statistical test	***Statistical significance p-value***	***Statistical significance the exact value***
Kruskal-Wallis	$p<0,01$	$p = 1.628e-09$
Wilcoxon Mann-Whitney	$p<0,01$	$p = 1.723e-09$
Two Sample t-test	$p<0,01$	$p = 3.737e-11$

6.4 Discussions. The existence of statistically significant differences is noted in all of the analysis carried out, both individually for each separate tooth and for the group of teeth. However, we can note in the individual analyses, the fact that the most significant differences are found on the molar 1, where the dental technician had to start restoring the tooth from scratch, without having a minimum of landmarks, as opposed to the case of the 2nd premolar and the 2nd molar, for which the teeth were prepared in the form of abutments. This shows that the existence of a landmark on the model (e.g. prosthetic abutment) leads to obtaining superior results in layout compared to situations where teeth are completely missing.

6.5 Conclusions. Analyzing both macroscopically and from the measured values point of view, we can conclude the following:

- Restoring the occlusal design using analog wax-up tends to produce volumetric changes, values recorded for all analyzed teeth, statistically significant;
- Volumetric changes for analog wax-up do not have a fixed pattern, the restored teeth being over- or under-sized in different areas;
- Restoring missing teeth creates the biggest volumetric differences;
- Restoring the occlusal design using digital wax-up produces statistically insignificant volumetric changes;
- Even if the models were made following the occlusal records, the dimensional variations did not follow the same pattern, being an obvious difference between the analog and the digital method
- The analog wax-up depends on the experience and skill of the dental technician, each model being unique in its own way;
- The digital wax-up is based on the data stored by the program but corrected by the technician;
- There are statistically significant differences between models made by analog wax-up and digital wax-up;
- Digital waxing benefits from increasingly powerful and calibrated equipment to deliver predictable results on a regular basis.

CHAPTER 7 – VALIDATION OF THE DIGITAL WAX-UP METHOD THROUGH COMPARATIVE ANALYSIS WITH ANALOGUE WAX-UP IN THE REPRODUCTION OF DENTAL MORPHOLOGY IN THE MAXILLARY FRONTAL AREA

7.1 Introduction (working hypothesis and specific objectives). The objective of this study is to comparatively evaluate the dental aesthetics obtained using two wax-up methods, analog and digital, in the preview of the final result within the prosthetic treatment of the maxillary frontal area. For this, three biometric variables were analyzed:

- accuracy;
- comparison of the width and height of the teeth included in the study;
- individual and group symmetry.

7.2 Material and method. To carry out this study, a number of 22 patients were initially selected. Following initial analysis, five of the participants met all criteria and were included in the study group. The study was approved by the Ethics Committee of Scientific Research of UMF "Carol Davila" Bucharest, with Opinion No. 11579/30.04.2024.

Classic, analog wax-up modeling was done using additive techniques and inlay wax. The outer surface of the teeth was thus modified by over-contouring or by removing parts of the teeth where necessary. The process was done continuously with the jaw model mounted in the articulator. At the end of it, the model and the wax-up were scanned to obtain a virtual model used further in the comparative analysis.

The digital wax-up was done in the Exocad program after mounting the models in the virtual articulator, using the analysis result from Digital Smile Design.

In order to avoid the errors that can occur in the process of transferring from wax-up to mock-up, the research we have done has reduced to minimum unnecessary and confusing steps. Thus, the initial model was analyzed, the analog wax-up was performed on the same model, and the digital wax-up was performed on the virtual version, obtained by scanning the initial model.

To reduce errors, all laboratory procedures were performed by a single person, a dental technician with more than 10 years of experience. The digital analyses were carried out by me, as a Phd student - evaluator, also to reduce the degree of error.

