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MICROSTRAIN OVERVIEW IN IMPLANT-SUPPORTED PROSTHESES IN ATROPHIC MAXILLARY AREA

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Abstract: The present study aims to evaluate the literature about the rehabilitation of implant-supported fixed prostheses located in the posterior region of the maxilla, in a situation of maxillary sinus pneumatization, as well as the three-dimensional finite element method, as well as its use in computational studies with greater validity and reproducibility. Foi realizada uma busca eletrônica nas bases de dados, Pubmed e Google Scholar, utilizando os seguintes descritores, obtidas a partir do DeCS: Finite Element Analysis; Sinus Lift; Computer Simulation; Prosthodontics; resultando em 100 artigos, no período de 1969 a 2023. The main methods for investigation and biomechanical analysis are: analysis by the Finite Element Method, which offers a way to calculate the distribution and concentration of stress and deformations in the components of the system, through a computerized two- or three-dimensional structure; birefringence analysis (photoelasticity), which uses polarized monochromatic light and implants anchored in plastic models, where forces are applied; "in vivo" and "in vitro" load measurement, where more precise data can be obtained regarding the forces exerted on the system, through the use of appropriate sensors called extensometers; studies of the bond strength between the implant and bone tissue, performed through shear, traction, and compression tests. It can be concluded from this study that according to the information collected by the literature, in conditions where the oblique load is more angulated, it is suggestive of greater damage to the bone structure. About prosthetic components, structures that are adapted to a short implant present better mechanical behavior. Last but not least, the stresses in the cortical bone showed higher values for the tilted implant and lower values in the model with bone graft. However, more research is needed to better understand this material and its long-term

clinical behavior.

Keywords: Finite Element Analysis; Sinus Lift; Computer Simulation; Prosthodontics.

INTRODUCTION

In implants, unlike teeth, there is an absence of the periodontal ligament, which acts as a buffer element for occlusal loads that affect the tooth and are transmitted to the bone. When the natural tooth undergoes loading, the set of fibers of the periodontal ligament tends to allow only tensile stresses at the tooth-bone interface, whereas in implants these stresses are mostly compressive (Brånemark et al., 1977).

Biomechanical factors play an important role in maintaining the implant-bone interface (Skalak, 1983). Inadequate stresses cause diffuse bone atrophy, while excessive local stress around the implant results in pressure necrosis of the host bone, microfractures, and marginal bone loss with potential implant failure.

The transmission of tensions from the prosthesis-implant system to the surrounding bone tissue and its biomechanical aspects were evaluated by Skalak (1983) who described that the distribution of vertical and oblique loads is directly related to the number, arrangement, and resistance of the implant and restoration. prosthetic. As the implant is directly connected to the bone, a more rigid structure of the prosthesis would fully transmit the stresses generated by static and dynamic forces. Another aspect put forward by the author is that the use of more resilient materials could help absorb and distribute stress more effectively.

Bidez & Mish (1992) stated that knowledge of the tensions exerted on implants and biological tissues are crucial for the longevity of restorations. These forces can act, maintaining the integrity of the bone-implant interface, or they can also destroy it. The only way to control these tensions is to practice based on a better understanding of the problems involving the biomechanics of these implants.

The purpose of implants is to restore masticatory function to the patient, and that research should be more concerned with studying the nature and how masticatory forces are transferred to tissues, and what are their reactions. According to the author, studies on the modulus of elasticity and the shape of implants help to elucidate the transfer of strain but do not explain what kind of biological reaction will occur in the bone. More specific knowledge of the physiology of healing after implant installation and the study of the bone modeling and remodeling process should be better elucidated. Brunski (1992).

The present study aims to evaluate the literature about the rehabilitation of implant-supported fixed prostheses located in the posterior region of the maxilla, in a situation of maxillary sinus pneumatization, as well as the three-dimensional finite element method, as well as its use in computational studies with greater validity and reproducibility.

METHODOLOGY

SOURCE SELECTION

A bibliographic search was carried out in the main health databases PUBMED (www.pubmed.gov) and Google Scholar (www.scholar.google.com.br), in which articles published from 1969 to 2023 were collected. the list of retrieved articles was examined by reading titles and abstracts. In the second stage, the studies were selected by reading the complete content. Two authors (JDMM and GRSL) carried out steps 1 and 2. Experimental clinical studies, laboratory studies, case reports, systematic reviews, and literature reviews, developed in living individuals, were included. Therefore, articles were excluded that did not deal with the rehabilitation of implant-supported fixed prostheses located in the posterior region of the maxilla, in a situation of maxillary sinus pneumatization, as well as the three-dimensional finite element method, as well as its use in computational studies with greater validity and reproducibility.

DATA SOURCE

Through bibliographic research, 100 articles were selected, 65 articles from PUBMED (www.pubmed.gov) and 35 from Scholar Google (www.scholar.google.com.br). The following titles of specific medical subjects and keywords were used: Dentistry; (DeCS / MeSH Terms), Computing Methodologies (DeCS / MeSH Terms), Computer Simulation (DeCS / MeSH Terms).

RESULTS

According to the analysis of variance carried out in this study, evaluating the mean and standard deviation, it appears that the average number of articles published in the period from 1969 to 2023 in the Pubmed database was 2.74 and with a standard deviation of 1.99. On Google Scholar, the mean was 0.98 and the standard deviation was 0.85. Thus, it is possible to verify that there was a significant variation in the number of articles, in both databases.

DISCUSSION

According to Spiekermann (1995), the main methods for investigation and biomechanical analysis are: (1) analysis by the Finite Element Method (FEM), which offers a way to calculate the distribution and concentration of stress and deformations in the components of the system, through a computerized two- or three-dimensional structure; (2) birefringence analysis (photoelasticity), which uses polarized monochromatic light and implants anchored in plastic models, where forces are applied; (3) “in vivo” and “in vitro” load measurement, where more precise data can be obtained regarding the forces exerted on the system, through the use of appropriate sensors called extensometers; (4) studies of the bond strength between implant and bone tissue, performed through shear, traction, and compression tests.

