MEDICAL UNIVERSITY
“PROF. DR. PARASKEV STOYANOV” – VARNA

Faculty of Dental Medicine
Department of DENTAL MATERIALS SCIENCE AND PROSTHETIC DENTAL MEDICINE

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„Laboratory Investigation of the Accuracy of Cemented Superstructures on Abutments Manufactured Using Different Impression Taking Protocols.“

Abstract

Of PhD Thesis

Scientific specialty: Prosthetic dental medicine

Scientific Advisor:

Assoc. Prof. Dr. Stoyan Georgiev Katsarov, DMD, PhD

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The dissertation contains 190 pages and is illustrated with 20 tables, 105 figures and 3 applications. The bibliography consists of 299 sources, 23 of which in Cyrillic and 276 in Latin.

The PhD thesis has been approved at a meeting of the Department of Dental Materials Science and Prosthetic Dentistry at the Medical University "Prof. Dr. Paraskev Stoyanov" – Varna on 13.09.2024.

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The defense materials are available at the Scientific Department of MU – Varna and are published on the website of MU – Varna.

Note: In the abstract, the numbers of the tables and figures do not correspond to the numbers in the dissertation.

CONTENT

ABBREVIATIONS USED

CAD/CAM - computer-aided design and computer-aided manufacturing
DDA - defects of the dental arches.
DI – digital impression
DMD – doctor of dental medicine
ELS - extraoral laboratory scanner.
FP – fixed prosthetics
FDP – fixed dental prosthesis
HDT – hard dental tissues
IPT – implant prosthetic treatment
ISS- intraoral scanning systems.
PDM – prosthetic dental medicine
PEEK - polyether ether ketone
SA- scan abutment
SB – scan body
STL - Standard Tesselation Language
3D - three dimensional

I. INTRODUCTION

Modern prosthetic dentistry aims to improve the quality of life for patients with various types of edentulous conditions by replacing removable prosthetic restorations with fixed ones.

Currently, the issue of implant-prosthetic treatment (IPT) for defects of the dental arches (DDA) is highly relevant. This approach offers several advantages, the most significant from a preventive standpoint being the prevention of bone loss around functionally loaded implants, improvement of masticatory efficiency, and restoration of occluso-articulatory balance, which significantly increases patient comfort. This way, structural and functional changes following the loss of single or multiple teeth, as well as in totally edentulous jaws, are avoided, ensuring lasting rehabilitation of the masticatory system and the aesthetic appearance of the dentition.

Digitalization is rapidly advancing with the introduction of CAD/CAM technologies (computer-aided design and computer-aided manufacturing). They find wide application in various fields of dentistry, increasingly dominating work in both clinical settings and laboratories. Implant-prosthetic treatment (IPT) using digital technologies has also made significant progress in recent years, displacing analog methods. Digital technologies are integrated throughout the entire process of creating prosthetic restorations, from the clinical stage of taking impressions, through planning the design in software, to its manufacturing using various methods. Their implementation allows work with fully digital protocol or a partially digitalized approach, incorporating an intermediate step and combining it with conventional methods at some stages.

The introduction of intraoral scanners (IOS) and transfer components for scanning (scan abutments) designed for taking impressions on implants brings a new dimension to the impression process, allowing for the creation of a digital positive virtual model of the prosthetic field, which serves for the subsequent manufacturing of the prosthetic restorations using either a subtractive method or an additive method.

The correct transmission of information from the clinic to the laboratory through the impression, whether conventional or digital, is a key factor for successful treatment. Regardless of the materials and manufacturing technology used, implant-supported restorations must meet certain criteria to be considered clinically acceptable. These criteria include aesthetics, mechanical strength, good marginal adaptation, and passive fit. Discrepancies between the prosthetic restoration and the osseointegrated implants can lead to internal stress and create unnecessary load on them, compromising the treatment.

The continuous improvement of digital technologies have necessitated more in-depth research into the accuracy of implant superstructures made using subtractive and additive methods.

II. PURPOSE AND TASKS

II.1. PURPOSE

The aim of this dissertation is to conduct a comparative assessment of the accuracy of superstructures fabricated using different methods and impression-taking protocols, cemented onto abutments, and measured on microsections of laboratory micro-grinds.

II.2. TASKS

1. Survey Study

1.1. Conduct a survey among doctors of dental medicine regarding their awareness and preferences for impression techniques for transferring implant superstructures.
1.2. Conduct a survey among dental technicians regarding their awareness of protocols for transferring implant positions and fabricating fixed restorations on implant supports.

2. Comparative Assessment of the Accuracy of Implant-Supported Superstructures which involves measuring the thickness of the cement layer in copings transferred using two methods with an intraoral scanner and made from zirconium dioxide via subtractive technology.

2.1. Directly scanned abutment.
2.2. Directly with a scan body.

3. Comparative Assessment of the Accuracy of Implant-Supported Superstructures which involves measuring the thickness of the cement layer in copings transferred using two methods with an intraoral scanner and made from Co-Cr alloy via additive technology—selective laser melting (SLM).

3.1. Directly scanned abutment.
3.2. Directlywith a scan body.

4. Comparative Assessment of the Cement Layer Thickness between copings transferred using scan bodies and directly scanned abutments with an intraoral scanner, comparing subtractive and additive technologies.

III. MATERAILS AND METHODS

To formulate and structure the experimental setups for the subsequent tasks and to gather information regarding awareness and preferences for impression techniques for transferring implant superstructures, anonymous survey questionnaires were created for doctors of dental medicine and dental technicians.

III.2. Research Methods

This dissertation is based on data collected from laboratory (in vitro) studies and statistical methods. The investigation was conducted in a controlled laboratory environment and involves the systematic collection of experimental data, which were subsequently used to pursue a thorough statistical analysis to validate the results and formulate conclusions.

III.2.1. Methodology for Task 1

For the first task, two types of anonymous survey questionnaires were created (Application No. 1, No. 2) targeted at two groups of respondents: doctors of dental medicine and dental technicians.

The two survey studies, consisting of 12-14 questions, sought the opinions of dental practitioners and dental technicians regarding their experience in the field of fixed prosthetics on implants, preferences for impression techniques, difficulties encountered with digital and conventional methods, their awareness of the laboratory work protocol, and difficulties in fabricating these prosthetic restorations. A total of 61 DMD and 47 dental technicians participated in the survey.

III.2.2. Methodology for Task 2

Based on the conducted research and analysis of the results from the first task, we aimed to investigate the parameter "accuracy" of constructions when using scan bodies and when scanning superstructures in laboratory conditions.

The study compares two working protocols by measuring the internal fit and marginal adaptation of samples produced using CAD/CAM technology on implant supports and designed after scanning with an intraoral scanner.

One protocol involves scanning abutment , while the other includes using a scan body to transfer the implant position. According to the survey results, the first protocol is the most commonly used, with a significant part of participants preferring it due to its effectiveness.

In this task, each superstructure was fabricated using a subtractive method. The laboratory study evaluated two parameters: marginal adaptation and internal fit. The distance obtained between the abutments and the inner surface of the test specimens provides information about the accuracy of the constructions.

For the purposes of the study, the thickness of the cement layer was measured at several different points on microsections using a stereomicroscope. First, measurements were taken in the vertical direction between the outermost point of the margin and the inner surface of the test specimen, and these were averaged to determine the marginal adaptation parameter.Second, measurements were made at two points along the axial wall between the abutment and the specimens, which were averaged to assess the internal fit on the abutments.

Technology for Fabricating Test Specimens

For the purposes of the study, we used a training model of the lower jaw (Frasaco™ GmbH, Germany), which was scanned with an extraoral scanner (3Shape™ D850®, Denmark) and converted into a digital format (.STL file) **(Fig. 1)**. To minimize potential reflections from surfaces and ensure precise scanning, we utilized a scan spray (IP Scan Spray, IP Division GmbH).

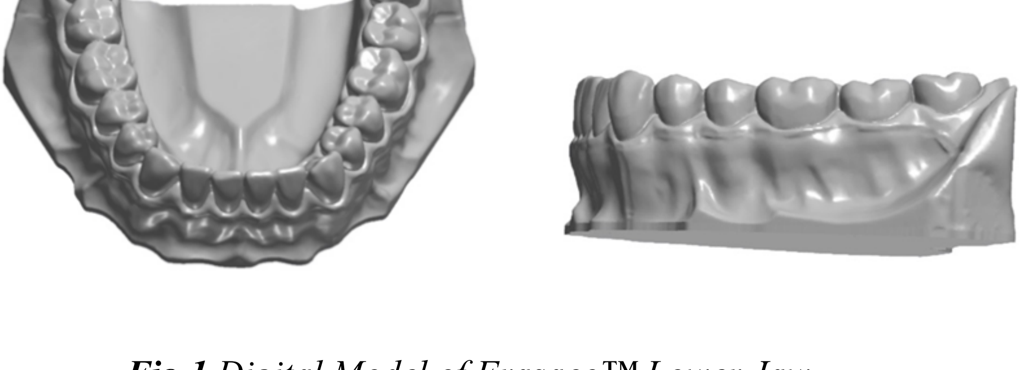


Fig.1 *Digital Model of Frasaco™ Lower Jaw*

To execute the second task, a 3D model (master model) with a defect in the area of teeth 35-37 and a gingival mask was created. All test specimens were fixed onto this model during the experiment. The design of the master model was developed using specialized 3D design software, Tinkercad (**Fig.2**). For the purposes of the study, a defect was defined in the area of teeth 35, 36, and 37, where implant analogs could be placed to replace teeth 35 and 37.

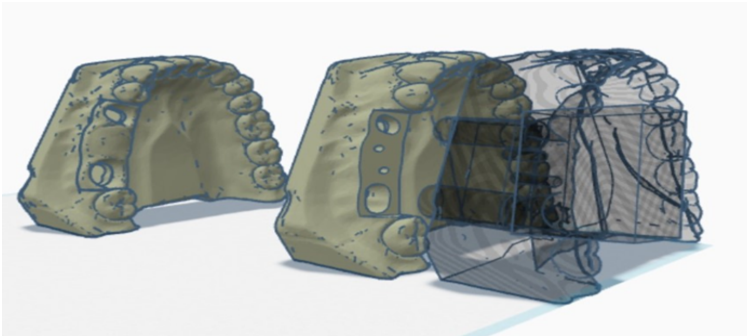


Fig.2 *3D Modeling of the Design for Creating the Master Model in Tinkercad*

After transferring the .stl file to the printing preparation software PreForm (Formlabs), the model was printed using the selective laser polymerization method with the Form 2® 3D printer (Formlabs™) from low-viscosity resin (Anycubic Grey) (365-410 nm), which ensures a higher printing speed.

Once the model was converted into a physical form, the implant analogs were placed in the edentulous area with the corresponding angulations. For the purposes of the study, implant analogs from the Neodent Gm Analog system were selected, specifically Titanium, 5.0/6.0 mm, along with Neodent abutments (Titanium base, Ti, 4.5x6x1.5) (Fig.3). To prevent displacement due to the expansion of the gypsum and to maintain parallel alignment during measurements, prior laser welding was performed using the LaserStar T plus, BEGO, Germany.

Fig. 3 *3D Printed model with gingival mask and placed Neodent abutments (Titanium Base, Ti, 4.5x6x1.5) in implant analogs*

To obtain the first subgroup of samples, we scanned the original model with the abutments using the Medit i600 intraoral scanner, ensuring that the scanner was calibrated first.

To obtain the second subgroup of samples, scanning bodies made of PEEK from the Neodent system (GM scan body, Neodent) were fixed onto the implant analogs (Fig.4). After subsequent scanning and generating a virtual model, superstructures were selected.

Fig. 4 *Scanning Implant Body GM Scan Body from the Neodent System Made of PEEK*

After scanning the model, a virtual design of the specimens was created using the specialized software 3Shape Dental System®. They were modeled as copings connected by a bar measuring 24.22 mm in length and 3.73 mm in diameter **(Fig. 5).**

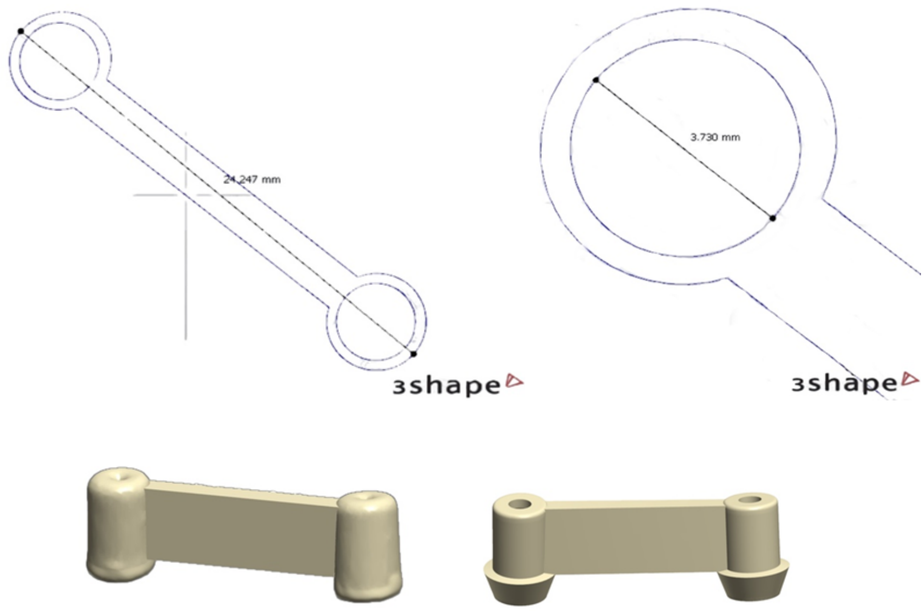


Fig. 5 *Software design of the test specimens*

In the design of all test specimens, standard settings were used in 3Shape: 0.020 mm cement gap, 0.080 mm extra cement gap, and 1 mm distance to the margin line. After completing the design of the samples, the .stl file was exported to the milling machine for preparation for materialization using the subtractive method. A total of 20 test specimens were produced, with 10 from each group, depending on the methodology used. All bars were milled from zirconium dioxide using a 5-axis milling machine (CORiTEC® 150i, Imes Icore, Germany).

After cleaning with alcohol and drying, a thin layer of resin-modified glass ionomer cement (GC Fuji Plus, GC, Japan) was applied to the superstructures of the printed working model and their inner surfaces using a brush. For better visualization, the cement was colored with a solution of fuchsine **(Fig. 6).**

Fig.6 *Test specimens made of zirconium dioxide obtained by the analog scanning method*

In the next stage, after 24 hours, the test specimens were placed on the model in the same position and cut through the middle of the connecting bar using a separator to facilitate subsequent packing and the production of microsections.

For the purposes of the study and to assist with the packing of the test specimens, a matrix design was created in the 3D design software Tinkercad to serve as a support for the subsequent packaging **(Fig.7).**

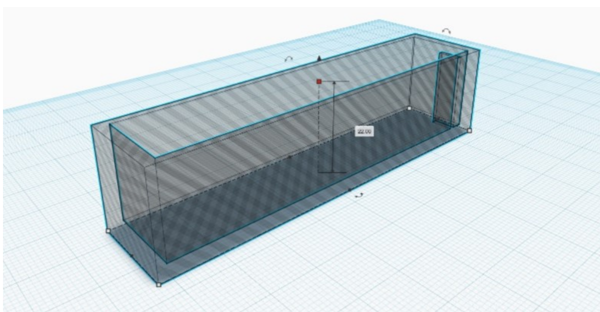


Fig.7 *Stages of the matrix design*

The specimens were placed on the supporting bars in mutual parallel alignment. They were then packaged with a photopolymerizing resin (Formlabs

Clear) in the polymerization device (Form Cure®). After preparing the specimens, they were fixed in the precision cutting machine IsoMet 1000 (Buehler Ltd., Lake Bluff, IL, USA) **(Fig. 8)** to create microsections, and were cut along their longitudinal axis using a diamond blade with water cooling (IsoMet Diamond Watering Blades 15HC, Buehler Ltd., Lake Bluff, IL, USA).