For each tooth in the frontal group, five landmarks were established for analysis, as follows (Figure 7.1):

- The gingival zenith (the highest point of the cervical edge of the teeth);

- The middle of the incisal edge or the tip of the canine;
- Half the distance between the gingival zenith and the middle of the incisal edge/tip of the canine;
- The mesial contact point;
- The distal contact point;

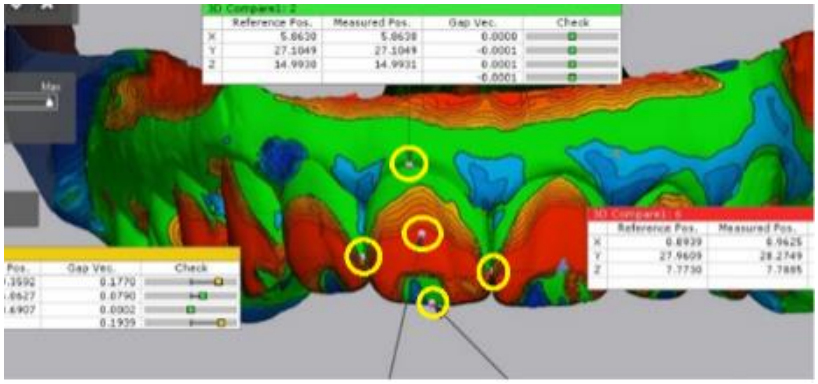

Figure 7.1 - Biometric landmarks used in accuracy analysis.

As it can be seen from Figure 7.1, the Geomagic Control X program, based on the differences determined between two analyzed models, can make a color map. Having established a tolerance limit of ± 0.3 mm, the over-contoured areas, where the analyzed model is larger than the reference one, appear in shades of orange to red, while the under-contoured areas appear in shades of blue.

The results for the five landmarks were analyzed for each tooth in comparative analyses between models, individually (each landmark separately) and as a whole.

Comparison of the width and height of the teeth included in the study. Unlike *accuracy*, which provides detail on selected landmarks, this mode of analysis provides information about the vertical and horizontal dimensions of the teeth.

Symmetry analysis focused on how different established landmarks on the teeth are in symmetry with respect to the mid-sagittal plane. For this analysis, using the Geomagic Control X program, the front teeth on the right side were mirror-inverted and superimposed on the image of the front teeth on the left side (Figure 7.2). The following landmarks were analyzed for each tooth:

- The gingival zenith;
- The mesio-incisal angle;
- The disto-incisal angle.

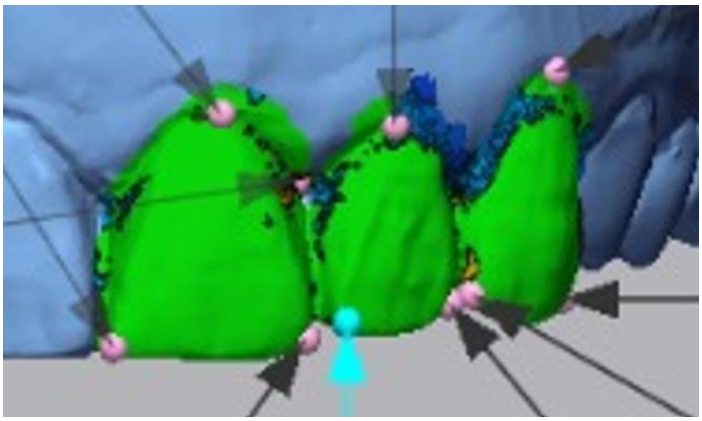

Figure 7.2 - Landmarks analyzed in image overlay.

This time, symmetry was analyzed only for the models on which the analog and digital wax-ups were performed, in order to evaluate how symmetrically the teeth included in the study were modeled. The teeth were evaluated within the same model, but also between the two categories of models.

Taking into account the particularity of this study, the difficulty of identifying and introducing patients into the study, the limited number of patients and implicit the small number of analyzed teeth, it was necessary to establish a p-value limit of 0.05 (95% confidence interval).

Statistically, the presence of significant differences, for all lines of analysis, was determined using the Kruskal-Wallis test ($p = 0.05$) [9] [5]. Subsequently, the Mann-Whitney-Wilcoxon test and t-test were used where statistically significant differences were identified for confirmation [6] [7] [8]. The starting null hypothesis is that analog and digital wax-up similarly restore the occlusal morphology of the analyzed teeth.

7.3 Results

7.3.1 Accuracy. Accuracy analyses were performed by relating the two types of wax-up, analog and digital, to the initial clinical situation. The values for the lateral incisors and canines, as well as the values for the whole set of teeth, were analyzed (Figure 7.3).

