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„CAROL DAVILA", BUCHAREST
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BIOMECHANICAL CONSIDERATIONS ON THE COMPLICATIONS OF COMPLETE DENTURES AND OVERDENTURES

PhD THESIS SUMMARY

PhD Coordinator:
PROF. UNIV. DR. PREOTEASA ELENA

PhD Student:
TEODORESCU CRISTIAN

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LIST OF ABBREVIATIONS

% = percentage;

ºC = Celsius degrees;

Cm = centimeters;

DVO = vertical dimension of occlusion;

ID = dental implant;

IM = maximum intercuspation;

Kg = kilograms;

KHN = Knoop hardness number;

Lb = pounds;

MEF = finite element method;

MID = mini dental implants;

Mm = millimeters;

MPa = megapascals;

N = Newton;

Ncm = Newton centimeter;

PMMA = polymethyl methacrylate;

Psi = pounds per square inch;

RC = centric relation;

SP = overdenture;

STL = stereolithography;

Wt% = mass percent.

INTRODUCTION

The biomechanical complications of complete dentures and overdentures on teeth and implants are the consequence of errors in the development of the treatment plan or technical errors, related to the properties of the materials, their behavior during the exercise of the functions of the dento-maxillary apparatus or the laboratory stages. Poor fit, lack of bilaterally balanced occlusion [1] and occlusal loading [2] are some of the main causes of fracture of acrylic bases, to which are added deficiencies in retention and stability [3], accidental falls and stresses through reduced, cyclic, flexural and bending forces [4].

The general trend of increasing life expectancy, which is manifested at the global level, from 64 years in 1990 to 73 years in 2019, with the expectation of reaching a threshold of 77.2 years in 2050, in the context in which the percentage of people with ages over 65 will increase from 10% in 2022 to 16% in 2050 [5], it also implies an increase in patients' expectations regarding the longevity of dentures and overdentures on teeth or implants, longer periods of wearing them and a higher risk of complications. The average life expectancy has increased, in Romania, from 70.53 years in 2000 to 76.05 in 2020, and the resident population over 65 years old reached, in 2020, approximately 19.12%, representing a fifth of Romanians [6]. The aging process of the population also increases the risk of tooth loss [7], as a consequence of the development of dental caries or periodontal diseases not properly treated [8], complete edentulism being one of the most common conditions of the adult population, approximately one third of people between the ages of 65 and 74 being affected by this pathology, in developed countries [9].

Complete edentulism affects the patients' quality of life through the consequences of losing all teeth [10], being a chronic condition, which can be considered a disability, in view of the functional inabilities it generates at the level of the dento-maxillary apparatus [11], also echoing at a systemic level, assessed by the physical and functional inabilities it can generate and by altering the perception of well-being [12].

Patients wearing complete dentures are more prone to complications than partial denture wearers [13], and in the conditions in which the occlusal and masticatory force of the edentulous is only one fifth of that of the dentate [12] and considering that complete edentulous patients wearing conventional full dentures require seven times more masticatory cycles to triturate food compared to edentulous individuals [12], overdentures on teeth or implants are a current prosthetic alternative for this category of patients, with a beneficial

impact on the quality of life and the degree of patient satisfaction [14], by improving the balance, reducing the rate of bone resorption and obtaining a better aesthetic appearance [15], as well as by increasing the efficiency of mastication, the masticatory force being almost twice as high as that of conventional denture wearers [16], an alternative that is not without the possibility of complications, the evolution of which is contributed by a series of risk factors and deficiencies in terms of compliance with the clinical-technical stages of making these prosthetic restorations [17].

I. GENERAL PART. THE CURRENT STATE OF KNOWLEDGE

1. BIOMECHANICAL ASPECTS OF COMPLETE DENTURES AND OVERDENTURES

1.1. BIOMECHANICAL BEHAVIOR OF COMPLETE DENTURES AND OVERDENTURES

Complete dentures and overdentures replace the oro-dental structures lost through the installation of complete edentulism and have the role of rehabilitating oral functions, such as mastication, phonation and swallowing or the aesthetic appearance of the face, so that through the shape, dimensions and physico-chemical characteristics of its components be integrated into the biological environment provided by the oral structures with which they come in direct and indirect relationships, with the fulfillment of biocompatibility standards.

During the exercise of the functions of the dento-maxillary apparatus, complete dentures and overdentures are subjected to simple demands, with various directions and aspects [18], such as tension, compression, bending, shear and torsion [19], and external forces cause deformations [18], that can affect both acrylic bases and underlying tissues. Impact shock or cyclic bending fatigue contribute to fracture of acrylic prosthetic bases [20] [21], the pattern of stress transmission being influenced by the thickness of the prosthetic superstructures, the type of polymer used, muscle strength, the condition of the underlying tissues, the stability of the prosthesis and the shape and position of the artificial teeth [22].

The greater strength of PMMA in compression than in tension or shear explains why areas where compressive stresses occur are less prone to fracture compared to areas where bending stresses predominate [23], and dentures can fracture after a small number of series of strong stresses or after an increased number of repeated, low-intensity stresses [18].

1.2. BIOMECHANICAL ASPECTS RELATED TO ACRYLIC BIOPOLYMERS USED IN MAKING COMPLETE DENTURES AND OVERDENTURES

The mechanical properties that are taken into account in the choice of a certain polymer, used to make complete dentures or overdentures on teeth or implants, are mechanical and wear resistance, dimensional stability, appropriate weight and elasticity, as well as aesthetics, ease of use and maintenance or affordable price [24].

The most widely used polymer for the creation of prosthetic superstructures, artificial teeth or for the repair of prosthetic works is polymethyl methacrylate [4], which allows the possibility of improving its properties such as impact or bending resistances through chemical modifications or mechanical reinforcements [25].

