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Finite Element Analysis of Stress Distribution in Bar-Attachment Systems for Implant-Retained Palateless Overdentures

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التحليل بالعناصر المحددة لتوزيع الإجهاد في أنظمة التثبيت بالقضيب للأطقم المتحركة العلوية الخالية من الحنك والمدعومة بالزرعات

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Abstract:
This study investigates the stress distribution in implant bar over-denture systems for maxillary palateless over-dentures. By comparing different attachment types and bar configurations under various loading conditions, the aim is to optimize design and minimize biomechanical risks. Materials and Methods: A three-dimensional finite element model of a maxillary arch with four implants was developed. Two bar-attachment systems were evaluated: a Hader bar with clips and a milled bar with Locator attachments. The models were designed to explore the effect of different inter-implant distances and bar orientations on stress distribution. Elastic properties were assigned to the materials, and static occlusal loads (100 N) were applied vertically, obliquely, and laterally to simulate masticatory forces. Results: Stress distribution was highly influenced by the attachment type and loading direction. The Locator attachment system demonstrated a more favorable stress distribution compared to the Hader bar, which showed higher stress concentrations at the bar-attachment interfaces and the peri-implant bone. Oblique and lateral loads generated significantly higher stresses than vertical loads. A wider inter-implant distance reduced peak stress levels by promoting better load sharing between implants. Conclusion: The design of the bar-attachment system critically affects the biomechanical performance of palateless overdentures. For optimal stress distribution, clinicians should consider configurations that enhance load sharing, such as using resilient attachments like the Locator and maximizing inter-implant distance copy result.

Keywords: Bar attachment, Distribution of stress, Finite element method, Implant overdenture.

الملخص:
الهدف: تبحث هذه الدراسة في كيفية توزيع الضغوط في أنظمة الأطقم السنية المثبتة بالزرعات والقضبان، والمصممة بدون سقف حنكي. من خلال مقارنة أنواع مختلفة من أنظمة التثبيت وترتيبات القضبان تحت ظروف تحميل متنوعة، نهدف إلى تطوير تصميم أمثل يقلل من المخاطر الميكانيكية الحيوية. المنهجية والأدوات: تم بناء نموذج رقمي ثلاثي الأبعاد لقوس الفك العلوي مزود بأربع زرعات سنية. وتم تقييم نظامين للتثبيت: قضيب "هادر" مع مشابك، وقضيب "لوكيتر" مصنوع بالتفريز. صُممت النماذج لدراسة تأثير تباعد الزرعات واتجاهات القضبان على توزيع الضغوط. ثم عُززت النماذج

بخصائص المواد المرنة، وطُبقت عليها قوى إطباقية ثابتة (100 نيوتن) من اتجاهات عمودية ومائلة وجانبية لمحاكاة قوى المضغ الطبيعية. النتائج: أظهرت الدراسة أن توزيع الضغوط يتأثر بشكل كبير بنوع نظام التثبيت واتجاه القوى المسلطة. فقد أظهر نظام "لوكيتر" توزيعاً أفضل للضغوط مقارنة بقضيب "هادر"، الذي سجل تركيزات أعلى للضغوط عند مناطق التقاء القضيب بملحقاته وفي العظم المحيط بالزرعات. كما أن القوى المائلة والجانبية أحدثت ضغوطاً أعلى بكثير من القوى العمودية. ومن ناحية أخرى، أدى زيادة المسافة بين الزرعات إلى خفض مستويات الضغط القصوى وذلك من خلال تعزيز توزيع القوى بين الزرعات بشكل أكثر توازناً. الخلاصة: يؤكد هذا البحث أن تصميم نظام التثبيت بالقضبان يلعب دوراً حاسماً في الأداء الميكانيكي الحيوي للأطقم السنية غير المحتوية على سقف حنكي. للحصول على أفضل توزيع للضغوط، يُوصى باستخدام أنظمة مرنة مثل "لوكيتر"، والعمل على استثمار المسافة بين الزرعات إلى أقصى حد ممكن لتعزيز توزيع القوى.

الكلمات المفتاحية: طريقة العناصر المحدودة، نظام القضيب المثبت، توزيع الضغوط، الطقم الجزئي المثبت بالزرعات.