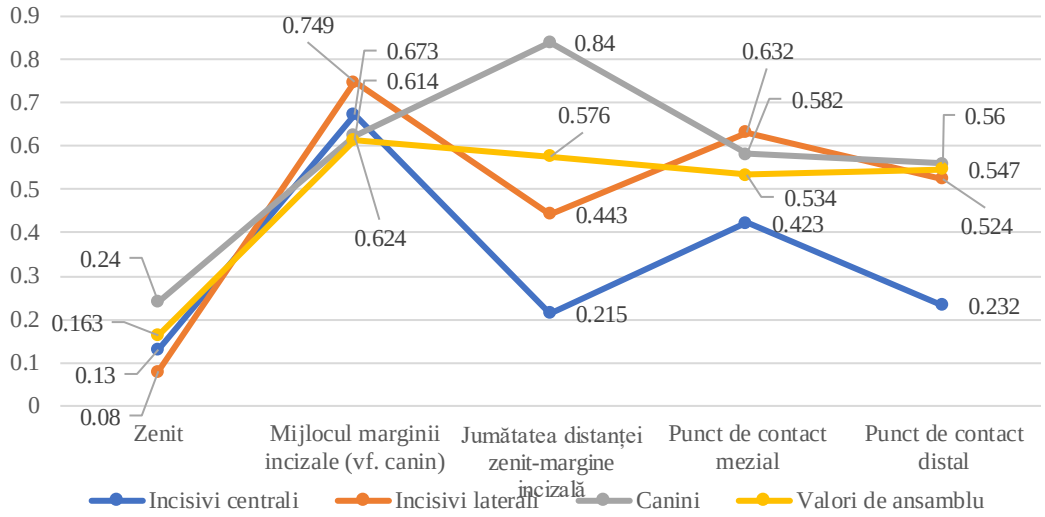

Figure 7.3 – Centralized values for analog wax-up.

As it can be noted, the smallest variations occur at the central incisors (blue line – three of the five landmarks have the lowest value) and this is because they are the most important teeth in the frontal group from the perspective of aesthetics and, implicit, the technician pays the greatest attention during their restoration.

Similarly, the values measured in the case of digital wax-up were analyzed to notice the differences compared to the initial situation. In the first stage, the average values of the vector differences for each type of established landmark, measured at the level of each tooth, were centralized (Figure 7.4).

Figure 7.4 – Example of measurements made in the comparison between the digital wax-up and the initial clinical situation.

The analysis was carried out by groups of teeth, as well as the overall analysis of the entire upper frontal group.

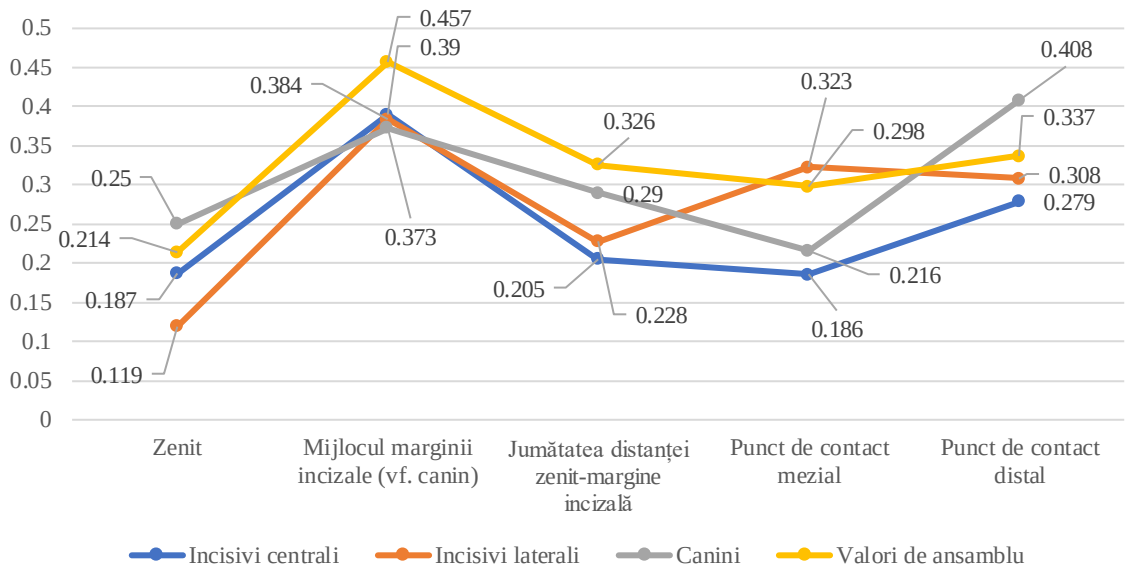

Figure 7.5 – Centralized values for digital wax-up.