The resistance to bending consists in the ability of the material to withstand the loads arising during mastication [26], the bending modulus being associated with the stiffness of the material [27] [28] [29] [30] [31], and the greater the rigidity of the prosthetic superstructure, the more symmetrical is the transmission of masticatory forces to the supporting mucosa, bone or remaining teeth [28].

2. BIOMECHANICAL COMPLICATIONS OF COMPLETE DENTURES AND OVERDENTURES

2.1. RISK FACTORS IN THE APPEARANCE AND EVOLUTION OF COMPLICATIONS OF COMPLETE DENTURES AND OVERDENTURES

The predisposing factors of biomechanical complications are classified into anatomic, functional, and prosthetic factors [4], some of the morphological aspects involved in the fracture of the acrylic bases being the ogival palatal vault, with or without the presence of the palatal torus, the severe and asymmetric atrophy of the alveolar ridge, associated with the high insertion of the peripheral ligamentous formations, as well as the presence of some root remnants or implants under dentures [32] [4].

Other factors associated with complications are the presence of parafunctions, hypodivergent facial typologies and unstable, non-functional occlusions [4], or deficiencies of the dentures or the technical stages of their production [3] [22].

2.2. DESCRIPTIVE ANALYSIS OF THE COMPLICATIONS OF COMPLETE DENTURES AND OVERDENTURES

Manifestations of biomechanical complications of complete dentures and overdentures can occur at the oral, facial or general level, or at the level of prosthetic works and their components [33]. Mechanical prosthetic complications are among the most common [34], the frequency rate of acrylic base fractures being high [35], especially at the level of the median line [36] [37], the main causes being accidental fall, poor adaptation and retention, occlusal deficiencies, incorrect fitting of artificial teeth or factors associated with the properties of acrylic resins [2] [37].

II. SPECIAL PART

3. SCIENTIFIC RESEARCH METHODOLOGY

Through the main research directions, the approach of some current problems in the field of dental prosthodontics, related to the biomechanical complications of complete dentures and overdenture supported by teeth or implants, with the identification of the risks and etiology of complications faced by complete edentulous patients, wearers of removable prostheses, conventionally or on implants, by corroborating data on the perception and level of awareness of dentists regarding the incidence of these categories of complications, their attitudes in particular clinical situations of fracturing prosthetic superstructures, loss of maintenance or stability of prostheses or damage to oral structures, prosthetic and implant structures, with experimental data related to the biomechanical behavior of overdentures on implants, depending on their topographical location, the physical properties of the polymers from which the prosthetic bases are made, the type of occlusal loading and the number and location of implants that may undergo changes.

The three research directions were represented by a descriptive cross-sectional study, which identified the perception and attitudes of general and specialist or primary dentists in different branches of dentistry on the complications of dentures and overdentures, as well as two experimental studies, carried out in silico, through the finite element method (FEM), which followed two distinct directions, respectively the analysis of some biomechanical aspects and complications regarding mandibular overdentures on two or four implant units inserted interforaminal, as well as the analysis of some biomechanical aspects and complications regarding the mandibular overdentures on four implant units, two of which are inserted interforaminal, in the canine area, and two laterally, in the molar area, with prosthetic bases made of modern acrylic resins, injected under pressure, and conventional

acrylic resins, with the analysis of the consequences of losing a number of one, two or three implant units, upon application of frontal, unilateral or bilateral occlusal forces, by recording the von Mises equivalent stresses (Figure 3.1.), expressed in MPa, and displacements (Figure 3.2.), expressed in millimeters, with predictive value.

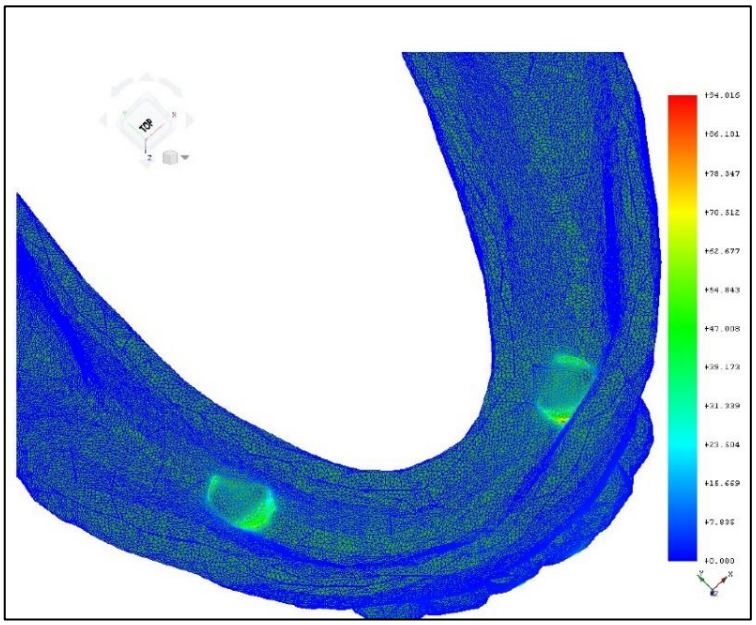

Figure 3.1 The scale of equivalent von Mises stresses at the level of a mandibular overdenture