Brunski (1999) reported that it is also important to consider that in mastication, the vertical and transverse load induces axial forces and flexion moments that result in stress gradients in the implants and in the bone and, mainly, the oblique forces, which are quite common. during normal chewing, they cause more tension than axial forces, and this must be emphasized among the loading characteristics of the prosthesis and the implant.

Rubo & Souza (2001), in a conceptual article, discussed the use of the FEM in Dentistry, reporting that the FEM has shown great growth, and its diversity of applications has resulted in a great increase in its use in other areas of research, specifically those linked to engineering-related problems. This method consists of a mathematical analysis that performs the discretization of a continuous medium into small elements, maintaining the same properties of the original medium. These elements are described by differential equations and solved by mathematical models so that the desired results are obtained. The FEM can be used in several areas of the exact and biological sciences and, due to its great applicability and efficiency, there are works with this methodology in several dental specialties, when one wants to analyze loads, tensions, or displacements. With the advantages over other available methods, it is extremely important to know the technique so that its use can provide scientific benefits and allow clinicians to know the basic concepts of FEM so that the results of the work are better interpreted. While results in past studies relied on solid model tools to create approximate geometry for analysis, the availability of advanced imaging techniques is now enabling a more accurate representation of three-dimensional geometric models for finite element analysis and other numerical analysis techniques. In the specific case of implant dentistry, the key factor for the success or failure of a dental implant lies in the way in which stress is transferred to the surrounding bone, and the finite element method becomes important, as it allows researchers to predict the distribution of this stress. in the contact area of implants with cortical bone and around the apex of implants in cancellous bone

Koca et al. (2005) used a three-dimensional finite element model simulating a posterior maxilla section of type 3 bone to determine the amount and location of functional stress on implants and adjacent bone sites when implants were placed posteriorly in proximity to the maxillary sinus. Different bone dimensions were simulated to perform non-linear calculations. Implants measuring 4.1 X 10 mm were inserted in the maxilla with a height of 4, 5, 7, 10, or 13 mm. In some models, the implants penetrated the maxillary sinus. Cobalt chromium was used for the structure of the crowns, and porcelain was used for the occlusal surface. An average occlusal vertical load force of 300 N was applied, with 150 N on the palatal cusp and 150 N on the mesial fossa of the crown. The maximum stress value was observed in the palatal cortical bone adjacent to the neck of the implant. There was no localized tension in the spongy bone. High stress occurred within the implants, at all bone levels. The highest stress was located at the neck of the implants, at the 4mm and 5mm bone levels, and for the 7, 10, and 13mm bone levels, even higher stress occurred within the implants. The proportion of the crown and implant was also researched, for a better understanding of its importance.

Ogawa et al. (2010) evaluated the axial forces and bending moments on implants supporting a fixed dental prosthesis with a 10 mm cantilever compared to a fixed dental prosthesis supported by an inclined (13 mm) or short (7 mm) posterior implant through an in vitro voltage measurement. Nine implants were used, as follows: (1) short distal implants supporting the cantilever; (2) long and inclined distal implants, and (3) absence of distal implants supporting the cantilever. A vertical load of 50 N was applied to the first molar. The use of distal posterior implants reduced the impact of axial flexural force on implants supporting a fixed dental prosthesis, compared with those with a distal cantilever. No difference in mechanical loading was observed between angled and short implants.

The installation of short dental implants has been proposed as an alternative to reduce surgical risks related to advanced grafting procedures. Chang et al. (2012) evaluated the biomechanical behavior and influence of the diameter of short dental implants with a length of 6 mm and a diameter of 6, 7, and 8 mm on three types of bone quality, from normal to osteoporotic, in an atrophic posterior maxilla. Computed tomography and CAD system were combined to build finite element models. Simulation results showed that implant diameter did not influence bone stress under axial load. Bone tension increased by 58.8% in the less dense bone under lateral loading. Lateral loading induced higher bone stress in the implant than vertical loading. The authors concluded that an appropriate occlusal scheme design or selective occlusal adjustment to reduce the lateral occlusal force on short dental implants is recommended.

De Paula et al. (2012) compared the distribution of stresses on prostheses supported by teeth and implants, and prostheses only supported by implants with two different pontic spaces, three units, and four units. The authors observed that prostheses supported by teeth and implants with short space and large diameter implants resulted in more homogeneous stress distribution and less stress concentration on the implants. The larger space presented the highest stress concentration on the implants and between the politics and, in all models analyzed, the stress concentration was present on the implants.

Perelli et al. (2012) evaluated the 5-year survival rate of short porous dental implants in the posterior maxilla, combined, when necessary, with crystal elevation of the maxillary sinus and frequent addition of inorganic bovine bone. In 87 patients, partially edentulous, 110 short porous implants were placed and followed up for 5 years. The implants used were of two heights, 5 and 7 mm, and two diameters, 4.1 and 5 mm, and were chosen according to the height and thickness of the available bone ridge. Failures in prostheses and implants were evaluated; the presence of complications; and peri-implant marginal bone resorption. In 47 sites, osteotomy for maxillary sinus elevation was performed, in 8 cases with basal bone compaction and, in 39, adding a xenogeneic graft was. A period of 6 months waited. A total of 63 implants were restored with single crowns and 47 were joined to adjacent implants. After the follow-up period, the survival rate for implants was 90%, and for the rehabilitated implants it was 93.1%. The use of short porous implants showed an acceptable clinical result in the treatment of the posterior maxilla over this 5-year follow-up period.

Alvarez-Arenal et al. (2013) evaluated the stress distribution in the prosthetic connection and the prosthetic retention screw of a single implant supporting prosthesis with platform switching and conventional. Two finite element models were created, simulating osseointegrated implants with a 4.1mm platform and connection of 4.0mm and 3.8mm in diameter, respectively. A maximum axial and oblique load of 150 N was applied. It was demonstrated that the tension was lower in the retaining screw and in the connection when using platform switching, and that, when the load angle was increased, the tension was greater in both models. The authors concluded, citing the importance of knowing the type of prosthetic component and the main stress concentration in these components to provide guidelines for avoiding and preventing mechanical and technical risks.