In the case of the upper lateral incisors, the only statistically significant difference was noted in the case of the mesial contact point.

Additional tests confirmed the statistical significance obtained by the Kruskal-Wallis test in the case of the mesial contact point (Table VII.1).

Table VII.1 – Statistical significance of the differences between analog wax-up and digital wax-up on the upper lateral incisors – mesial contact point landmark.

Statistical test	***Statistical significance p-value***	***Statistical significance the exact value***
Kruskal-Wallis	***p < 0,05***	***p = 0.0472***
Wilcoxon Mann-Whitney	***p < 0,05***	***p = 0.05556***
Two Sample t-test	***p < 0,05***	***p = 0.04075***

In the case of the analysis of the differences at the upper canines, statistically significant differences were noted for the zenith-incisal edge half distance landmark, but also for the overall analysis of the landmarks (Table VII.2 and VII.3).

Table VII.2 – Statistical significance value for the Kruskal-Wallis test in the analysis of differences for upper canines.

Landmark analyzed	***Statistical significance p-value***	***Statistical significance the exact value***
Gingival zenith	*p* > 0,05	*p* = 0.754
Tip of the canine	*p* > 0,05	*p* = 0.4647
Half of the incisal edge zenith distance	***p* < 0,05**	***p* = 0.0472**
Mesial contact point	*p* < 0,05	*p* = 0.4647
Distal contact point	*p* > 0,05	*p* = 0.3472
All landmarks	***p* < 0,05**	***p* = 0.03051**

Table VII.3 – Statistical significance of the differences between the analog wax-up and the digital wax-up at the upper canine level in the overall analysis of all landmarks.

Statistical test	***Statistical significance p-value***	***Statistical significance the exact value***
Kruskal-Wallis	***p*<0,05**	***p* = 0.03051**
Wilcoxon Mann-Whitney	***p*<0,05**	***p* = 0.03039**
Two Sample t-test	***p*<0,05**	***p* = 0.0186**

The analysis of all the landmarks for the entire group of the studied teeth, showed that there is a statistically significant difference between the analog wax-up method and the digital wax-up method, even if individually for each landmark there are no significant differences (Table VII.4).

Table VII.4 – Statistical significance value for the Kruskal-Wallis test in the analysis of differences for the set of analyzed teeth.

Landmark analyzed	***Statistical significance p-value***	***Statistical significance the exact value***
Gingival zenith	*p* > 0,05	*p* = 0.6015
Tip of the canine	*p* > 0,05	*p* = 0.0758
Half of the incisal edge zenith distance	*p* > 0,05	*p* = 0.1172
Mesial contact point	*p* > 0,05	*p* = 0.3472
Distal contact point	*p* > 0,05	*p* = 0.1172
All landmarks	***p* < 0,05**	***p* = 0.01266**

7.4 Discussions. The predictability of obtaining the best possible aesthetic result with the help of the prosthetic treatment is not guided by some exact, well-defined principles. Over time, numerous ways have been proposed that use different aspects or morphological elements to direct the treatment towards a result as close as possible to the patients' requirements, based on idealistic principles or mathematical formulas [10]. However, the smile is dominated by human subjectivity and is far from a precise mathematical formula. For this reason, the design of the prosthetic restorations in the frontal area must take into account all the factors involved: doctor, dental technician and patient. The physical transposition of the future restoration is a task that the technician must solve either by classical methods or by modern modeling methods. The advantages of modern techniques are obvious, but the time consumption can be an impediment to the economy of the whole process.

Since the advent of digital technology flows, most of the problems related to the dimensional accuracy of the restorations have been fixed. However, the finesse aspects are still being analyzed to see if digital technology can be used successfully in prosthetic treatments in the maxillary frontal area, which require provisional restorations to be done to help preview the final result [11].