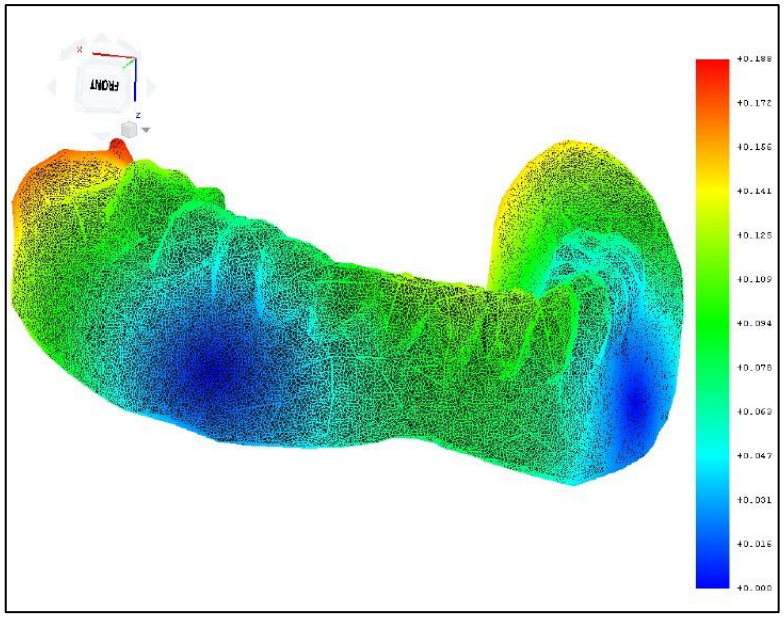

Figure 3.2. The scale of displacements at the level of a mandibular overdenture

4. STUDY I. PERCEPTION AND ATTITUDES OF DENTISTS ON THE COMPLICATIONS OF COMPLETE DENTURES AND OVERDENTURES

4.1. INTRODUCTION (AIM, WORKING HYPOTHESIS AND SPECIFIC OBJECTIVES)

Dentists represent the main category of professionals who are responsible for the evaluation, diagnosis and therapeutic approach of the changes that appear in the oral structures, with the installation of complete edentulism. The aim of the study was to evaluate the perception of specialist dentists in different branches of dentistry on the complications of dentures and overdentures on teeth or implants, as well as their attitude regarding the approach to these complications and therapeutic alternatives, the objective consisting in identifying the level of awareness of dentists regarding the imminence of complications of dentures and overdentures on teeth or implants, depending on the clinical activity they carry out for prosthetic purposes and the cases they observe in their daily professional activity.

4.2. MATERIAL AND METHOD

The descriptive cross-sectional study was carried out by means of a questionnaire in Romanian, distributed online, in which a convenience sample of 63 general dentists and specialists or primary doctors in the fields of prosthodontics, oro-maxillo-facial or dento-alveolar surgery, endodontics, orthodontics and dento-facial orthopedics, periodontology and general dentistry, participated on a voluntary basis, by expressing informed consent, over a period of approximately ten weeks.

The questionnaire consisted of 24 questions with single or multiple answers, of closed or open type, and the data analysis was carried out by means of the SPSS Statistics V26 program (IBM, Armonk, NY, USA) and consisted in a first part in the analysis of indicators of central tendency, and in the second part, specific techniques of analysis of multiple-choice questionnaires were applied.

4.3. RESULTS

Among the 63 dentists participating in the study, the majority were female (n=49; 77.8%), aged between 30 and 39 (n=33; 52.4%), who worked in private offices (n=46; 73%), especially from the urban environment (n=58; 92.1%). Although most of the participants were dental prosthodontic residency graduates (n=25; 39.7%), an important aspect of the study was that almost a quarter of the participants were under the age of 30 (n= 15; 23.8%),

most of them having professional experience between 5 and 10 years (n=23; 36.5%), followed by those with less than five years of experience (n=21; 33.3 %). Two thirds of the participants were specialist or primary doctors, almost half being prosthodontists, that is, dentists with advanced knowledge in the field of dentistry, which was an important aspect in analyzing the results, despite their experience and younger age.

The doctors participating in the study stated that female patients (n=49; 77.8%) most frequently request acrylic prostheses, the average age of the majority of patients being between 40 and 60 years (n=30; 47.6 %). Approximately one third of the participants perform between 2 and 6 partial (n=18; 28.6%) and complete (n=22; 34.9%) acrylic dentures within a month, and as for overdentures on the teeth or on implants, they are performed in a much smaller number, most of the doctors stating that no more than two such dentures are requested per month (n=50; 79.4%). Repairs are not very frequent either, most performing two such interventions per month (n=51; 81%), and almost a fifth of doctors between two and six repairs (n=11; 17.5%), of which fracture of acrylic bases (n=21; 33.3%) and need for liners (n=14; 22.2%) were more common.

Among the complications, patients wearing conventional acrylic prostheses encountered lesions of the oral mucosa (n=33; 52.4%), retention deficiencies (n=28; 44.4%) or stability (n=25; 39.7%), as well as fracture of acrylic bases (n=9; 14.3%) or artificial teeth (n=6; 9.5%). In patients with overdentures on teeth or implants, anchoring systems detachment (n=29; 46%), complications of remaining teeth (n=25; 39.7%) or implants (n=9; 14.3%) were reported more frequently, as well as fracture of acrylic bases (n=10; 15.9%).

Maxillary complete denture (n=24; 38.1%) fractured most frequently, followed by mandibular (n=18; 28.6%) and maxillary partial dentures (n=8; 12.7%) and mandibular complete denture (n=5; 7.9%). Overdentures on implants, regardless of the arch on which they were located, fractured more frequently than those on teeth. More than half of the physicians observed midline fracture (n=37; 58.7%) due to accidental falls (n=42; 66.7%). Other common causes of acrylic base fracture were high masticatory force (n=19; 30.2%), instability (n=18; 28.6%) or occlusal deficiencies (n=17; 27%).

The anatomical risk factors most frequently involved in the occurrence of prosthesis fracture were ridge asymmetry (n=24; 38.1%), pronounced bone resorption (n=24; 38.1%), the presence of torus (n=23; 36.5%) or the presence of antagonistic dentate ridges (n=21; 33.3%). Other anatomic risk factors mentioned by the participating doctors were the balance

ridge, reduced prosthetic space, high insertion of peripheral formations, reduced mucosal resilience or protruding tuberosity.

