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Oral Implantology and Bioengineering: From "Digital Guided Surgery" to Personalized Medicine

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There are three professions which are entitled to wear a gown: the judge, the priest, the scholar. This garment stands for its bearer's maturity of mind, his independence of judgment, and his direct responsibility to his conscience and to his God. It signifies the inner sovereignty of those three interrelated professions: they should be the very last to allow themselves to act under duress and yield to pressure.

Ernst Kantorowicz, "The fundamental Issue: documents and marginal notes on the University of California Loyalty oath", 1960

Sommario

INTRODUCTION

Background

Implantology in a branch of oral surgery, it deals with the replacement of missing teeth with the use of dental implants, which can be used to replace a single tooth or as supports for fixed bridges or for anchoring mobile prostheses. In fact, the rehabilitation of one or more dental elements using implantology requires a multidisciplinary approach for each individual case to be treated. Since 1952, the year in which Prof. Branemark discovered the phenomenon of implant osseointegration [1], to date industry and research have produced dental implants with morphologies and coating surfaces so innovative as to guarantee increasingly reliable results to the point of allowing us to reduce also the waiting time between the moment when the dental implant is inserted and when it is connected to the dental prosthesis; in fact, from 6-8 months of the old protocols, to the same day (immediate load) 2-3 months for the current ones. A dental implant is a small titanium screw designed to replace the root of a missing natural tooth. Titanium is perfectly biocompatible; it is the same material used for the construction of orthopedic prostheses. Dental implants are inserted into the bone where before there were natural teeth. Thanks to the biocompatibility of titanium, the dental implant integrates perfectly with the bone and becomes a good anchoring point for the replacement tooth (crown).

Implant rehabilitation is an innovative implantology technique that allows you to rehabilitate an entire dental arch without excessive trauma for the patient and ensuring comfort similar to that of natural teeth and certainly much higher than removable prostheses or dentures [2]. Implant rehabilitation is necessary when the patient has lost all his teeth and especially in the case in which he has used dentures for years, in fact, in these cases there is a loss of bone material due to the natural resorption process, in turn caused the lack of the root system of the tooth [2]. The lack of one or more teeth affects 240 million people in the industrialized world [3]. Metal-free prostheses now have a market share of 7-8%. The interpretation of this data is twofold, on the one hand it can be stated that about 93% of dental prostheses are still made with traditional materials and methods attributable to metal-ceramic crowns and bridges, on the other hand that the growth margins in market terms of metal-free prostheses is very high, especially when compared to a request of the same that comes from civil society, increasingly sensitive to aspects related to biocompatibility, aesthetics and functional and biomechanical performance of the prostheses at least superimposable to those made in metal-ceramic [4]. The new computer-guided technologies allow the dentist to carry out implantology interventions by exploiting, for the insertion of dental implants, the areas of the maxillary or mandibular bone in which there has been a greater preservation of bone material, or in any case a preservation sufficient to give the right anchor. Everything starts from the execution of a Computed Tomography or Cone Beam, it is a three-dimensional examination that, through a software, allows to virtually process an entire implant surgery and therefore to examine the real possibility of performing, without further interventions, an implant rehabilitation of the dental arch with the "All on Four" or "All on Six" technique. With this technology it is possible to identify points of the bone where it is possible to anchor the dental implants, four or six, on which to apply the prostheses, in fact, in some cases it is even enough to simply change the inclination of the pin to insert the implant. without further intervention. If, from the virtual processing, these measures are found to be insufficient to give the right anchorage to the dental implants, it is possible to proceed with tissue grafts, in this way implant rehabilitation is possible even in case of bone insufficiency [5-7]. The grafts can be performed with different types of materials, the choice depends on the will of the patient or on his clinical condition, it can be autologous material (taken from the same patient), heterologous or alloplastic [8,9]. Thanks to bioengineering, nowadays it has been possible to improve all the prosthetic components and increase the predictability of the rehabilitations. A useful tool put in place is Finite Element Analysis (FEM) [10,11].

Aim

Prosthetically guided surgery, referring to dental implants, is becoming routine in clinical dental practice. As briefly mentioned, this is concerned with planning the implant insertion according to a completely digital workflow, once the patient's radiographic examinations and digital oral scans have been obtained. The insertion of the dental implants, which will be carried out through a surgical guide, which will guide the surgeon during this phase to limit the margin of error as much as possible, has the purpose of inserting the dental implants in the planned position through the examinations. The aim of this method is to improve the position of the dental implants, in order to allow a correct prosthetic rehabilitation, limiting the angles of the prosthetic abutments and allowing less biomechanical stress. Obviously, this stress and the forces that are created are not calculated in the current clinical practice, and are limited to inserting the implants so that the latter have positions compatible with the chosen prosthetic rehabilitation. The purpose of this study is to guide the positioning of the implants, not only on the basis of what the prosthetic rehabilitation will be, but also on the basis of the patient's anatomical conditions, and on this general framework to carry out a finite element study that can predict the behavior of the implant fixtures and therefore improve their planning, with the ultimate aim of placing the implants in the best possible point, from an anatomical-prosthetic-biomechanical point of view, thus creating a digitally guided surgery.

MATERIALS AND METHODS

Prosthodontics and Dental Biomechanics

Dentistry is, among the medical disciplines, the one that is most affected, in its daily applications, by biomechanical problems in activities such as dental prosthetics, orthodontics and conservatives. Scientific progress in medicine and, therefore, also in dentistry, requires minimally invasive surgical techniques, high-tech and highly biocompatible dental prostheses, which use the least amount of material possible without reducing the quality of the products, and finally, predictability of the result over time in terms of both biomechanical and aesthetic performance [12]. The dental prosthesis should respond, on the one hand to a need for simplification in its design, construction and application, and on the other to the need for an overall reduction in both production costs and those, ultimately, destined and borne by the end user-patient [13,14].

Figure 1. Example of removable denture (CCBY 4.0)

Prosthetic dentistry is a medical discipline dedicated to restoring the patient's oral functions and aesthetic appearance, without surgery (Figure 1). The goal of prosthetics is to ensure the patient's well-being through functional solutions of undoubted aesthetic value. The lack of one or more teeth within the oral cavity leads to imbalances in chewing and anatomical alterations. Usually, a physiological factor known as tooth mobility means that the gap left by the loss of a tooth is filled in by neighboring teeth [15].

This phenomenon determines both a change in the physiognomy of the patient's face and potentially harmful malocclusions both for the teeth, which are more prone to trauma due to the chewing load, and at a postural and muscular level [16,17].

Dental prostheses are divided into 3 macro-groups:

- mobile dental prostheses;

- fixed dental prostheses;
- combined dental prostheses: they combine fixed elements to support mobile orthodontic structures.

Depending on the state of the oral cavity, mobile dental prostheses are anchored to the teeth (skeletonized with hooks or attachments, temporary nylon prostheses), or placed directly on the gums (total mobile prosthesis, overdentures on dental implants) [18,19]. Among the most used materials, we find zirconium. It is a material characterized by high resistance and a high aesthetic yield. Being translucent, zirconium is in fact able to return an effect very similar to that of natural teeth. This material also makes it possible to create high quality dental prostheses at affordable prices and to create metal free prostheses, as it replaces the metal base of metal ceramic prostheses. Ceramic is used for dental restorations that require a high aesthetic effect. Ceramic also offers high resistance and is therefore able to last over time. It can be used in metal-ceramic and zirconium-ceramic prostheses or as an all-ceramic. In the first case it is necessary to rely on a production technique that takes the name of laser melting. In particular, this procedure makes it possible to produce metal components with mechanical properties comparable to those that can be obtained with traditional processes [20]. In some cases, the metal is replaced with zirconium giving life to the ceramic zirconium prostheses. Integral ceramic, on the other hand, consists of a single layer entirely made of ceramic, so there are no metal parts or the presence of zirconium [21]. They were developed after those consisting of two layers. Their strong point is to give the tooth an appearance as close as possible to that of a natural tooth, and ceramic is an extremely biocompatible material. Since 2005, all-ceramic consisting of lithium disilicate-based glass-ceramic, has established itself on the market (Figure 2) [22].

Figure 2. Felspathic ceramic example (CCBY 4.0)

Resin, on the other hand, is a much cheaper material than zirconium and ceramic. Like the latter, in fact, it is able to return a high aesthetic effect, making teeth indistinguishable from natural ones. At the same time, however, it has a less effective resistance and more easily undergoes wear. It is therefore used more for temporary prostheses or for total prostheses such as the Toronto Bridge in order to obtain a lower cost compared to other materials [13,23-25].

The metals used in these products range from titanium to chromium-cobalt-molybdenum, up to the most common gold alloys of platinum, palladium and silver with a gold content ranging from 200 to 600 thousandths per gram. Ceramic materials are non-metallic inorganic materials. Metal-free ceramics can be divided into two large families characterized by the composition and peculiarities that define the different indications and operating procedures:

- feldspar, vitreous and lithium disilicate-based ceramics (traditional silicate-based ceramic materials)
- high strength ceramics (advanced neo ceramics): pure oxides, nitrides, carbides, silcides.

Feldspathic ceramics have a low flexural strength between 50 and 80 MPa (Megapascal), leucite-based vitreous up to 120 MPa, lithium disilicate-based ones up to 400 MPa resistance. These ceramics, still widely used in dentistry today, due to their aesthetic characteristics of translucency, have limited applications in bridge and crown structures due to their low resistance in relation to the stresses to which they must be subjected in occlusal and masticatory functions. But it is the use of high-strength ceramics that has led to a breakthrough in dental prosthesis applications: These are alumina which has a flexural strength of about 600 MPa and zirconia (zirconium dioxide; zirconium is a metal) which has a flexural strength of approximately 1200 MPa. Zirconia is the one that has the best biomechanical characteristics to be used in crowns and bridges both of the anterior (incisors and canines) and posterior (premolars and molars) sectors. The zirconia most frequently used in dentistry is that toughened with yttrium oxide (Y-TZP) but zirconia toughened with Magnesium oxide (Mg-PSZ) and alumina toughened with zirconia (ZTA) are also used. Full ceramics are also used as veneers for anterior teeth, or as aesthetic coatings that integrate and / or replace tooth enamel with a minimally invasive technique to correct aesthetic defects due to discoloration and shape or position anomalies. Both alumina and zirconia are oxides. Zirconia is a zirconium dioxide and is, in dental applications, toughened with yttrium (YZTP) which improves its dimensional stability [26-28].

Bioengineering in Dentistry

Contributions of technology have been decisive, just think of the biomaterials that are used in dental surgery of all levels: from cements to photopolymerizable resins, to the materials used for the construction of the implants and the surface treatments to which they are subjected. However, many of these technologies have not been developed specifically for the dental sector, but have been "inherited" from other medical disciplines such as orthopedics and neurosurgery. Speaking of dedicated contributions in the strict sense, on the other hand, instrumental dental diagnostics has been particularly favored by the introduction of the cone beam acquisition technology, which, with a reduced dose of rays compared to traditional tomographic acquisition, returns to the clinician diagnostic images of high quality on which to develop a complete treatment plan. Diagnosis and therapy make up the two parts of the patient's treatment plan and technologies have focused on developing both. The diagnostic process is probably the one that has undergone the most evolutions over the years, given that the entire therapeutic and rehabilitative path of the patient depends on the decisions taken by the cynic in this phase. Today it is possible to use equipment in the studio that until a few years ago were not very accessible; cone beam technology has emerged both in the form of large-field analysis machines, such as the complete skull, and incorporated into “multi-function” digital panoramas, supporting the clinician's decisions in an exhaustive and often three-dimensional way. The information acquired with these technologies can be interpreted with very high-precision diagnostic software that allows you to perfectly reconstruct the subject's anatomy and simulate the surgery on the virtual model [6,29,30]. This planning can be translated into the real therapeutic plan thanks to the possibility of working in guided surgery, or transferring the virtual project into a surgical guide customized to the needs of the clinician and patient, and to prepare in advance a temporary prosthesis to be fitted in the post-surgery phase. in case it is possible to carry out an immediate load. All this is also supported by the CAD-CAM technologies provided in modern dental laboratories, whose art is combined with the use of increasingly sophisticated materials and machines [10,31,32].