This study, as designed, is unique in the way it is structured and the landmarks considered for analysis. There are studies that have analyzed different landmarks than the present study, however, showing the effectiveness of the digital wax-up method [12] [13]. However, through this study, the aim was to expand the analyzed landmarks, established as the defining ones for the teeth in the frontal area and with a significant impact on the human smile [14].

At the same time, it should be noted that the use of a large number of landmarks led to statistically significant results in terms of the quality of digital wax-up restorations.

7.5 Conclusions

Limitations imposed by the study, and in particular the difficulty to find suitable patients for the study to meet the inclusion criteria, resulted in the reduction of the confidence level from 99% to 95%. Results were obtained that confirm the efficiency of using the digital wax-up technique compared to the analog wax-up technique.

The accuracy is statistically significantly better when using the digital wax-up ($p = 0.01266$) at the general level, even if individually, on groups of landmarks or groups of teeth, no statistically significant differences are obtained.

The analysis of the height and width of the analyzed teeth did not signal significant differences between the two wax-up methods, revealing results that are based on the dimensional difference of the analyzed teeth.

Similar to the accuracy, the values for *the symmetry* of the restorations showed that, although individually, on landmarks or groups of teeth, the differences are not significant, in general, using the digital wax-up method, restorations with a statistically significant better symmetry are obtained compared to the analog wax-up method.

Increasing the number of patients included in the study will have the main effect of increasing the level of confidence to 99% ($p=0.01$), and possibly obtaining significant results for the study related to the width and height of teeth in the frontal area restored using digital wax-up.

CHAPTER 8 – CONCLUSIONS AND PERSONAL CONTRIBUTIONS

Based on the studies carried out in this Doctoral Thesis, the following conclusions can be drawn:

- by changing the occlusal morphology of the lower first molar and creating an interference, the movement parameters showed variations in terms of the extent and direction of movement, both at the dental and condylar level. Respecting the initial morphology and its harmonious adaptation to individual functional parameters is a good premise for maintaining the balance between the component parts of the dento-maxillary system.
- the possibility of customizing prosthetic abutments for implants through CAD-CAM technology allows the creation of more refined prosthetic models that lead to superior implant prosthetic restorations in terms of aesthetics, biocompatibility and durability.
- restoring the occlusal design using analog wax-up tends to produce volumetric changes, values recorded for all analyzed teeth, statistically significant;
- the volumetric changes for analog wax-up do not have a fixed pattern, the restored teeth being over- or undersized in different areas;
- restoring missing teeth creates the biggest volumetric differences;
- restoring the occlusal design using digital wax-up, produces statistically insignificant volumetric changes;
- similarly, the variations do not follow a certain pattern, although in both cases the occlusal records were followed;
- analog wax-up depends on the experience and skill of the dental technician, each model being unique in its own way;
- digital wax-up is based on the data stored in the program, but corrected by the technician;
- there are statistically significant differences between models made with analog wax-up and digital wax-up;
- digital wax-up benefits from increasingly powerful and calibrated equipment to provide predictable results on a regular basis;

- *The accuracy* is statistically significant better when using the digital wax-up (p = 0.01266) at the general level, even if individually, on groups of landmarks or groups of teeth, no statistically significant differences are obtained;
- The analysis of *the height and width* of the analyzed teeth did not signal significant differences between the two wax-up methods, revealing results that are based on the dimensional difference of the analyzed teeth;
- Similar to the accuracy, the values for the *symmetry* of the restorations showed that, although individually, on landmarks or groups of teeth, the differences are not significant, in general, using the digital wax-up method, restorations with a statistically significant better symmetry are obtained compared to the analog wax-up method;
- The increase in the number of patients included in the study will have the main effect of increasing the level of confidence to 99% (p=0.01), and possibly obtaining significant results for the study related to the width and height of teeth in the frontal area restored using digital wax-up;
- Thus, results were obtained that confirm the efficiency of using the digital wax-up technique compared to the analog wax-up technique.