Repeated fracture of dentures (n=39; 61.9%), repeated linings (n=21; 33.3%) or wear of artificial teeth (n=39; 61.9%) were the most frequent risk factors in relationship with the previous state of the mobile dentures, which the dentists participating in the study observed, and among the risk factors associated with prosthetic complications, antagonists represented by natural teeth or fixed prosthodontic restorations were specified (n=32; 50.8%) , unstable occlusion (n=20; 31.7%) or incorrect fitting of artificial teeth (n=20; 31.7%), along with overestimation of DVO, acrylate porosity or hypodivergent facial typologies.

Regarding dentists' attitudes, the majority chose to use conventional thermosetting acrylic resins due to ease of repair (n=39; 61.9%) and low price (n=37; 58.7%), and among the alternative technological methods of improving the mechanical resistance are mentioned the reinforcement of the acrylic bases with metallic (n=52; 82.5%) or non-metallic (n=11; 17.5%) inserts, as well as the use of modern resins, injected under pressure or those resistant to impact.

4.4. CONCLUSIONS

This study revealed that the involvements in removable prostheses, repairs and optimization of prostheses and overdentures are different, in relation to age, training and clinical experience or environment of performing dental care activities. Dentists, regardless of specialization, were aware of the risks that prosthodontic treatment can have, in accordance with particularities of the alveolar ridges and arches antagonistic to the edentations, as well as aspects that the materials and technologies for making prostheses can have.

The training of patients regarding the use of prosthetic works and their correct hygiene, as well as dispensary, become essential elements in preventing complications, the clinical experience of dentists being important for a good design, realization and monitoring of these categories of prosthetic restorations.

5. STUDY II. ANALYSIS BY THE FINITE ELEMENT METHOD (FEM) OF SOME BIOMECHANICAL ASPECTS AND COMPLICATIONS REGARDING MANDIBULAR OVERDENTURES SUPPORTED BY INTERFORAMINALLY INSERTED IMPLANTS

5.1. INTRODUCTION (AIM, WORKING HYPOTHESIS AND SPECIFIC OBJECTIVES)

Overdenture on two interforaminally inserted implants is the first treatment alternative recommended in the case of complete mandibular edentulism, according to the McGill Consensus (2002, Canada) and recognized at the European level by the York Consensus (2009).

The in silico study by the finite element method was carried out with the aim of evaluating the stresses and displacements manifested at the level of mandibular overdentures on two or four implants/mini-implants inserted in the interforaminal area, with prosthetic bases made of modern acrylic resins, injected under pressure, or acrylic resins obtained by conventional techniques, as well as analyzing the biomechanical consequences caused by the loss of an implant unit, the simulated situations being frontal loading, specific to food incision, and uni- and bilateral loading, specific to food mastication and swallowing, as biofunctional aspects.

The objectives of the study are to identify some biomechanical aspects on the behavior of mandibular overdentures on two or four implants/mini-implants, inserted in the interforaminal area, which can be correlated with clinical observations, with predictive value: recording the von Mises equivalent stresses, expressed in MPa, as possible indicators of the risk of fracturing the acrylic bases, and displacements, expressed in millimeters, as possible indicators of the risk of balance deficiencies, having consequences on the functionality and integrity of the support structures.

5.2. MATERIAL AND METHOD

The Finite Element Method (FEM) allowed the evaluation of the consequences of the application of occlusal compressive forces, at the frontal or lateral level, depending on the simulated masticatory stage: the loading of the frontal teeth during food incision and the uni- or bilateral loading of the lateral teeth, specific to the position of maximum intercuspation, swallowing and mastication. The three-dimensional simulation, numerical evaluation and prediction of the biomechanical impact of the loss of an implant unit on

mandibular overdentures on two or four interforaminally inserted ID/MIDs was possible through MEF, which took into account the occlusal loading conditions and the physical properties of the polymers used in the manufacture of prosthetic bases (conventional PMMA type resin and Vitaplex thermopolymerizable acrylic resin (Roko Dental Systems, Częstochowa, Poland), injected under pressure by means of an automated injection device), respectively the modulus of elasticity and Poisson's ratio.

The scanning of a mandibular overdenture allowed the modeling by finite elements, after obtaining a three-dimensional model, represented by a network of linked triangles. The complex geometry of the mandibular overdenture on two or four interforaminally inserted ID/MIDs was insignificantly modified by adding some cylinders in the direction of application of pressures, according to the topographical positioning of the implant units, in the interforaminal area, with the elimination of the spherical shape of the abutment, to reduce the complexity of the model. The occlusal load was represented by a pressure on the surface of the cylinders, the total equivalent force being 150 N [4] [38] [39]. The linear elastic analysis was carried out by dividing into tetrahedral elements without intermediate nodes, and by rolling the data displacements were obtained as primary quantities and stresses, considered equivalent von Mises stresses.

The simulated clinical situations were: mandibular overdentures on two interforaminally inserted ID/MIDs, made of conventional acrylic resin and pressure-injected acrylic resin (situation 1) and mandibular overdentures on four interforaminally inserted ID/MIDs, made of conventional acrylic resin and pressure-injected acrylic resin (situation 2). For all variants, the biomechanical impact of occlusal stresses during unilateral or bilateral incision and mastication, as well as the effects of the loss of an implant unit, were evaluated.

5.3. RESULTS

From the comparative evolution of von Mises stress values at the level of the mandibular overdentures on two interforaminally inserted ID/MIDs, in the initial situation and following the loss of an implant unit, it can be seen that the tension values are very close for both types of overdentures, respectively those made of acrylic resin injected under pressure and those made of conventional acrylic resin, and in the unfavorable situation of losing an implant unit, two aspects are evident: the values triple in the case of frontal or bilateral loads, and in the case of unilateral loading, the stresses become approximately five

times higher; also, greater differences are observed between the stresses manifested at the level of the two types of acrylic resins, the conventional ones being subjected to the highest stress values.