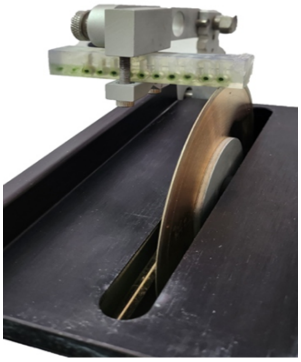


Fig.8 *Fixed zirconium dioxide specimens in the IsoMet 1000 precision cutting machine*

After obtaining the microsections, measurements were taken at six points for each specimen using a Leica M80 stereomicroscope (Leica Microsystems GmbH, Wetzlar, Germany) equipped with a Leica IC90E camera. The measurements were conducted at a magnification of x50 and with the Leica Application Suite V4.13.0 software. The distance between the inner surface of the test specimens and the abutments was recorded through the thickness of the cement layer. Measurements were made at six points on each specimen from the medial and distal walls, and the values were documented in a pre-prepared table (Application No. 3), **(Fig.9).**

The measurement points for the medial abutment (35) are as follows:

1. External point of the medial shoulder - point MR1
2. Base of the medial axial wall - point MR2
3. Middle of the distal axial wall - point MR3
4. External point of the distal shoulder - point DR1
5. Base of the distal axial wall - point DR2
6. Middle of the distal axial wall - point DR3

The measurement points for the distal abutment (37) are as follows:

1. External point of the medial shoulder - point MR4
2. Base of the medial axial wall - point MR5
3. Middle of the medial axial wall - point MP6
4. External point of the distal shoulder - point DR4

5. Base of the distal axial wall - point DR5
6. Middle of the distal axial wall - point DR6

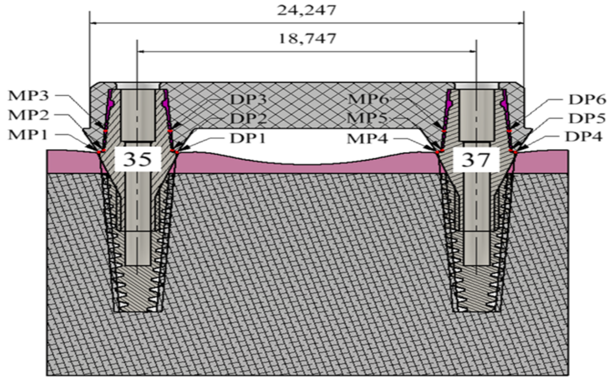
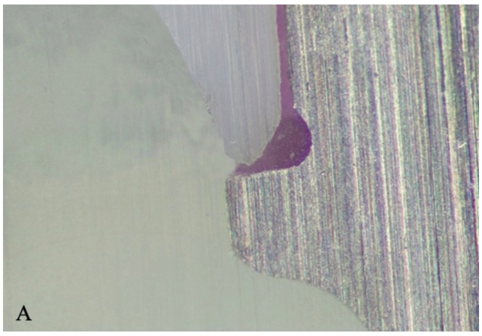


***Fig. 9** Schematic representation of measurement points*

Marginal adaptation was calculated by taking the average values for the medial and distal walls of 35 (MP1, DP1) and 37 (MP4, DP4) for each specimen. The fit accuracy was determined by averaging the values for the medial and distal walls of 35 (MP2, MP3, DP2, DP3) and 37 (MP5, MP6, DP5, DP6) for each test body. The data obtained from the study were used for statistical analysis **(Fig.10).**



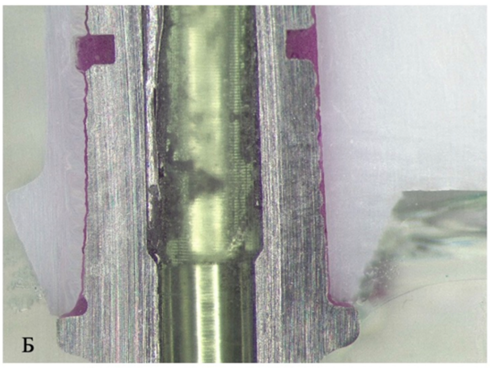


***Fig. 10** Measurement of Marginal Adaptation and Fit Accuracy under Stereomicroscope for Zirconia Test Bodies A) Medial Wall in the Area of 35, B) Overall View of the Section in the Area of 35*

III.2.3. Methodology for Task 3

The second group of test bodies was produced using SLM technology from cobalt-chromium alloy powder for the manufacture of removable and fixed restorations, utilizing a metal 3D printer.

From the prepared .stl file, 20 test bodies were produced, divided into two groups (n=10): the first group from a scanned abutment and the second group from a scanned analog. These samples were fabricated using the Arrow LMP100 SLM metal 3D printer **(Fig.11)** from Dentas, LLC. For the production of the Co–Cr–W–Mo alloy samples, the following parameters were selected: laser power of 70 W, scanning speed of 800 mm/s, track overlap of 40%, and layer thickness of 0.025 mm. The shielding gas used was nitrogen, and the laser focus diameter was 0.035 mm.

Fig.11 *Dentas LMP 100 metal 3D printer*

After the completion of the process, the test specimens were treated with aluminum oxide (110-250 μm) at a pressure of 2-4 bar, cleaned with steam, and degreased with ethyl alcohol. This was followed by cementation with resin-modified glass ionomer cement (GC Fuji Plus, GC, Japan) **(Fig. 12),** separating the test specimens into two halves, and packaging them in resin. The microsections were obtained after fixing and cutting using a precision cutting machine IsoMet 1000 (Buehler Ltd., Lake Bluff, IL, USA) **(Fig. 13).**

Fig.12 *Co-Cr specimens fixed onto the model.*

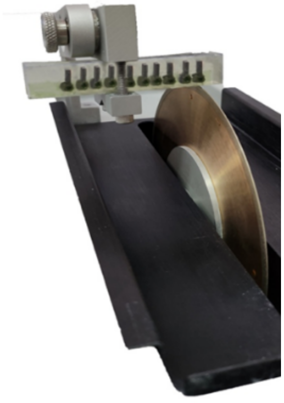


Fig.13 *Fixed Co-Cr specimens in the IsoMet 1000 precision cutting machine.*

The measurements were taken at 6 points for each specimen from the medial and distal walls, and the values were recorded in a pre-prepared table (Application 3) **(Figure 14).**

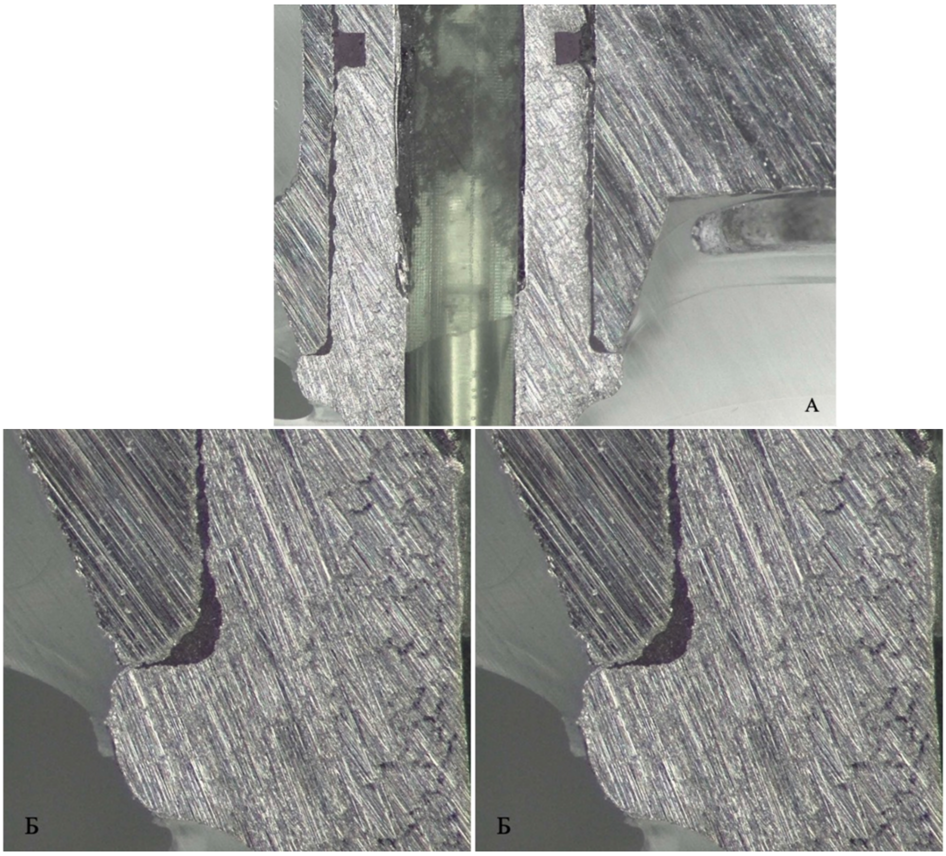


Fig.14 *Measuring marginal adaptation and internal fit under a stereomicroscope for the Co-Cr alloy specimens. A) Overall view of the section in the area of 35, B) Medial wall in the area of 35, and C) Distal wall in the area of 35.*

III.2.4. Methodology for Task 4

Statistical Methods for Data Processing

The data were entered and analyzed using advanced functions of the statistical software package SPSS (SPSS Statistics v.22, developed by IBM Corp) and Microsoft Excel, utilizing the Data Analysis tool. The statistical methods applied include a variety of techniques for processing and interpreting the data, allowing for the extraction of significant and accurate results from the conducted studies. The methods used are a crucial part of the analytical process to ensure the reliability of the conclusions, such as:

- **Analysis of Variance (ANOVA)**
- **Comparative Analysis**
- **Regression Analysis**
- **Variational Analysis of Quantitative Variables**
- **Risk Assessment Analysis**
- **Correlation Analysis**
- **F-test for Two Samples**
- **t-test for Two Samples**
- **Graphical and Tabular Representation of Results for visualizing and analyzing the statistical data**

In all conducted analyses, a significance level of $p<0.05$ was accepted, with a confidence interval of 95%. This approach ensures a high degree of reliability and accuracy in the results, minimizing the probability of Type I error.

IV. RESULTS AND DISCUSSION

IV.1 Results and Discussion for Task 1

IV.1.1 Analysis of the professional preferences of dental practitioners regarding awareness and preferences for impression techniques in the transfer of implant prosthetic superstructures.

The prepared anonymous survey is directed toward dental practitioners. It contains two types of questions: those with only one possible answer and those with more than one possible answer.

The survey results show that the majority of respondents are general dental practitioners, making up 68.5%. Those with a specialty in prosthetic dentistry comprise 26.3%, while the remaining are specialists in oral surgery at 2.6% and in operative dentistry and endodontics at 2.6% **(Fig.15).**

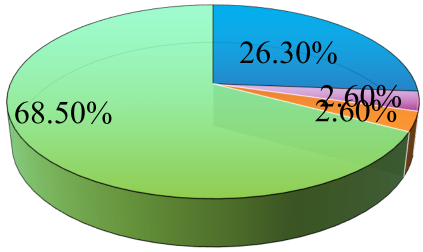
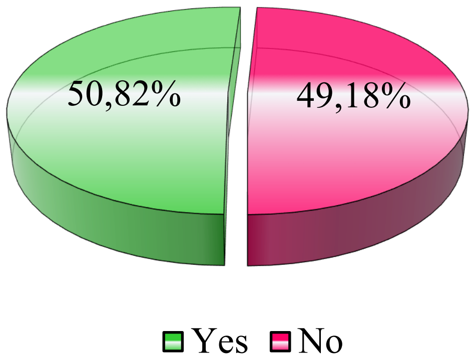


Fig.15 *Percentage distribution of responses to the question "Do you have a specialized qualification?" (%)*

In the studied group, 31 (50.82%) of dental professionals report that they create prosthetic constructions on implants in their clinical practice, while the remaining 30 (49.18%) do not practice implant prosthetics (Fig.16).



Фиг.16 *Percentage distribution of responses to the question: Do you perform prosthetics on implants?" (%)*

Analysis of the survey results shows that the largest number of dental professionals use the conventional method for producing prosthetic constructions (49.2%), while the digital method is used by 9.84%. The hybrid method is selected by 40.96% of the respondents **(Fig.17).**

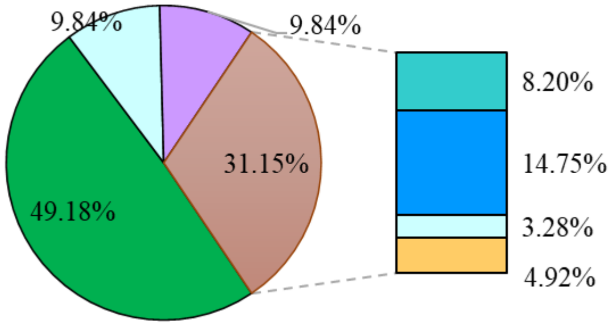


Fig.17 *Distribution of responses to the question: "What method do you use for producing prosthetic constructions in your practice?" (%)*

In examining the choice of impression techniques among dentists who perform implant prosthetics in their clinical practice, a significant difference was found: 45.90% prefer conventional impression techniques, while 24.6% use a combined method depending on the clinical case. A smaller portion of dental practitioners 22.95% report using intraoral scanning and scan bodies, while only 6.56% indicated that they use a standard tray for taking impressions from the abutment (**Fig.18).**

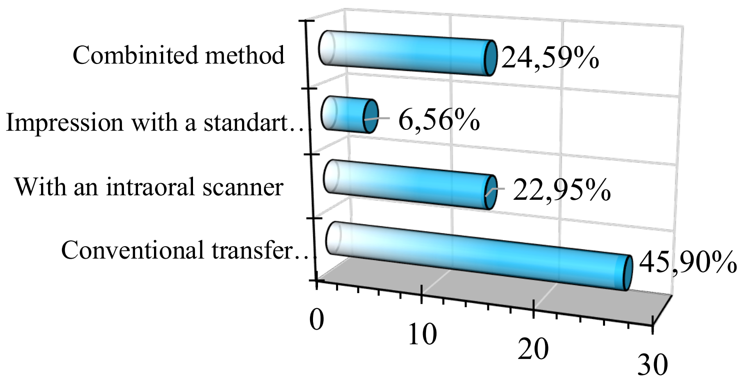


Fig.18 *Distribution of responses to the question: "What impression technique do you use for taking impressions from implants?" (%)*

In the case of working entirely according to a physical impression protocol, the preferences for selecting an impression technique are presented in **Figure 19.**

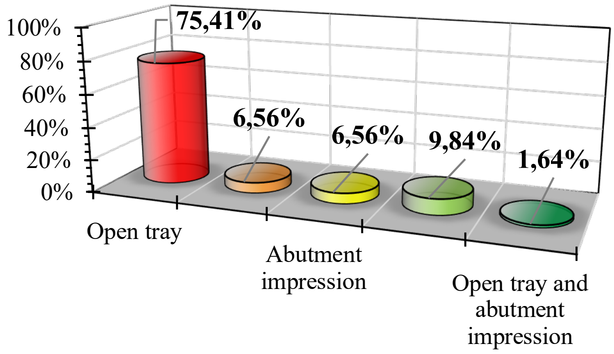


Figure 19 *displays the distribution of responses to the question: "If you use a physical impression protocol instead of a digital one, which method of transfer would you prefer?" (%)*

The processed results indicate that dental professionals who take impressions using an intraoral scanner experience difficulties during the process. These challenges are illustrated in **Fig.20**.

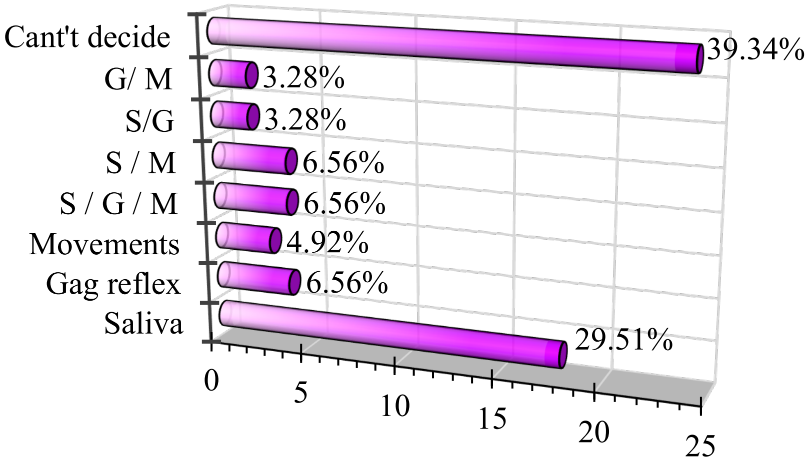


Fig. 20 *shows the distribution of responses to the question: "What do you think are the biggest challenges in taking impressions with an intraoral scanner?" (%)*

Regarding whether practitioners face difficulties when scanning specific areas of the prosthetic field while taking a digital impression, the obtained results are presented in **Fig. 21**.