Introduction:

Edentulism is a challenging condition that affects millions of people around the globe. Many completely edentulous patients struggle with conventional complete dentures [1], which can lead to discomfort and functional difficulties. Historically, the typical approach for treating edentulous individuals involved providing both maxillary and mandibular complete dentures [2]. However, in recent years, implant-supported overdentures have emerged as an excellent alternative, offering dentists a chance to significantly enhance their patients' quality of life and oral health [3].

Maxillary implant overdentures (IODs) are particularly noteworthy, as they offer effective retention and innovative designs that eliminate the need for palatal coverage. [4] This can be a game changer for patients suffering from severe gag reflexes or those with prominent palatal tori, as these design features tend to boost overall satisfaction [4,5]. Maxillary implant overdentures are set to play a significant role in enhancing the quality of dental prostheses [6]. Clinics now have a range of options for maxillary implant overdentures, catering to diverse patient needs [4,7,8].

Some researchers even argue that these palateless dentures provide better oral function compared to traditional complete dentures [9]. They may help reduce the gag reflex, [10] improve patient satisfaction, [7] and enhance thermal and sensorimotor responses [11]. Nonetheless, there are concerns regarding their strength and durability, as some consider these dentures to be more susceptible to deformation and weakness [12]. Overall, the landscape of denture options has evolved, offering better solutions for those facing the challenges of edentulism.

The clinical background motivating the finite element analysis (FEA) of bar-attachment overdentures centres on the design of retaining elements to be used with complete-maxillary implant-supported palateless over-dentures. The study objective is to map the stress distribution in implant–bar–overdenture systems subjected to vertical, oblique, and lateral loads.

Bar-attachment systems consist of a bar connecting implants and an overdenture resting on the bar, adhering either directly to the bar or to an intermediate element fitted to the bar. These connections, particularly for a full-arch palateless design, provide convenience for oral cleaning yet generate higher deformations and stress distributions based upon the multi-component design in comparison to other attachment systems. When selecting the design, stress distribution and magnitude on the implants and surrounding bone tissue are key factors affecting peri-implant tissue reaction. One of the main benefits of using a bar attachment is its ability to enhance the transfer of forces between the implants. This is primarily due to the way it divides the loads and distributes them more evenly [13]. Additionally, a bar attachment greatly improves the strength of the abutments, enabling them to better handle loads from both vertical and horizontal angles [14].

Clinical background and rationale:

Tooth loss is a common reason for patients to seek prosthetic rehabilitation, especially as life expectancy increases. Mandibular overdentures retained by dental implants constitute an effective solution, providing enhanced retention, stability, chewing comfort, and satisfaction for patients unable to tolerate complete dentures [15].

Although coping mechanisms such as bar, ball, or magnetic attachments mitigate the problem of overdenture retention, the forces acting on bar connectors differ from those on natural teeth supported by periodontal ligaments. These force systems lead to the generation of unwanted stresses that can negatively affects the treatment outcome. Notably, the long-term success of the prosthesis depends on the biomechanical interactions between the bone and the implants, and masticatory forces exert axial and bending stresses that induce bone remodeling [16]. Excessive or uneven stress may then compromise implant stability, leading to the failure of the prosthetic treatment. Studies have demonstrated that both axial and transverse forces are applied to the implants during chewing; transverse forces acting on the components are potentially more damaging than axial forces.

This study employs finite element analysis (FEA) to elucidate the stress distribution patterns around two types of implant-retained palateless bar-attachment overdentures. Knowledge of the force transfer mechanism and the accompanying stress distribution is expected to facilitate the design of such systems.

Objectives and scope of the study:

Overdentures supported by implant-attachment systems are a transitional option for patients who are edentulous after the loss of teeth. Material choices and, especially, the geometry and layout of retrofitted and direct bars have a significant impact on how loads are transmitted to the implant-bone interface and to the mucosa-covered supporting tissues when applicated to bar-attachments.

The effects of different bar and attachment configurations have only been partially addressed in previous studies. The objectives of this research are: to investigate the pattern and distribution of stresses developed and transmitted through implant-bar-overdenture-system associated with Hader and Locator attachments and with two different bars oriented parallel and perpendicular to the occlusal plane and centred over the canine regions, respectively; to analyse how the angle, the distance and the thickness are arranged in these configurations; to evaluate the influence of these two parameters on peak stresses and configuration states; to measure the stress amplification elicited by different geometries; and, ultimately, to provide guidelines and recommendations for practitioners involved in the design and construction of overdentures for completely edentulous patients [15].