Regarding the displacements manifested at the level of the mandibular overdentures on two interforaminally inserted ID/MIDs, in the initial situation and following the loss of an implant unit, it is observed that in the initial situation, the two categories of overdentures, regardless of the type of acrylic resin from which the bases are made, are subject to displacements almost similar in value, the differences being slightly greater in the case of unilateral loading. With the loss of an implant unit, displacement values increase considerably, with bilateral loading generating nearly ten-fold increases and unilateral loading nearly thirteen-fold increases, for both categories of acrylic overdentures. Also, in the second situation, there is a greater increase in the differences between the displacements manifested at the level of overdentures made of pressure-injected resins and those made of conventional acrylic resins.

The comparative results of the MEF study on the two types of mandibular overdentures on two interforaminally inserted ID/MIDs , in the initial situation and following the loss of an implant unit, were summarized in tables V.1. and V.2.

Table V.1. Biomechanical changes of the loss of an implant unit on the mandibular SP on 2 interforaminally inserted ID/MIDs, with the prosthetic base made of pressure-injected acrylic resin

	PRESSURE-INJECTED ACRYLIC RESIN MANDIBULAR OVERDENTURE			
	2 ID/MID		**1 ID/MID, DUE TO LOSS OF AN IMPLANT UNIT**	
OCCLUSAL LOADING	**VON MISES STRESS (MPA)**	**DISPLACEMENT (MM)**	**VON MISES STRESS (MPA)**	**DISPLACEMENT (MM)**
Anterior loading	76	0,17	243,88	0,45

Bilateral loading	89,27	0,24	267,49	2,6
Unilateral loading	117,69	0,37	593,14	5,1

Table V.2. Biomechanical changes of the loss of an implant unit on mandibular SP on 2 interforaminally inserted ID/MIDs, with the prosthetic base made of conventional acrylic resin

	CONVENTIONAL ACRYLIC RESIN MANDIBULAR OVERDENTURE			
	2 ID/MID		**1 ID/MID, DUE TO LOSS OF AN IMPLANT UNIT**	
OCCLUSAL LOADING	**VON MISES STRESS (MPA)**	**DISPLACEMENT (MM)**	**VON MISES STRESS (MPA)**	**DISPLACEMENT (MM)**
Anterior loading	79,78	0,16	255,96	0,41
Bilateral loading	91,48	0,22	286,94	2,38
Unilateral loading	121,58	0,33	615,92	4,69

The comparative evolution of von Mises stress values at the level of mandibular overdentures on four interforaminally inserted ID/MIDs reveals the fact that in the initial situation, the differences between the tension values manifested at the level of the two types of overdentures, respectively those made of resins injected under pressure and those made of resins conventional acrylics, are small, but the loss of an implant unit causes increases in this difference and significant increases in von Mises stresses, with bilateral loading generating 1.5 times increases in tensile values, and unilateral loading almost two times increases in these values.

Regarding the displacements manifested at the level of the mandibular overdentures on four interforaminally inserted ID/MIDs, in the initial situation and following the loss of

an implant unit, it is observed that in the initial situation, the two categories of overdentures, regardless of the type of acrylic resin from which they are bases are made, are subject to almost similar displacements in value, the differences being slightly larger in the case of bi- and unilateral loading, but the differences become larger with the loss of an implant unit, as do the tension values, with unilateral loading causing increases of nearly four times these values.

The comparative results of the MEF study on the two types of mandibular overdentures on four interforaminally inserted ID/MIDs, in the initial situation and following the loss of an implant unit, were summarized in tables V.3. and V.4.

Table V.3. Biomechanical changes of the loss of a distal implant unit on mandibular SP on 4 interforaminally inserted ID/MIDs, with the prosthetic base made of pressure-injected acrylic resin [39]

	PRESSURE-INJECTED ACRYLIC RESIN MANDIBULAR OVERDENTURE			
	4 ID/MID		**3 ID/MID, DUE TO LOSS OF A DISTAL IMPLANT UNIT**	
OCCLUSAL LOADING	**VON MISES STRESS (MPA)**	**DISPLACEMENT (MM)**	**VON MISES STRESS (MPA)**	**DISPLACEMENT (MM)**
Anterior loading	26,96	0,065	32,91	0,069
Bilateral loading	70,41	0,15	103,56	0,48
Unilateral loading	91,5	0,27	155,72	1,14

Table V.4. Biomechanical changes of the loss of a distal implant unit on the mandibular SP on 4 interforaminally inserted ID/MIDs, with the prosthetic base made of conventional acrylic resin

	CONVENTIONAL ACRYLIC RESIN MANDIBULAR OVERDENTURE			
	4 ID/MID		3 ID/MID, DUE TO LOSS OF A DISTAL IMPLANT UNIT	
OCCLUSAL LOADING	**VON MISES STRESS (MPA)**	**DISPLACEMENT (MM)**	**VON MISES STRESS (MPA)**	**DISPLACEMENT (MM)**
Anterior loading	27,65	0,058	31,73	0,062
Bilateral loading	71,69	0,13	107,95	0,44
Unilateral loading	89,98	0,25	167,13	1,03

5.5. CONCLUSIONS

In the first situation, of a mandibular overdenture on two ID/MIDs inserted in the interforaminal area, the values of equivalent von Mises stresses and displacements were almost similar for the two prosthodontic variants, respectively the one made of pressure-injected acrylic resin and the one made of conventional acrylic resin, highlighting a slight increase in tension values when using PMMA, accompanied by a very small decrease in displacements, for all simulated occlusal loading situations. With the loss of an implant unit, significant changes in tension values and displacements were observed, for both types of overdentures, as a clinical indicator of increased risk of fracture of acrylic bases and impairment of functionality and prosthetic support structures.