Digital Workflow in Dentistry

Thanks to the evolution of information technology and the application of bioengineering to dentistry, it is now possible to proceed with rehabilitations, diagnoses, treatment plans and definitive manufactures directly with a completely digital workflow (Figure 3). Obviously this thanks to the acquisition of three-dimensional radiographic images and intraoral scans, which if coupled allow us to have a reliable reconstruction of our patients. Some software developed in recent years allow us to complete this digital workflow, such as Digital Smile Design (DSD). DSD allows for a complete planning of the treatment; the programmed results and those obtained after the surgery are comparable. The increase in the clinical crown is an intervention that must always be appropriately planned. Patients accept better oral surgical techniques if techniques such as DSD are used [33].

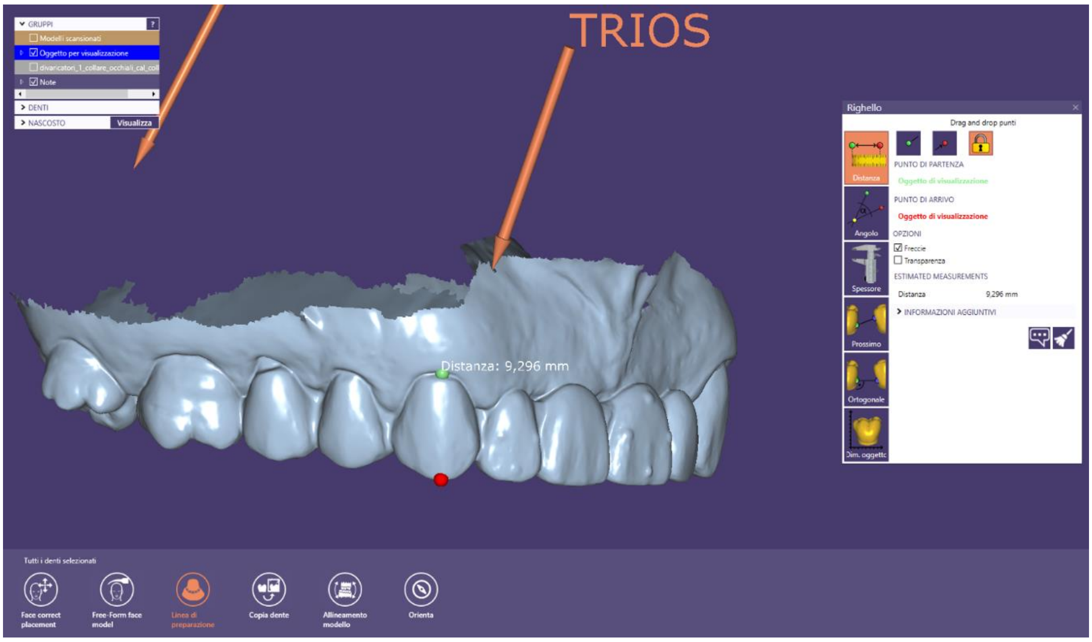

Figure 3. Intraoral Scan and example of measurement (CCBY 4.0)

Finite Element Analysis

The use of finite element analysis (FEA) in oral implantology helps understand the characteristics of the individual implant-prosthetic components, their physical and chemical properties and the optimal environmental conditions because they offer the best performance. The FEM is a numerical technique designed to seek approximate solutions of problems described by partial differential equations by reducing the latter to a system of algebraic equations. Although it competes in some limited areas with other numerical strategies (finite difference method, finite volume method, boundary element method, cell method, spectral method, etc.), FEM maintains a dominant position in the panorama of numerical techniques. approximation and is the kernel of most of the automatic analysis codes available on the market. In general, the finite element method lends itself very well to solving partial differential equations when the domain has a complex shape (such as the chassis of a car or the engine of an airplane), when the domain is variable (for example a reaction solid state with variable boundary conditions), when the required accuracy of the solution is not homogeneous on the domain (in a crash test on a car, the required accuracy is greater near the impact zone) and when the sought solution is missing of regularity [10].

The FEM has its origins in the need to solve complex elastic and structural analysis problems in the field of civil and aeronautical engineering. The origins of the method can be traced back to the years 1930-35 with the works of A. R. Collar and W. J. Duncan, who introduced a primitive form of structural element in the resolution of an aeroelasticity problem, and to the years 1940-41 with works by Alexander Hrennikoff and Richard Courant, where both, although in different approaches, shared the idea of dividing the domain of the problem into subdomains of simple form (the finite elements). However, the actual birth and development of the finite element method took place in the second half of the 1950s with the fundamental contribution of M. J. Turner of Boeing, who formulated and perfected the Direct Stiffness Method, the first approach to elements. ended up in the field of continuity. Turner's work found diffusion outside the narrow fields of aerospace engineering, and in particular in civil engineering, through the work of John Argyris at the University of Stuttgart (who in the same years had proposed a formal unification of the method of forces and of the displacement method by systematizing the concept of assembling the relations of a structural system starting from the relations of the component elements), and by Clough at the University of Berkeley (who first spoke of FEM and whose collaboration with Turner he had given birth to the famous work, considered as the beginning of the modern FEM). Other fundamental contributions to the history of FEM are those of B. M. Irons, to whom are due the isoparametric elements, the concept of shape function, the patch test and the frontal solver (an algorithm for solving the linear algebraic system), by R. J. Melosh, who framed the FEM in the class of Rayleigh-Ritz methods and systematized its variational formulation (a rigorous and famous exposition of the mathematical basis of the method was also provided in 1973 by Strang and Fix) and by E. L.Wilson, who developed the first (and largely imitated) open source FEM software that gave birth to SAP. In 1967 Zienkiewicz published the first book on finite elements. Since the 1970s, FEM has found widespread use as a numerical modeling strategy for physical systems in a wide variety of engineering disciplines, for example electromagnetism, fluid dynamics, structural calculus and geotechnics. Over the years most of the commercial FEM analysis codes were born (NASTRAN®, ADINA®, ANSYS®, ABAQUS®, SAMCEF®, MESHPARTS®, etc.) still available today [34].

The FEM it is applied to physical bodies which can be subdivided into a certain number, even very large, of elements of defined shape and small size. In the continuum, each single finite element is considered a numerical integration field of homogeneous characteristics. The main feature of the finite element method is the discretization through the creation of a grid (mesh) composed of primitives (finite elements) of coded form (triangles and quadrilaterals for 2D domains, tetrahedra and hexahedron for 3D domains). On each element characterized by this elementary form, the solution of the problem is assumed to be expressed by the linear combination of functions called basic functions or shape functions. It should be noted that sometimes the function is approximated, and the exact values of the function will not necessarily be those calculated in the points, but the values that will provide the least error on the whole solution. The typical example is that which refers to polynomial functions, so that the overall solution of the problem is approximated with a polynomial function in pieces. The number of coefficients that identifies the solution on each element is therefore linked to the degree of the chosen polynomial. This, in turn, governs the accuracy of the numerical solution found. In its original form, and still more widespread, the finite element method is used to solve problems based on linear constitutive laws. Stress problems are typical - deformations in the elastic range, the diffusion of heat inside a material body. Some more refined solutions allow to explore the behavior of materials even in a highly non-linear field, hypothesizing plastic or visco-plastic behaviors. In addition, coupled problems are sometimes considered, within which various complementary aspects can be solved simultaneously, each attributable on its own to an FEM separate. Typical in this sense is the geotechnical problem of the behavior of a given soil (geomechanical field) in the presence of groundwater filtration motions (hydrogeological field). To arrive at the model at the final elements, we follow the fundamental steps, each of which involves the insertion of errors in the final solution:

- Modeling: this phase is present in all engineering type studies: we move from the physical system to a mathematical model, which abstracts some aspects of interest from the physical system, focusing attention on a few aggregate variables of interest and "filtering" the remaining ones. For example, when calculating the bending moment of a beam, interactions at the molecular level are not taken into account. The physical system if complex is divided into subsystems. In the case in question, it is not necessary, or it can be assumed that it is a part belonging to a more complex system, for example a ship or an airplane. The subsystem will then be divided into finite elements to which a mathematical model will be applied. Unlike the analytical treatments, it is sufficient that the chosen mathematical model is suitable for the simple geometries of the finite elements. The choice of an element type in a software program is equivalent to an implicit choice of the mathematical model underlying it. The error that can lead to the use of a model must be evaluated with experimental tests, an operation that is generally expensive in terms of time and resources.

- Discretization: in a numerical simulation it is necessary to pass from an infinite number of degrees of freedom (condition proper to the "continuum") to a finite number (situation proper to the grid). The discretization, in space or time, aims to obtain a discrete model characterized by a finite number of degrees of freedom. An error is inserted given by the discrepancy with the exact solution of the mathematical model. This error can be appropriately evaluated if there is a mathematical model suitable for the entire structure (therefore preferable to use with respect to FEM analysis) and in the absence of numerical calculation errors, this can be considered true using electronic calculators.

The definition of the geometry of the model that idealizes the real structure is carried out by placing nodes, or nodal points, on the structure in correspondence with characteristic points. When positioning the nodes on the structure, some considerations must be taken into account:

- the number of nodes must be sufficient to describe the geometry of the structure. For example, in correspondence with the beam-pillar connection, changes in direction, etc.
- the nodes must also be positioned at the points and on the breaklines. For example, where the characteristics of the materials, the characteristics of the sections, etc. change.
- nodes can be placed in points not necessary for the geometric definition of the structure but whose displacements and internal stresses are to be known
- if the software does not foresee it, nodes must be positioned at points where concentrated loads or nodal masses are applied

- nodes must be placed in all the points to be constrained
- in the case of two-dimensional structures (plates, slabs, etc.) the subdivision (mesh) in two-dimensional finite elements must be sufficiently dense to capture the variations in stress or displacement in the regions important for the analysis [35,36].

In the physiology of the stomatognathic apparatus there are maximum occlusal forces ranging on average from 155 N of the incisors to 208 N of the canines up to 288 N of the premolars and 565N of the molars. In particular conditions of occlusal stress, the molars can exert maximum occlusal forces of up to 800N. Otherwise the maximum masticatory forces vary between 70N and 150N. On the other hand, the forces acting on the dental restorations in a patient with a fixed bridge who replaces a molar in an emiracate, with the other hemi-arch intact, are on average around 240 N in the hemi arch where the bridge is present and about 300N in the intact hemiarcata.

These considerations on the maximum occlusal forces and on the masticatory forces must be taken into great consideration when we are going to evaluate the possible load stress of a prosthetic structure subjected to biomechanical stress in its occlusal physiological function [35,37,38].