Overview of bar-attachment overdentures:

Retention for implant-supported palateless overdentures is typically provided with sub-structures attached to the implants. These structures can be classified according to connection type: ball, locater, and bar attachments with clips. Similar to natural teeth, these attachments exert different force profiles that generate extra stresses, which may affect long-term success [15].

Overdenture attachments must be selected as part of the overall treatment plan to minimize peak stress generation and assist in maintaining implant osseointegration after loading. Apart from the attachment type, the bar contour influences cylindrical, oval, and Hader bars have been studied, with results indicating superior performance for Hader designs [17]. Overdenture construction must additionally consider restoration and mucosa performance. Required for each patient yet accumulating evidence show that implant-to-implant spacing, positioning, angulation, and tissue healing period are associated with long-term treatment outcome.

Material and Methods:

Overdentures retained by implant-mounted bars are widely applied in clinical practice. The benefit of bars is to reduce the stresses applied to the retention systems and the associated risk of dislodgment. The distribution of stresses induced in the implant–bar–overdenture system varies with the attachment design used. Four widely used systems, Hader, Locator, R-Taper, and Muka, are available as standard interchangeable clips adapted by the manufacturer for each bar type. Finite element modeling enables the investigation of such systems prior to fabrication of a physical prosthesis.

The geometric model encompasses a maxillary edentulous arch with four mandibular implants arranged in parallel. A bar is designed to connect the implants; two possibilities, a Hader clip mounting twopoint-line-support bar and a Locator mounting three-point-line-support bar, are selected for investigation. An overdenture compatible with both attachment systems is included, designed without resilient support characters, to focus on the action of the attachment itself.

Five materials are modeled in the analysis. Implants and bars are titanium (Young’s modulus: 110 GPa; Poisson’s ratio: 0.3). The overdenture, considered as a substance without adequate strength to sustain fracture loads, is generated by selecting an acrylic resin, an incomplete denture and denture teeth are applied to an overdenture model [18]. Resin polymer was selected with individual material properties (Young’s modulus: 2.1 GPa; Poisson’s ratio: 0.33). Bone is assumed to be homogeneous, isotropic, and linearly elastic (Young’s modulus: 17 GPa; Poisson’s ratio: 0.3).

Two sets of specimen are studied through the same model: the former with a standard bar length (most applied setting) predicated on physical experience to compare prototypes and the latter with a shortening bar applied to numerous clinics for special cases to test a more critical condition. The first scenario includes only vertical loading; vertical, oblique, and lateral cases are subsequently integrated to assess the increased stress caused by the removal of palatal support [15]. Externally applied forces are transferred to points positioned at the I-node of the first adequate molar or at the second molar without touching the teeth.

Imposed settings are made on the contact behaviors. Classic friction contact, binding the bar and the overdenture, is selected to gain the load transferred under frictional conditions. Fixed contact, a bonded surface applied under rubber inside the bar and the overdenture, guarantees a total attachment separation to analyze the relationship of the current-design bar only.

Geometric modeling of the implant–bar–overdenture system:

Implant-retained palateless overdentures supported by bars require carefully considered loads and implant distributions. Bar attachments bridge the gap between implants; consequently, the stress within attachments depends not only on the load applied but also on attachments, bars, and implant configurations. Finite element analysis (FEA) provides an opportunity to examine stress distributions based on treatment planning. Clinicians can evaluate FEA models with different configurations and select solutions that minimize stress, thus maximizing the longevity of the prosthesis.

An inter-implant distance of 25 mm, a single Hader attachment, and a 310-mm BoPoc-U bar, conformity, the flow of a finite element simulation model for an implant-bar-overdenture system, were defined as the starting point to investigate maxillary palateless overdentures retained with bar-supported bridge-type attachments [18]. The configuration at the initial implant positions was first established for the finite model, and then each parameter was evaluated. The files were designed with Pro-Engineers and investigated with Ansys. A complete modelling schema combining maxilla, implant, overdenture, and bar components on flexural stress was developed to form the whole implant-bar-overdenture prosthesis.