In the second situation, of a mandibular overdenture on four ID/MIDs inserted in the interforaminal area, the use of conventional resins to make the prosthetic bases determined, as in the first situation, slightly lower displacement values, regardless of the occlusal load variant. Likewise, the loss of an implant unit generated an increase in tension values and displacements, for both prosthodontic variants, with unilateral loading generating the most unfavorable results. Moreover, the unilateral loading was the most unfavorable in all simulated situations, regardless of the number of implant units or the type of acrylic resin from which the mandibular overdenture was made, and the frontal loading determined the lowest equivalent von Mises stresses and the lowest displacements.

The addition of the number of implants or mini-implants inserted interforaminally, from two to four, determined an almost three-fold reduction in the values of equivalent von Mises stresses and displacements in the situation of frontal loading of the overdentures, regardless of the type of acrylic resins they are made of, observing a tendency to reduce these parameters for all types of occlusal loads. The loss of an implant unit caused a significant increase in von Mises stresses and displacements in the situation of mandibular overdentures on two ID/MIDs, but increasing the number of implants or mini-implants, from two to four, generated smaller changes of tension values and displacements through the loss of a distal implant unit.

In conclusion, the biomechanical aspects in the mandibular overdentures on two or four ID/MIDs inserted in the interforaminal area are related to the number of implant units, the characteristics of the materials from which the prosthetic bases are made, but also to biofunctional aspects (pressures in the incisal area, uni- or bilateral) and the occurrence of complications such as the loss of an implant unit, which causes increased stresses and displacements at the level of the prosthetic superstructure.

6. STUDY III. ANALYSIS BY THE FINITE ELEMENT METHOD (FEM) OF SOME BIOMECHANICAL ASPECTS AND COMPLICATIONS REGARDING MANDIBULAR OVERDENTURES SUPPORTED BY IMPLANTS INSERTED IN THE INTERFORAMINAL AND LATERAL AREAS

6.1. INTRODUCTION (AIM, WORKING HYPOTHESIS AND SPECIFIC OBJECTIVES)

In the case of complete edentulism, a treatment alternative that presents a number of advantages compared to conventional complete dentures are overdentures on implants or mini-implants, the number of implants, respectively of retention systems, and their distribution providing a good balance of the dentures and increased functional efficiency, as well as improving physical and mental comfort and quality of life. The in silico study using the finite element method was carried out with the aim of evaluating the stresses and displacements manifested at the level of a mandibular overdenture on four ID/MIDs, of which two are interforaminally inserted, in the canine area, and two laterally, in the molar area, as well as to analyze biomechanical consequences caused by the loss of one, two or three implant units. The objective of the study was to identify some biomechanical aspects

on the behavior of mandibular overdentures on four ID/MIDs, inserted in different topographic locations (anterior and lateral), the dentures being made of acrylic resins, obtained by conventional or modern techniques, injected under pressure, aspects which can be correlated with clinical observations with predictive value in terms of stress concentration and increased risk of fracture, as well as displacement tendency, with balance deficiencies and damage to supporting structures.

6.2. MATERIAL AND METHOD

The finite element method (FEM) was used as an analysis method, which allowed the evaluation of the consequences of the application of occlusal compressive forces, at the frontal or lateral level, depending on the simulated masticatory stage: loading of the front teeth during food incision and uni- or bilateral loading of the lateral teeth, characteristic aspects of mastication, maximum intercuspation position and swallowing. Through the finite element method, which takes into account the occlusal loading conditions and the physical properties of the polymers used in the fabrication of the prosthetic bases, namely the modulus of elasticity and the Poisson's ratio, it was possible and carried out the three-dimensional simulation, the numerical evaluation and the prediction of the biomechanical impact of the loss of a number of implant units on four ID/MIDs mandibular overdentures, of which two are interforaminally inserted, in the canine area, and two are inserted laterally, in the molar area.

The clinical situations of some mandibular overdentures on four ID/MIDs, with different locations, of which two inserted in the interforaminal area, in the canine areas, and two laterally, in the molar areas, were simulated, with the evaluation of the biomechanical impact of the occlusal stresses during the incision and unilateral or bilateral mastication, as well as the effect of the loss of one, two or three implant units, as follows: the loss of one implant unit from the molar area, the loss of one implant unit from the canine area, the loss of two implant units, respectively one from the canine area and one from the molar area, the loss of two implant units from the canine areas and the loss of three implant units, respectively two from the canine areas and one from the molar area. The simulated overdentures considered two different situations regarding the material component, being made of conventional and modern acrylic resins, injected under pressure.

6.3. RESULTS

The comparative evolution of von Mises stress values at the level of mandibular overdentures on 4 ID/MIDs, of which two inserted interforaminally and two inserted in the lateral area, in the initial situation and following the loss of one, two or three implant units, in the variant in which the denture base was made of resins injected under pressure, it highlights the fact that for all categories of occlusal loads an increase in tensional values is visible, with the loss of implant units, the highest values being observed in the unfavorable situation of the loss of three of the four implant units. In this situation, the frontal loading generated the highest equivalent von Mises stress, which was almost thirty times higher than the initial situation. It is also observed that the frontal loading generated higher tension values than the unilateral loading even in the case of the loss of one or two implant units in the canine area, and the bilateral loading generated the lowest values of the equivalent stresses in all the simulated variants.

By analyzing the displacements manifested at the level of mandibular overdentures on 4 ID/MIDs, of which two inserted interforaminally and two inserted in the lateral area, in the initial situation and following the loss of one, two or three implant units, in the variant in which the denture base was made of resins injected under pressure, it is observed that the highest displacement values were recorded in the case of unilateral loading, in the unfavorable situation of the loss of three implant units, respectively two from the canine areas and one from the molar area.