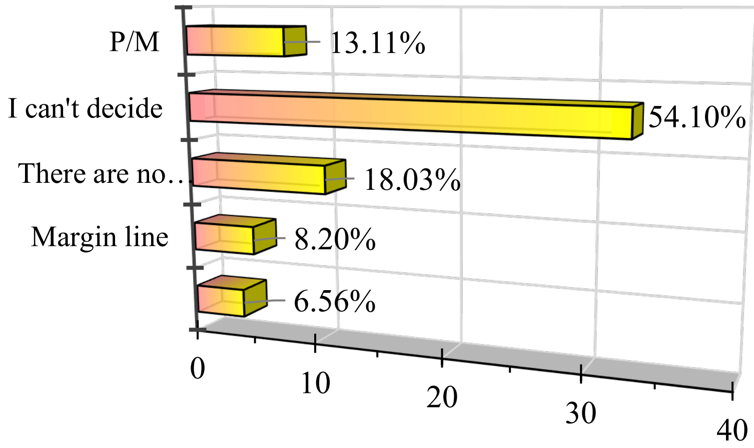


Fig. 21 *shows the distribution of responses to the question, "Do you have difficulties scanning certain areas of the prosthetic field when taking a digital impression?" (%)*

The highest percentage (40.98%) of clinicians report that the dental laboratory they work with scans at the model stage **(Figure 22).**

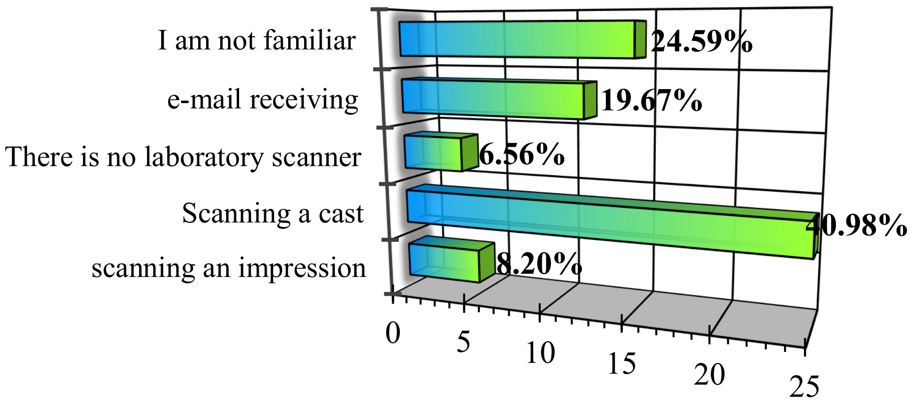


Fig. 22 *Distribution of responses to the question: "Does the dental laboratory you work with use a laboratory scanner, and at what stage does it conduct scanning?" (%)*

Regarding the use of scan bodies during laboratory scanning, 47.54% report that their dental technicians use them, while 6.56% do not use them, and 45.90% are not familiar with them **(Fig.23).**

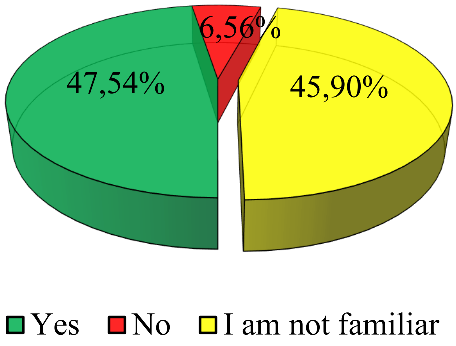


Fig.23 *Distribution of responses to the question: "Does the dental laboratory you work with use a body scanner?" (%)*

The conducted survey reveals that the highest percentage of surveyed doctors (44.26%)prefer to use screw-retained constructions on implants **(Fig. 24).**

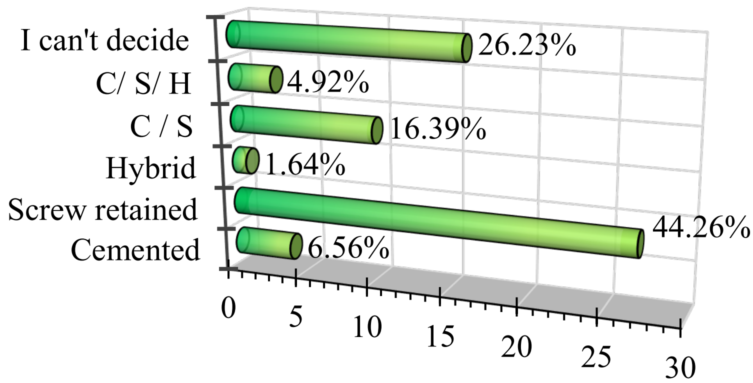


Fig.24 *Distribution of responses to the question: "What types of constructions on implants do you create in your practice?" (%)*

From the experience of clinicians in removable dental prosthetics, it is evident that regarding the time required for taking a conventional transfer impression and a digital one with a scan body, 34.43% believe that the digital provides better results, while 11.48% respond in favor of the conventional method **(Fig. 25).**

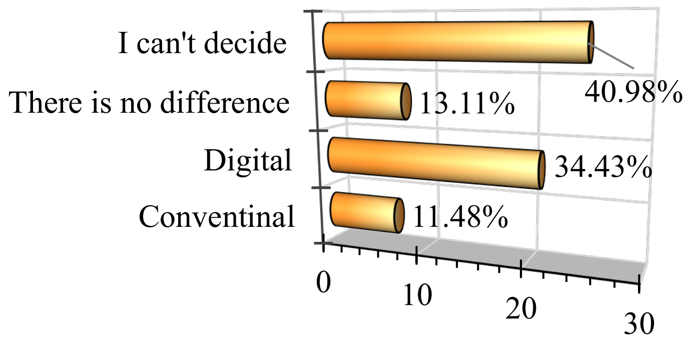


Fig.25 *Distribution of responses to the question: "How do you assess the time taken for a conventional transfer impression and a digital one with a scan body?" (%)*

Fig.26 shows that 27.08% of dental technicians believe that the adjustment time for constructions is shorter with the digital approach compared to the conventional one.

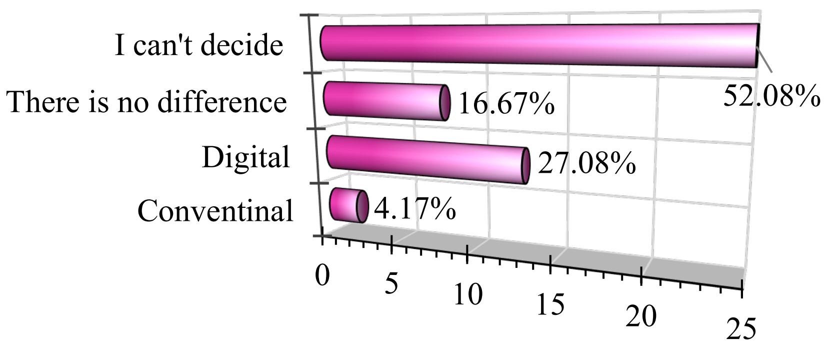


Fig.26 *Distribution of responses to the question: "Is there a difference in the adjustment time of a construction made using a conventional versus a digital protocol?" (%)*

Almost half of the dentists (47.54%) cannot determine whether there is a difference in the accuracy of constructions made using a conventional or digital protocol, and in which areas it might be observed, while 19.67% do not believe there is a difference (**Fig.27**).

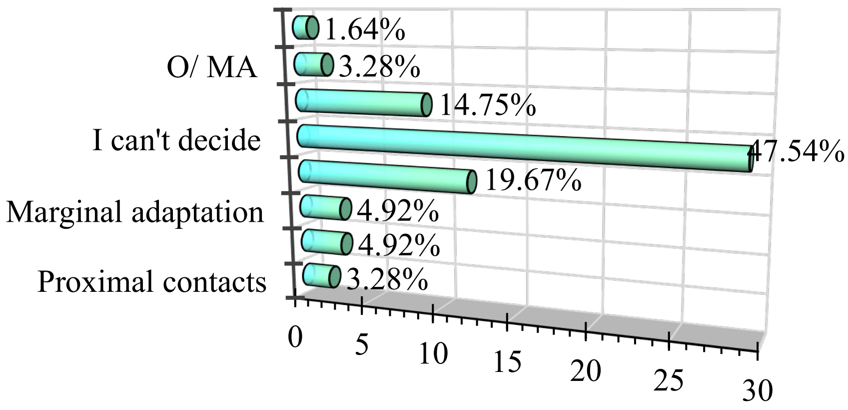


Fig.27 Distribution of responses to the question: "Is there a difference in the accuracy of a construction made using a conventional versus a digital protocol, and in which area?" (%)

Fig.28 shows the preferences for cements used in the fabrication of cement-retained constructions on implants.

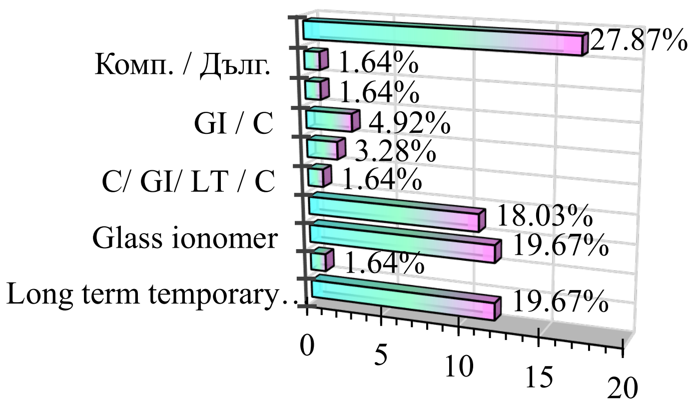


***Fig.28** Distribution of responses to the question: "What cement do you use when fabricating cement-retained constructions on implants?" (%)*

IV.1.2 Analysis of dental technicians' opinions on their awareness of the laboratory protocol for transferring the implant position and fabricating fixed constructions on implant abutments.

The analysis of the results shows that, based on years of experience, the largest group (38%) falls into the second category with 11-19 years, followed by 30% with 20-29 years, 21% with up to 10 years, and the smallest group (11%) has over 30 years of experience (Fig. 29).

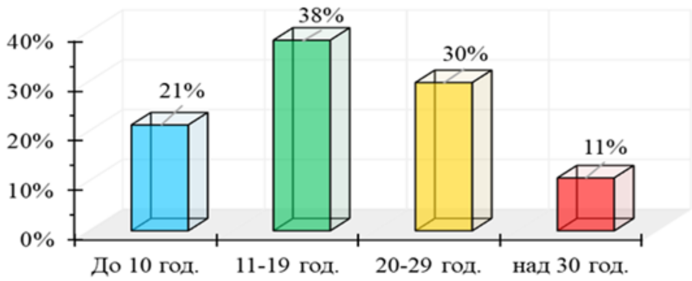


Fig.29 *Distribution of responses to the question: "What is your total work experience as a dental technician?" (%)*

The results of the analysis show that 87% of the dental technicians who participated in the survey fabricate prosthetic constructions on implants in their practice **(Fig. 30).**

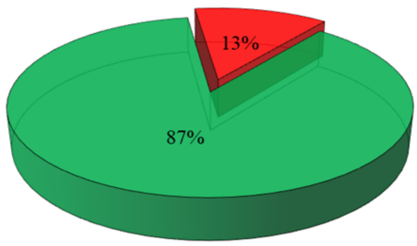


Fig.30 *Distribution of responses to the question: "Do you fabricate constructions on implants?" (%)*

Fig.31 shows that a significantly larger percentage (68%) receive the physical transfer impression in their practices, compared to 32% who receive it digitally via email.

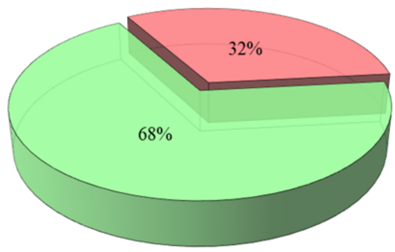


Fig.31 *Distribution of responses to the question: "In what form do you most often receive impressions taken from implants?" (%)*

The graph presented in **Fig.32** shows that younger dental technicians, in the groups with up to 10 years and 11-19 years of experience, more frequently work using the digital method.

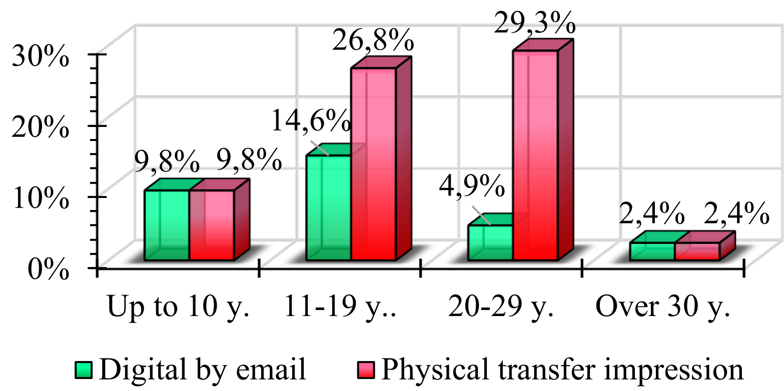


Fig.32 *Percentage distribution of the method for receiving impressions in practice based on the work experience of the surveyed dental technicians. (%)*

The graph in **Fig.33** shows that 61.84% of dentists and 68.29% of dental technicians work with physical transfer impressions, while 38.18% of dentists and 37.71% of dental technicians use digital methods.

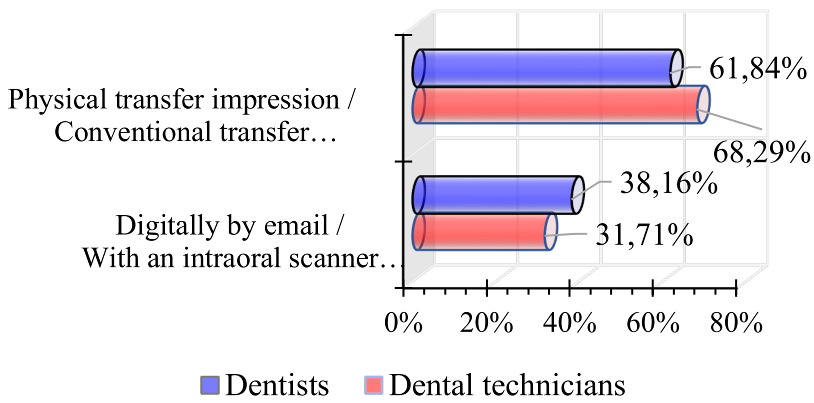


Fig.33 *Percentage distribution based on the most commonly used impression method and its transfer to the dental laboratory. (%)*

The analysis reveals that in practice, the most commonly used transfer impressions are taken with an open tray (64%), followed by impressions with a standard tray for the superstructure (25%), and the least frequently obtained are with a closed tray (11%) **(Fig. 34).**

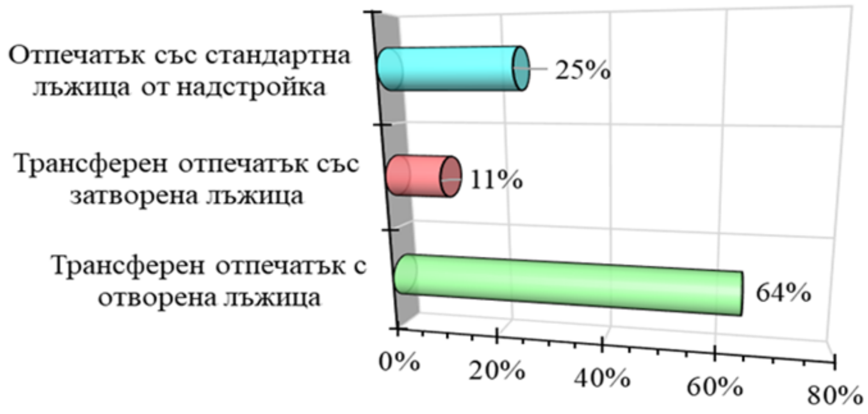


Fig.34 *Distribution of responses to the question: "What types of conventional impressions of implants do you most often receive in your practice?" (%)*

The results illustrated in **Fig.35** indicate that the hybrid protocol is the most preferred among dental technicians at 56%, followed by the digital protocol at 32% and the conventional protocol at 12%.

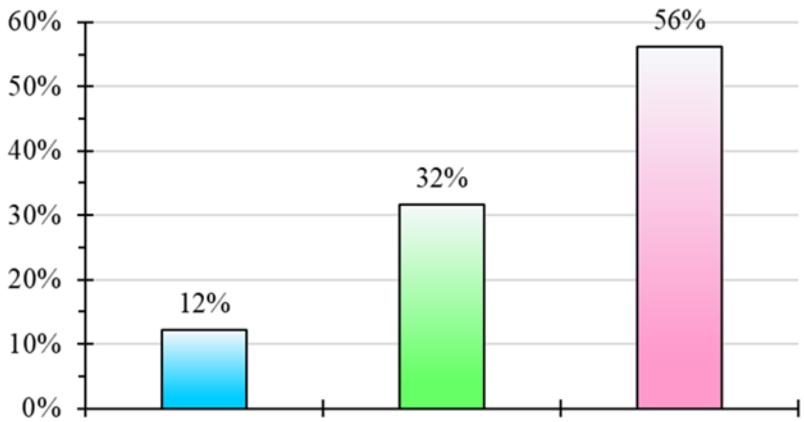


Fig.35 *Distribution of responses to the question: "What protocol for fabricating fixed prosthetic constructions on implants do you most often apply in your practice?" (%)*

The graph in **Fig.36** shows that the largest percentage of dentists (77.94%) and dental technicians (64.29%) indicate an impression with an open tray as the most commonly used method for conventional transfer impressions.

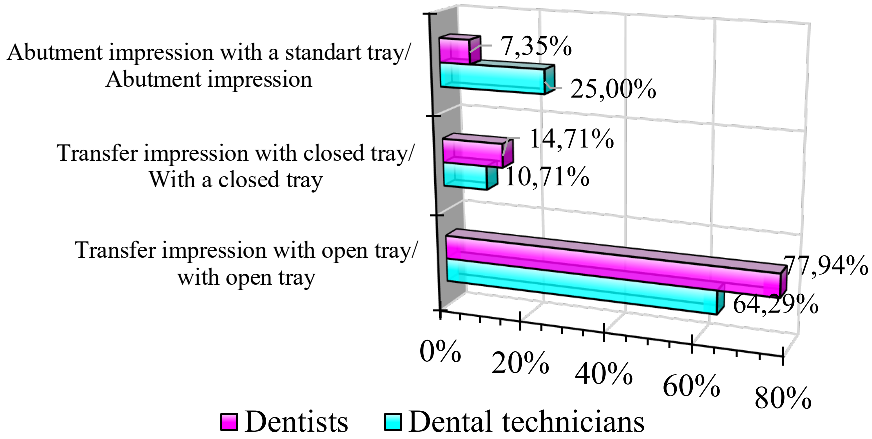


Fig.36 *Percentage distribution between dentists and dental technicians regarding the most commonly used conventional transfer impression. (%)*

The next graph clearly shows a preference among the surveyed groups of dentists and dental technicians for a specific method of fabricating constructions on implants **(Fig.37).** A widely adopted practice is to go through a conventional step and transition to virtual work in the next stage, which makes the approach hybrid.