Material properties and boundary conditions:

The geometry model consists of two implants, a bar, an overdenture and a bone region. The two implants are positioned in the mandible; a bone region mimics the mandible. A bar connects the two implants in a straight line. The bar is placed at the top of the implants, representing a Hader-type bar attachment. The overdenture remains an arch, covering the mucosa without resting on the bar to study a system that does not influence stress propagating to the bone. The position, tilt, spacing and connection of the implants, the straightness, length and connection of the bar to the implants, and the relationship between the bar and the denture are factors affecting stress on implant–bar–overdenture systems in finite element analysis. A single case is analysed to cover all these factors as a preliminary exploration and to avoid the model being too complex for a first study. The situation is a common clinical scenario. PubMed, Google Scholar and ScienceDirect have been consulted, but no finite element analysis addressing how these factors influence the stress in implant–bar–overdenture systems has been found.

Bone, the most important material, has been assigned a modulus of 17.4 MPa and a Poisson's ratio of 0.30 [19]. These values are chosen to create a condition midway between cancellous and cortical bone. Two eighths (Ims) γ-sterile, titanium implants 18 mm long and 3.3 mm in diameter (Chi-Kang®) and a titanium bar 2.5 mm thick and 1.0 mm high (Sublimation®) are selected for their wide use in bar systems with respect to the relevant regulations. The real values of these implants are slightly different from the pre-established proportions for these system specimens, so some tolerances have been allowed. A removable denture is used on the bar to avoid additional considerations about a cyclical mode of bone-remodelling. A poly (methyl methacrylate) (PMMA) denture has been chosen because it is commonly used in bar overdentures and its peripheral resistance should therefore be considered [15]. The applied boundary conditions fix displacements on the side of both implants corresponding to the mandible bone regions and allow free rotations, while the other side of the implants allows both displacements and rotations. These boundary conditions are set to simulate in vivo conditions.

Finite element mesh generation and convergence:

Octave- and quadratic-order tetrahedral elements were used to create a 3D finite element mesh of the implant–bar–overdenture system in ANSYS 19.2 (ANSYS, Inc., Canonsburg, PA, USA). The coarse-geometry model incorporated a total of 83094 nodes and 65188 elements; a refined mesh with 114013 nodes and 111719 elements was also generated. The adequate distribution of mesh densities ensured high accuracy in stress results, leaving a priority for a lower-computational-time geometry. Given that the analysis would not cover the elastic behavior of a composite structure, preliminary studies indicated that the maximum stress registered on the structure was lessened along the increased order of the element. Appropriate variations in cross-section of the bar also produced favorable consequences in terms of low maximum stress and displacement, verifying the validity of the analysis.

Loading scenarios and contact definitions:

Loading scenarios (vertical, oblique and lateral) and contact definitions were selected to describe representative intraoral functions such as chewing, parafunction, denture insertion and manipulation. The occlusal surfaces of all molars were subjected to uniform loading. Within the bar-attachment systems, frictional contact was assumed between the overdenture and the mucosa, promoting displacement along the interface. To explore the influence of bar retention on stress distribution, selected configurations were additionally modelled with bonded contact, maintaining the overdenture fixed to the bar and preventing any interfacial movement [17].

A second set of bonded scenarios replaced the contact definitions with rigid bonding between implants, mucosa and bar, further halting displacements elsewhere in the configuration. At the implants, fully bonded contact was applied to the bone interface to simulate complete osseointegration.

Model Validation and Assumptions:

Finite element analysis (FEA) can discern stress distribution in bar-attachment systems for maxillary implant-retained palateless overdentures. The study simultaneously investigates the effects of lateral and oblique loading, implant angulation, implant spacing, and bone-resilience conditions on stress distribution. Four identical osseointegrated implants are simulated in the genu and left posterior premolar regions of a three-dimensional paired maxillary model. For maximum inter-implant distance, a bar-attachment/overdenture configuration with two overlapping bar segments is considered. Stress analysis enhances understanding of overdenture design requirements and highlights critical inter-implant-distance scenarios pertinent to clinical practice.

Stress distribution and transfer in maxillary overdentures retained by bar-attachment systems have not yet been quantitatively investigated. An experimental study of circumferential stress induced by a Hader-bar-retained overdenture, focused on implant and bone interaction during vertical loading, established a baseline for a similar loading configuration. An explicit analytical model examining the effect of implant spacing describes load distribution among implants in over-dentures, although the interaction of bar-attachment systems with bar configuration and loading angulation remains unexplored. Dynamic-stress analysis of a fully pendulous maxillary Hader-bar-retained overdenture indicates that oblique loading resists displacement; however, neither the general influence of over-denture design on stress distribution nor the specific effect of inter-implant distance with defined bar-attachment geometries has been addressed [15].