Bibliography

1. **Ebert A, Hedderich J, Kern M,.** Retention of zirconia ceramic copings bonded to titanium abutments. *Int J Oral Maxillofac Implants*. 2007, Vol. 22, 6, pg. 921-7.
2. **Tribst JPM, Dal Piva AMO, Borges ALS, Bottino MA,.** Different combinations of CAD/CAM materials on the biomechanical behavior of a two-piece prosthetic solution. *Int J Comput Dent*. 2019, Vol. 22, 2, pg. 171-176.
3. **Medit.** MEDIT Link. *meditlink.com*. [Interactiv] [Citat: 18 02 2024.] https://www.meditlink.com/home.
4. **Statistics, Laerd.** Kruskal-Wallis H Test using SPSS Statistics. *Laerd Statistics*. [Interactiv] [Citat: 16 01 2024.] https://statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics.php.
5. **McDonald JH.** Kruskal-Wallis test. *Handbook of Biological Statistics*. [Interactiv] [Citat: 16 01 2024.] http://www.biostathandbook.com/kruskalwallis.html.
6. **Sava FA.** Tehnici de comparatie între grupuri - Testele parametrice t si z. *Pagina de statistică socială.* [Interactiv] [Citat: 16 01 2024.] https://statisticasociala.tripod.com/teh_par.htm.
7. **LaMorte WW.** Mann Whitney U Test (Wilcoxon Rank Sum Test). *Nonparametric Tests*. [Interactiv] [Citat: 16 01 2024.] https://sphweb.bumc.bu.edu/otlt/mph-modules/bs/bs704_nonparametric/bs704_nonparametric4.html.
8. **McClenaghan E.** Mann-Whitney U Test: Assumptions and Example. *technologynetworks.com*. [Interactiv] [Citat: 16 01 2024.] https://www.technologynetworks.com/informatics/articles/mann-whitney-u-test-assumptions-and-example-363425.
9. **Laerd Statistics.** Kruskal-Wallis H Test using SPSS Statistics. *Laerd Statistics*. [Interactiv] [Citat: 16 01 2024.] https://statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics.php.
10. **Magne P, Gallucci GO, Belser UC.** Anatomic crown width/length ratios of unworn and worn maxillary teeth in white subjects. *J Prosthet Dent*. 2003, Vol. 89, 5, pg. 453-61. doi: 10.1016/S0022-3913(03)00125-2. PMID: 12806322.
11. **Kollmuss M, Jakob FM, Kirchner HG, Ilie N, Hickel R, Huth KC,.** Comparison of biogenerically reconstructed and waxed-up complete occlusal surfaces with respect to the original tooth morphology. *Clin Oral Investig*. 2013, Vol. 17, 3, pg. 851-7. doi: 10.1007/s00784-012-0749-6.
12. **Abduo J, Bennamoun M, Tennant M, McGeachie J,.** Impact of digital prosthodontic planning on dental esthetics: Biometric analysis of esthetic parameters. *J Prosthet Dent*. 2016, Vol. 115, 1, pg. 57-64. doi: 10.1016/j.prosdent.2015.07.005.
13. **Abduo J, Bennamoun M.** Three-dimensional image registration as a tool for forensic odontology: a preliminary investigation. *Am J Forensic Med Pathol*. 2013, Vol. 34, 3, pg. 260-6. doi: 10.1097/PAF.0b013e31829f6a29.
14. **Roca-Obis P, Rius-Bonet O, Zamora-Olave C, Willaert E, Martinez-Gomis J.** Sex-specific reference values for the crown heights of permanent anterior teeth and canines for assessing tooth wear. *Acta Odontol Scand*. 2023, Vol. 81, 1, pg. 73-78. doi: 10.1080/00016357.2022.2084157.
15. **Vâlsan MI, Oancea L, Păuna MR, Gagiu C, Petre AE,.** The Influence of Altering the Morphology of the First Mandibular Molar on Functional Mandibular Movements: A Pilot Study. *Dent Oral Biol and Craniofacial Res*. 2021, Vol. 4, 2, pg. 1-7. doi: 10.31487/j.DOBCR.2021.02.01.
16. **Valsan IM, Pauna MR, Petre AE, Oancea L,.** Biologic and Esthetic Outcome of CAD/CAM Custom Ceramic Implant Abutment: A Clinical Report. *Maedica (Bucur)*.