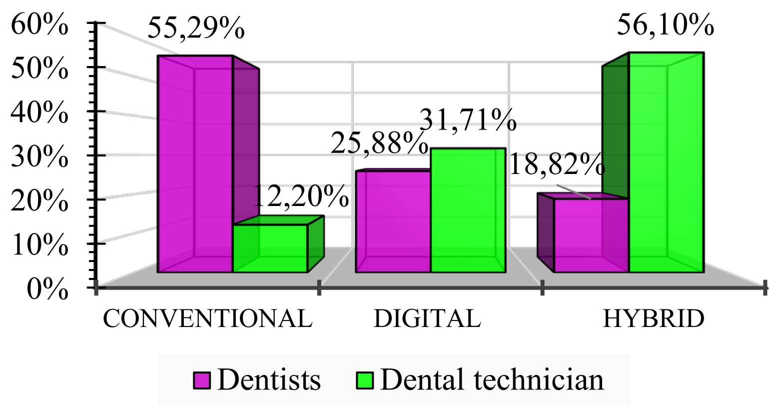


Fig.37 *Distribution based on the most commonly used method for restorations on implant abutments between dentists and dental technicians. (%)*

Among the dental technicians who indicated a hybrid method of work in practice and conduct scanning with a laboratory scanner, those who scan the abutment in the cast dominate at 70%, while only 30% use a scan body **(Fig. 38).**

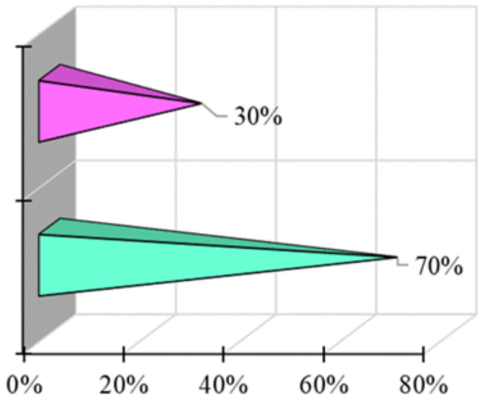


Fig.38 Distribution of responses to the question: "How do you conduct scanning with a laboratory scanner when fabricating fixed prosthetic constructions on implants?" (%)

Fig.39 shows the most commonly fabricated type of prosthetic construction on implants by the surveyed dental technicians. The analysis of the results reveals a near-equal distribution between full-arch zirconia constructions at 44% and those made of metal-ceramics at 40%, zirconia with ceramic 10% and hybrid constructions 6%

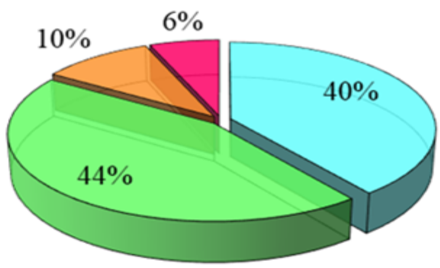


Fig.39 Distribution of responses to the question: "What material do you most often use to fabricate fixed prosthetic constructions on implants in your practice?" (%)

Regarding the method of fabrication, the leading technology is the milling of zirconium dioxide for the production of metal-free constructions at 47%. For the fabrication of metal-ceramic constructions, the most commonly applied method is the printing of a resin framework and casting withporcelain application, used by 27% of dental technicians, followed by direct printing of a metal framework and porcelain application at 13% (**Fig. 40**).

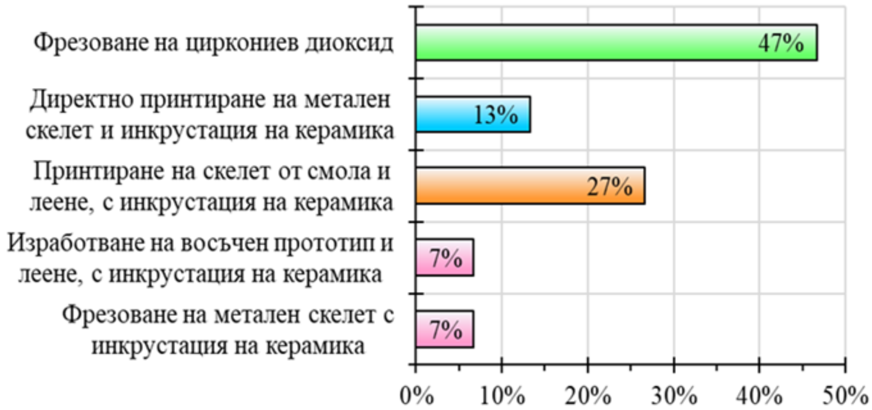


Fig.40 *Distribution of responses to the question: "What method do you use to fabricate fixed constructions on implants in your practice?" (%)*

A large percentage of the respondents reported that they have had constructions returned for correction, with the distribution shown in **Fig.41**.

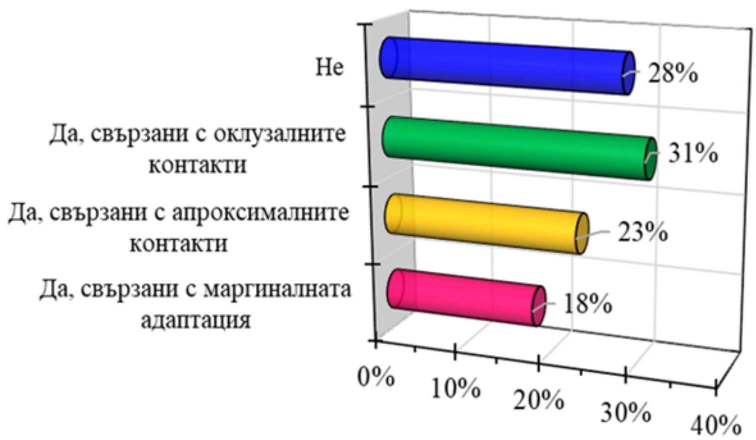


Fig.41 *Distribution of responses to the question: "Have you had cases of fixed constructions on implants returned for correction based on a conventional impression?" (%)*

Among the dental technicians who use the digital method in their practice, the largest percentage (38%) indicate that they have not had constructions returned for correction (**Fig. 42).**

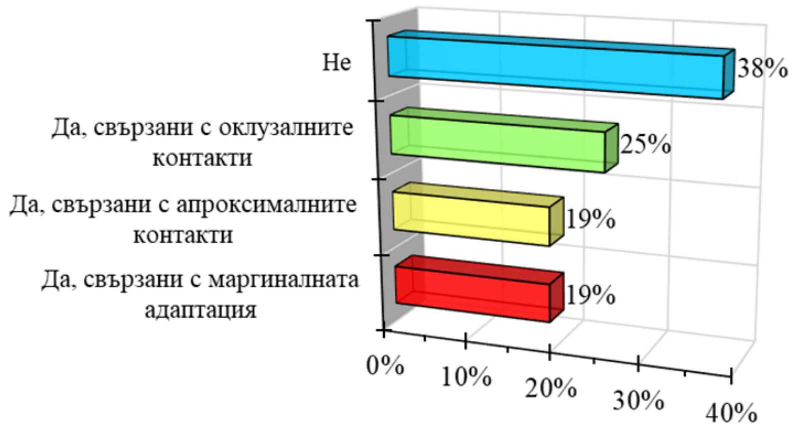


Fig 42 *Distribution of responses to the question: "Have you had cases of fixed constructions on implants returned for correction based on a digital impression?" (%)*

IV.1.3 Discussion on Task 1

Analysis of the professional preferences of dentists and dental technicians regarding awareness and preferences for impression techniques for transferring implant superstructures and the laboratory protocol for the fabrication of fixed restorations on implant supports.

As a result of the conducted survey among dentists, it was found that most of those who fabricate prosthetic constructions on implant supports still prefer to work with the conventional method in their practice. We believe that the higher percentage is due to the fact that the method is well-known among dental practitioners, and they are aware of its advantages and disadvantages.

A larger proportion of clinicians prefer using the conventional open tray transfer impression for transferring implant supports to the dental laboratory, compared to the digital method that employs an intraoral scanner and scan body. These results are attributed to the familiarity with the impression technique and materials used. Additionally, we recognize the significant investment required for purchasing an intraoral scanner, as well as the necessary training to effectively operate the corresponding system and scanning strategy.

The digitalization of the workflow aims to shorten clinical and laboratory times, minimize errors associated with conventional methods, enable quick digital planning, and simplify the materialization of prosthetic constructions. Despite advancements, most dental practitioners report that technicians primarily scan models made from traditional impressions using elastomeric materials. The conventional method still prevails in clinics, with only a partially digitized protocol in laboratories, mainly due to the lack of intraoral scanning systems in many dental practices.

The survey data indicate that most clinicians using intraoral scanners encounter challenges during their work. A significant percentage (half) of participants struggle to identify the factors causing these difficulties and the specific areas of the prosthetic field that are hard to scan adequately. Frequently mentioned problem areas include the margin and proximal zones, likely due to the limited access to light in these regions of the prosthetic field.

Dentists notes that not all dental technicians in laboratories utilize scan bodies during extraoral scanning. A common practice remains scanning a pre-selected structure from the model and subsequently designing it in the software, as revealed by the survey conducted among them.

IV.2. Results of the laboratory study aimed at analyzing and comparing the accuracy of superstructures on abutments scanned using two methods with an intraoral scanner and milled from zirconium dioxide. The first group was created through scanning the abutment, while the second group utilized a scanning analog.

IV.2.1. Results of the first group - scanning of the abutment:

In graphical form in **Fig.43,** the obtained results are presented as average values with standard deviation from the measurements of the distance between the test bodies and the abutments at specific points on the medial wall of 35. The graph shows values for points MP1, MP2, and MP3 on the surfaces of ten test bodies.

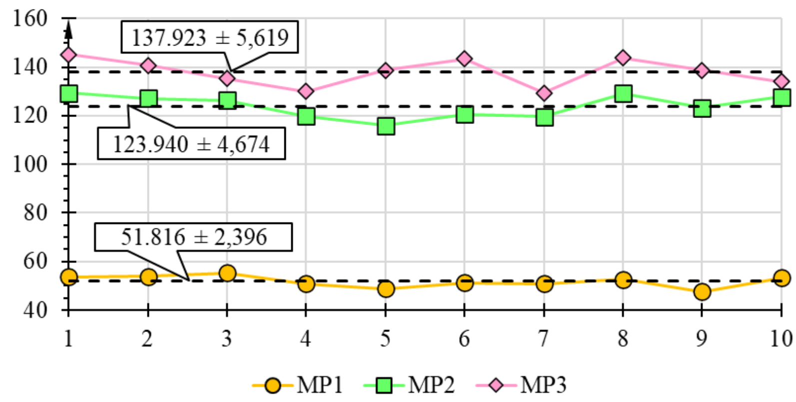


Fig.43 *Comparative analysis of the distance along the medial wall between the restoration and the abutments at the examined points for 35:*

MP1 - external point of the margin line , MP2 - base of the axial wall, MP3 - center of the axial wall in µm

In graphical form, **Fig.44** presents the results obtained from the distal wall of 35. The graph shows the values of the parameters t.DP1, t.DP2, and t.DP3 on the examined surfaces.

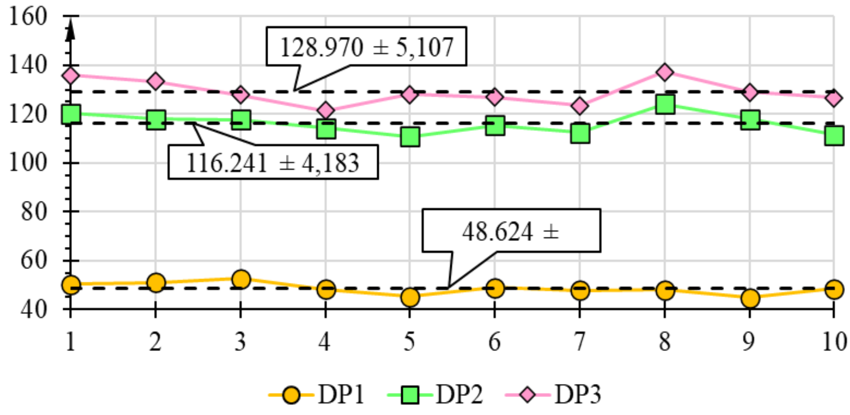


***Fig.44** Comparative analysis of the distance along the distal wall between the restoration and superstructures at the examined points for 35 in µm.*

The graphs in **Fig.45** and **Fig.46** show the obtained mean values with standard deviation along the medial and distal walls of 37.

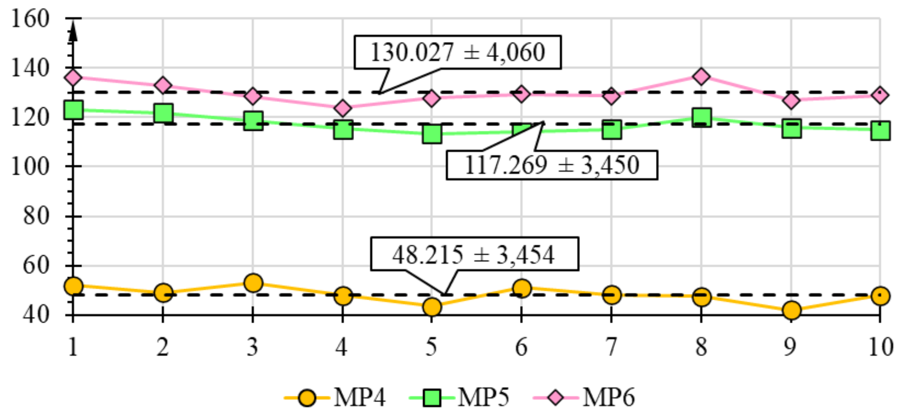


***Fig.45** Comparative analysis of the distance along the medial wall between the restoration and the abutments at the examined points for 37 in µm.*

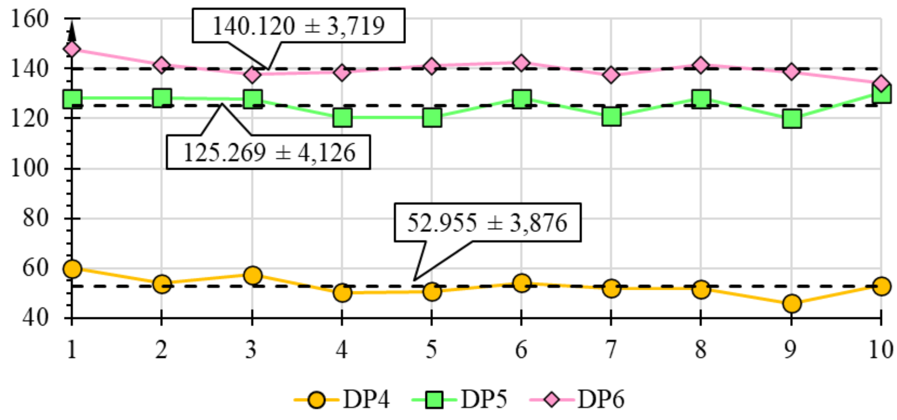


Fig.46 Comparative analysis of the distance along the distal wall between the restorationand the abutments at the examined points for 37 in µm.

In **Fig.47** , the results of measurements of the thickness of the cement layer between the supports and the abutments in the area of 35 for the group of scanned abutments are summarized. The diagrams illustrate the distribution of measurements for the specified parameters, including mean values, interquartile range, as well as the maximum and minimum measured values.

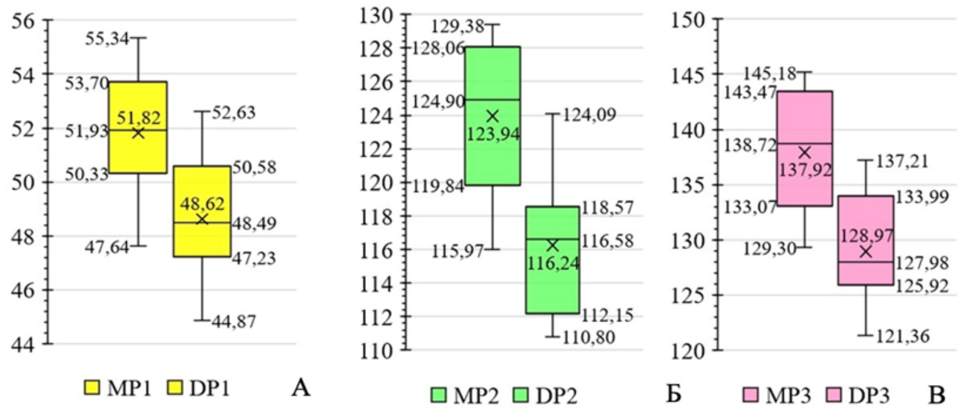


***Fig.47** presents the results from the analysis of measured distances between samples made of ZrO2 and the scanned abutment for 35, from points MP1 to DP3.*

Fig.48 presents a summarized comparison of the thickness of the cement layer between the suprastructers and abutments in the area of 37, shown as box plots. It is observed that the values on the side of the beam are lower than their corresponding points on the side of the teeth with limiting defects.