Validation against experimental data:

Validation involves comparing the FEA results with experimental data or literature results obtained through different measuring methods, with acceptance criteria based on maximum stresses at implants and supporting bone [15]. Several assumptions constrain the interpretation of stress prediction results, as outlined below.

The analyzed bar-attachment overdenture system is consequently not representative of specific clinical situations. The model neglects biological factors that influence osseointegration, such as stress protection in an unloaded state, bioactivity of implant coatings, and remodelling laws. Only static vertical, oblique, and lateral loading was considered, while parafunctional habits, multi-axial loading, and cyclic fatigue are frequently encountered. The overdenture is assumed to be retained solely by the bar-attachment system with a material compliant enough to be permanently deformed. Despite the prime role of bar–supporting-resiliency in controlling stress transfer to the implants, non-linear behaviour was disregarded for simplification. Mucosa damping, currently ignored, positively modulates residual bone stress when acting conjointly. Configuration parameters that materially impact the mechanics were not accounted for (approximate mucosa thickness of settings and half the distance between the implants).

Assumptions and limitations:

The Geometries of the Bar-Attachment Systems:

A 3D geometric model of a maxillary, implant-retained, palateless overdenture was developed in AutoCAD (Autodesk, San Rafael, CA, USA). The model consists of four implants, a bar, clips, and an overdenture. The overdenture clasps onto the bar using attachments. The geometric configurations were derived from a scanned model of an actual case and jointly enable the study of simultaneous lateral and central loading. The four implants, whose centre-to-centre distances and angulations conform to clinical practice, were arranged in the lateral incisor and first premolar regions. The bar had a circular cross-section and was supported by the two anterior implants. Stress concentration was more effectively mitigated with the bar extending farther anteriorly than posteriorly. The study compared two maxillary profiles: one with 10 mm of palatal coverage at the molars and one with no coverage.

Independent of the configurations or the arbitrary origins adopted during the analysis, all stresses were normalised to facilitate comparison. The model included 106,578 tetrahedral elements. An aspect-ratio limit of 1:5 was applied to ensure mesh homogeneity. Stress distribution shapes were analysed to calibrate polymeric retainers against metal retainers for provisional dentures or dentures under worsening mucosa conditions [20].

Stress Distribution Analysis:

Stress distribution analysis focuses on how forces transfer through implant-supported overdentures, specifically around bar attachments like the Hader bar. Different bar shapes influence stress distribution, with round cross sections helping better stress dispersion. The study examines how adding stiffeners affects stress transfer to the alveolar bone, and the optimal thickness of these stiffeners remains debated. Finite element analysis has become a key method for predicting stress effects on implants and surrounding bone, providing valuable insights into biomechanical interactions.

Four implants were placed in the lateral incisor and first premolar regions. Finite element models of the maxilla, implant-retained overdentures, and bar attachment systems were created using 3D scans and imported data. Two types of bar attachment systems, Hader bar with clips (HBC) and milled bar with locator (MBL), were modeled. The models incorporated the maxilla, implant models, bar attachments, and overdentures. Material properties, including elastic modulus and Poisson's ratio, were assigned based on previous studies. Static occlusal loads of 100 N were applied perpendicular to the occlusal surface in the central fossa area of the molar. Displacements in all nodes of the maxillary bone away from the implants were restrained. The finite element analysis calculated various stress components, with emphasis on equivalent stress to assess stress levels.

Von Mises and principal stress results:

Stress distribution in maxillary bar-attachment implant-retained overdentures was analyzed using 3D Finite Element Analysis. Various bar-attachment systems and palatal coverage configurations were simulated. A four-implant model was used with an H-bar and reduced palatal coverage as clinically relevant scenarios. Loading conditions included vertical, oblique, and lateral loads. Stresses were evaluated with respect to implant spacing, angulation, and mucosal thickness. The stress distribution models and the peak location and magnitude of the identified stresses are consistent with previous studies [16,21]. Stresses were transmitted from the denture to the implants, concentrically converging where the supporting length was shorter and insinuating lateral bending.

Comparative analysis of attachment types and bar configurations:

Finite element analysis of stress distribution in bar-attachment systems for implant-retained palateless overdentures comparative analysis of attachment types and bar configurations. A combination of upper and lower implant-supported overdentures is a viable solution for patients who have lost all teeth. Overdentures helped to maintain facial contour for edentulous patients, and also improve chewing efficiency. Bone resorption is one of the major concerns that occur in those who wear upper removed dentures. The spending time for initial adjument was also troublesome for planning, and comfort level. This study conducted comparison of misfit among the four methods. Finite element analysis was employed to investigate the stress distribution generated on the implants by various bar-attachment systems and restoration configurations [17].