Finite Element Analysis and Dental Implants

The total prosthesis on implants today represents a first-choice option, especially in cases of more or less elderly in which there is a need to anchor the lower classic denture patients, always more difficult to stabilize than the upper prosthesis. It is important to remember that an osteointegrated implant, although it gives good retention and support to our prosthetic, differs significantly from the natural tooth. The most important difference from the bio- mechanical point of view is the absence of the periodontal ligament (PDL), which in the natural tooth performs the amortization functions of occlusal loads, the proprioceptive sensitivity and promotes bone regeneration activities. Under load, the complex movements of a natural tooth, first involving the PDL and subsequently the alveolar bone. In an osteointegrated dental implant, for the absence cushioning action of the PDL, it has a linear model of the deflection force that depends exclusively on the elastic deformation of the alveolar bone [39].

For these reasons, excessive masticatory loads, which are often not perceived as such by the patient because of the lack of the PDL, may lead to implant loss. Among the different types of forces that make the occlusal load the most dangerous are those that are discharged in the transverse direction, that is, those forces which act in the transverse direction or if the point of application of these away from the axis of the implant, since this will tend to rotate or flex. These forces are less favorable and more harmful than those axial compression [39].

The main difficulty in simulating the biomechanical behavior compensatory bone-implant-prosthesis than the tensile forces lie in the modeling of the maxilla and mandible of man and their reaction to the load. To perform this analysis usually these parameters are used: Young's modulus (Exx, Eyy, Ezz), Poisson's ratio (νxx, νyy, νzz), tangential modulus (Gxx, Gyy, Gzz) and density (ρ) have been considered [21,40-42]. The bone tissues (cortical and cancellous), were considered as orthotropic (Table 1).

Table 1. Material properties accordingly to the literature [1–4].

Properties	**Cortical Bone**	**Cancellous Bone**
ρ [g/cm^3]	1.8	1.2

E_{xx} [GPa]	9.6	0.144
E_{yy} [GPa]	9.6	0.099
E_{zz} [GPa]	17.8	0.344
ν_{xx}	0.55	0.23
ν_{yy}	0.30	0.11
ν_{zz}	0.30	0.13
G_{xx} [GPa]	3.10	0.053
G_{yy} [GPa]	3.51	0.063
G_{zz} [GPa]	3.51	0.045

Von Mises

The criterion of maximum distortion (in the technical field commonly called von Mises criterion, even if the root is uncertain) is a resistance criterion relative to ductile materials (it is therefore a yield criterion), isotropic, with equal tensile and compressive strength. In the three-dimensional space of the principal stresses, this domain corresponds to a cylinder with a circular section with an axis placed in the trisector of the positive octant. This cylinder circumscribes the straight prism with a hexagonal base associated with the criterion of maximum tangential stress. The von Mises criterion assumes that the yield strength of the material is reached when the distortion energy reaches a limit value, where the distortion is the component of the deformation that causes a change in the shape, but not in the volume, of a volume element. The criterion can originally be attributed to Maxwell (1856), who proposed it on the basis of purely mathematical-formal considerations. In a more strictly mechanical context, the criterion was subsequently proposed by Richard von Mises (1913) and, almost independently and on the basis of different considerations, also by Huber (1904) and Hencky (1924) [43].

Fracture Mechanics Analysis

Bone has a hierarchical structure consisting of collagen, water and minerals. The arrangement of these components in different functional units creates a light and resistant structure, multifunctional and able to adapt to different mechanical environments. To understand the influence of bone quality, characterized by bone material composition and structural design, on its mechanical properties, it is necessary to study how bone resists fracture at different length scales. As a living tissue, bone has a unique ability to repair itself through growth and remodeling processes, which give it a dynamic structure. The remodeling process allows the bone structure to adapt to external changes. This continuous process also removes damaged bone tissue and replaces it with new bone material. However, excessive remodeling of microdamage induced by aging and bone disease degrades bone quality and increases the possibility of fracture. Therefore, to better understand fracture phenomena in bone, it is necessary to improve our understanding of changes in structure and composition related to aging, which, in turn, affect the mechanical properties of bone. At the microstructural level, the main structural features that control cortical bone fracture toughness include osteons, cement lines, and extended discontinuities such as Haversian canals. Such discontinuities could turn out to be sites of stress concentration for the initiation of cracks. Finally, at the microscale and beyond, bone microstructures and material properties vary with age, which significantly affects bone toughness at the macroscale [44].

Most FEM analyzes of bone deformation and nanoscale failure used a two-dimensional representation of the staggered arrangement of mineral platelets in a collagen matrix. For example, Raeisi Najafi et al. [45] investigated the growth trajectory of cracks in cortical bone using an FEM model. Their results show that a trajectory of microcracks deviates from the osteon (Figure 4).

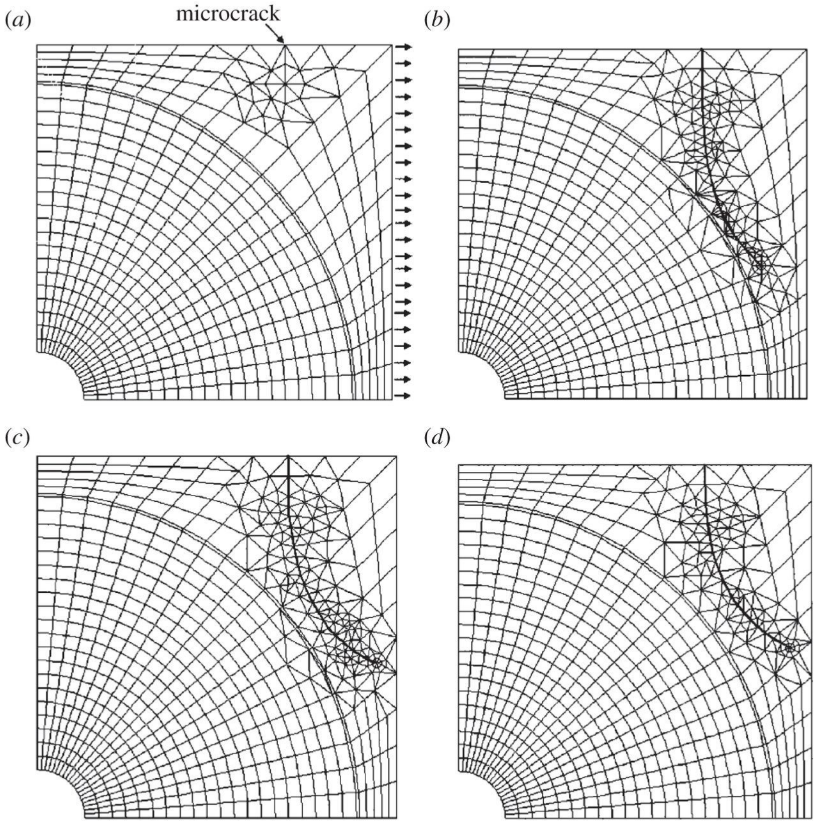

Figure 4. Bone cracks trajectory simulation. All rights reserved [44].

Some studies have used a cohesive FEM technique to model the bone fracture on the microscale. Ural and collaborators used this modeling technique [46] in an idealized two-dimensional model of a single osteon, surrounded by a cement line and an interstitial bone (Figure 5), and investigated the mechanisms influencing possible crack deflection and penetration. near the concrete lines. Subsequently, they expanded their study to a multiosteonic model based on microscopic images of cross-sections of human cortical bone 2 [47].

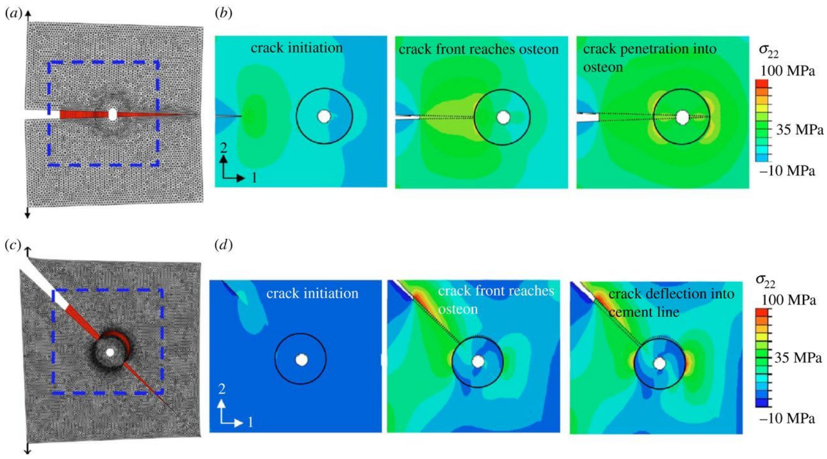

Figure 5. Cohesive FEM model for single osteon. All rights reserved [44].

The extended finite element method (XFEM) was also used to study the growth path of the fissure in a haversian cortical bone. In this way, it is possible to model the growth of multiple cracks in human cortical bone under tension to create a constitutive law at the macroscopic level and to study the influence of microstructure morphology on bone failure. A two-dimensional fracture model was developed for osteonal bovine cortical bone taking into account its microstructure (Figure 6). The topology of the bone microstructure was obtained using an optical microscope and the mechanical properties of the microstructural features were measured by a nanoindentation method. It confirmed a significant role of the bone microstructure in the crack propagation path.

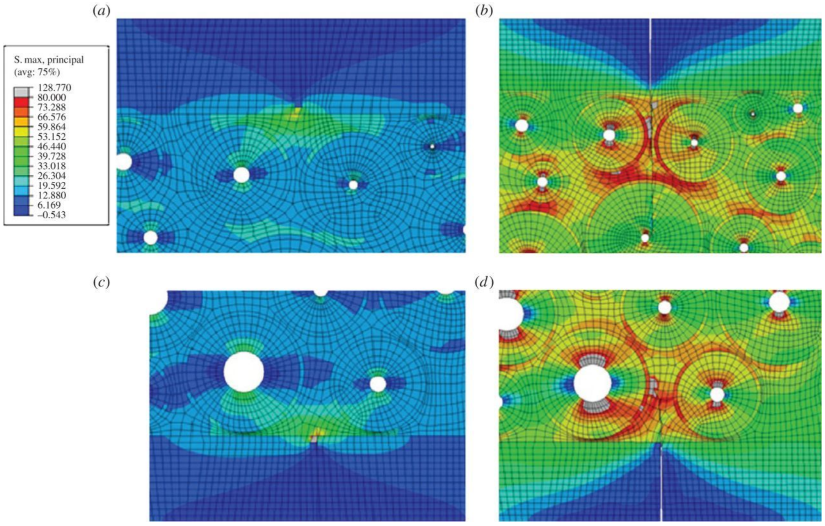

Figure 6. Model for stress distribution and microcracks analysis. All rights reserved [44].

Dental implants

The implant-prosthetic components need to respond to a series of requirements which are:

• Reliability, in terms of optimal biological response by the tissues, sustainable healing times and adequate connection between the various elements (given the presence of a series of interconnected devices such as the intraosseous component that simulates the root of the dental elements, the supra-bone component that simulates the prosthetic posts as we know them for conventional fixed prosthetic preparations and a component that simulates the morphology of the dental elements).

• Simplicity, which is a very important factor because the evolution goes towards the optimization of the shapes and everything related to the possibility of replacing missing elements with dental implants, but this must take place with a whole series of procedures and reduced steps in time-consuming, procedures that are easy to learn and with little surgical instrumentation.

• Versatility, that is the characteristic of being able to use implant devices indifferently for several areas of the mouth, as a connection method that can work well in many cases.

• Patient needs, understood as chief complaint.

• Clinical case, because choices cannot be standardized but

but aimed at the individual patient.

• Experience of the operator.