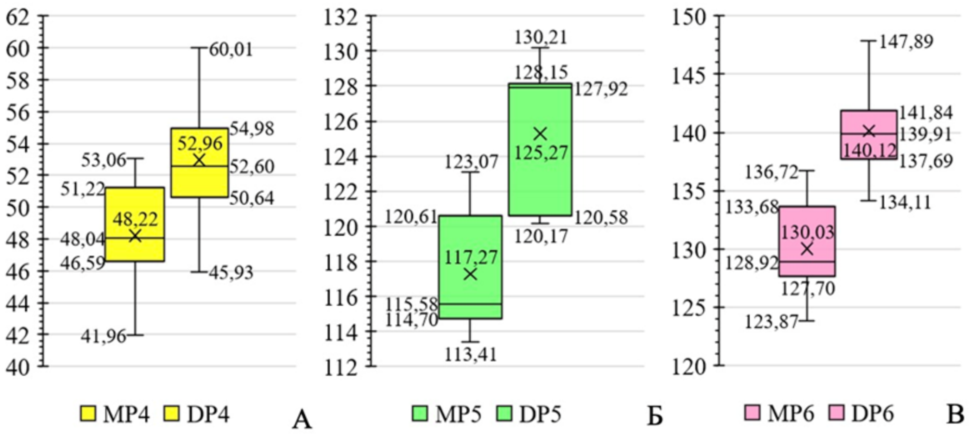


Fig. 48 Results of the analysis between the measured distances for the test specimens made from ZrO2 and scanned abutments for 37, between points MP4 and DP4.

IV.2.1. Results of the second group - scanning of the scan body:

In graphical form, **Fig.49** presents the average results with standard deviation from the measurements of the distance between the test bodies and the abutments after scanning the scanning analogs at specific points along the mesial wall of tooth 35. The graph displays values for three different measured parameters: t.MP1, t.MP2, and t.MP3. Following statistical analysis, the average values recorded were t.MP1 - 32.209 µm, t.MP2 - 96.898 µm, and t.MP3 - 113.472 µm.

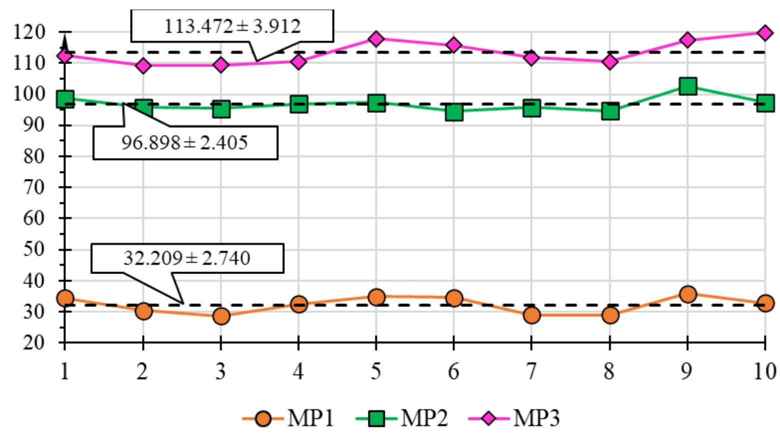


Fig.49 shows a comparative analysis of the distance along the mesial wall between the bridge retainers and the superstructures at the examined points for tooth 35, measured in micrometers (µm).

Fig.50 present the results from the measurements of the distance between the test bodies and the abutments along the distal wall of tooth 35. The graph illustrates the distribution for points t.DP1, t.DP2, and t.DP3. After data processing, the average values recorded were t.DP1 = 30.584 µm, t.DP2 = 95.625 µm, and t.DP3 = 113.178 µm.

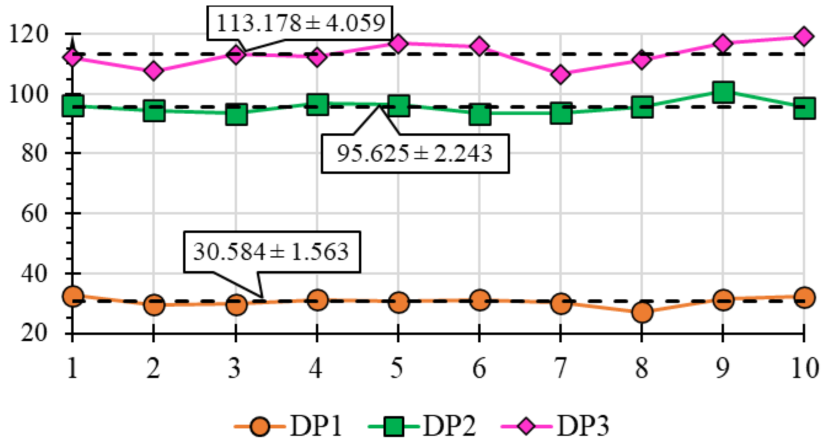


Fig.50 Comparative analysis of the distance along the distal wall between the bridge retainers and the superstructures at the examined points for tooth 35 in µm.

In graphical form, **Fig.51** and **Fig.52** presents the results obtained from the medial wall of 37. The graph shows the values of the parameters DP1, DP2, and DP3 on the examined surfaces.

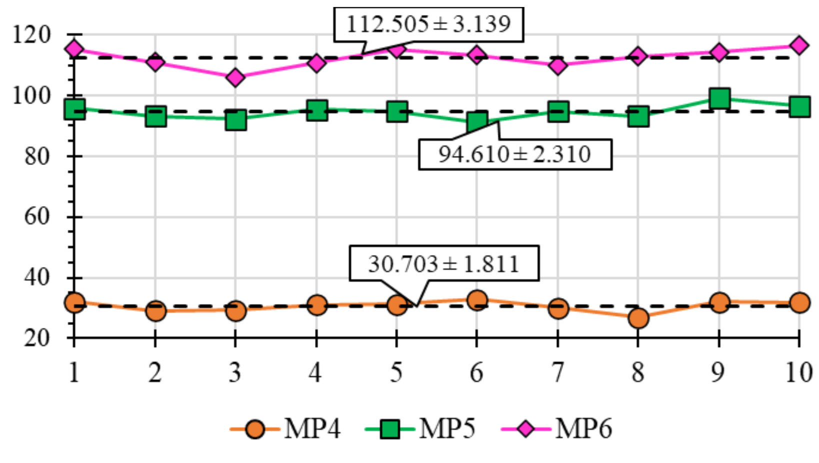


Fig.51 presents a comparative analysis of the distance along the medial wall at the measured points for 37, expressed in micrometers (µm).

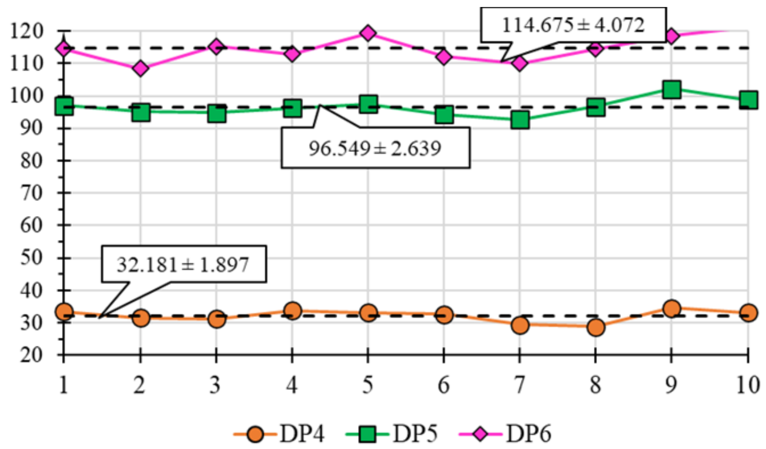


***Fig.52** presents a comparative analysis of the distance along the distal wall at the measured points for 37, expressed in micrometers (μm).*

The results obtained from measuring the thickness of the cement layer between the connectors and superstructures in the areas of 35 and 37 within the group of scanned analogs are summarized in **Fig. 53** and **Fig.54**. The diagrams illustrate the distribution of measurements for the specified parameters, average values, as well as the maximum and minimum measured values.

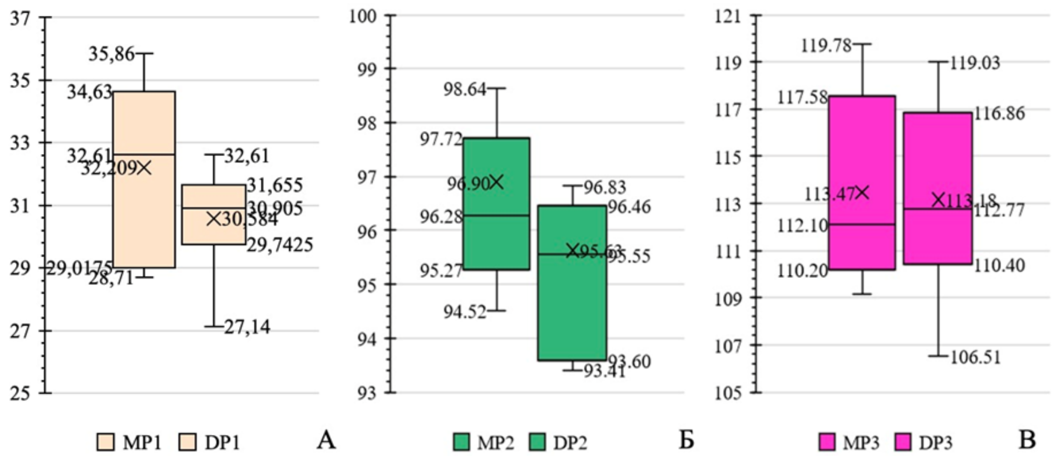


***Fig.53** presents the results of the analysis between the measured distances for the specimens made of ZrO2 and the scanned analog for 35, from points MP1 to DP3.*

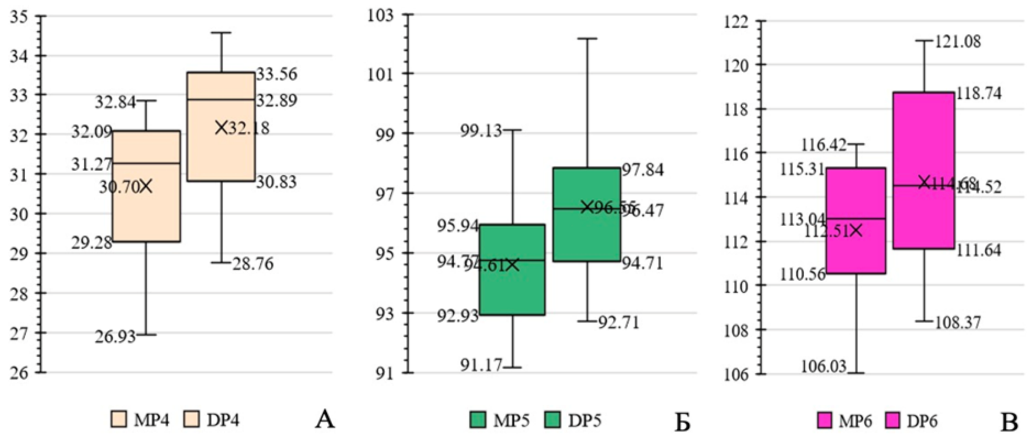


Fig.54 *presents the results of the analysis between the measured distances for the test specimens made of ZrO2 and the scanned analog for 37, from points MP4 to DP6.*

IV.2.3 Discussion on the task 2

The current laboratory study aims to analyze and compare the marginal adaptation and fit accuracy of test bodies made of zirconium dioxide on abutments, produced in two different ways:

1. Scanning the abutment with an intraoral scanner.
2. Scanning a scan body with an intraoral scanner.

In our study, we found a difference in marginal adaptation and fit accuracy of the constructions between the two groups. Measurements conducted at points MP1, DP1, MP4, and DP4 (external margin line points from the medial and distal walls of the tested bodies) and the subsequent comparative analysis provided insights into the “marginal adaptation” metric. Notably, the values in the group scanned with scab body were lower than those associated with abutments. After analysis, it was established that the values obtained for the distal wall of 35 and the medial wall of 37, i.e., from the side of the beam in the group of scanned structures, were lower than the corresponding "external points" towards the neighboring teeth limiting the defect. On the other hand, the average values for these points in the group of specimens made from scanning analogs were significantly lower than those measured in the group of scanned structures. In the scan body group, no significant differences were observed between the medial and distal walls. The analysis suggests that superstructures made using the scan body technique provide better marginal adaptation. However, despite this, the results in the scanned structure group do not exceed the allowable values for CAD/CAM technology restorations, which is set at 100 μm. From the data collected for points

MP2, MP3, DP2, DP3, MP5, MP6, DP5, and DP6, we obtained information regarding the internal fit parameter. Upon reviewing the results, it became evident that the measurements favored the scanned analogs. Additionally, in the group of scanned abutments, there is a difference between the values on the side of the connecting beam and those on the opposite side for the base and the middle of the axial wall.

The accuracy of constructions in the marginal area is crucial for the success of prosthetic treatment. Greater discrepancies in this area increase the susceptibility of the cementing agent to dissolution by oral fluids. Additionally, plaque-retentive factors can lead to inflammation in soft tissues and subsequent complications. The health of the soft tissues is essential for maintaining a stable relationship between the periodontium and the prosthetic structure.

The stages of the laboratory process are closely linked to the final marginal adaptation and fit accuracy of the constructions. On one hand, there are the steps involved in designing the superstructures, while on the other hand, there is the actual manufacturing process. The manufacturing techniques, the type of material used, the milling process with different bur diameters, and the sintering cycles can all influence the results. These factors may lead to shrinkage, which can subsequently affect marginal adaptation.

The study indicates that using scan bodies during the scanning phase results in cement thickness in marginal area values below the critical of 100 microns. This suggests that this scanning method allows for more accurate and controlled positioning of the constructions, which can reduce the risk of subsequent complications and ensure clinical success.

Given the results of the comparative analysis, it is evident that there is a difference in measurements between the medial and distal walls of the supports in the group of scanned superstructures. These deviations may be attributed to the presence of a connecting beam between teeth 35 and 37, which can provide additional mechanical strength and a more uniform distribution of stress during the milling process, potentially leading to lower deformation. Another important factor is the sintering stage, which occurs at very high temperatures, causing additional shrinkage that may be less pronounced on the side of the beam.

The analysis clearly indicates a trend towards more precise results in the scan body group, where the values for the examined parameters are lower. In this group, there is no significant difference between the measured points on the medial and distal walls of the test specimens. This leads us to consider that a likely reason for the differences between the two examined groups—scanning abutments and scanning analogs—could be the scanning method itself, as the objects differ in their optical properties and geometry.

IV.3. Results and Discussion on Task 3

This section presents the findings from the laboratory investigation aimed at analyzing and comparing the accuracy of superstructures on abutments scanned using two methods with an intraoral scanner and printed using SLM technology. The first subgroup was created by scanning the superstructure, while the second subgroup involved using a scanning analog.

IV.3.1. Results from the first group - scanning of the abutment:

The results are presented graphically in **Fig.55,** showing the average values with standard deviations from measurements of the distance between the test bodies and the superstructures at specific points along the medial wall of tooth 35. The graph illustrates three measured parameters: MP1, MP2, and MP3 for ten test samples. After statistical analysis, the average values were recorded as MP1 - 82.226 µm, MP2 - 141.034 µm, and MP3 - 159.024 µm.

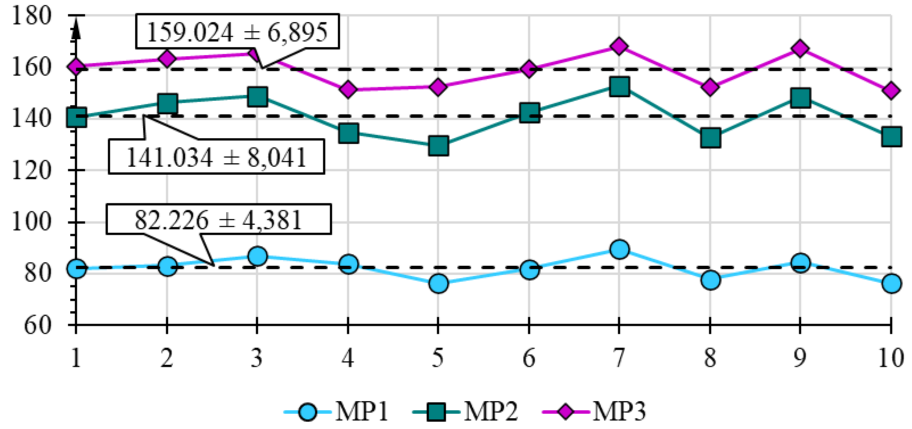


Fig.55 *presents a comparative analysis of the distance along the medial wall between the bridge retainers and the abutments at the measured points for tooth 35. The points include MP1 (outer point of the margin), MP2 (base of the axial wall), and MP3 (middle of the axial wall), with values expressed in micrometers (µm).*

Fig. 56 present the results for the distal wall of tooth 35. The graph shows measurements for points DP1, DP2, and DP3. After data processing, the average values were calculated as follows: DP1 - 78.384 µm, DP2 - 133.880 µm, and DP3 - 152.100 µm.