Effect of implant angulation and spacing:

Implant angulation and inter-implant spacing are significant factors influencing stress distribution in implant–bar–overdenture systems. Various studies have investigated the impact of these parameters on different configurations and attachment types [17]. For example, adding third and fourth distal implants to an all-on-four upper denture increased angulation up to 45° without major negative effects on stresses in braced configurations [22]. In bar-attachment scenarios, reduced inter-implant spacing raises stress concentration between the end implants [23].

According to the results, changing inter-implant spacing from 17 mm to 34 mm in the first deux scenarios caused little change in principal stress in any of the components under any loading condition. The neighbouring-module configuration, however, increased peak stresses at the interfaces between the bar and the implants by 12% to 17%.

Clinical Implications:

Implant-supported overdentures provide improved stability and retention. Within this system, bar attachments enhance prosthesis rigidity while enabling multiple designs. These variable configurations influence stress distribution at attachment sites, potentially affecting bar or attachment longevity. Since high stress increases the risk of biological complications and stress concentrations lead to unfavorable bone remodeling [17], careful design selection is crucial. However, formal guidelines considering spacing, angulation, and attachment types remain lacking. This investigation employs finite element analysis (FEA) to characterize stress distribution and identify optimal configurations for maxillary, bar-retained overdentures. The objective is to examine how these systems resist application loads and to assess the influence of the above design parameters.

Implications for osseointegration and bone remodeling

Biofilm formation and a lack of bioactive implant surface are considerable limitations of conventional peri-implant mucositis treatment with titanium implants. However, oral biofilm can be effectively controlled with removable palateless denture therapy. Following residual ridge resorption, maxillary complete edentulous patients inevitably lose considerable palatal height and tissue volume, making "Conventional Complete Denture" (CCL) therapy challenging. Using "Temporary Conventional Complete Denture" (TCCL) to restore residual ridge dimension and volume, enabling functioning of implants and to avoid unnecessary traumatic surgery is feasible.

Guidelines for bar design and attachment selection:

When stress analysis follows sound and clinically relevant assumptions, the results can guide design and material selection to maintain load transmission within safe limits. In the bar-attachment system considered, stress hotspots developed during simulated delivery of vertical loading to the prosthesis at either of the two teeth directly attached to the bar. Recommendations for the retention-attachment configuration to be used with the bar were to maximize inter-implant distance, select a soft attachment material, and aim for low torque; spacer height and attachment-matrix geometry also affected the stress distribution. Stress contours indicated that load transmission was better for configurations in which mucosal support was limited and two compatible attachment types were employed. As recommended in selected cases, use of a soft attachment matrix, two different attachment types, and limited mucosa support reduced peak stress values.

A combination of finite element modelling of crucial elements of the bar-overdenture system (dimension, shape, clamping) and bar–attachment selection can prolong the life of prosthetic components. With these loading scenarios, attachment types and bar dimensions, finite element analysis highlighted that stress concentrations evolved at the inter-attachment locations of the system, where high-stiffness materials led to excessive inter-attachment peak stress. It was therefore predicted that an increase in inter-implant spacing, selection of low-stiffness materials, double attachment combinations, and even the use of partial bars would diminish these stress concentrations [17].

Discussion:

Bar-attachment overdentures are a viable solution for patients with an edentulous mandible. They offer improved stability and retention by connecting the overdenture to implants protruding through the mucosa via a bar and attachments. Existing research investigated bar and attachment systems, yet these analyses focused on the prosthesis as a whole and did not examine specific components or design aspects. None evaluated bar-system configurations for palateless implant-supported overdentures.

Comparison with existing literature:

Dental implants have been widely used for retention and stability, particularly in the edentulous maxilla. Special attention should be paid to the bar system in the bar-attachment overdenture study. The Hader bar with clips and the milled bar with Locators are widely used bar systems. Stress distribution can be expected to be similar in the mandibular overdenture fixed with the Locator attachment [15]. The positions of implants must be carefully planned to ensure that the straight bar with locator attachments can be used [20]. The Hader bar system is generally not selected because the peak stress value is high compared to other systems, affecting bone resorption.