Moreover, unilateral loading generated the largest displacements in most simulated situations, except for the initial situation and the loss of two implants in the canine areas, where frontal loading generated the largest displacements. Also, bilateral loading generated larger displacements than frontal loading in situations of loss of one implant in the molar area or two implants, one in the canine area and one in the molar area.

The comparative evolution of von Mises stress values at the level of mandibular overdentures on 4 ID/MIDs, of which two inserted interforaminally and two inserted in the lateral area, in the initial situation and following the loss of one, two or three implant units, in the variant in which the denture base was made from conventional acrylic resins showed that the highest tension values were recorded during frontal loading, in the situation of the loss of three implant units, two of which were from the canine areas and one from the molar area, and the situations in which the unilateral loading generated equivalent stresses higher

than the frontal loading are the initial situation, the loss of one implant in the molar area and the loss of two implants, one in the canine area and one in the molar area. Bilateral loading generated the lowest stress values in all situations of loss of several implant units, except for the initial situation, where the lowest stress was observed following frontal loading.

Regarding the displacements manifested at the level of mandibular overdentures on 4 ID/MIDs, of which two inserted interforaminally and two inserted in the lateral area, in the initial situation and following the loss of one, two or three implant units, in the variant in which the denture base was made from conventional acrylic resins, it is observed that the highest values were recorded during unilateral loading, in the case of the loss of three implant units, of which two from the canine areas and one from the molar area, and the lowest displacements in the case of frontal and bilateral loadings, in most cases, except for the case of the loss of two implants in the canine areas, in which the frontal loading generated the most important displacement value, or in the case of the loss of one implant in the canine area and one in the molar area , where bilateral loading generated a greater displacement than frontal loading, but twice less than unilateral loading.

The comparative results of the MEF study on the two types of mandibular overdentures on 4 ID/MIDs, of which two inserted interforaminally and two inserted in the lateral area, in the initial situation and following the loss of one, two or three implant units, were synthesized in tables VI.1. and VI.2.

Table VI.1. The biomechanical changes of the loss of a variable number of implant units on the mandibular SP on 4 ID/MIDs, two of which are inserted interforaminally and two are inserted in the lateral area, with the denture base made of pressure-injected acrylic resin [39]

	ANTERIOR LOADING		**BILATERAL LOADING**		**UNILATERAL LOADING**	
Pressure-injected acrylic resin mandibular overdenture	von Mises stress (MPa)	Displacement (mm)	von Mises stress (MPa)	Displacement (mm)	von Mises stress (MPa)	Displacement (mm)

4 ID/MID	35,8	0,061	40,87	0,028	82	0,057
3 ID/MID, after the loss of an implant in the molar area	91,67	0,088	55,13	0,15	110,66	0,28
3 ID/MID, after the loss of an implant in the canine area	166,1	0,11	50,92	0,07	113,08	0,15
2 ID/MID, after the loss of two implants: one in the canine area and one in the molar area	344,81	0,51	177,27	2,26	384,79	4,7
2 ID/MID, after the loss of two implants in the canine areas	586,3	0,58	103,61	0,17	161,82	0,24
1 ID/MID, after the loss of three implants: two in the	1194,35	2,04	469,61	4,33	949,44	8,49

canine area and one in the molar area						

Table VI.2. The biomechanical changes of the loss of a variable number of implant units on the mandibular SP on 4 ID/MIDs, two of which are inserted interforaminally and two are inserted laterally, with the denture base made of conventional acrylic resin

	ANTERIOR LOADING		**BILATERAL LOADING**		**UNILATEARL LOADING**	
Conventional acrylic resin mandibular overdenture	von Mises stress (MPa)	Displacement (mm)	von Mises stress (MPa)	Displacement (mm)	von Mises stress (MPa)	Displacement (mm)
4 ID/MID	35,36	0,063	40,99	0,026	82,26	0,052
3 ID/MID, after the loss of an implant in the molar area	91,62	0,081	58,10	0,13	116,63	0,26
3 ID/MID, after the loss of an implant in the canine area	166,62	0,10	53,45	0,063	121,27	0,14
2 ID/MID, after the loss of two implants: one in the canine area and one in	346,21	0,47	188,27	2,07	406,36	4,29

the molar area						
2 ID/MID, after the loss of two implants in the canine areas	584,21	0,53	106,75	0,15	173,08	0,21
1 ID/MID, after the loss of three implants: two in the canine area and one in the molar area	1195,94	1,86	475,44	3,93	958,88	7,76

6.4. CONCLUSSIONS

The loss of some implant units demonstrated the occurrence of important differences in von Mises stresses and displacements, with clinical consequences on the stability of overdentures, the functionality of the dento-maxillary apparatus and the risk of fracture of acrylic bases. Due to the loss of an implant unit from the canine area, significant differences in equivalent stresses were observed, following frontal loading a 4.6 times higher tension increase was recorded, and unilateral loading generated, following the loss of an implant unit from the molar area, an almost five-fold increase in displacement value, with no significant differences evident between the two types of overdentures. Loss of two implant units out of four resulted in increases in von Mises equivalent stresses of more than 16 times in frontal loading, when the two lost implant units were from the interforaminal areas, and the greatest displacement was observed following unilateral loading, by losing both implant units on a hemiarcade. The loss of three implant units generated the highest values of von Mises stresses following frontal loading, for both the four ID/MIDs mandibular overdentures made of pressure-injected acrylic resins and those made of conventional acrylic resins. The highest values of the displacements were recorded following unilateral loading.