Baggi et al. (2013) compared dental implants, based on the platform switching concept, with different dimensions and thread types, using the three-dimensional finite element method, and studied the influence of implant design, in terms of diameter, height, and thread shape, in addition to the depth of placement in the bone and the morphology of the bone crest on the transfer of load in the implants and bone. Models of the implants and connections were constructed, using design software, and provided the possibility of consistent comparisons, simulating a bone segment of a premolar, obtained by the three-dimensional model of an edentulous maxilla. Aspects such as subcrustal positioning, the influence of infra-osseous positioning depth, and the influence of marginal bone loss on crystal positioning were evaluated. The results identified the influence of these various factors that affect the load transfer mechanism from the implant to the bone. They concluded that the implant diameter is a more effective design parameter than the implant length, as well as the thread design, can significantly affect the stresses in the peri-implant bone, especially for short implants.

Fuh et al. (2013) evaluated bone stresses and wear at the bone-implant interface in titanium and zirconia implants with thread design, and different interface conditions for treatment with immediate and conventional loading. Zirconia reduced bone tensions in the crystal cortical region. Bone stresses and wear at the bone-implant interface were stronger depending on the thread design, the frictional coefficient, and the immediate loading.

Gujjarlapudi (2013) evaluated and compared the bone stress distribution around parallel and non-parallel titanium and zirconia implants under axial and non-axial load supporting fixed prostheses at three different angulations. Three models for titanium implants and three models for zirconia implants were created, representing different situations, namely, two parallel implants supporting a fixed prosthesis, two buccolingually angled implants, and two mesiodistally angled implants with medium angulation in groups of 5 degrees. Zirconia implants showed lower stresses in the cortical bone and higher stresses in the medulla compared to titanium implants. Zirconia implants left lower stresses in the peri-implant region than titanium implants.

Jimbo et al. (2013) evaluated the loss of marginal bone structure accompanied by bone fracture under vertical load on implants in the buccolingual direction, using the three-dimensional finite element method. Excessive tension, reported in the study, was associated with mechanical changes, and the marginal bone loss that occurred, surrounding the internal connection implant, was attributed to prosthetic misfit. To avoid complications, the selection of an intermediate prosthetic component was suggested, to dissipate loads and relieve tension in the peri-implant bone.

Mangano et al. (2014), in a prospective clinical study with a follow-up of 1 to 10 years, evaluated the long-term results of short conical implants supporting single crowns in the posterior region and analyzed the influence of different factors on the survival of these implants, and rates of success of crowns over implants. 215 implants were placed in 194 patients. The success rate was 95.8% for the implants. They concluded that the use of short, 8-mm conical implants is a predictable treatment modality for the restoration of single tooth spaces lost in dentition.

Xia et al. (2013) evaluated the stress distribution in the bone around implants with conventional connection and platform switching with marginal bone loss created on models and subjected to vertical and oblique loading. The concentration of tension was located in the cervical area, extending to the apex. There was a biomechanical advantage for platform switching when force was applied to models where marginal bone resorptions were created, but this difference was reduced when resorption was greater.

Le et al. (2013) investigated the survival rate of short implants, 9 mm or less, restored with unbonded single crowns, after a mean follow-up of 37 months. 221 implants were placed in 168 patients, 44 in the maxilla and 176 in the mandible. The survival rate of short implants restored with unbonded single crowns, considering an average period of 37 months, was favorable and comparable to long implants. These findings suggest that, in situations where short implants failed, this was more common during the first 4 months of implant function, and for implants that remained four months, their survival prognosis beyond 3 years was excellent.

Huang et al. (2014) investigated the correlation between implant neck design and cortical bone thickness using the three-dimensional finite element method. Four commercial implant models for type IV bone were created. These models were compared in terms of mechanical load transmission and risk of bone overload under functional conditions. Micromovements and relative displacement between the implant and the surrounding tissue were used to assess the behavior of bone healing in the early stages of implantation. The results showed that the maximum stress in the peri-implant bone decreased when the thickness of the cortical bone increased. They also showed that the regions with the highest stress concentration were located in the cervical part of the implant and the cortical-medullary bone interface. They also verified that the level of micromovements in complete osseointegration is smaller when compared to the implant with incomplete osseointegration, and, also, these micromovements decrease when we increase the thickness of the cortical bone. The authors concluded that the thickness of the cortical bone is a preponderant factor in the primary stability of the implants.

Kang et al. (2014) evaluated the biomechanics of short dental implants. Three-dimensional finite element analysis was used to simulate the stress distribution in 8mm high implants, with six different diameters, in four types of bone density, types I to IV, thus obtaining 24 simulated models. In this study, axial vertical loads of 200 N and buccolingual oblique loads of 450 of 100 N at the top of the implant connection were applied to the casts. The results indicated that the stress was concentrated in the cortical bone under vertical load at any type of bone density, while the most uniform distribution was observed in the medullary bone, in addition, the stress value gradually decreased in the vertical direction. For the implants, the stress was mainly concentrated in the cervical portion and gradually decreased in an apical direction. In this study, the results indicated that the greatest stresses occurred in implants with a smaller diameter and low bone density and that the stresses on the implant-bone interface tended to decrease when the implant diameter and bone density increased.

Kim et al. (2014) used three-dimensional finite element analysis to evaluate the biomechanical behavior of short dental implants in the posterior maxilla. Short implants were installed at different heights of residual bone, and compared with dental implants of conventional height. In this study, maxillary first and second molars were replaced in models developed by bonded gold crowns supported by two implants. A total of five models of posterior edentulous maxillae were developed, with various heights of residual bone, group 1 (control) with a residual bone height of 13 mm and group 2, four models with a variable residual bone height of 7, 6, 5 and 4 mm, respectively. 4.5 x 11mm implants (OsseoSpeed, Astra Tech) with a 6 x 2.5mm connection (Direct Abutment, Astra Tech) and a 6 x 5.7mm implant (Bicon) with a 6 x 5mm connection were used, respectively. A load of 30 degrees and 187 N was applied to the central fossa of the two implant-supported crowns. Numerical simulation showed that, without maxillary sinus bone grafting, the most effective stress distribution could be better obtained in 7,6,5, and 4mm residual bone with short dental implants, than in 13mm residual bone with conventional dental implants. It can be concluded, according to the results of this finite element model, that the tension applied to the alveolar bone can be efficiently distributed by changing the implant diameter without bone graft from the maxillary sinus in places with little amount and low bone density.