In front of the patient who is visited for the first time, who is edentulous and who requires the replacement of dental elements that are missing, first of all it is important to understand what the subject's need is, because it does not always represent our common thread and sometimes the request turns out to be impractical; then it will be necessary to take into consideration other aspects, including a more careful study of the clinical case and the preparation of a treatment plan in which the prosthetic aspect plays a predominant role, because in the end dental implants do not represent the ultimate goal but one tool to reach the goal, and in all this the operator's experience plays a very important role.

Speaking of implant-prosthetic techniques, we will have to consider a series of fundamental parts including: the fixture (intraosseous component), accessories (to insert dental implants) and prosthetic components (supraosseous) (Figure 7) [48,49].

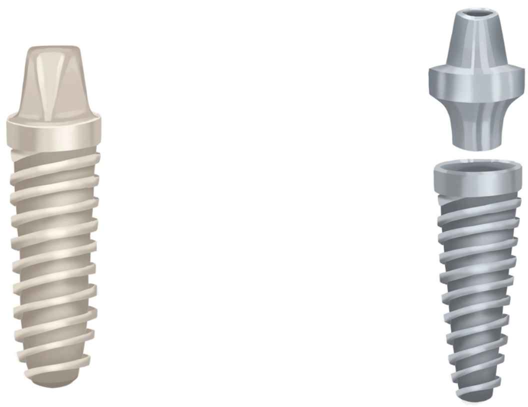

Figure 7. Monophasic and bi-phasic dental implant examples. For gentle concession of AuthorityDental CC 2.0.

The term " fixture " is the Anglo-Saxon synonym for dental implant. This component is now formed by a cervical part called the neck, a central part formed by coils that give greater primary mechanical stability called the body and an apical part called the tip. Trivially it could be assimilated to a vine, but it is to this vine that we entrust an important function and consequently the components that make it up are extremely relevant. The other aspect that is asked of the clinician, case by case, and this is not only related to the patient's request, but related to the analysis and implementation of the treatment plan, is to try to identify a series of conditions relating to both prosthetic and anatomical areas, relating to the diameter and length of the implant, suitable for the replacement of the specific dental element. This means that in terms of diameter the choice may vary depending on whether dental elements of the anterior sector, elements such as canine or premolar, or molars are to be replaced [50,51].

This involves the possibility of inserting implants with a standard diameter between 3.75 and 4.5 mm for many dental elements, such as central incisors, canines, molars, but there is also the morphological indication to use smaller diameter implants in case of dental elements that have mesio-distal width and reduced profile emergencies, such as the upper lateral incisors and the lower incisors. As for the length of the implants, over the years there has been a great revaluation in the literature. The starting point was the use of dental implants of adequate length (for example, for the rehabilitation of total mandibular edentulousness, in the interforaminal area, implants with a length never less than 12-14 mm were used). There were many reasons for this choice: first of all, the initial phase of implantology did not allow to go further, the implants were also smooth and untreated on the surface, so the possibility of developing secondary stability was not so important. In these cases, having rather consistent implants regarding the vertical dimension could represent a considerable advantage. The other aspect that has been taken into consideration over the years has been to try to identify rules coming from conventional dental prostheses [52,53].

The choice of the fixture also depends on the surgical technique performed and on the different integration modalities to be obtained on the hard and soft tissues. We therefore recognize transumucous implants that have a smooth neck that is positioned above the bone margin and on which the soft tissues rest, submerged implants that are positioned at the level of the bone margin and closed by the cap screw or surgical closure screw and covered with surgical flaps, intermediate implants that have the possibility of being positioned at the bone level but which are not submerged with the insertion of cap screws but rather closed with healing screws that protrude with respect to the soft tissues and which allow, even in this case, soft tissue integration directly in the osseointegration phase. The clinician can choose whether to use a transumucous, submerged or semisubmerged implant insertion protocol based, for example, on the management of soft tissues: since in the event that this parameter is not strictly relevant, as in the posterior region, a transgingival implant will be preferred , while if this is also essential from an aesthetic point of view, as in the frontal sectors, the endosseous implant will allow the management of the soft tissues in a more gradual way. However, the choice of a submerged implant over a transmucous one may be dictated by other factors, such as situations of poor primary stability of the implant (as happens in D4 bone that is particularly poor from a qualitative and / or quantitative point of view, with 'goal of absolutely avoiding any movement of the implant during the first delicate phases of osseointegration), situations in which, simultaneously with the insertion of the implant, it is necessary to proceed with bone regeneration (therefore it is imperative that there is no bacterial contamination of the materials used for regeneration), situations in which you want to be sure that the implant positioned in the post-extraction site does not risk bacterial contamination (therefore you can resort to immediate post-extraction implants), situations in which an undamaged gum above the implant at the time of reopening to increase bone shape and volume, or situations in which the patient has risk factors that increase the possibility of failure to osseointegrate the implant [54].

This diversity present on the market will entail the possibility of carrying out different surgical procedures; for example, transmucosal implants require only one surgical time because they are structured in such a way that the emergence of the implant head is already determined in the first healing phase and therefore do not need a second surgical time, which instead must be performed if you opt for implants placed at the bone level (because if you cover and suture everything, you will necessarily have to re-open to replace the cover screw with a healing screw or abutment). Another aspect that allows us to classify the fixtures is the shape. One shape we got used to in the first part of modern implantology was the cylindrical or conical shape with thread. The trend in recent years seems to go more towards the conical shape, but there are also implants with a hybrid morphology, for which the first portion following the neck is cylindrical and then the subsequent portion is conical. The intraosseous component, which can be totally submerged or trans-mucosal and which represents the real body of the fixture, must then be connected to an overlying prosthetic device which represents the actual structure and which connects the dental prosthesis with the intraosseous portion [55-57].

The connection of the fixture to the prosthetic components takes place according to two systems:

- External connection
- Internal connection

This means that on the head of the implant neck there can be a threading system and anti-rotational device that can protrude (and then we will be facing an external connection), or that it can be inside the body of the implant (and then we will have an internal connection). The general trend in recent years is to use internally connected implants, because apparently if a vacuum is created inside the implant in some way, it weakens it, but at the same time the ease of use of the prosthetic components increases. The external hexagon was the first connection system used in implantology and was born with Brånemark at the beginning only as a coupling mechanism with a guide function to facilitate the insertion of the abutment, then it expanded its functions to become a true and its own anti-rotational mechanism. In the literature there are several studies that document the incidence of technical complications affecting implants equipped with the external hexagon connection system with percentages ranging from 6 to 45%. In fact, in a 3-year follow-up on 69 implants with an external hex connection, Jemt noticed that, only in the first year of loading, in 31 cases it was necessary to retighten the abutment connection screw. However, the problem recurred also in the following two years and precisely in the second year in 27 cases and in the third in 21. According to a study, the percentage of screw loosening amounts to 27% in fixed prostheses. However, the importance of perfect adaptation between the implant and the abutment hexagon should also not be forgotten. According to a study, in fact, when the erosion of the fixing force reaches a threshold level, the abutment rotates counterclockwise. To try to overcome the biomechanical complications, such as loosening of the connection screw or the fracture of the abutment or of the connecting screw, the manufacturers of implants with external hexagon connection, and not only, have introduced the use of torque wrenches that gave the screw a calculated torque. This measure, however, has not completely eliminated the problem while causing a reduction in its incidence. The loads applied on the interfaces between the various implant components then lead to the occurrence of various discrepancies at the level of the same, greatly reducing the adaptation and accuracy of the connection. Among the internal connections, the most used are the connections with internal hexagon, internal octagon, screw cones or Morse cone (an 8 ° cone and an octagon for the repositioning of the prosthetic components). The internal connections immediately demonstrated greater mechanical stability and better stability than the external ones. It can also be said that the internal connections have been shown to better resist the prolonged application of lateral forces [57].

The internal portion of the implant has a thread that allows the screwing of the connecting and connecting screw and anti-rotational systems that will allow the prosthetic implant posts or abutments to represent the second level of implant-prosthetic rehabilitation.

The anti-rotational systems are used to ensure that the mechanical connection between the fixture and the prosthetic abutment remains stable despite the masticatory stresses and for this to happen every house creates a connection method that is usually the result of a proprietary patent and that differentiates a fixture from another. This is also the reason for the screws that have an internal connection with an internal thread with an anti-rotational system that has a hexagonal shape, for example.

The quality of the systems is the result of a series of industrial precision procedures and this is a characteristic of it, because the realization of the anti-rotational system is the result of an extremely refined milling work, given that the risk is to create anti-rotational systems. -rotational in which the corners are not milled in a perfect way, for which they occur with angular openings greater or less than they should be, an event that involves the connection with the overlying prosthetic system will not be precise [58,59].

The effect may be that a stable condition does not arise between the fixture and the overlying prosthetic abutment, especially where we have significant chewing loads. The connection systems that allow the engagement between the two parts carried out by means of a screw must not allow rotation (this is possible with the use of polygonal connections) and must be perfect engagements, without twisting movements at the vertices of the polygons (for example the double internal octagon is very stable and versatile but presents more complications due to the presence of many vertices and the possibility of movement of 30 ° by 30 °, or there are conical connections that fit together with conical pyramids, responding as well as to the criterion of the `` morse taper '' which physically allows the two mechanical pieces to be locked due to the presence of a sliding friction) [58].

The neck of the implants can be:

• Transgingival: in this type of implant the turning process is extremely important, in fact only if well controlled will the necks be produced which are properly smoothed, in order to avoid the adhesion of the bacterial biofilm;

• Submerged implants: these implants do not have a particularly consistent smooth neck because their upper margin must be placed at the level of the bone margin. There are also dental implants that have a zirconium neck positioned in the most cervical part of the implant, but also implants completely made with this material. The problem with totally zirconium implants is that it is a monoblock (implant-abutment), where the abutment will therefore have a fixed, non-variable morphology. The coils are characterized by a pitch, that is the distance between two adjacent coils measured parallel to its axis; the smaller the pitch, the greater the number of turns on the implant body per unit of length and therefore the greater the functional surface per unit of length of the implant body. The pitch of the coils is therefore very important, especially in solutions with immediate load, because in this case the aggressiveness of the coils leads to the development of greater primary stability and determines a reduction in the micro-movement, which must be avoided in the first weeks in which the prosthesis is applied, since there is a loss of primary stability and still the secondary stability is not well defined, therefore the aggressiveness of the coils gives more support from the mechanical point of view. The shapes of the coils are another very important feature. The shapes of the threads of dental implants are mainly: standard V-threads, spur-shaped threads and square threads. These shapes determine a different distribution of loads [60-62].

In the original implant model introduced by Brånemark in 1965, the design of the implant was characterized by coils having a V-thread. The original design has been modified in recent years to allow for a better distribution of loads [63].

There are also implants without coils on the market, which have a surface roughness, obtained by depositing titanium. Furthermore, there are implants with a more aggressive cutting profile in the most apical part while more stabilizing in the body and cervical portion, so when they are inserted, they create a thread in the bone, because the threads are much sharper on the edge of the apical portion (progressive cutting profile). There are also systems with escape routes, or vertical grooves that serve to avoid too much blood compression on the bone walls during the insertion of the fixture [64].

The implants are made of titanium alloys, classified according to an ASTM (American Society for Testing Materials) subdivision from Grade 1 to Grade 5 alloys. This classification is based on the amount of titanium and oxygen, as well as on the presence of metals suitable for surgical use or prosthetic use. For example, grade 5 alloys contain a component of other materials besides titanium, such as to make them more consistent from the biomechanical point of view and therefore more suitable for use in the prosthetic field, or for supra-bone components; Grade 1 titanium alloys, on the other hand, are usually used for surgical use, or for the creation of fixtures, since they favor osseointegration [65].