2021, Vol. 16, 1, pg. 145-148. doi: 10.26574/maedica.2020.16.1.145. PMID: 34221171; PMCID: PMC8224707.
17. **Paolucci B, Calamita M, Coachman C, Gurel G, Shayder A, Hallawell P.** Visagism: The Art of Dental Composition. [autorul cărții] Duarte S. *Quintessence of Dental Technology 2012*. London : Quintessence Pub Co, 2012, pg. 187-201.
18. **McLaren EA, Culp L,.** Smile Analysis - The Photoshop® Smile Design Technique: Part I. *J Cosm Dent*. 2013, Vol. 29, 1, pg. 94-108.
19. **Măcriș A.** *Estetică dentară. Reconstrucții coronare. Soluții de tratament.* București : Ed. Universitară "Carol Davila", 2014. pg. 15-47.
20. **Goldstein RE, Chu SJ, Lee EA, Stappert CFJ,.** *Ronald E. Goldstein's Esthetics in Dentistry*. 3rd ed. Hoboken : John Wiley & Sons, Inc, 2018. pg. 17-701. Vol. 1.
21. **Dorobăț V, Stanciu D.** *Ortodonție și ortopedie dento-faciala*. București : Ed. Medicală, 2014. pg. 153-177.
22. **Petre A, Ioniță S, Trăistaru T.** Criteriile estetice în medicina dentară consemnate în literatura de specialitate. *Rom J Stom.* 2011, Vol. 51, 4, pg. 278-286.
23. **Layton DM, Morgano SM, Muller F, Kelly JA, Nguyen CT et al,.** The Glossary of Prosthodontic Terms. *J Prosthet Dent 2023*. 10th edition, 2023, Vol. 130, 4s1, pg. e1-e126. PII: S0022-3913(23)X0002-X.
24. **Coachman C.** Digital Smile Design. *digitalsmiledesign.com*. [Interactiv] 2015. [Citat: 11 02 2024.] https://digitalsmiledesign.com/.
25. **Perdosa VO, Franca FMG, Florio FM, Basting RT.** Study of the morpho-dimenional relationship between the maxillary central incisors and the face. *Braz Oral Res*. 2011, Vol. 25, 3, pg. 210-6. doi: 10.1590/s1806-83242011005000010.
26. **Manfredini D, Perinetti G, Guarda-Nardini L,.** Dental malocclusion is not related to temporomandibular joint clicking: a logistic regression analysis in a patient population. *Angle Orthod*. 2014, Vol. 84, 2, pg. 310-5. doi: 10.2319/041613-295.1.
27. **Manfredini D, Stellini E, Marchese-Ragona R, Guarda-Nardini L,.** Are occlusal features associated with different temporomandibular disorder diagnoses in bruxers? *Cranio*. 2014, Vol. 32, 4, pg. 283-8. doi: 10.1179/2151090314Y.0000000008.
28. **Manfredini D, Perinetti G, Stellini E, Di Leonardo B, Guarda-Nardini L,.** Prevalence of static and dynamic dental malocclusion features in subgroups of temporomandibular disorder patients: Implications for the epidemiology of the TMD-occlusion association. . *Quintessence Int*. 2015, Vol. 46, 4, pg. 341-9. doi: 10.3290/j.qi.a32986.
29. **Wang C, Yin X,.** Occlusal risk factors associated with temporomandibular disorders in young adults with normal occlusions. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2012, Vol. 114, 4, pg. 419-23. doi: 10.1016/j.oooo.2011.10.039.
30. **Radke JC, Kull RS, Sethi MS,.** Chewing movements altered in the presence of temporomandibular joint internal derangements. *Cranio*. 2014, Vol. 32, 3, pg. 187-92. doi: 10.1179/0886963413Z.00000000028.
31. **Kutkut A, Abu-Hammad O, Mitchell R,.** Esthetic Considerations for Reconstructing Implant Emergence Profile Using Titanium and Zirconia Custom Implant Abutments: Fifty Case Series Report. *J Oral Implantol*. 2015, Vol. 41, 5, pg. 554-61. doi: 10.1563/AAID-JOI-D-12-00274.
32. **Alani A, Corson M,.** Soft tissue manipulation for single implant restorations. *Br Dent J*. 2011, Vol. 211, 9, pg. 411-6. doi: 10.1038/sj.bdj.2011.904.
33. **Qutub OA, Basunbul GI, Binmahfooz AM,.** Influence of abutment material on the shade of dental implant restorations in the esthetic zone: a single case report. *Clin Cosmet Investig Dent*. 2019, 11, pg. 73-80. doi: 10.2147/CCIDE.S199635.