Verri et al. (2015) evaluated the stress distribution in fixation screws, connection, and in bone tissue around implants that support single crowns of different heights. Models were designed and analyzed using the three-dimensional finite element method. Each model was developed, simulating a mandibular segment of bone, including an installed internal hexagon implant, supporting a retained, unitary metal-ceramic crown. The height of the installed crown was

10, 12.5, and 15mm, with a crown-to-implant ratio of 1:1; 1.25:1; 1.5:1, respectively. The application of forces was 200 N (axial) and 100 N (oblique). The increase in crown height showed differences with oblique loading in some situations. The highest tension area was concentrated in the fixation screw/implant and the connection/implant interface of crowns on implants, in the proportions of 1:1, 1.25:1, and 1.5:1, respectively. The buccal region showed the highest intensity of tensile stress, while the distal region showed the highest compressive stress in all models. The increase in the crown/implant ratio must be carefully evaluated, as this increase is proportional to the increase in mean tension, both for the fixation screw and for the bone tissue. Increasing crown height significantly influenced the level of microstrain of bone tissue under axial and oblique loading. The oblique load was more dangerous for the analyzed structures.

High bite force, bone density, and small dimensions associated with the posterior maxilla cause relatively high failure rates when short dental implants are placed to replace missing teeth. To simulate a single crown supported by a single implant, a 3D section around the first molar in the right maxillary quadrant was segmented from the full maxilla. Van Staden et al. (2014) evaluated, through FEM, four designs of different short implants, and their influence on the stress characteristics in the posterior maxilla. Bicon, Neodent, Nobel Biocare, and Straumann implant designs were used, according to the catalogs. The results showed that increased stress concentrated in the crystal bone region around the neck of the implant was attributed to the combination of the relationship between crown height and implant length and the natural inclination of the masticatory force, which induced a bending moment on the bone crest around the head of the implant itself. They concluded that special care must be taken when choosing implants for placement in the posterior region, on low-quality bone.

Monje et al. (2014) performed a systematic review to evaluate the effect of implant height on peri-implant bone loss, and the influence of other associated factors. Implants smaller than 10mm supporting fixed prostheses were investigated and the relationship between the effect of marginal bone loss size and implant height was evaluated. Additionally, a subgroup analysis compared the amount of marginal bone loss with different levels of factors, such as type of connections and type of prostheses. Among the limitations of this review, it could be concluded that short dental implants, smaller than 10mm, had marginal bone loss similar to conventional implants larger than 10mm, to support fixed prostheses.

Mezzomo et al. (2014) performed a literature review and selected articles with similar methodology, to assess failures and complications of short implants, smaller than 10 mm, supporting single crowns in the posterior region and their potential risk factor. Implant failure, proportional biological and prosthetic failure, and marginal bone loss were evaluated. They concluded that single crowns supported by short implants in the posterior region are a predictable treatment option, with reduced failure rates and reduced biological and prosthetic complications, and minimal bone loss. The use of inclined implants and distal cantilevers in prostheses can avoid the placement of implants in posterior regions and the reduction in the length of the cantilever, making it possible that a better load distribution can be achieved. But this technique requires an adequate bone volume in the anterior maxilla, for the placement of at least 4 implants, also, it must be considered that long cantilevers, with more than 15 mm are reported to be associated with the reduction of the prosthesis survival rate and implants. However, this implant inclination may also contribute to an increase in the inter-implant distance.

Bellini et al. (2009) evaluated the stress pattern at the implant-bone interface of tilted and non-tilted implants in the edentulous maxilla using a finite element model. In the "All-on-four and All-on-six" configurations, the distal implants were tilted mesially, at 30 degrees, and the position of the other implants was defined by the anatomy of the maxilla. For the conventional Branemark configuration, short implants were inserted in the most distal region. Analyzes showed an absolute value of maximum principal compressive stress, close to the cervical area, and distal to the implants, in all models. Tilted implant configurations showed a lower absolute value of compressive stresses compared to non-tilted implants, indicating their possible biomechanical advantage in reducing stress at the bone-implant interface.

Silva et al. (2010) compared, using the three-dimensional finite element method, the biomechanical behavior of the "All-on-Four" System with that of a maxillary prosthesis supported by six implants with inclined distal implants. The stresses induced on the implants, under different loading simulations, were located and qualified. In both models, in the loading simulation, the maximum stress peak was always located at the tipped distal implant neck. Stress location and distribution pattern were similar in both models. The addition of implants resulted in the reduction of maximum stress values and the use of the cantilever significantly increased stresses.

Maló et al. (2011) reported the need to create rehabilitative solutions for partial edentulism in the posterior maxilla, thus reducing the need for grafts in these areas. The results of rehabilitation of partial edentulism in the posterior maxilla with a bridge supported by two implants, an anterior one placed in the axial position and a posterior implant placed distally inclined, were reported. 35 patients with a mean age of 55.5 years, rehabilitated with an implant-supported partial bridge, were followed up between 4 months and 8 years, with a mean time of 53 months. The mean level of bone resorption was 1.05 mm at the 12-month follow-up and 1.47 mm at 5 years, and no statistically significant differences were reported between straight and angled implants at 1-year and 5-year evaluations. Among the limitations of the study, the authors reported a high rate of success and long-term survival, low marginal bone resorption to the implants, and low frequency of complications.

To avoid complex procedures, such as bone grafting in atrophied edentulous sites, Kawasaki et al. (2011) evaluated the placement of inclined conical implants. 15 patients were treated with 24 prostheses supported by 65 inserted implants. Implant locations, height, and angulations were determined by three-dimensional computed tomography data. Tapered implants and surgical techniques and modified models were used. 16 implants were positioned axially and 48 implants were tilted. Periodic follow-up after prosthetic rehabilitation ranged from 24 to 46 months. Clinical outcomes were evaluated through clinical observations and survival data. In atrophied edentulous sites, the inclined installation of conical implants, using this method, proved to be a valid procedure, without the need for more complex procedures such as bone grafting. However, prosthetic procedures are a complication. The question of whether tilted implants pose a greater risk of failure than axially placed implants has received increased attention in recent years. As treatment philosophies change over time, a periodic review of different concepts is necessary to refine techniques and eliminate unnecessary procedures.