There are many mechanisms that make an implant rough, but they can be divided into two main techniques:

• Subtractive technique: for example, chemical substances can be used as in etching, which can corrode the surface and make it rough;

• Additive technique: for example, " titanium plasma spray " can be used, i.e. titanium made liquid by temperature, sprayed at high pressure on the surface and the droplets, solidifying, make the surface rough [65].

Bone anatomy and physiology

In order to correctly implement an implant-prosthetic treatment plan it is essential to classify the degree of bone resorption of the jaws because this will determine both quantitative (volumetric) and qualitative (structural and density) alterations.

Over the years, several authors have tried to classify bone remodeling at the level of the maxillary bones but the one most recognized by the scientific literature is the classification developed by Cawood and Howell in 1988 [66].

The two authors examined all the classifications present at that time and, evaluating them as incomplete, decided to use a sample of 300 human skulls and first measured the changes in shape of the mandible and upper jaw and subsequently classified these structural changes.

Once all the data had been collected, they ascertained that the basal bone did not undergo significant changes, as opposed to what happened to the alveolar process.

They classified and distinguished six classes of bone atrophy of the jaw bones:

- Class 1) The dental elements are present, so there is no reabsorption;
- Class 2) The alveolar ridge presents post-extraction alveoli;
- Class 3) The alveolar ridge has undergone the slight resorption but it is well
- rounded, adequate in height and thickness;
- Class 4) The alveolar ridge has a sufficient height but insufficient thickness, in fact it is defined as " knife blade " due to its peculiar morphology;
- Class 5) The alveolar ridge is flattened, with a resorption that has generated insufficient height and thickness;
- Class 6) Applies only to the mandible, in which the alveolar ridge has a strong bone depression and a slight loss of basal bone (Figure 8) [66].

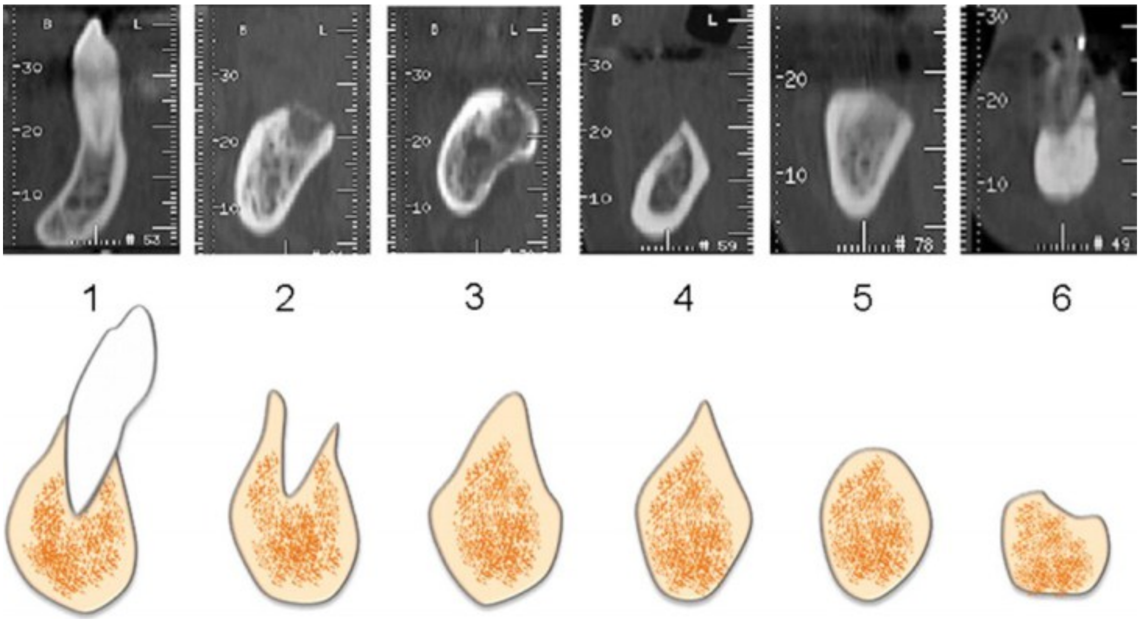

Figure 8. Cawood and Howell [66] classification. From implantalogi.it, all rights reserved.

Oral surgery, guided surgery and dental implant surgery

The positioning of an implant fixture within the bone structure must be considered as a damage to the integrity of the organism. Around a plant there is always an empty, micrometric space in which complex biological phenomena occur. An ischemia of the tissues with necrobiosis occurs immediately on the bone side. The increase in vascular permeability in the surgery area determines the pouring of undifferentiated mesenchymal cells to fill the gap between the bone surface and the implant (cell and vascular migration and colonization). After the first four days, cell differentiations and the organization of the peri-prosthetic tissue occur to allow the removal of cellular and bone debris in necrosis operated by macrophages to begin the reparative phase.

New bone formation follows all the stages that characterize direct ossification: arrival of osteoblasts, deposition of osteoid tissue, formation of immature bone with intertwined fibers.

Around the sixth week, the primitive bone is progressively reabsorbed and replaced by mature lamellar bone; this process then leads to the formation of bone around the inserted implant.

Implant surgery is a branch of oral surgery, entrusted to the latter professional figure who aims at the positioning of one or more implant fixtures for prosthetic, rehabilitative or orthodontic purposes.

The insertion of the fixture can take place at different times:

1) A surgical period, as is the case for transmucosal where, after osseointegration, the gum will not have to be re-incised to see the position of the implant;

2) Two surgical stages, as is the case for fully submerged in which, after osseointegration, the gum will have to be re-incised to see where the implant is and allow it to be connected to the suprabony prosthetic devices.

Alongside these two canonical methods, there are others linked above all to the timing of implant insertion with respect to the extraction of the dental element that will be replaced:

1. Immediate post-extraction implants, in which the implant is inserted immediately after the extraction;
2. Deferred post-extraction implants, in which the insertion of the implant takes place a few weeks after dental extraction, when healing of the molal tissues has occurred;
3. Delayed post-extraction implants, in which the insertion of the implant takes place after 12-16 weeks of dental extraction;
4. Late post-extraction implants, in which the implant is inserted 3-4 months after extraction.

The positioning of the implant fixture is a surgical intervention that should take place in sterile conditions. After having carried out an antiseptic wash to the area affected by surgery and the peri-oral area, we proceed to the loco-regional anesthesia phase of the affected area. Manual implant surgery subsequently provides for the surgical incision and the preparation of a full-thickness mucoperiosteal flap with an incision that varies according to the district, the number of implants to be placed. After the exposure of the cortical bone, if the bone surface is regular, a first drilling with a pilot drill is carried out according to previous planning, using a previously planned inclination and depth. Subsequently, the caliber of the implant preparation is increased using drills with a gradually larger diameter until the one corresponding to the implant to be placed is reached, depending on the surgical kit of drills used. At this point it will be possible to proceed with the positioning of the implant fixture, which only now must be removed from its sterile packaging, and in the shortest possible time (to limit the risk of contamination) must be positioned on the site of the implant preparation, or with a manual instrument. or rotating mechanical. At this point, proceed with the screwing of the latter until the desired position is reached according to the maximum torque recommended by the implant house. Once the mounting device has been removed, where present, the cap screw will be positioned, then the surgical flap will be repositioned, and a suture will follow, respecting the general principles of oral surgery in the management of the flaps. After osseointegration, in the two-step techniques, with biphasic implants, it will be possible to proceed to a new extension of the flap, even reduced, and to the positioning of the healing abutment. Once the soft tissues have matured, the impression can then be taken via analog transfer or scan body for digital impression, then the prosthetic phase begins (Figure 9).

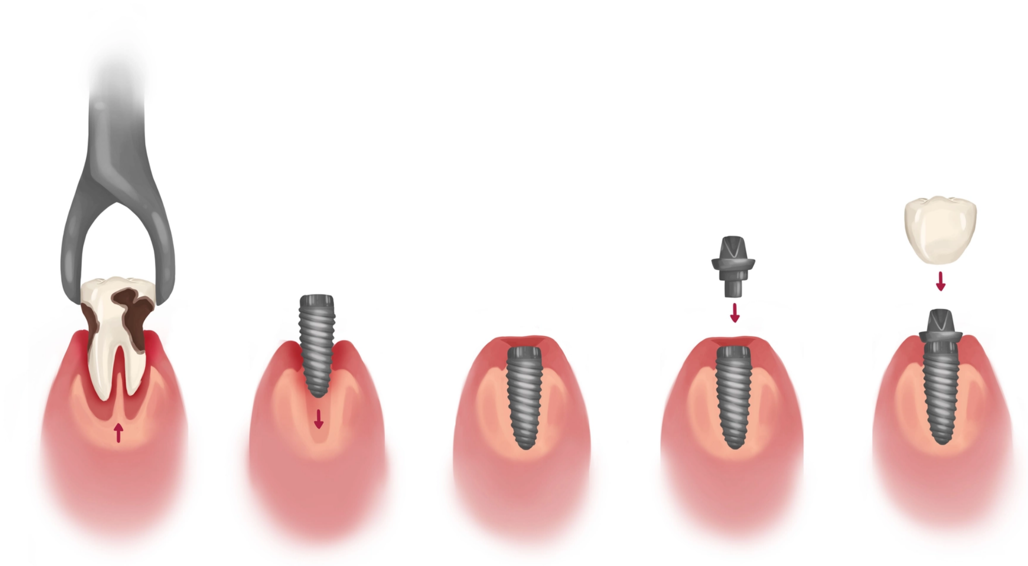

Figure 9. Dental implant surgery phases. For gentle concession of AuthorityDental CC 2.0.

Obviously, this described is one of the surgical procedures for inserting dental implants, for clarity and brevity of the speech other techniques such as those using osteotomes or ultrasonic instruments are not described [67].

RESULTS

Digital assisted pre-guided implant surgery

Through the interpretation of the materials and methods, through bioengineering and dental medicine methods, applied to oral surgery, it is possible to devise the following.

Assuming different implants as true, it is possible to draw as a conclusion a new method useful for implant-prosthetic planning, which aims to improve the short-long term predictability of oral rehabilitations. This method can be applied to simple or complex type rehabilitations, and can be made more precise by improving the resolution of the

FEM simulations. Furthermore, it is possible to calculate not only the main components of the restorations, such as prostheses, implants and bone, but also all the smaller components, such as abutments, passing screws, or other structures present.

The FEM analysis allows us to carry out a biomechanical simulation of the simulated masticatory forces on a specific component (implant-prosthetic). It all starts with an intraoral scan and a three-dimensional radiographic examination of our patient. Once these images have been matched, it is possible to proceed with the realization of the .stl model. Theoretically, a determined value of bone density can be assigned according to the identified Hounsfield scale of the radiographic .dicom type images (Figure 10,Figure 11).