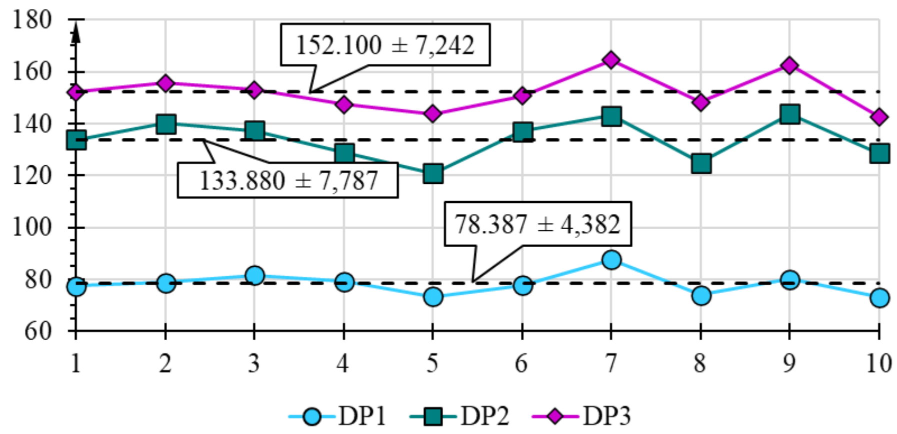


Fig.56 *presents a comparative analysis of the distance measured along the distal wall between the pontics and the abutments at specific points for tooth 35, in micrometers (µm).*

The analysis of the results in **Fig.57** and shows the average values with standard deviations for the medial wall points MP4, MP5, and MP6, as well as the distal wall points DP4, DP5, and DP6 of tooth 37.

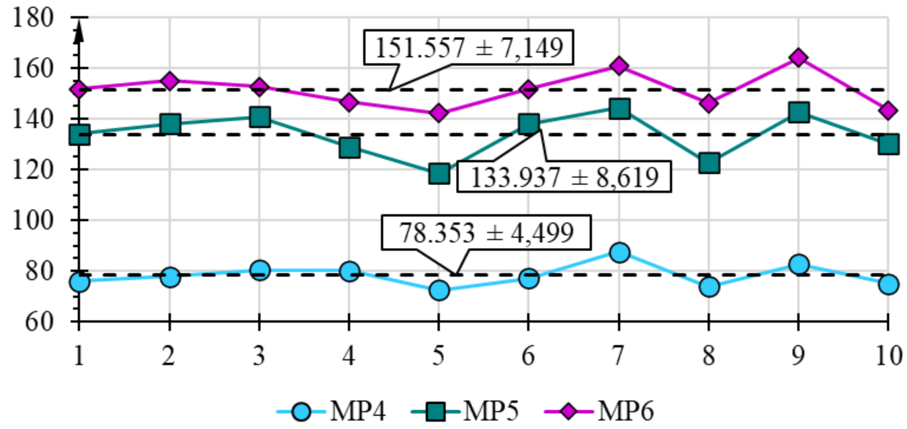


Fig.57 *presents a comparative analysis of the distances measured along the medial wall between the bridge retainers and abutments at specific points for tooth 37, expressed in micrometers (µm).*

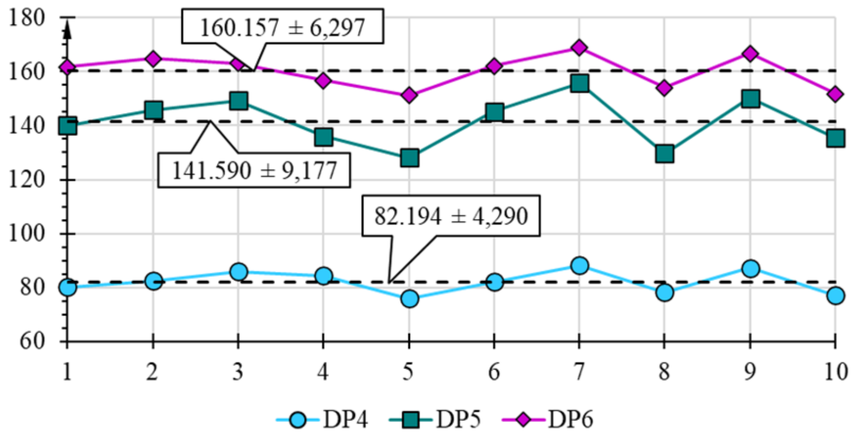


Fig.58 *presents a comparative analysis of the distances measured along the distal wall between the bridge retainers and abutments at specific points for tooth 37, expressed in micrometers (µm).*

After conducting a descriptive analysis based on the external and internal points of teeth 35 and 37, average values with standard deviations were obtained. The results from these measurements are presented in Table 1. The analysis shows a difference between the medial and distal surfaces at points MP1 and DP1 for tooth 35, as well as between points MP4 and DP4 for tooth 37. It was observed that the values on the beam side were lower ($p<0.05\%$), indicating a statistically significant variation.

Table 1 *provides a comparative analysis of the distances measured at specific points along the medial and distal surfaces of the test specimens, obtained through the abutment scanning method, using a stereomicroscope for teeth 35 and 37. The measurements focus on the marginal area (threshold) and are expressed in micrometers (µm).*

Groups	***35***		***37***	
Co-Cr specimen and abutment scan	*Mean value ± SD*	*Min. / Max.*	*Mean value ± SD*	*Min. / Max.*
External medial margin line point	***p.*** MP_1		***p.*** MP_4	
	82,226±4,381	*76,29 / 89,53*	*78,353±4,499*	*72,59 / 87,53*
External distal margin line point	***p.*** DP_1		***p.*** DP_4	
	78,387±4,382	*73,26 / 87,75*	*82,194±4,290*	*75,92 / 88,17*
P-value	*> 0,05*		*> 0,05*	

Table 2 presents a comparative analysis showing the measurements of the distance between the bridge supports and abutments at points MP2 and DP2 at 35, as well as at points MP5 and DP5 at 37, across the medial and distal walls. It can be seen that there is a difference between the medial and distal surfaces at points MP2 and DP2 for 35, as well as between MP5 and DP5 for 37. It is observed that for both supports, the values on the side of the beam (points DP2 and MP5) are smaller compared to the corresponding points on the side of the limiting defect teeth (points MP2 and DP2) ($p < 0.05\%$).

***Table 2**: Comparative analysis of the distance at specific points on the medial and distal surfaces of the test bodies using the scanned overlay method measured with a stereomicroscope at 35 and 37: at the base of the axial walls in µm.*

Groups	***35***		***37***	
Co-Cr specimen and abutment scan	*Mean value ± SD*	*Min / Max.*	*Mean value ± SD*	*Min. / Max.*
Medial axial wall	***p. MP_2***		***p. MP_5***	
	141,034±8,041	*129,78 / 152,82*	*133,937±8,619*	*118,68 / 144,41*
Distal axial wall	***p. DP_2***		***p. DP_5***	
	133,880±7,787	*120,91 / 143,77*	*141,590±9,177*	*128,13 / 155,82*
P-value	*> 0,05*		*> 0,05*	

Table 3 compares the measurements between points MP3 and DP3 at 35, as well as points MP6 and DP6 at 37, across the medial and distal walls. The conducted analysis shows that there is a difference between the medial and distal surfaces at points MP3 and DP3 for 35, as well as between MP6 and DP6 for 37. It is observed that for both supports, the values on the side of the beam (points DP3 and MP6) are smaller compared to their corresponding points on the side of the limiting defect teeth (points MP3 and DP6) ($p < 0.05\%$).

***Table 3**: Comparative analysis of the distance at specific points on the medial and distal surfaces of the test bodies using the scanned overlay method measured with a stereomicroscope at 35 and 37: at the center of the axial walls in µm.*

Groups	***35***		***37***	
Co-Cr specimen and abutment scan	*Mean value ± SD*	*Min. / Max.*	*Mean value ± SD*	*Min. / Max.*
	p. MP_3		***p. MP_6***	

Center of the medial axial walls	*159,024±6,895*	*150,78 / 168,14*	*151,557±7,149*	*142,38 / 164,15*
Center of the distal axial walls	***p. DP_3***		***p. DP_6***	
	152,100±7,242	*142,72 / 164,58*	*160,157± 6,297*	*151,23 / 168,91*
P-value	*< 0,05*		*< 0,05*	

IV.3.2. Results from the second group scanning of the scan body:

The results obtained in average values with standard deviation from the measurements of the distance between the test bodies and the overlays at specific points on the medial wall at 35 are presented graphically in **Fig.59**. The graph shows values for three different measured parameters: points MP1, MP2, and MP3 for ten test bodies. After statistical analysis, average values were recorded as follows: MP1 - 82.226 µm, MP2 - 141.034 µm, and MP3 - 159.024 µm.

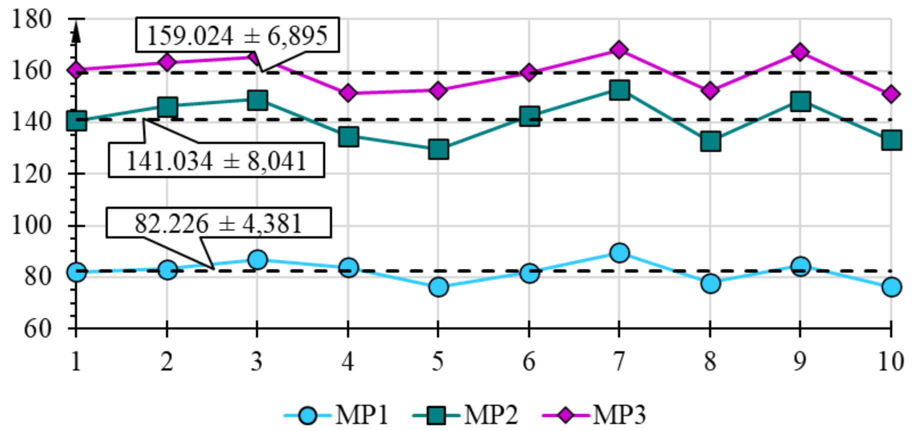


Fig.59 *Comparative analysis of the distance along the medial wall between the bridge supports and the overlays at the investigated points for 35: MP1 - external point of the threshold, MP2 - base of the axial wall, and MP3 - center of the axial wall in µm.*

Fig.60 present the results for the distal wall at 35. The graph displays the measurements for DP1, DP2, and DP3. After processing, the average values recorded are as follows: DP1 - 78.384 µm, DP2 - 133.880 µm, and DP3 - 152.100 µm.

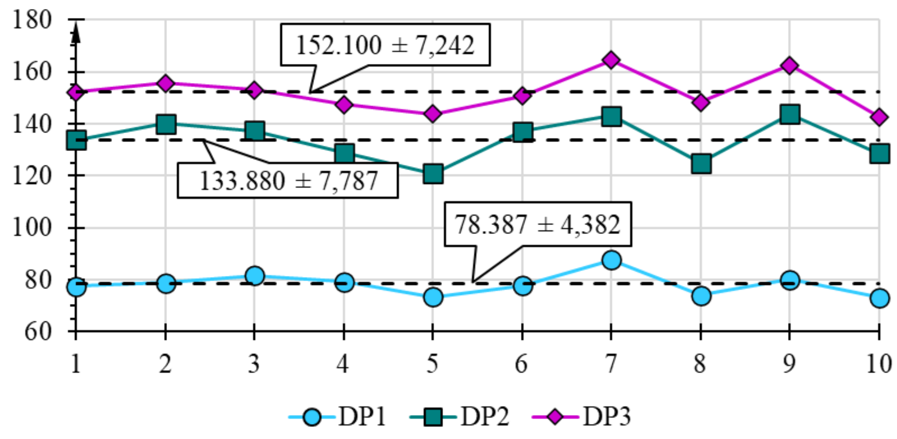


Fig.60 *Comparative analysis of the distance along the distal wall between the bridge supports and the overlays at the investigated points for 35 in µm.*

The analysis of the results in **Fig.61** and shows the average values with standard deviation for the medial points MP4, MP5, and MP6, as well as for the distal points DP4, DP5, and DP6 at 37.

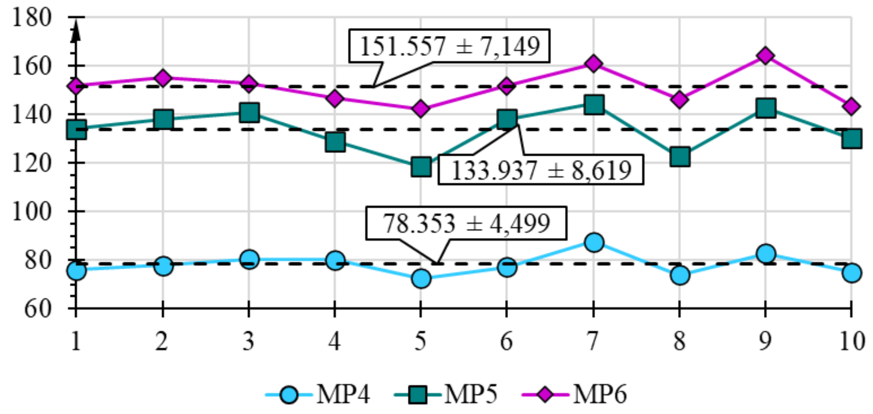


Fig.61 *Comparative analysis of the distance along the medial wall between the bridge supports and the overlays at the investigated points for 37 in µm.*

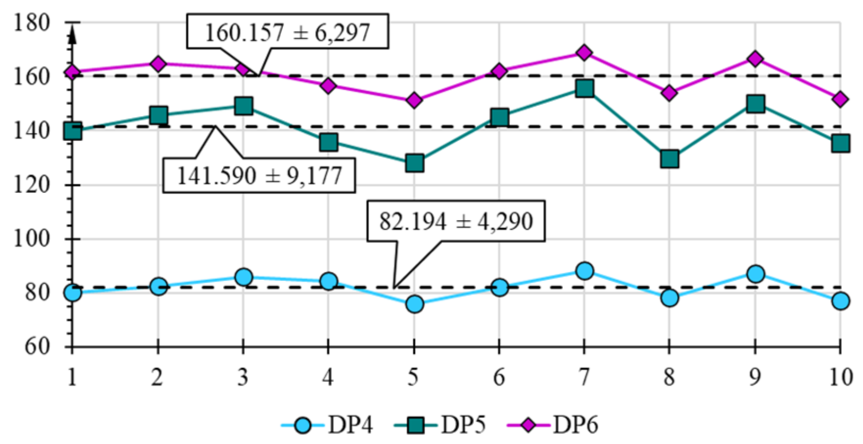


***Fig.62**: Comparative analysis of the distance along the distal wall between the bridge supports and the overlays at the investigated points for 37 in µm.*

After conducting a descriptive analysis regarding the external and internal points at 35 and 37, average values with standard deviations were obtained. The results of the measurements are presented in Table 4. According to the analysis, there is a difference between the medial and distal surfaces at points MP1 and DP1 for 35, as well as between MP4 and DP4 for 37, with the values on the side of the beam being lower ($p < 0.05\%$).

***Tab. 4** Comparative analysis of the distance at specific points on the medial and distal surfaces of the test bodies using the scanned overlay method measured with a stereomicroscope at 35 and 37: in the area of the threshold in µm.*

Groups	**35**		**37**	
Co-Cr specimen and scanning analog	*Mean value ± SD*	Min. / Max.	*Mean value ± SD*	Min. / Max.
External medial margin line point	**p. MP_1**		**p. MP_4**	
	63.013±2.759	59.16 / 66.57	62.145±2.118	58.55 / 64.39
External distal margin line point	**p. DP_1**		**p. DP_4**	
	63.191±3.299	59.14 / 71.21	63.541±2.524	58.21 / 66.39
P-value	> 0,05		> 0,05	

Table 5 presents a comparative analysis of the obtained results for four different measured parameters: MP2 to DP2 and MP5 to DP5, with average values on the medial wall at 35 and 37, as well as the minimum and maximum measured values. No significant difference is observed between the medial and distal surfaces.

Tab.5 Comparative analysis of the distance at specific points on the medial and distal surfaces of the spesimens using the scanned analog method measured with a stereomicroscope at 35 and 37: at the base of the axial walls in µm.

Groups	**35**		**37**	
Co-Cr specimen and scanning analog	*Mean value ± SD*	Min. / Max.	*Mean value ± SD*	Min. / Max.
Medial axial wall	**p. MP_2**		**p. MP_5**	
	121.486±4.017	115.96 / 126.68	120.915±3.681	116.04 / 126.47
Distal axial wall	**p. DP_2**		**p. DP_5**	

	120.215±2.636	116.61 / 124.87	122.071±3.578	116.72 / 126.85
P-value	> 0,05		> 0,05	

Table 6 presents the results for 35 and 37. According to the analysis, it can be seen that there is no significant difference between the medial and distal surfaces. The difference between the average values is minimal (p > 0.05%).