Monje et al. (2012), through a systematic review, compared the amount of marginal bone loss around straight and angled implants. As a secondary endpoint, the incidence of biomechanical complications was compared. This study was not able to confirm the hypothesis that tilted implants that were explanted to support fixed prostheses had more marginal bone loss. Additionally, there was not enough evidence to confirm a higher incidence of biomechanical complications with tilted implants.

Peñarrocha-Oltra et al. (2013) performed a literature review to evaluate the rehabilitation of atrophic maxillae with inclined implants. Clinical studies with at least 10 rehabilitated patients and with follow-ups of at least 12 years after prosthetic loading were included. Surgical technique, type of prosthesis, time of prosthetic loading, success rate and marginal bone loss in axial and inclined implants, complications, and level of customer satisfaction were evaluated. This literature review on tilted implants demonstrated that placement with this technique, whether used alone or combined with axially placed implants, and rehabilitated with different prosthetic options, has high success rates, minimal complications, and high customer satisfaction.

Chrcanovic et al. (2015) performed a review and selected 44 publications. A total of 5029 dental implants were placed at an angle and 5732 were placed axially to test the null hypothesis of implant failure rate, marginal bone loss, and postoperative infection for patients to be rehabilitated. It has been suggested that differences in dental implant angulation do not affect implant survival or marginal bone loss. However, a statistically significant difference was found for implant failures, when studies evaluating the insertion of tilted implants in the maxilla were considered about axially placed implants. These differences were not found for implants inserted into the mandible.

Almeida et al. (2015) analyzed the stress distribution in the bone tissue around short implants and inclined implants installed with different angulations, supporting fixed prostheses and prosthetic connections in atrophic maxillas, through the use of three-dimensional finite elements and statistical analyses. Maxilla models were used, built based on tomographic images of patients, and implant models were based on micro-computerized tomographic images. Study results showed that oblique loading was more damaging to bone tissue, particularly when associated with external hex implants, and there was a higher stress concentration over the buccal region compared to all other regions under oblique loading. They concluded that distal tipping and short distal implants resulted in increased stress on the maxillary bone compared to straight vertical implants.

Wentaschek et al. (2016), to evaluate, in an in vitro study, the increase in the polygonal area of implant-retained prostheses in edentulous maxillas, used inclined distal implants and compared them to the use of straight distal implants, using a variety of heights of implants. implants. They demonstrated that, in an edentulous maxilla, the transverse and sagittal inter-implant distance, as well as the more distal presence of the connection-implant interface, results in an increase in the polygonal area of implant-supported prostheses. They suggested that the area of implant-supported prostheses could be enlarged by using angled implants, from 12 to 16 mm in height with 42 to 45 degrees, compared to the use of straight 8 mm implants.

Toljanic et al. (2016) carried out a 5-year prospective clinical study, whose objective was to make it possible to evaluate the results of using an immediate loading protocol for an edentulous maxillary arch, without bone augmentation. Individuals with edentulous maxillary arches received six implants placed in native bone. Where there was insufficient posterior bone volume, placement of angled implants was employed. Fixed provisional prostheses were delivered within 24 hours of implant placement. Implant installation sites, insertion torque value, and implant dimensions were recorded. Permanently fixed prostheses were placed within 24 weeks of implantation. Parameters of marginal bone levels at implant sites were measured using periapical radiographs as well as plaque count and peri-implant bleeding references were obtained. Subjects were examined 6 months after implant placement and then annually for 5 years with follow-up periapical radiographs and plaque counts and bleeding. Predictable long-term results were demonstrated in individuals who had total maxillary edentulism, using a rehabilitation protocol with implants in available native bone, without the inclusion of a bone augmentation procedure, and with immediate loading with fixed provisional prostheses. Despite these reported favorable results, challenges remain in planning for immediate loading with a fixed provisional prosthesis for the edentulous maxilla, due to the decrease in alveolar bone quality and quantity, and another factor to consider is that limited native alveolar bone availability may reduce the number of sites considered to be ideal for implant placement without the inclusion of bone tissue augmentation procedures. In response to these challenges, the authors suggest that favorable results can be obtained following the use of this protocol of immediate loading of implants in the edentulous maxilla, without the use of bone augmentation, with the use of angled implants.

Another described alternative is bilateral maxillary sinus floor augmentation, to allow the placement of implants in a severely atrophic posterior area. Three-dimensional finite element analysis of osseointegrated implants in a spatially complex structure, such as the augmented maxillary sinus, has been little described. Tepper et al. (2002), in a classic published study, carried out research to simulate the use of implants in a highly atrophic maxilla under load conditions, using this method. The aim was to research the amount of bone needed to graft the maxillary sinus, to provide optimal support for implants with long-term survival, and the best arrangement of graft material around implants. One point of interest was whether bone regeneration by complete or near complete peri-implant filling provided long-term mechanical and survival benefits to implants compared to implants projecting into the maxillary sinus with a very thin or absent bone covering around them, in the middle third and the extremity. Finding the ideal implant for the best anchorage in compromised host bone and stress distribution around long thin conventional implants were compared with short wide implants. Severe bone loss in the maxilla often results in a residual ridge with almost no cortical bone remaining, so implants are supported only by medullary bone. The absence of cortical bone was also evaluated by simulating the effects of implant length in non-grafted sinuses. The von Mises criterion was used to assess stresses in bone tissue and titanium implants. The highest levels of bone strain were found in cases without sufficient implant coating. In models with adequate bony implant support, intraosseous stress was generally reduced by up to 40% Results showed that greater peri-implant fill reduces implant displacement, intraosseous stress, and stress at the implant-bone interface.

Pieri et al. (2012) evaluated a surgical and prosthetic protocol for the installation of implants and immediate rehabilitation of areas grafted in atrophic maxillae, comparing them to areas with non-grafted native bone, and achieved a success rate of 98.7% for implants and for the 100% full-arch fixed prostheses, however, observed a lower implant insertion torque in grafted areas. The authors observed that the total treatment time and costs can be reduced without compromising the success rate when compared with late protocols. Safety factors for using this protocol include the use of an implant with an osteoconductive surface, under-drilling of the osteotomy sites, and stabilization of the implants with rigid and passive connections.