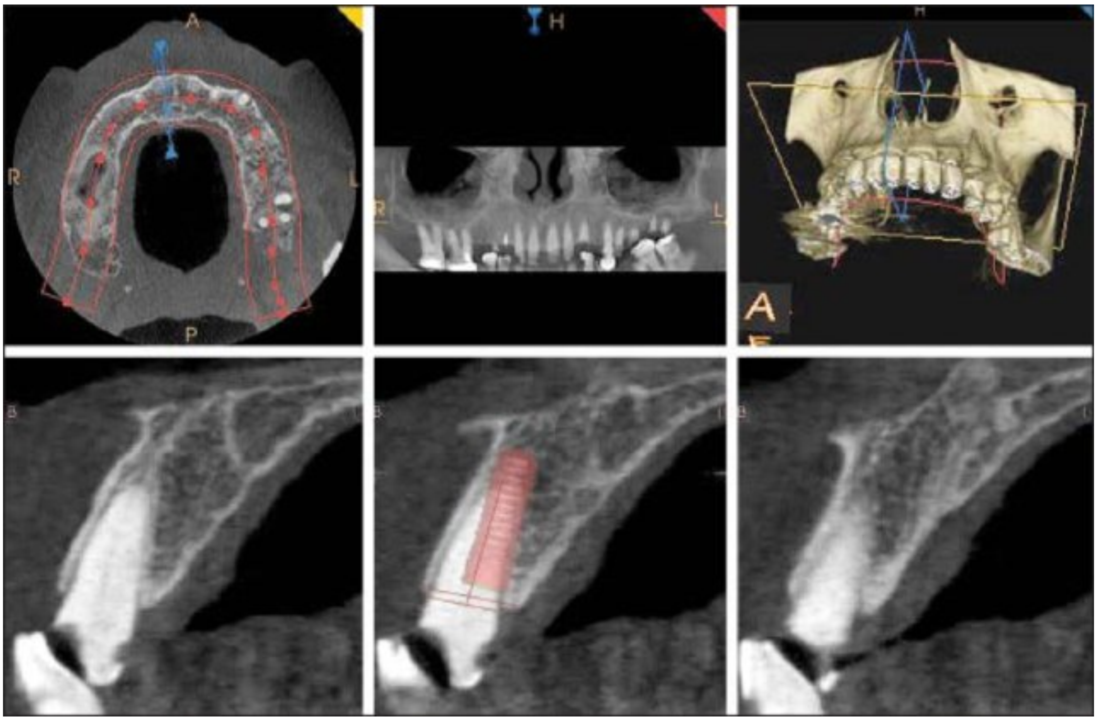

Figure 10. Cone beam computed tomography planning in the maxilla [68].

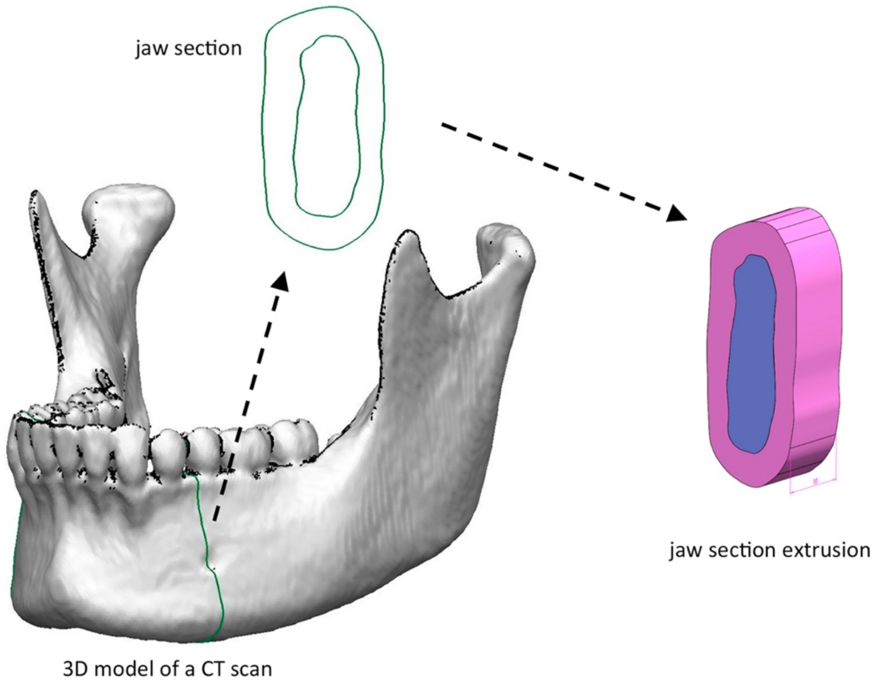

Figure 11. From radiographic images (.dicom files) to .stl. All rights reserved [69].

The masticatory forces can also be measured in vivo on the patient with the use of precision electromyographs, with customized forks that measure the masticatory force, currently already on the market (Figure 12).

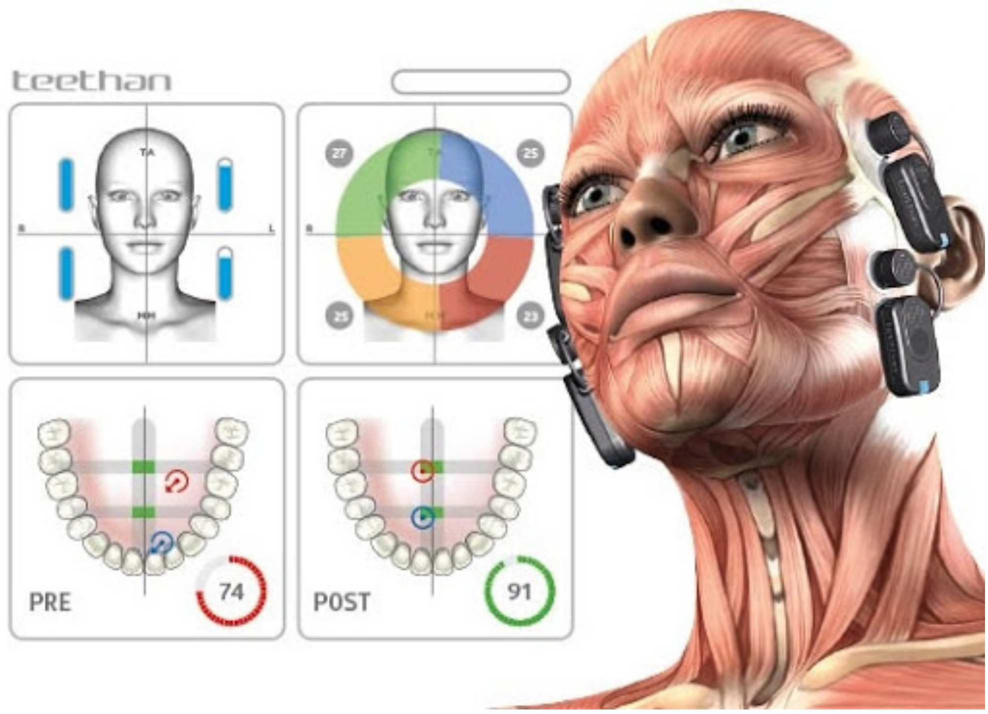

Figure 12. Tool for bite force measuring.

Once these values have been obtained, and obtained the .stl model of our patient, we can proceed with the realization of the prosthesis and the surgical planning.
Having roughly identified, in the first instance, the ideal position of the dental elements to be rehabilitated, it is therefore possible to proceed with the digital positioning of the implant fixtures, respecting where possible the patient's bone anatomy, or evaluating any contextual regenerative maneuvers. Only at this point will it be possible to proceed with the positioning of the abutment and therefore with the design of the definitive prosthesis. Having obtained this structure, it will be possible to proceed with the simulation by applying, with cycles as described above, and with the forces previously measured, to the FEM analysis. If the analysis shows stress peaks on the cortical or bone marrow, at this point it will be possible to proceed with the rescheduling of the implant placement, so as to reduce the stress on the hard tissues. This obviously in order to obtain an image in which the distribution of the loads is uniform and allows a correct biomechanical function. it was analyzed how bone is not a static structure, but a highly dynamic one and is able to respond to certain mechanical stimuli, as also mentioned by Wolff's law [70].
If the stimulus, however, is excessive, this can induce bone damage or resorption, which can indeed trigger peri-implant disease or the loss of the fixture itself. Usually in the biomechanical field the tension distribution is analyzed with particular attention, both in biological structures, to see how much the coupling with an artificial structure (e.g., prosthesis, implant) modifies their structural response to external stresses, and in artificial structures to check their resistance capacity. The identification of the distribution and extent of tensions in a structure is important as it highlights which areas are most stressed and at risk of rupture. Furthermore, in the case of biological tissues, necrosis or hypertrophy and which areas are less stressed which, in the case of biological tissues, could induce atrophy. In analysis of the stress state of the biomechanical systems,

particular attention was paid to the mandibular cortical bone, as it was one of the most stressed parts and the tension values in the areas of interface with the implant were compared, that experience indicates as being most affected by bone resorption. According to other studies [71], the forces transferred by dental implants on cancellous bone and cortical bone vary according to the implant geometry, respectively between 4-13MPa and 12-29Mpa. Once an optimal analysis has been obtained from the point of view of the distribution of forces on the cortical and medullary bone, we then move on to the evaluation of the implant-prosthetic components, in order to correctly distribute the forces on these as well. Obviously, this phase can be much more difficult if we are talking about prostheses screwed on four, five or six dental implants as shown in Figure 13.

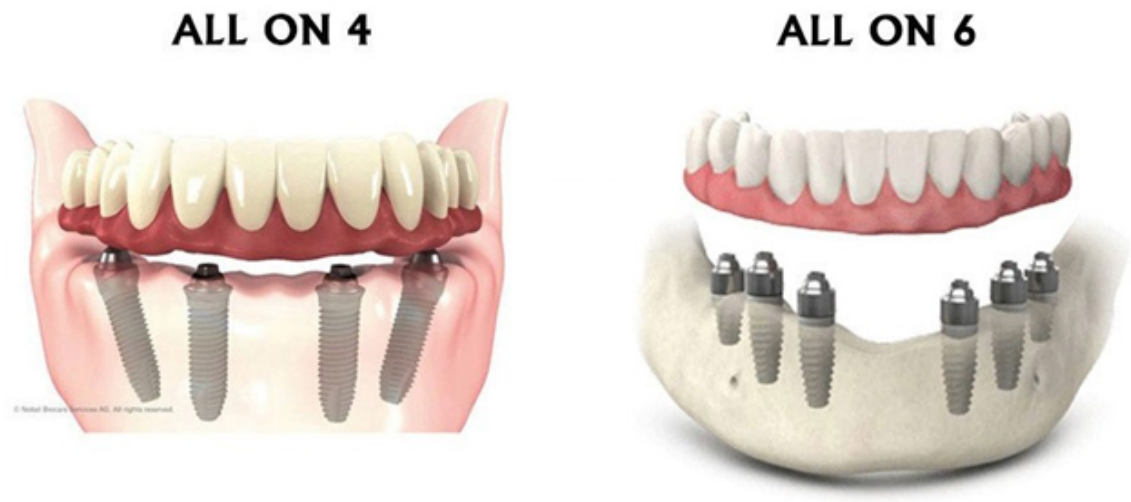

Figure 13. Fixed prosthodontics on four and six implants examples.

Only after the last simulation and the single analysis of all components will it be possible to confirm the planning carried out and move on to the next phase. Making a surgical guide (template) that the surgeon will use to place the implants as planned (Figure 14).

Figure 14. Dental implant template, for four implants placement. Blog.iti.org, all rights reserved.

For this reason, the manufacturers of dental implants are also often met, which in recent years have now created surgical kits for the positioning of implants with a template. Surgery is one of the simplest phases then, once the template has been positioned, the protocol and planning are followed.

In summary, therefore, the following phases can be summarized:

1. Anamnestic collection
2. Instrumental examinations (three-dimensional radiography, intraoral optical impression)
3. Image matching and transformation from .dicom to .stl
4. First design of a prosthodontic with an advantageous position from a biomechanical point of view.
5. Implant positioning respecting anatomy as much as possible.