7. CONCLUSSIONS AND PERSONAL CONTRIBUTIONS

In the first study, we presented important results regarding the correlation between the biomechanical complications of dentures and overdentures on teeth and implants and the particularities of oral structures or the deficiencies of prosthetic works, acrylic resins and technological methods of realization. Through the lens of observation and professional experience, the doctors participating in this cross-sectional descriptive study identified the main types of complications that can be faced by edentulous patients, wearers of conventional removable dentures or overdentures on teeth or implants, their causes, in relation to anatomical risk factors, factors related to the previous condition of the removable denture or the prosthodontic status, as well as the therapeutic attitude they have in relation to the prevention or reduction of the unfavorable effects of the installation of these complications, taking into account the current modern alternatives in the field of polymers, acrylic base reinforcements and overdentures. Understanding the local and general characteristics of patients and strict adherence to the principles of conventional and implant-based removable prosthodontics, as well as patient training and dispensary, tends to reduce the risk of complications of these prosthodontic options. The results obtained from this study supported the working hypothesis, and the expected results were confirmed, with the fulfillment of the established objectives.

In the studies carried out by the finite element method, the research method based on the numerical experimental analysis of the new alternatives of prosthodontic treatment on implants of the complete edentulous patient, as overdentures and new materials introduced for the realization of prosthodontic superstructures, by pressure injection techniques, through the prism of the reaction of prosthetic restorations in different clinical situations of occlusal loading, allowed the evaluation of the tensions, stresses and displacements to which they are subjected. The simulation of the most recommended overdenture alternatives on two or four implants or mini-implants took into account the biofunctional characteristics regarding occlusal stresses and the possibility of losing some implant units. The loss of several implant units generated important differences in von Mises stresses and displacements, the clinical consequences being manifested by the increased risk of fracture of the acrylic bases, together with the presence of areas of stress concentration, the instability of prosthetic restorations and the functional imbalances of the dento-maxillary apparatus, with the possibility of affecting the supporting structures. Overdentures made of conventional resins recorded higher tension values, regardless of the type of occlusal loading, but slightly lower

displacements, compared to overdentures made of modern, pressure-injected acrylic resins, the physical properties of the polymers having an influence on the results, which agreed with those expected.

It was highlighted that the frontal loading of a mandibular overdenture on four interforaminally inserted ID/MIDs generated the lowest von Mises equivalent stress, regardless of the type of acrylic resin from which the prosthetic superstructure was made, this representing the most favorable situation to support occlusal loads. When the four ID/MIDs were inserted both interforaminally and laterally, the lowest tension values were recorded, for most cases, following bilateral loading, regardless of the number of outstanding implant units, except for the initial situation, when the frontal loading determined a lower equivalent stress, for both types of acrylic resins used in the fabrication of prosthetic bases.

Studies have shown that increasing the number of implant units from two to four in the interforaminal area caused a decrease in the equivalent stresses by almost three times in the case of frontal loading and by approximately 1.5 times following uni- or bilateral loading, and in the unfavorable situation of loss of one of the implant units, the addition of implants determined an even more important reduction of the tensional values, with frontal loading being observed an almost eight-fold decrease in the equivalent von Mises stresses, regardless of the type of acrylic resin used. The choice of the lateral area as the place of insertion of two implant units, next to the interforaminal area, also determined a reduction of the tension values, compared to the situation of the mandibular overdentures on two interforaminally inserted ID/MIDs, the values being close to those found in the case of the mandibular overdentures on four interforaminally inserted ID/MIDs.

The maximum loading situation, which generated the highest equivalent von Mises stress, was determined by the frontal loading of a mandibular overdenture on four ID/MIDs, two of which were inserted interforaminally and two in the lateral area, following the loss of three implant units, two from the canine areas and one from the molar area, without the type of acrylic resin from which the prosthetic superstructure was made having a significant influence. The frontal loading proved to be unfavorable and generated the highest tensional values in the situation of the loss of some implant units in the anterior areas of the dental arch, respectively of one or both implants in the canine areas, but when the distal implants were the ones that were lost, unilateral loading resulted in higher equivalent stresses. Also, unilateral loading generated the highest stresses in the situation of mandibular overdentures

on two or four interforaminally inserted ID/MIDs, both in the initial situations and following the loss of a distal implant unit.

Regarding stability, the lowest displacement was observed in the situation of the mandibular overdenture on four ID/MIDs, two of which inserted in the interforaminal area and two in the lateral area, with the prosthetic base made of conventional acrylic resin, following bilateral loading, the value being close to that of the situation of using injected under pressure resins. The addition of the number of implant units from two to four in the interforaminal area determined a decrease in displacements for all variants of occlusal loads, in the initial situation or following the loss of an implant unit, regardless of the type of acrylic resin from which the prosthetic superstructure was made. In the case of overdentures on two or four interforaminally inserted ID/MIDs, frontal loading generated the lowest displacements, and in the case of overdentures on four ID/MIDs, two of which inserted in the interforaminal area and two in the lateral area, bilateral loading determined the lower values of displacements in most cases, except for situations where the loss of an implant unit in the molar area occurred, when the frontal loading generated smaller displacements.

The greatest displacement tendency was generated by the unilateral loading of the mandibular overdentures on four ID/MIDs, two of which inserted interforaminal and two in the lateral area, with the prosthetic base made of pressure-injected resin. Moreover, unilateral loading generated the largest displacements in most cases, regardless of the number and topographical location of the implant units. In the case of mandibular overdentures on four ID/MID, two of which inserted interforaminal and two in the lateral area, the frontal loading generated larger displacements in the initial situation and in the case of the loss of the two implants in the canine areas, for both types of acrylic resins used.

Through the studies we carried out clinically and through numerical simulation, we brought valuable clarifications regarding the correlation of the clinical aspects with the biomechanical aspects specific to implant overdentures, as new prosthodontic alternatives, but also as new possibilities of using the materials indicated for the realization of prosthetic bases, which could have a pressure-absorbing and displacement-reducing effect, with decreased risk of fracture of prosthodontic restorations.

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