Hernández-Alfaro et al. (2013) conducted a study to evaluate, through cone beam computed tomography, the combined use of intraoral autogenous bone blocks and biomaterials for total reconstruction of atrophic maxilla. Consecutive cases of total maxillary edentulism treated with bilateral maxillary sinus floor elevation, block bone graft taken from the mandible, and biomaterials were prospectively evaluated. Implants were placed 14 to 16 weeks after grafting in 14 patients who participated. Cone beam computed tomography was performed preoperatively, immediately after bone grafting and at surgical re-entry. Success in the integrátion of the grafts occurred, without complications, and the results suggest that the use of mandibular bone blocks in combination with biomaterials is an effective and reliable procedure for the rehabilitation of severely resorbed maxillae. Significant volume increase and adequate stability of the enlarged areas on reentry were found, with tomographic analysis. The bone graft provided sufficient mechanical support to allow immediate provisionalization and loading. This technique provided restoration of function and esthetics, with fixed rehabilitation at 4 months.

Guljé et al. (2014) evaluated the clinical performance of single crowns in the posterior maxilla, supported by 6 mm or 11 mm implants, combined with a maxillary sinus lift. Several inclusion and exclusion criteria were established. Autogenous grafts were used, combined with xenogeneic grafts, without the use of membranes. Both 6 mm and 11 mm implants, combined with sinus lift surgery, were equally successful in supporting single crowns in the resorbed posterior maxilla, after one year of clinical and radiographic follow-up. Seker et al. (2014), in an analysis using the Finite Element Method, used computational models of the atrophic maxilla, created from tomographic images of patients, and simulated the installation of implants to investigate the biomechanical effects of bicortical fixation, and grafts in the maxillary sinus, through of variations in height, diameter, and angulation of implants in the atrophic posterior maxilla, and studied the acceptability of various treatment options for an implant-supported fixed partial denture, analyzing functional stress around implants and supporting tissues. Oblique forces were applied to simulate masticatory movements. The authors concluded that, as a consequence of bicortical anchorage, a short, large-diameter implant may reduce the stress transmitted to the surrounding bone, compared to long implants placed in a grafted maxillary sinus or placed at an angle in native bone. In cases of possible crystal bone resorption, however, the biomechanical advantage of a long implant should not be overlooked and, in cases of limited bone height, the use of a short and a long implant was found to be the most acceptable approach in the posterior maxilla. Otherwise, when long implants can be used, rather than an inclined implant, a bone grafting solution appears to be more appropriate.

Felice et al. (2015) compared long-term clinical outcomes of short implants with long implants placed using a minimally invasive approach of maxillary sinus lift through the crest to see which of the two procedures would be preferable. The objective of this trial was to compare the results of a fixed prosthesis supported by two or three short implants (5 or 6 mm) instead of long 10 mm implants, placed in crystally raised sinuses, according to the technique Cosci et al. (2000), and grafted with inorganic bovine bone. The original plan was to report data for 10 years after loading. This was the first publication made. Two groups were elaborated: 1- one to three long implants of 10 mm - placed with the maxillary sinus lift procedure through the crest (group of long implants), and grafted with granules of inorganic bovine bone, and; 2- one to three 5 or 6 mm implants (short implant group). All patients had an edentulous posterior maxilla with a residual bone height between 5 and 7 mm and a thickness of at least 7 mm. Several exclusion criteria were respected. A healing period of 4 months was expected. Among the outcomes measured were implant and prosthesis failure, any other complication, radiographic marginal peri-implant bone level change, and, where possible, the degree of patient satisfaction. All patients were followed up for one year. The authors emphasized that the conclusions of this study can apply only to patients with similar characteristics, treated with the same procedures and materials. Both techniques achieved excellent results and no difference was observed between prostheses supported by one or two 5- to 6-mm implants or 10-mm implants in an atrophic posterior maxilla, up to one year after loading. decide which procedure to use, although longer follow-ups are needed, to understand whether one of these procedures might be more effective.

Esposito et al. (2015) evaluated, in a randomized controlled pilot trial, the effectiveness of complete maxillary prostheses supported by short implants of 5.0 mm in diameter by 8.5 mm compared to long implants, of at least 11.5 mm in length, installed in the atrophic maxilla. As a criterion for inclusion in the study, the residual vertical bone height had to be at least 5 to 9 mm, and the bone thickness, at least 5 mm, when measured with computed tomography. Patients were selected also considering several exclusion criteria. In one group of patients, bone reconstruction was previously performed with a graft harvested from the extraoral region of the iliac crest, and four months after this bone augmentation procedure, a new CT scan was performed. In one group of patients, 4 to 8 short implants (5.0 X 8.5 mm) were placed and another group of patients received implants of at least 11.5 mm in length in the maxilla. The use of provisional prostheses was only allowed after one month. All patients were called for postoperative care after 30, 60, and 90 days. The implants and the removable prostheses used were identical for both groups and the implants were installed after another 4-month osseointegration period when the stability of the implants was evaluated and the provisional prostheses were made. After a further 4 months, stability was tested, and the definitive fixed full-arch prosthesis was completed. The degree of patient satisfaction, 30 days after completion of rehabilitation, was evaluated. In a total of 28 patients, 92 implants were placed in the bone augmentation group and 86 in the short implant group. There was no difference, statistically significant, for the bone level, in implants with loading and after one year of loading between the two groups, however, both groups presented gradual peri-implant bone loss. The authors concluded that one year after loading, both techniques provided effective results. However, short implants may be a preferable choice compared to long implants with bone augmentation due to the shorter treatment time required, lower financial cost, and lower associated morbidity. It was suggested that these preliminary results should be confirmed by larger trials with longer follow-ups.