Tab.6 *Comparative analysis of the distance at specific points on the medial and distal surfaces of the specimens using the scanned analog method measured with a stereomicroscope at 35 and 37: at the center of the axial walls in µm.*

Groups	**35**		**37**	
Co-Cr specimen and scanning analog	*Mean value ± SD*	Min. / Max.	*Mean value ± SD*	Min. / Max.
Center of the medial axial walls	**т. MP_3**		**т. MP_6**	
	138.688±3.887	133.71 / 145.13	137.375±4.050	130.74 / 143.19
Center of the distal axial walls	**т. DP_3**		**т. DP_6**	
	136.859±3.356	132.05 / 141.04	137.655±4.101	131.24 / 142.31
P-value	> 0,05		> 0,05	

IV.3.3 Discussion on the task 3

The present laboratory study aims to analyze and compare the marginal adaptation and fit accuracy of test specimens made from Co-Cr alloy using SLM technology on abutments, produced in two different ways:

1. Scanning the abutment with an intraoral scanner.

2. Scanning a scan body with an intraoral scanner.

For the scanned abutments, the values on the side of the teeth limiting the defect are higher than those measured on the side of the connecting beam. Compared to the other studied group, these values are also higher. Based on the analysis, we have reason to believe that using scan bodies leads to better results regarding the "marginal adaptation" indicator compared to the group of scanned abutments. This methodology provides greater precision in this otherwise critical area for the success of prosthetic treatment. When comparing the marginal adaptation indicator of the test bodies produced by the two methodologies, it became clear that the scan body group had lower average values. This would suggest that superstructures made using this methodology would be subject to less microleakage and cement dissolution from oral fluids. However, the values obtained in the group of scanned abutments are also within acceptable limits and do not exceed 100 microns, which indicates that, when executed correctly, this method can also be reliable.

Regarding the fit accuracy, it was found that the group of scanned analogs demonstrated better results. In all measurements, the results were consistent, with no significant deviations observed. In the group of scanned abutments, the measured values were higher. Additionally, in this group, a difference was observed between the values on the side of the connecting beam and the opposite side at the base and middle of the axial wall. These differences may be due to the different scanning methodologies of the models, as well as the specifics of the workflow.

The material from which the constructions are made and the technology used for their production can influence the marginal adaptation and fit accuracy.The specifics of the manufacturing process and technological regimen play a crucial role in creating constructions with minimal defects. Additionally, parameters such as laser power, scanning speed, particle size of the powder, the step between individual layers, and their thickness can cause uneven melting of the powder particles, which may affect the accuracy of the objects.

The comparative analysis shows a difference in the measurements between the medial and distal walls in the group of scanned abutments. A possible reason for this is the connecting beam between 35 and 37. Since the layer-building process in selective laser melting occurs at very high temperatures, followed by rapid cooling, stresses and defects in the individual layers may arise. Additionally, the metal particles undergo phase transformations during these processes, associated with expansion during melting and contraction during subsequent cooling. We can assume that the connecting beam provides stability and prevents distortions and deformations in these areas during the alternating cycles.

From the analysis of the results, it becomes clear that in the group of scan bodies, no significant differences are observed between the medial and distal walls of the supports. The same parameters were used for all test bodies during the software modeling stage of their design, as well as in the subsequent stages of the manufacturing process. Since in the previous task, the results for the group of scan bodies were also lower, this gives us reason to focus attention on the scanning methodology. We believe that a probable cause for this is the difference in geometry, optical properties of the scanned objects, and software compatibility. The excellent optical properties of the scan bodies facilitate the accurate transfer of the implant position, which helps in obtaining more precise data for the subsequent production of the restorations.

IV.4. Results and Discussion on Task 4

Comparative evaluation of the thickness of the cement layer between copings, transferred using a directly scanned abutment and scanning analogs with an intraoral scanner through subtractive and additive technology.

IV.4.1 Results from the first group – scanning of the abutment:

The current analysis aims to investigate the differences between measurements taken of the distance from the test bodies to the abutments at specific points for 35 and 37 corresponding to the external point of the medial and distal margins, labeled as MP1, DP1, MP4, and DP4. The samples are subjected to two different manufacturing technologies: milling of ZrO2 and printing of Co-Cr. The data are presented in the form of a diagram of mean values and standard deviations, as well as a histogram depicting the distribution of values (**Fig. 63**).

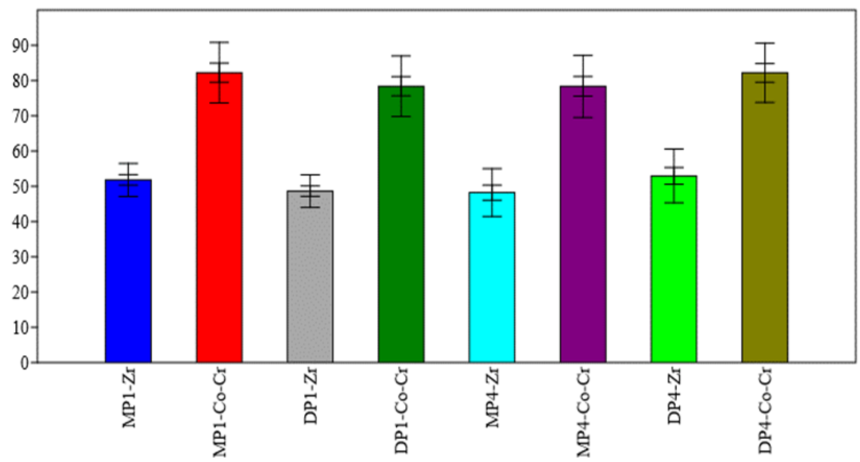


Fig. 63 *Diagram of mean values and standard deviations for measurements from MP1-ZrO2, MP1-Co-Cr, DP1-ZrO2, DP1-Co-Cr, MP4-ZrO2, MP4-Co-Cr, DP4-ZrO2, and DP4-Co-Cr.*

The histograms (**Fig. 64**) show the distribution of values for each group. The measurements MP1-ZrO2 and DP1-ZrO2 have distributions with mean values around 50 µm, indicating relative homogeneity in these measurements. The measurements MP1-Co-Cr and DP1-Co-Cr have distributions with higher mean values and greater dispersion, suggesting greater variability in the processing of Co-Cr. The MP4 and DP4 groups follow similar trends.

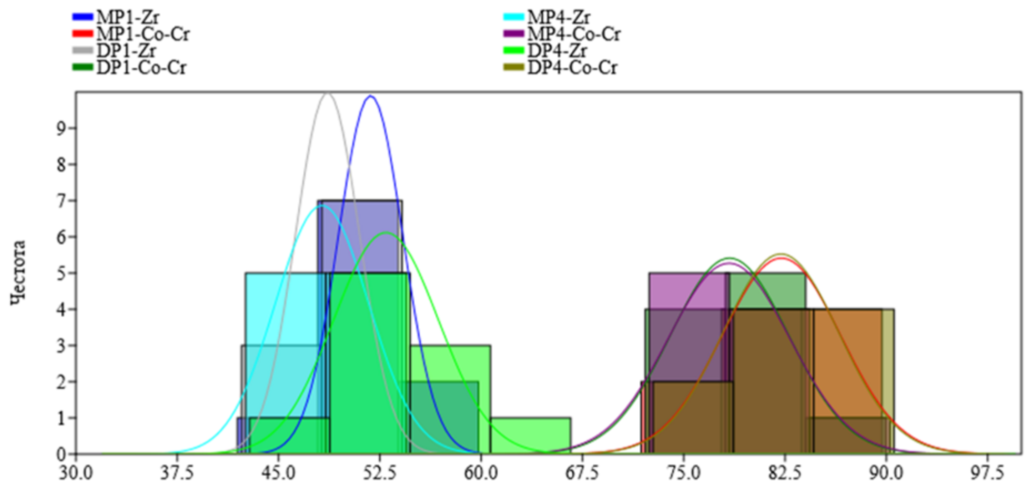


Fig. 64 *Histogram of the distribution of values for each combination of measurements and materials from MP1-ZrO2, MP1-Co-Cr, DP1-ZrO2, DP1-Co-Cr, MP4-ZrO2, MP4-Co-Cr, DP4-ZrO2, and DP4-Co-Cr.*

The Tukey's test was conducted for multiple comparisons following ANOVA to determine which specific groups significantly differ from each other. The results of the Tukey's test indicate that there are significant differences between the various groups, with most comparisons rejecting the null hypothesis of equality of means.

Tab. *7 Comparison of groups with ZrO2 and Co-Cr between MP1, DP1, MP4, and DP4.*

Group 1	Group 2	Mean difference, µm	p-value	Lower level, µm	Upper level, µm
DP1-Co-Cr	DP1-ZrO2	27,05	0,001	24,555	29,545
DP1-Co-Cr	DP4-ZrO2	25,64	0,001	23,145	28,135
DP1-Co-Cr	MP1-ZrO2	26,28	0,001	23,785	28,775
DP1-Co-Cr	MP4-ZrO2	28,07	0,001	25,575	30,565
DP1-ZrO2	DP4-Co-Cr	-20,46	0,001	-22,955	-17,965
DP1-ZrO2	MP1-Co-Cr	-23,43	0,001	-25,925	-20,935
DP1-ZrO2	MP4-Co-Cr	-29,59	0,001	-32,085	-27,095
DP4-Co-Cr	DP4-ZrO2	19,05	0,001	16,555	21,545

DP4-Co-Cr	MP1-ZrO2	19,69	0,001	17,195	22,185
DP4-Co-Cr	MP4-ZrO2	21,48	0,001	18,985	23,975
DP4-ZrO2	MP1-Co-Cr	-22,02	0,001	-24,515	-19,525
DP4-ZrO2	MP4-Co-Cr	-28,18	0,001	-30,675	-25,685
MP1-Co-Cr	MP1-ZrO2	22,66	0,001	20,165	25,155
MP1-Co-Cr	MP4-ZrO2	24,45	0,001	21,955	26,945
MP1-ZrO2	MP4-Co-Cr	-28,82	0,001	-31,315	-26,325
MP4-Co-Cr	MP4-ZrO2	30,60	0,001	28,105	33,095

From the analysis of the data and visualizations, we can conclude that the specimens made of Co-Cr exhibit higher values compared to those processed from ZrO2 for all the examined groups.

The diagram presented in **Fig.65** shows the following key trends: The measurement for MP2-ZrO2 indicates a mean value of approximately 123.38 µm with relatively low variation. For MP2-Co-Cr, significantly higher mean values are observed, around 140.72 µm, highlighting the difference in measurements between the two groups. The mean values for DP2-ZrO2 are about 120.12 µm, while for DP2-Co-Cr, they are approximately 133.9 µm, again reflecting the higher values in specimens made of Co-Cr. Similar patterns are also observed in the MP5 and DP5 groups.

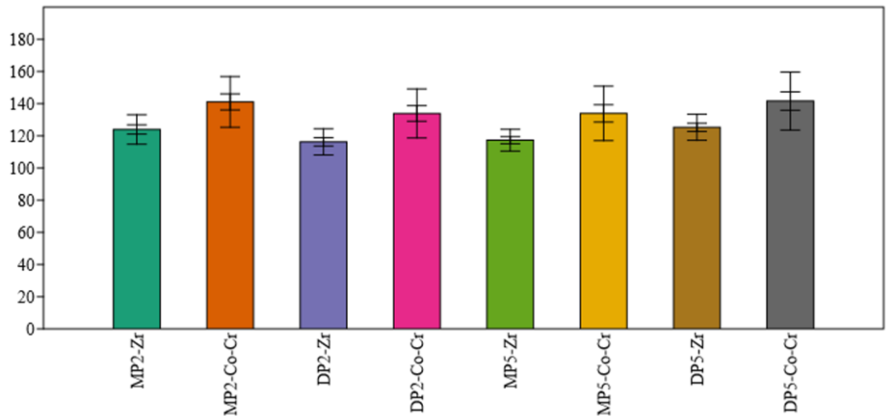


Fig.65 *Diagram of mean values and standard deviations for measurements from MP2-ZrO2, MP2-Co-Cr, DP2-ZrO2, DP2-Co-Cr, MP5-ZrO2, MP5-Co-Cr, DP5-ZrO2, and DP5-Co-Cr.*

The histograms illustrate the distribution of values for each group (**Fig. 66).**

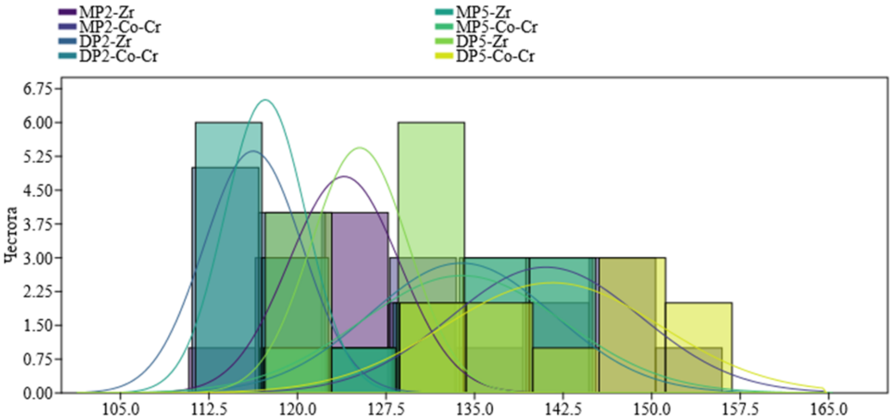


***Fig.66** Histogram of the distribution of values for each combination of measurements and materials from MP2-ZrO2, MP2-Co-Cr, DP2-ZrO2, DP2-Co-Cr, MP5-ZrO2, MP5-Co-Cr, DP5-ZrO2, and DP5-Co-Cr.*

The results of the Tukey's test show significant differences between the groups, with at least two groups exhibiting statistically significant differences in their mean values. These results indicate that there is a significant difference between the MP2-Zr and MP2-Co-Cr groups. From the analyses conducted thus far, we can conclude that the specimens made of Co-Cr yield higher values compared to those made of ZrO2 for all examined groups.

From the diagram in **Fig.67**, the following key trends can be observed: MP3-Co-Cr shows significantly higher mean values compared to MP3-ZrO2, while DP3-Co-Cr also demonstrates a higher value relative to DP3-ZrO2. Similar results are observed in the MP6 and DP6 groups.

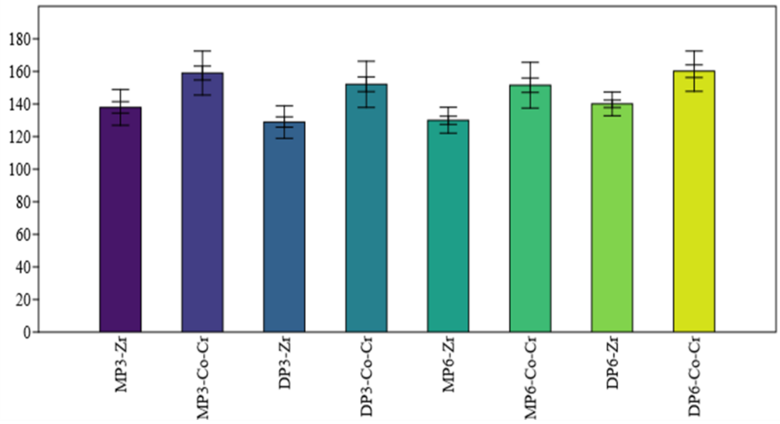


Fig.67 Diagram of the mean values and standard deviations for measurements from MP3-ZrO2, MP3-Co-Cr, DP3-ZrO2, DP3-Co-Cr, MP6-ZrO2, MP6-Co-Cr, DP6-ZrO2, and DP6-Co-Cr.

The histograms illustrate the distribution of values for each group (**Fig. 68).**

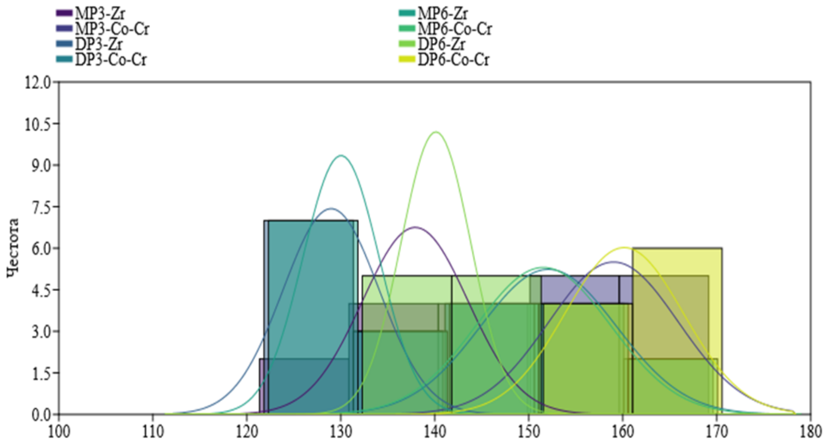


Fig.68 Histogram of the distribution of values for each combination of measurements and material from MP3-ZrO2, MP3-Co-Cr, DP3-ZrO2, DP3-Co-Cr, MP6-ZrO2, MP6-Co-Cr, DP6-ZrO2, and DP6-Co-Cr.