34. **Tribst JPM, Piva AMDOD, Borges ALS, Bottino MA,.** Influence of crown and hybrid abutment ceramic materials on the stress distribution of implantsupported prosthesis. *Rev Odontol UNESP*. 2018, Vol. 47, 3, pg. 149-154. doi:10.1590/1807-2577.04218.
35. **Lops D, Bressan E, Chiapasco M, Rossi A, Romeo E,.** Zirconia and titanium implant abutments for single-tooth implant prostheses after 5 years of function in posterior regions. *Int J Oral Maxillofac Implants*. 2013, Vol. 28, 1, pg. 281-7. doi: 10.11607/jomi.2668.
36. **Bertolini Mde M, Kempen J, Lourenço EJ, Telles Dde M,.** The use of CAD/CAM technology to fabricate a custom ceramic implant abutment: a clinical report. *J Prosthet Dent*. 2014, Vol. 111, 5, pg. 362-6. doi: 10.1016/j.prosdent.2013.08.016.
37. **Adolfi D, Tribst JPM, Adolfi M, Dal Piva AMO, Saavedra GSFA, Bottino MA,.** Lithium Disilicate Crown, Zirconia Hybrid Abutment and Platform Switching to Improve the Esthetics in Anterior Region: A Case Report. *Clin Cosmet Investig Dent*. 2020, 12, pg. 31-40. doi: 10.2147/CCIDE.S234980.
38. **Papadiochou S, Pissiotis AL,.** Marginal adaptation and CAD-CAM technology: A systematic review of restorative material and fabrication techniques. *J Prosthet Dent*. 2018, Vol. 119, 4, pg. 545-551. doi: 10.1016/j.prosdent.2017.07.001.
39. **Farag E, Sabet A, Ebeid K, El Sergany O,.** Build angle effect on 3D-printed dental crowns marginal fit using digital light-processing and stereo-lithography technology: an in vitro study. *BMC Oral Health*. 2024, Vol. 24, 1, pg. 73. doi: 10.1186/s12903-024-03851-4.
40. **Muric A, Gokcen Röhlig B, Ongul D, Evlioglu G,.** Comparing the precision of reproducibility of computer-aided occlusal design to conventional methods. *J Prosthodont Res*. 2019, Vol. 63, 1, pg. 110-114. doi: 10.1016/j.jpor.2018.10.002.
41. **Orozco-Varo A, Arroyo-Cruz G, Martínez-de-Fuentes R, Jiménez-Castellanos E.** Biometric analysis of the clinical crown and the width/length ratio in the maxillary anterior region. *J Prosthet Dent*. 2015, Vol. 113, 6, pg. 565-70.e2. doi: 10.1016/j.prosdent.2014.11.006.
42. **Shaweesh AI, Al-Dwairi ZN, Shamkhey HD.** Studying the relationships between the outlines of the face, maxillary central incisor, and maxillary arch in Jordanian adults by using Fourier analysis. *J Prosthet Dent*. 2015, Vol. 113, 3, pg. 198-204. doi: 10.1016/j.prosdent.2014.08.009.
43. **Scoble HO, White SN.** Compound complex curves: the authentic geometry of esthetic dentistry. *J Prosthet Dent*. 2014, Vol. 111, 6, pg. 448-54. doi: 10.1016/j.prosdent.2013.10.025.
44. **Raj V.** Esthetic paradigms in the interdisciplinary management of maxillary anterior dentition-a review. *J Esthet Restor Dent*. 2013, Vol. 25, 5, pg. 295-304. doi: 10.1111/jerd.12028.
45. **Machado AW, Moon W, Gandini LG Jr,.** Influence of maxillary incisor edge asymmetries on the perception of smile esthetics among orthodontists and laypersons. *Am J Orthod Dentofacial Orthop*. 2013, Vol. 143, 5, pg. 658-64. doi: 10.1016/j.ajodo.2013.02.013.