Treatment with implants in the posterior maxilla is often seen as a major challenge, due to limited residual bone height and poor bone quality. Shi et al. (2015) developed a randomized controlled trial study protocol, with 5 years of follow-up, to try to answer the researched questions: what is the best treatment option in the atrophic maxilla with a residual bone height of 6 to 8 mm: short single implant of 6 mm or 8 mm implant combined with osteotomy for sinus floor elevation or conventional 10 mm implants combined with osteotomy for sinus floor elevation. The results of this trial tried to help in the best decision of treatment with dental implants in atrophic maxillary ridges. The evaluation was carried out with measurement of the resonance frequency analysis, immediately after surgery, 2 weeks later, and 3 months later, in addition to patient reports on the perception of the different procedures performed. The authors concluded, based on the results obtained, that the use of short implants can avoid additional procedures used for inserting implants, thus reducing the operative time, complexity, and postoperative discomfort.

Zill et al. (2016) reported the use of osteotomes in maxillary sinus lift to assess whether apical bone gain depends on initial residual bone height and whether initial residual bone height has an influence on the amount of marginal bone loss. Furthermore, the study aimed to assess whether Schneiderman membrane perforations or residual bone height are potential indicators of implant survival. Implants, after sinus floor elevation with osteotomes, have shown excellent survival and success rates after 5 years of loading. Apical gain of newly formed bone was positively correlated with initial bone height, showing statistical significance. However, initial residual bone height is also an indicator for implant survival, and survival is increased 1.6 times with every additional millimeter of initial residual bone height.

Bechara et al. (2016), in a randomized clinical trial, used, in the atrophic posterior maxilla, short implants of 6 mm and long implants of 10 mm or more in length, in combination with maxillary sinus lift and bone graft, to verify the viability of both clinical conduct. After patient selection, respecting several inclusion and exclusion criteria, 53 patients, 33 in the test group, received one to four short implants, and 20 patients, in the control group, received one to four graft-associated implants simultaneously, making a total of 45 implants in each group. After a 4-month waiting period for osseointegration, provisional prostheses were installed and maintained for another 4 months, and only afterward, definitive prostheses were installed. Early and late failures, after the prosthetic connection was installed, were recorded. Stability was analyzed during the installation of the implants, the installation of the final restoration, and after 1 and 3 years of treatment. Imaging exams were performed, digitized, and evaluated by software, and the mesial and distal bone loss was measured, having as reference the coronal margin of the implant, the most coronal implant/bone contact point, and to adjust possible distortions, the distance between two implant threads was recorded. The degree of patient satisfaction was also verified and statistical analysis was performed. The results showed that up to 3 years after prosthetic loading, both approaches provided good results; however, with short 6 mm implants, the treatment was faster and less costly. Furthermore, the authors suggested that a long-term, randomized controlled trial with larger patient samples is needed to confirm these results.

Finite element analysis of peri-implant stress considers a bone-implant contact of 100%, even knowing that this contact is approximately 50% or less. However, the recent development of ultraviolet treatment of titanium immediately before use, known as photo functionalization, significantly increases this contact to 98.2%. Ohyama et al., 2016, evaluated, through finite element analysis, the cortical bone abutment and medullary bone of implants with 10 mm in height and diameters of 3.3, 3.75, and 5 mm with BIC (implant-bone contact) 53% (conventional treatment) and 98.2% (photo functionalization treatment). Six models were obtained, to provide all variations in diameter and bone-implant contact. The finite element test was carried out under simulation of a load of 50 N, applied vertically, and 50 N, applied obliquely, with 45o, in the buccolingual direction. The authors reported that photo functionalization and large-diameter implants were associated with reduced stress around tissues and that under vertical loading, photo functionalization had a greater effect than larger-diameter implants in stress reduction. Under oblique loading, implants of increased diameter had a greater effect than photo functionalization in reducing stress. Under oblique loading, the images show that the stress concentration around the neck area of the implant was present on the contralateral side of the oblique force. Tension was intense under oblique loading, 2 to 3 times greater than vertical loading, regardless of the level of bone-implant contact or implant diameter. Under vertical loading, a significant increase in stress concentration was observed for the narrow implants with 53% BIC in an area that was located at the neck of the implant. During maximum main stress, no significant stress difference was observed at the bone-implant interface.

Cinar et al. (2016) conducted a study to determine the amount and location of functional stress in single-piece Straumann 4.1 X 10mm implants, placed in an atrophic posterior maxilla with type 3 and type 4 bone, in the first molar region and with crowns of three different heights, using finite element analysis. Greater compressive stress was found in the alveolar bone around the neck of the implant in the cortical bone region. Thus, this region should be better preserved during the surgical procedure. Deformation, due to stress, was most evident in cancellous bone type 4, caused by increased crown height.

Gomes et al. (2017), in a controlled clinical trial, evaluated the stability of dental implants installed in the posterior maxilla of humans in the area of premolars and molars and investigated the evolution of primary and secondary stability in three different groups: patients with native bone, patient with partially regenerated bone and patients with new bone, almost completely regenerated. All surgeries were performed following a conventional surgical protocol with an elevation of the mucoperiosteal flap in all treated groups, and the implants were positioned slightly subcrestally, from 05 to 1 mm, according to the manufacturer's recommendations. The study sample included 135 implants placed in 59 patients. The primary stability of these implants was recorded, as well as their evolution to secondary stability, in the first healing period, using two separate indices: the insertion torque (IT) and the implant stability quotient (ISQ) with measurements up to 60 days. Significant differences were found in the level of implant stability between the three patient groups (native, partially regenerated, and almost completely regenerated bone), and demonstrated that the presence of regenerated bone can negatively affect the primary stability of implants. It is important to point out that the value of primary stability, obtained in the context of clinical difficulties in this study, was very high, and that the percentage of implants with high primary stability, in this study, tended to decrease in the group of patients with bone, partially and almost fully regenerated. In the end, the implant survival rate was 98.52%, that is, 133 out of 135 implants.