IV.4.2 Results from the second subgroup - scanning of scanning analogs:

The graph in **Fig.69** shows that MP1-ZrO2 has an average value of approximately 32.209 µm with relatively low variation. MP1-Co-Cr shows significantly higher average values of around 63.013 µm, suggesting the importance of the method of obtaining the Co-Cr specimens. The comparison of DP1-ZrO2 to DP1-Co-Cr indicates a higher value for the Co-Cr processing. Similar trends are observed in the MP4 and DP4 groups.

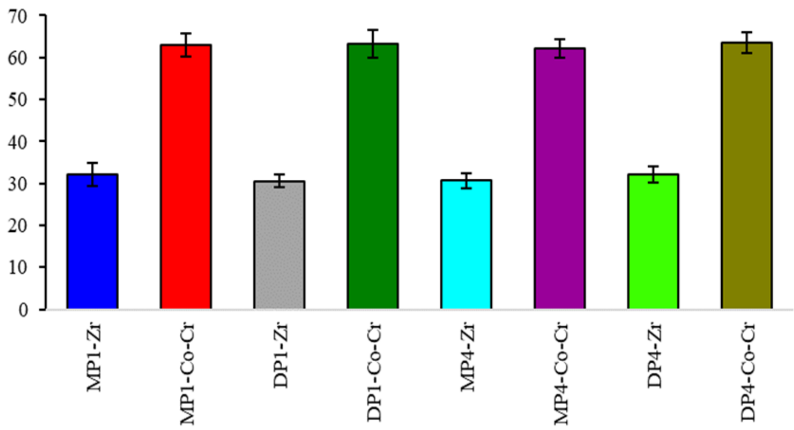


Fig.69 *Diagram of mean values and standard deviations for the measurements from MP1-ZrO2, MP1-Co-Cr, DP1-ZrO2, DP1-Co-Cr, MP4-ZrO2, MP4-Co-Cr, DP4-ZrO2, and DP4-Co-Cr.*

The histogram in **Fig.70** shows the distribution of values for each group. MP1-Co-Cr and DP1-Co-Cr have distributions with higher average values.

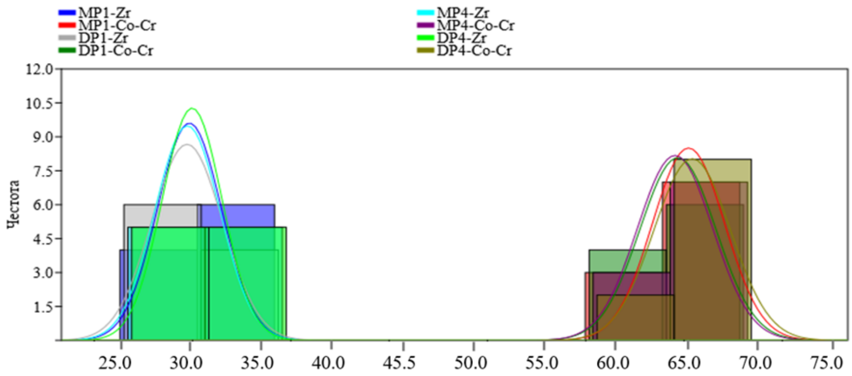


***Fig.70** Histogram of the distribution of values for each combination of measurements and material from MP1-ZrO2, MP1-Co-Cr, DP1-ZrO2, DP1-Co-Cr, MP4-ZrO2, MP4-Co-Cr, DP4-ZrO2, and DP4-Co-Cr.*

The Tukey's test was conducted for multiple comparisons after ANOVA to determine which specific groups differ significantly from each other, as shown in Table 8.

Tab.8 Comparison of groups with ZrO2 and Co-Cr between MP1, DP1, MP4, and DP4.

Group 1	Group 2	Mean difference, µm	p-value	Lower level, µm	Upper level, µm
DP1-Co-Cr	DP1-ZrO2	32,60	0,001	30,18	35,03
DP1-Co-Cr	DP4-ZrO2	31,01	0,001	28,48	33,54
DP1-Co-Cr	MP1-ZrO2	30,98	0,001	28,13	33,83
DP1-Co-Cr	MP4-ZrO2	32,48	0,001	29,99	34,99
DP1-ZrO2	DP4-Co-Cr	-32,96	0,001	-34,93	-30,98
DP1-ZrO2	MP1-Co-Cr	-32,43	0,001	-34,54	-30,32
DP1-ZrO2	MP4-Co-Cr	-31,56	0,001	-33,31	-29,81
DP4-Co-Cr	DP4-ZrO2	31,36	0,001	29,26	33,46
DP4-Co-Cr	MP1-ZrO2	31,33	0,001	28,86	33,81
DP4-Co-Cr	MP4-ZrO2	32,84	0,001	30,77	34,90
DP4-ZrO2	MP1-Co-Cr	-30,83	0,001	-33,06	-28,61
DP4-ZrO2	MP4-Co-Cr	-29,96	0,001	-31,85	-28,07

MP1-Co-Cr	MP1-ZrO2	30,80	0,001	28,22	33,39
MP1-Co-Cr	MP4-ZrO2	32,31	0,001	30,12	34,50
MP1-ZrO2	MP4-Co-Cr	-29,94	0,001	-32,24	-27,64
MP4-Co-Cr	MP4-ZrO2	31,44	0,001	29,59	33,29

From the analysis of the data and the examination of the graphs, we can conclude that for the specimens made from Co-Cr using additive technology, the measured values are higher compared to those for the milled specimens in the examined groups.

The next group subjected to analysis is for MP2, DP2, MP5, and DP5 for 35 and 37. The graph in **Figure 71** shows the average values and standard deviations for each group.

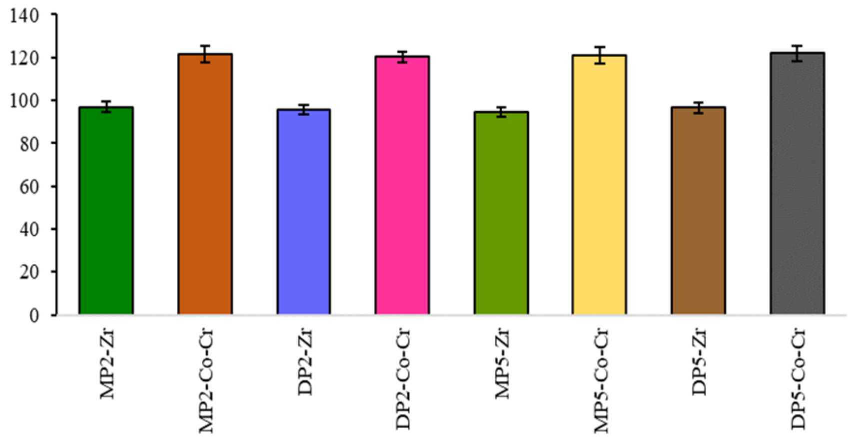


Figure.*71 Diagram of the average values and standard deviations for the measurements from MP2-ZrO2, MP2-Co-Cr, DP2-ZrO2, DP2-Co-Cr, MP5-ZrO2, MP5-Co-Cr, DP5-ZrO2, and DP5-Co-Cr.*

The histogram on Fig.72 shows the distribution of values for the studied groups.

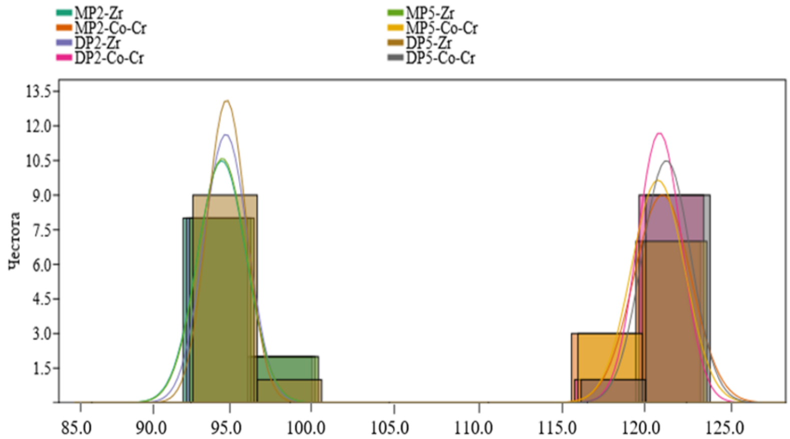


Fig.72 Histogram of the distribution of values for each combination of measurements and material from MP2-ZrO2, MP2-Co-Cr, DP2-ZrO2, DP2-Co-Cr, MP5-ZrO2, MP5-Co-Cr, DP5-ZrO2, and DP5-Co-Cr.

The results of Tukey's test show that there are significant differences between the groups, with most comparisons rejecting the null hypothesis of equality of means.

The graph of the mean values and standard deviations (**Fig.73**) shows the mean values and standard deviations for each group. MP3-Co-Cr shows significantly higher mean values of around 138.688 µm, suggesting a significant effect of the Co-Cr processing, compared to DP3-ZrO2, which has mean values of around 113.178 µm.

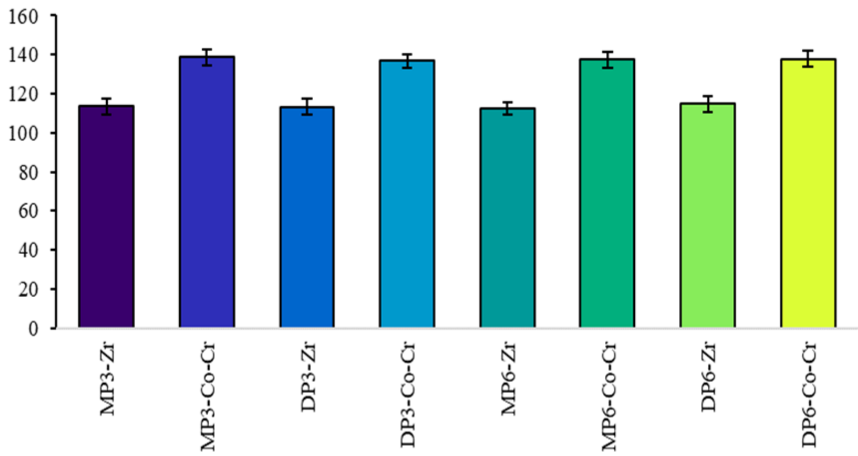


Fig.73 *Diagram of the mean values and standard deviations for the measurements from MP3-ZrO2, MP3-Co-Cr, DP3-ZrO2, DP3-Co-Cr, MP6-ZrO2, MP6-Co-Cr, DP6-ZrO2, and DP6-Co-Cr.*

The histogram on Fig.74 shows the distribution of values for each group.

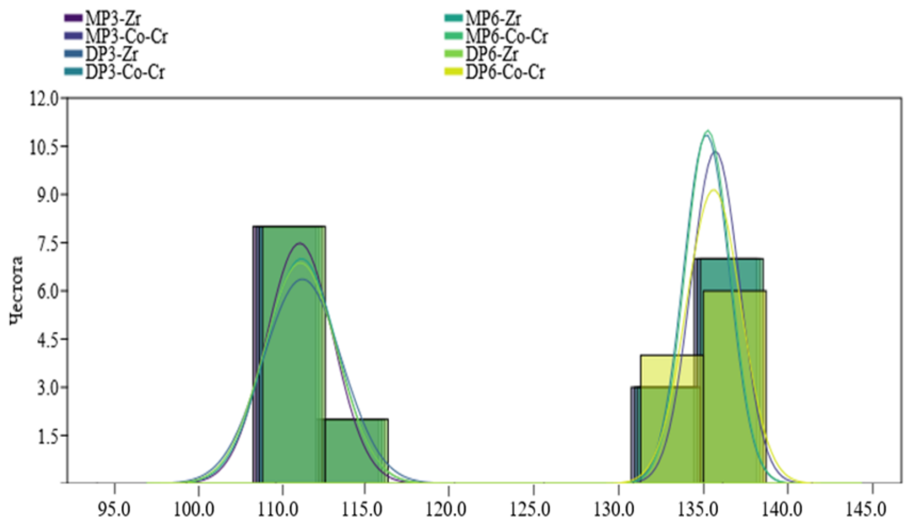


Fig.74 Histogram of the distribution of values for each combination of measurements and materials from MP3-ZrO2, MP3-Co-Cr, DP3-ZrO2, DP3-Co-Cr, MP6-ZrO2, MP6-Co-Cr, DP6-ZrO2, and DP6-Co-Cr.

A t-test is performed between two groups, for example, MP3-ZrO2 and MP3-Co-Cr, with results showing that there is a statistically significant difference between them. These results indicate a significant difference between the groups MP3-ZrO2 and MP3-Co-Cr.

IV.3.3 Discussion on the Fourth Task

Regardless of the statistical significance of the results in the studies, they fall within clinically acceptable limits. However, they demonstrate that the method using scan bodies and both production technologies provides less marginal discrepancy, which reduces the chance of cement dissolution and inflammation of the soft tissues. This is extremely important in prosthetic constructions supported by implants. Additionally, the indicators regarding internal fit in this group are also better. In the group of scanning analogs made from zirconium dioxide using subtractive technology, there is very little deviation among all examined samples.

V. CONCLUSIONS

1. Despite the widespread adoption of modern digital technologies, most of the surveyed dental practitioners still prefer conventional working methods.
2. Most of the surveyed dentists cannot determine whether there is a difference in the accuracy of restorations produced through digital protocols compared to traditional methods.
3. Most dental laboratories perform the scanning at the cast stage with a pre-selected abutment.
4. It is necessary to standardize and optimize the methods for transferring information between dental laboratories and dental practices, which can serve as a basis for future research aimed at improving communication and the precision of prosthetic construction fabrication.
5. A statistically significant difference has been established between the groups of scanned bodies and scanned abutments.
6. The use of scan bodies provides better marginal adaptation and accuracy of fit for implant suprastructures compared to scanning abutments, in both milling and selective laser melting technologies.
7. The geometry and optical properties of scan bodies ensure higher scanning precision and more accurate transfer of the implant position compared to scanning abutments.
8. It has been established that in the group of scanned abutment, the marginal fit accuracy shows higher values with both milling and selective laser melting technologies. These values are within clinically acceptable limits (under 100 μm).
9. It has been proven that the method of scan bodies provides higher accuracy compared to the method of scanning abutments.
10. It has been established that the fitting accuracy in both scanning methodologies and both manufacturing technologies is within the acceptable limits, providing marginal adaptation within the clinically acceptable threshold of 100 μm and fitting accuracy of less than 200 μm. The combination with the highest accuracy is the use of a scan body and milling, followed by scanned abutment and milling, scan body and selective laser melting, and finally scanned abutment and selective laser melting.

VI. CONCLUSION

This dissertation is motivated by the rapid development of digital dentistry, the increasing use of additive technologies, and the various possible working protocols.

The analysis of the opinions of dentists and dental technicians revealed that most of them still prefer the conventional method of transmitting information to dental laboratories, which, in turn, usually scan casts. This indicates that the complete digital protocol has not yet been fully implemented in many practices, and the partially digital approach is often used.

In our study, we investigate the parameters of "marginal adaptation" and "fit accuracy." We compared and analyzed the results obtained from two different methodologies for transferring information to the dental laboratory, in addition to two manufacturing technologies. We found that scanning the abutments leads to reflections from their surfaces, which can disrupt the distribution of light and the accuracy of the scan.

The results confirm that scan bodies provide better marginal adaptation and fit accuracy for implant suprastructures. In both manufacturing technologies, the values were found to be within clinically acceptable limits.

VII.CONTRIBUTIONS

Scientific and applied contributions

Original contributions

1.For the first time in our country, a methodology has been developed to standardize the technology for investigating the adaptation accuracy of fixed superstructures using a machine for hard cuts.

2. It has been established that the strategy using a scanning analogue provides higher accuracy compared to the method of scanning the abutment.

3. It has been established that the marginal adaptation and fit accuracy, which need to be ensured during treatment with implant superstructures, are achieved with both scanning methodologies and manufacturing technologies. The combination of the scanning method and the manufacturing process are ranked according to the achieved accuracy. First is the group of scan body and milling, followed by scanning of abutments and milling, scan body and selective laser melting, and scanning of abutments and selective laser melting.

Confirming contributions:

1. The use of scan bodies provides better marginal adaptation and fit accuracy of implant suprastructures compared to scanning abutments, and this applies to both manufacturing technologies—milling and selective laser melting.

2. The geometric and optical characteristics of the scan bodies are key factors influencing the achievement of higher scanning precision and more accurate transfer of implant positions compared to abutments.

Applicable contributions:

1. A newly developed methodology for creating spicemens for studying marginal adaptation and fit accuracy has been proposed, which can be used for future similar studies.

2. A classification of the combination of scanning method and manufacturing technology based on fit accuracy has been proposed, which can be successfully utilized in clinical practice.

VIII PUBLICATIONS, RELATED TO THE DISSERTATION

1. Kirova G. Difficulties in Taking an Impression with an Intraoral Scanner and Making Constructions by Digital Method. International Journal of Science and Research (IJSR), 2023:12(9)

2. Kirova G. Implant impression technique preferences-survey among dental practitioners. MedInform, 2023: 2;1708-1714

3. Kirova G, Katsarov S. Comparative analysis of marginal adaptation and internal fit of zirconia implant suprastructures fabricated using different scanning strategies. International Journal of Science and Research (IJSR), 2024:13(7);1478-1480