6. Realization of definitive prosthetic design.

7. First simulation.

8. Analysis of force peaks and attenuation by moving dental implant.

9. Definitive implant planning.

10. Realization of surgical guide.

11. Surgical intervention (Figure 15).

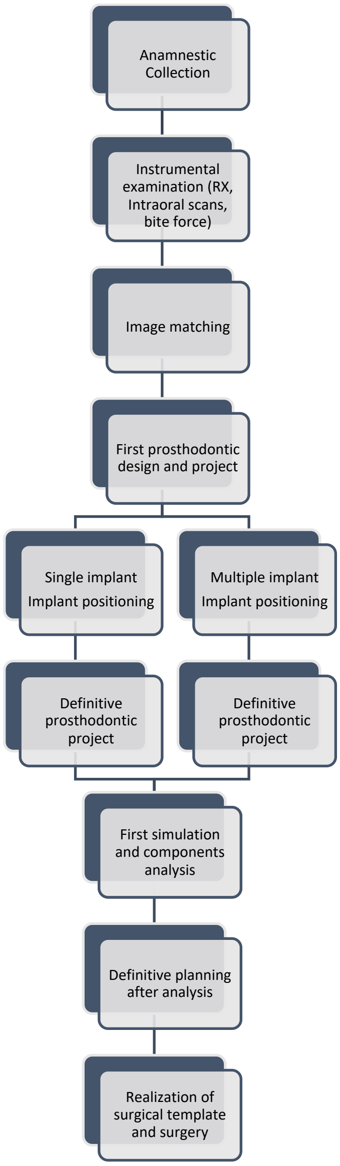

Figure 15. Digital assisted pre-guided implant surgery workflow.

DISCUSSION

From what has been said above, it is clear how important it is in the near future to be able to have electronic and computer equipment performing to such an extent as to allow the creation of a simulation of this kind ad hoc for each patient during the planning of implant insertion. As already discussed in different studies, the time to perform a single simulation of this kind can be more than 30 minutes. Obviously, the difficulties still lie in being able to "discretize" the patient's bone components with the lowest possible error rate, all starting from three-dimensional radiographic images contained in the .dicom files. The transformation of .dicom into .stl is currently possible. Obviously, the quality of the radiographic images is essential, and a bone density value should be applied, therefore biomechanical values, depending on the radiographic value identified in the gray scale (Hounsfield scale).

In a study of Cervino et al. [72] The components of dental implants were tested with a straight inclination of 30° and with dynamic loads 2000 times each (Figure 16).

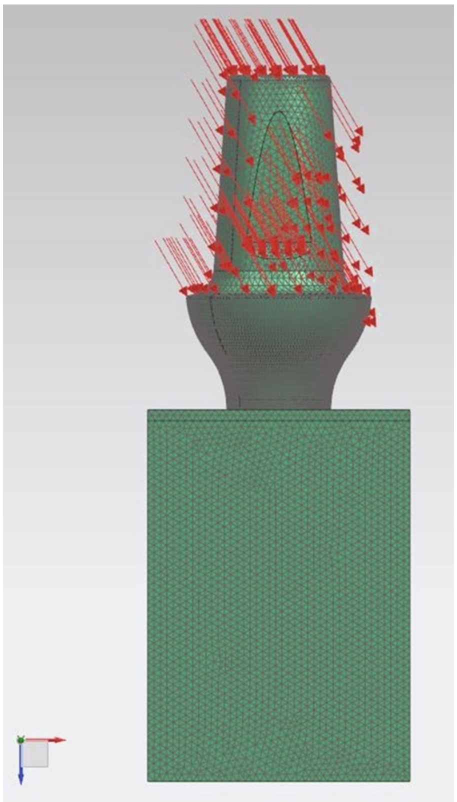

Figure 16. Example of 30° forces direction

Different loading conditions were considered. All loads were distributed on the implant surface components in contact with the tooth crown. The results demonstrated the relationship between the loads applied to the system involving the geometrical characteristics of the materials, the constraints and deformations. The program, by using Von Mises analyses, expresses the results in the form of a chromatic scale of colors ranging from blue to red for the minimum values to the maximum values. The values represent those of the respective solution found. Firstly, a static force of 800 Nmm was applied to the system and to each component of the fixture Figure 17.

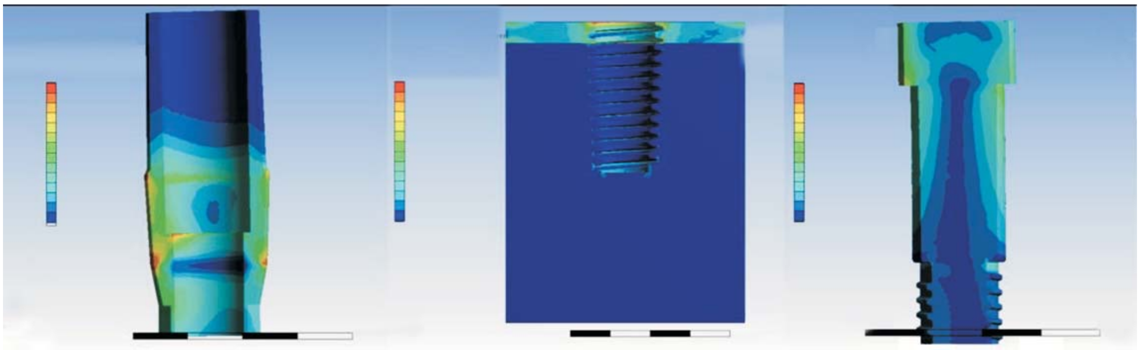

Figure 17. Chromatic distribution of stresses in (from left) abutment, dental implant neck, passant screw. From Author concession

The finite element analysis is a useful aid for the assessment of stress rising in the bone due to the presence of prosthetic devices. It represents an easy way to investigate complex biomechanical systems instead of experimental techniques that are difficult to apply. To perform a reliable simulation, several fundamental parameters have to be taken into account, such as the bone tissues material model, the state of osseointegration of the implant, and the preload of the internal screw [73]. In these two figures, it is easy to highlight how the dental implant neck characteristics could influence stresses over the bone (Figure 18, Figure 19).

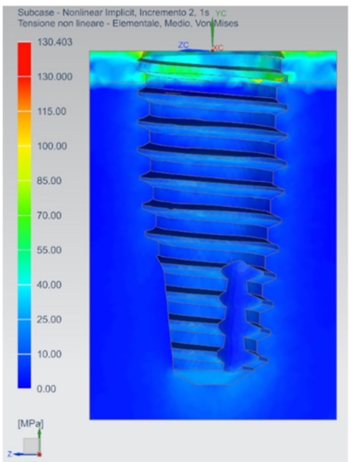

Figure 18. Stress distribution on the bone tissues (cancellous and cortical) for: AnyOne®(Megagen®, South Corea) External

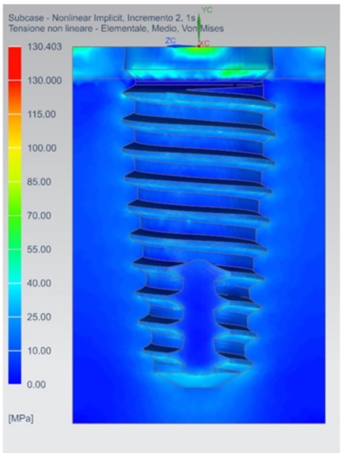

Figure 19. Stress distribution on the bone tissues (cancellous and cortical) for: AnyOne®(Megagen®, South Corea) Internal

This further study by the research group of the University of Messina [71], highlighted how evident the difference in the distribution of forces on the bone tissue and in any case of all peri-implant tissues, when the direction of the load changes. Considering that it is impossible to obtain a "pure" axial load during chewing, it would therefore be advisable to be able to plan the implant insertion, after a simulation of this type (Figure 20,Figure 21).

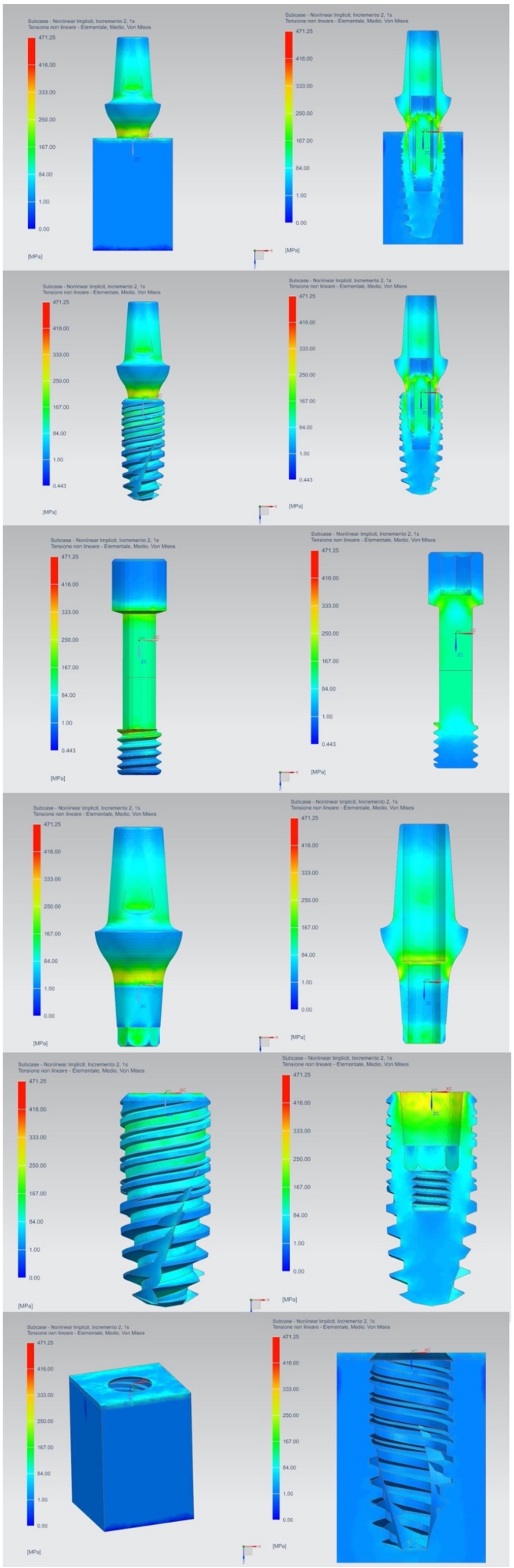
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Figure 20. Assial load and force distribution on dental implants, prosthetic components and bone.

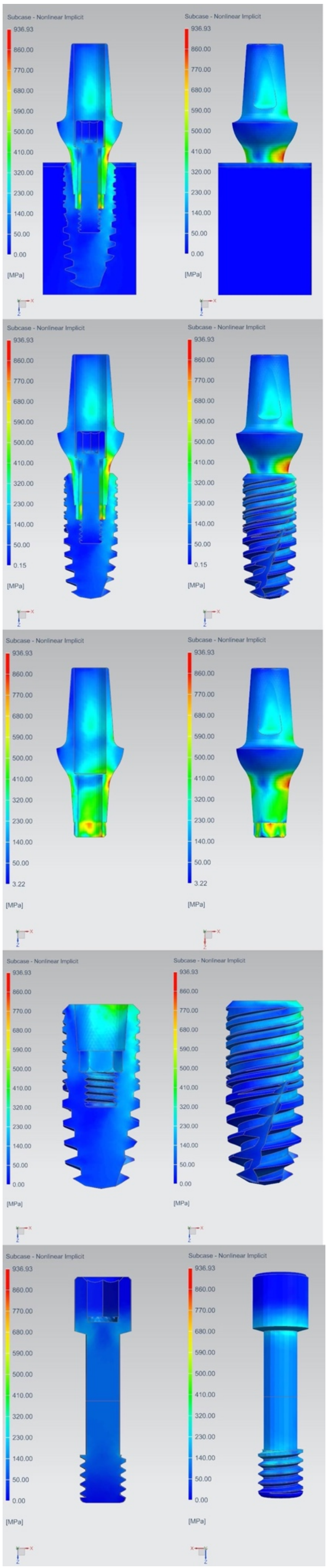
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Figure 21. 30° load and force distribution on dental implants, prosthetic components and bone.