Marsico et al. (2017) evaluated, using 3D finite element analysis, the stress generated on implants with different geometries (HE and HI) and surrounding bone by the application of functional load and overload on a 3-element fixed dental prosthesis in the posterior region. Occlusal splint interposition was also evaluated. Models with two 3.75 x 13mm implants, with the same connection system placed in the intact mandibular bone, in the region of the second premolar and second molar and restored with a 3-element fixed dental prosthesis, with a nickel-chromium structure, and with porcelain veneer material, were evaluated. The models with a medullary bone surrounded by a cortical bone with a thickness of 1 to 3 mm were created by the software. After preparing the finite element models, the axial load was applied on the occlusal surface of each element of the fixed dental prosthesis, being in the premolar region: a central load, with a contact area size of 1 mm2 and in molar: two equidistant 1.5 mm2 loading points, both associated or not with the occlusal splint device. Two different loads were applied: 100 N (functional load) and 300 N (overload). The movement restriction of the models was defined in other areas of the bone, to make possible the stability of the model. Maximum stress concentration between implants and bone was expressed, as well as the von Mises equivalent stress in MPa. Basic descriptive statistics were performed, as well as the complementary analysis on the color scale, in which each tone corresponds to the specific amount of tension of each structure. The authors concluded that internal hexagon implants showed less tension in the premolar and molar region than external hexagon implants under functional loading and overload and that the presence of the occlusal splint device on implant-supported fixed prostheses can be clinically useful to distribute stress towards the bone structure, aiming to maintain the implants in the long term.

Rand et al. (2017) developed a finite element model, simulating a non-linear contact, using an implant-based system with a virtual antagonist, and compared this with a conventional model that uses direct force transmission. In the conventional model, they used a bone segment with an implant and crown on the implant, including a connection, and a virtual occlusal load was applied directly on the crown of the implant (linear simulation) in the advanced model, a natural tooth together with its periodontal ligament was designed to act as an antagonist for indirect force transmission (non-linear simulation). Then, the model simulated the location of the occlusal contact area and frictional forces of the opposing occlusal surface in combination with physiological tooth movements under occlusal loading. In addition, the design of the cusps was slightly altered to allow for a variation in the number of occlusal contact areas. The authors concluded that among the limitations of this three-dimensional finite element study, in all contact situations, both with direct and indirect force transmission, the maximum and minimum principal stresses were always located in the cortical bone, along the bone-implant interface. The analysis of non-linear contacts always found a higher value of peri-implant bone tension than the linear analysis, and the phenomenon of sliding and friction in the model with indirect force transmission was considered closer to reality. Non-axial forces on the implant induced peaks in the peri-implant bone and were most often caused by single contacts, and non-axial forces resulted from unevenly distributed contact areas, especially in situations with only one contact, and recommended that single contact on the inner slope of the cusp should generally be avoided.

To investigate the functioning of different connections, Cho et al. (2018) evaluated using the three-dimensional finite element method, the stress distribution in an implant-connection set with preloading of the connection screw, comparing their fitting characteristics. Different models of implants: a single implant, two parallel implants, and mesial and distal implants inclined with the simulation of 1 mm of bone loss were proposed. A static axial force and an oblique force of 200 N were applied to the top of the occlusal prosthetic surface, with a preload of 30 N.cm on the connecting screw. The von Mises stress on the connection-implant assembly and the connection screw interface was measured. In the single-implant model, the conical-type connection demonstrated a wider distribution of stress than was demonstrated in the hexagonal connection. In the double socket system, the stress concentration was high in the lower contact area of the connection-implant socket. In the tilted implant model, the point of stress concentration was different from the parallel implant models, because of the difference in bone level. The authors concluded that the double socket system demonstrated a high-stress concentration in the lower area of the implant-connection interface and that, to decrease this stress concentration, the type of socket device should be carefully selected.

Increased bone stress and decreased implant stability are associated with low bone density, while high bone density improves the transmission and distribution of stress from the implant to adjacent bone. A common way to reduce this bone stress is to increase implant dimensions. Based on this, Linetskiy et al. (2017) evaluated the impact of annual bone loss on different bone qualities, with bone types I to IV, considering the success and duration of dental implants, and evaluating the functional load of bone loss, through a finite element study. The von Mises stress and the maximum principal stress distribution at the implant-bone interface were studied, and the final functional load was calculated. Nine three-dimensional geometric models with an inserted implant were generated, using computed tomography images to determine cortical bone thickness for four types of mandibular bone. In the first part of the study, it was defined that the implants were completely osseointegrated and placed in the middle of the bone segment. In the second part, a more critical bone loss scenario was analyzed: ten levels of annual bone loss from 0.2 mm to 2.0 mm were simulated. The authors concluded that, with bone loss, priority should be given to the choice of adequate implants, preferably to deal with bone types I to III. Furthermore, the longevity of implants in bone types II and III depends on the period of peri-implant cortical bone loss. Due to the occurrence of bone loss, type IV bone was, in this study, less suitable for implant placement. To achieve a high success rate in oral implantology, clinicians should consider the effect of bone loss on the durability of the implant-bone assembly.

Moraes et al. (2018) compared the effect of varying diameters, connection types, and loading conditions on stress distribution in cortical bone and in implants with a high crown-to-implant ratio. The three-dimensional finite element model was built on a bone block of the mandibular area, around a second molar with trabecular bone, and was surrounded by a 1 mm cortical bone. 6 models were built, 2 with an external hexagon connection, 2 with an internal hexagon connection, and two with a morse cone connection with two diameter variations:

3.75 mm and 5.0 mm, and the crowns were simulated, screwed to Hex connections, and HI and cemented for Morse taper connection with a height of 15 mm, resulting in a high ratio of 2:1 for all models. A load with an axial force of 200 N was applied at four points on the cusps, and the oblique load was divided into two points on the lingual cusps with 100 N. The results showed that, regardless of the type of connection, implants with larger diameters behaved more favorably in biomechanical performance, when compared with implants of regular diameter, mainly with oblique loading. Morse taper implants were biomechanically more favorable than other connections, especially during oblique loading, and external hexagon implants, under oblique loading, showed higher stress in cortical bone tissue, regardless of diameter. In the analysis of different regions (mesial, distal, buccal, and lingual) under axial and oblique loading, the proximal region (M and D) had higher compressive stress than the buccal and lingual areas, for both connections.

CONCLUSION

It can be concluded from this study that according to the information collected by the literature, in conditions where the oblique load is more angulated, it is suggestive of greater damage to the bone structure. About prosthetic components, structures that are adapted to a short implant present better mechanical behavior. Last but not least, the stresses in the cortical bone showed higher values for the tilted implant and lower values in the model with bone graft. However, more research is needed to better understand this material and its long-term clinical behavior.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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