According to Michailidis et al. [74] the increased rigidity of the implant material develops high stresses, while the adjacent cancellous bone is deformed, partially absorbing the induced load, thus determining a lower distribution of stresses. This is evident along the entire length of implant fixation and in all loading scenarios, which has been associated with the geometry of the cylindrical implant screw.

The simulations revealed that the length of implant fixation (length of the embedded screw) is of paramount importance for long-term stability. Poorly osseointegrated implants are insufficiently supported and could lead to fractures even under low forces. Bone resorption, altering the initial implant / crown ratio, has a significant effect on the biomechanical behavior of the prosthesis. Detection of the implant in the order of 15% of the total embedded length will lead to increased implant fatigue and possible fracture, even in mild load scenarios. The results of our study were verified by comparing simulated stress fields with fractured (clinically recovered) implants. The correlation confirmed the biorealistic development of stress, as the predicted critical regions calculated by the model are consistent with the fracture site of the prosthesis (Figure 22).

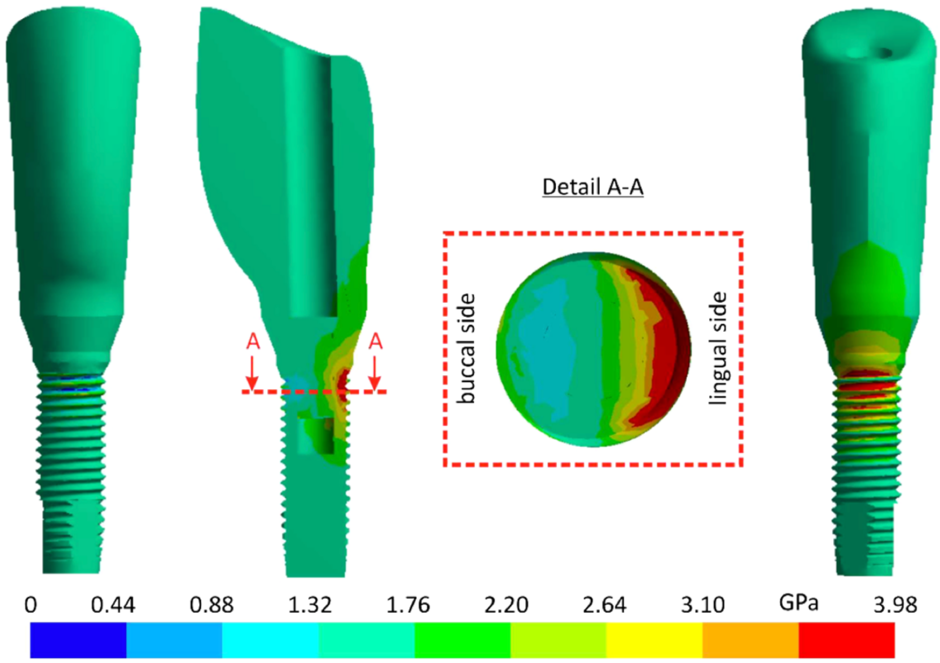

Figure 22. Stresses distribution over dental implants in periimplantitis conditions. All rights reserved [74].

The possibility of creating a virtual articulator, and even more of measuring the patient's masticatory force, and creating a simulation that is as close to reality as possible would certainly allow safe and predictable rehabilitations over time, identifying the best position for implant insertion. , and for prosthetic design. Allowing to limit the medium-long term implant failures linked to peri-implant processes induced by biomechanical parameters. In the event that the loss of an implant occurs shortly after having performed a dental implant surgery, therefore before osseointegration has taken place, the probable cause is not attributable to periimplantitis and can be:

- insufficient sterilization of the operating field
- overheating of the bone
- the lack of primary stability at the time of its insertion
- the occlusal overload of the implant screw

Periimplantitis is a bacterial infection that affects dental implants. This is determined by the accumulation of plaque and tartar and therefore poor or incorrect home oral hygiene associated with the lack of professional oral hygiene sessions, which in subjects predisposed to periodontitis and therefore to periimplantitis should have a quarterly frequency. The main causes of periimplantitis are:

- genetic predisposition as for periodontitis
- inaccurate crown which causes greater plaque accumulation around the implant
- lack of the contact point that determines food impaction, i.e., accumulation of food and plaque between the teeth
- presence of cement under the gum which is colonized by bacteria

The latter is probably the main cause of periimplantitis. For this reason, screw-retained prostheses on implants are now preferred. In fact, the onset of periimplantitis is linked to the conditions that cause greater accumulation of plaque and tartar under the gingiva. Generally, the infection manifests itself with spontaneous bleeding and swelling of the affected area, the presence of a metallic taste on salivation and ultimately the mobility of the dental implant. Periimplantitis acts in a similar way to periodontitis, causing bone resorption around the implants and causing the inevitable loss of the prosthesis. In any case, infection involving dental implants is a slow process, the more serious consequences of which, such as the loss of the dental implant, can be avoided through bone regeneration surgery. When the implant is mobile, unlike the dental elements, it is always lost. In any case, if the symptoms of periimplantitis are present, it is necessary to immediately contact an expert implantologist and periodontist for a thorough examination and radiographic examinations. An intraoral radiograph, a periodontal probe and a clinical examination will be sufficient to make a diagnosis of periimplantitis. Peri-implant area could be affected by non-axial loading, cantilever prosthetic elements, crown / implant ratio, type of implant-abutment connection, misfits, properties of restoration materials and antagonistic tooth. However, it is the macro-architectural design of the implant that establishes initial mechanical fixation, which is crucial in minimizing implant mobility in the first 3–4 weeks of function. In the search of a new macro-architectural design, an idea of adding a wing to the implant for extra primary stability was raised. Finite element analysis of the 'winged' implant, in comparison to a regular implant, revealed that when a 20 kg force is applied at an off-axis angle of 20 °, the amount of maximal displacement at the neck of a regular implant is 60% higher than observed with the 'winged'. In order to determine the clinical efficacy of this new implant, a study was undertaken to evaluate the implant in both jaws under conditions of immediate function. This implant will be presented with finite elements analysis and animal experiments with explanation of the biomechanics of periimplantitis. Another study by Macedo et al. [69], shows how the stresses analyzed with the von Mises method on the cortical bone were higher than those recorded on the trabecular bone, by axial or oblique load (Figure 23). In addition, Morse taper implants showed a higher volume of peri-implant bone at low stress and a lower volume of peri-implant bone at high stress. Therefore, Morse taper implant systems revealed better biomechanical behavior than external hex implants, with regard to significant bone volume subjected to a low intensity of stress. This also provides important information regarding the influence of an internal component of the dental implant on the bone.

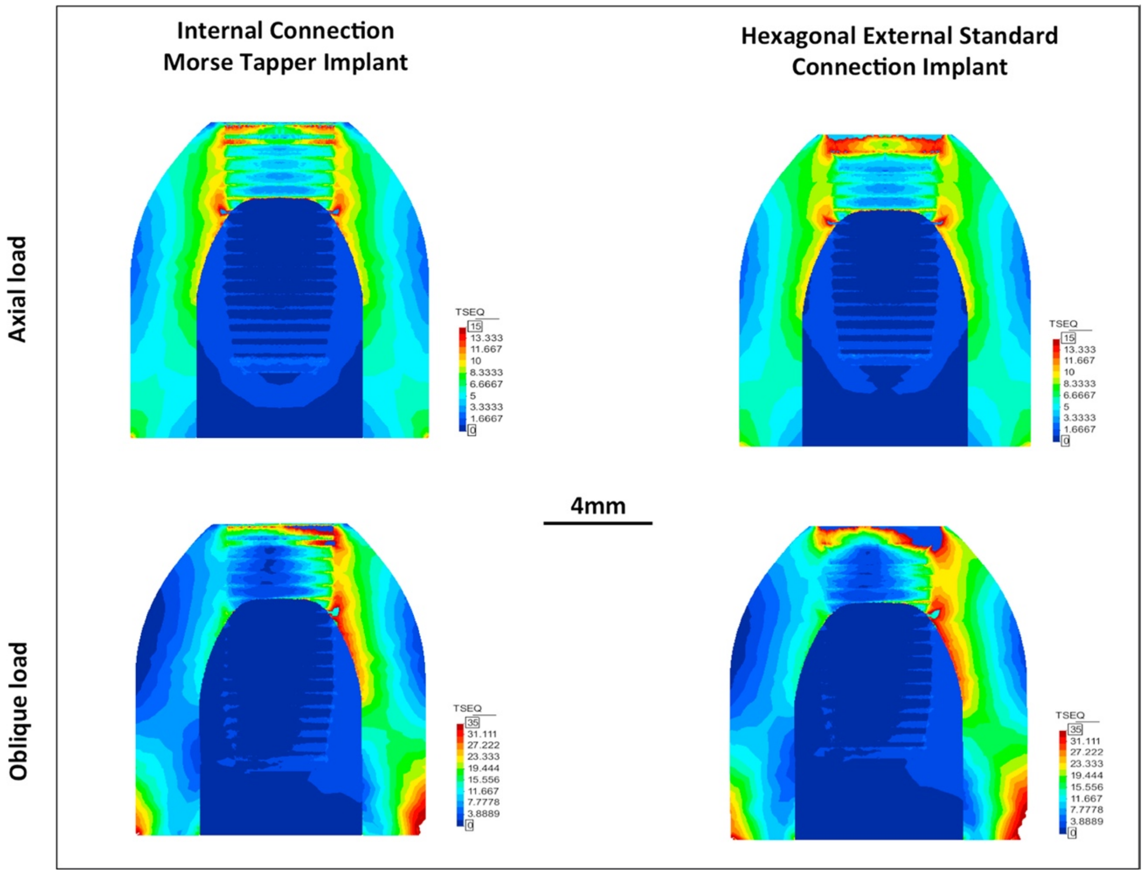

Figure 23. Effect of different internal connections to peri-implant bone.

Limitations

The main limitation of this study obviously lies purely in the fact that it is currently unable to carry out such a simulation, which would require not only a positive opinion from an ethics committee, but also resources, to collect the sample of patients, with a control group; to perform both simulations and surgical interventions with all surgical material and prosthetic implant.

CONCLUSION

What has been analyzed would certainly allow much safer and more predictable rehabilitation, thanks to the analyzes derived from bioengineering carried out. Nowadays, FEM analyzes allow us to improve implant fixtures, connections and individual

components. This is thanks to cyclical simulations and continuous scientific research in this area. Having such an instrument, defined as, chair-side, available to the dentist, would be a very important goal. Unfortunately, these simulations still require very high performance and expensive hardware, and the simulation times are very long. Among other things, the software is not easy to use and a dentist, albeit helped by a dental technician (who by now has necessarily had to apply himself to the digital world) does not have the skills or tools necessary to carry out this type of work.
The possibility of carrying out a simulation of this type, after having performed simple instrumental examinations which are now part of clinical practice, would allow simple and complex safe rehabilitations not only in the short but also in the long term.

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But dedication of this thesis is only one ...
A Ginevra

FIGURE CAPTION

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