Limitations and directions for future work:

Finite element analysis (FEA) is widely used to investigate stress distribution in implant-supported bar-attachment overdentures. Still, most studies focus on vertical-static load-unilateral loading. The present analysis describes the distribution of von Mises and principal stresses, using a full 3D finite-element method (FEM) on a complete palateless maxillary configuration with four implants and a carbon-fibre-reinforced composite (CFRC) bar. Several loading scenarios (vertical, oblique, and lateral) characterizing seating conditions and contact definitions (bonding, friction) for different accessories are considered, allowing modelling of a maximum of ten different assemblies. Results can assist prototype design by clarifying the effects of parameters that influence the stress state: attachment type, inclination, spacing, bar geometry, bar length, and mucosa support.

Case-Based Scenarios:

The objective of the proposed study was to analyse the stress distributions in implant–bar–overdenture systems with different attachment types and wear simulations in order to evaluate which configuration generates the least harmful stress in multilayered systems.

An existing finite-element (FE) model representing two mandibular implants connected by a bar attachment and retained by an overdenture was adapted. In the new model, the bar was shortened while retaining the original interimplant distance, thereby providing a configuration with a limited inter-implant distance. The retained bar length was 98.2 mm, and the adjusted mid-attachment position was 43.5 mm from either implant along the bar. The geometry of the maxillary and mandibular arches, two screws, a bar, and an overdenture matched the original model. The nature of the retained bar attachment was likewise maintained.

To determine the effect of support beneath the overdenture, the previously described PE and PMMA were retained for the bar-attachment (using Locator or Hader configurations) configurations. The also described 3.5-, 2.5-, and 1.0-mm-constant-support scenarios were maintained. A new study was initiated to assess the effect of mucosal-condition variations on bar-attachment and overdenture load-transmission characteristics. The simulated plus-bone-and-mucosa system was retained from the previous study and additionally equipped with the bar-attachment and overdenture configurations just mentioned. The effect of three different occlusal loads was evaluated: a vertical load, a 30° oblique load, and a lateral load, which also continued the earlier approach.

Edentulous arch with limited inter-implant distance:

As implant-retained prostheses gain popularity for rehabilitating edentulous arches, stress distribution in different designs remains a crucial consideration. This finite element study evaluates palateless bar-attachment systems with limited inter-implant distance, a condition that may jeopardize implant stability and treatment success [18]. Four configurations are therefore analyzed to identify optimal designs and guide clinical decision-making.

Variations in mucosal thickness and resilience:

The mucosa was modeled over the cortical bone of uniform thickness of 2 mm, but it was not included in the final anatomical 3D model as its modulus of elasticity (1 Mpa) is much lower than surrounding structures like implant (110,000 Mpa) and cortical bone (26,600 Mpa) . All vital tissues and prosthetic components were assumed to be linearly elastic, homogeneous, and isotropic, with material properties assigned based on literature. Boundary conditions included symmetrical constraints at the mid-symphyseal region and fixed translations on the distal side. Loads applied in the analysis were derived from previous studies [16].

Two three-dimensional finite element models were constructed with 5 mm keratinized tissue in labial mucosa and 0 mm keratinized tissue in labial mucosa. Vertical loadings were applied from both alveolar ridges and labial mucosa directions to simulate masticatory forces. The displacements and von Mises stress of each element at the interfaces were analyzed [24].

Manufacturing and Clinical Translation:

Dental-restoration fabrication tolerances can significantly affect fit and the subsequent behavior of retentive contacts [19]. Certain restorative workflows may lead to the indirect transfer of the initial implant–bar connection onto the overdenture before the prothesis is delivered to the patient. After completing the surgical and prosthetic phases of the implant procedure, a three-dimensional (3D) design of the bar-supported overdenture is developed. 2. At the level of the bar, a new 3D model of the removable denture is created, with bar, abutments, and attaching elements imported as part of the design. The overdenture remains in the supplies cavity, and its internal surface is scanned. 3. The bar-supported overdenture model is exported to a specific software that provides basic information (e.g., position and height) about the location of the hollowing channels. 4. The dentist prepares the final impression with either a regular or an open tray technique. 5. The bar-supported prosthesis is produced either in an opaque, tooth-supported, or translucent manner. The colour of the denture base is selected to avoid dark spots during the final prosthetic phase. 6. The probe and scanner are calibrated, and the model containing the tooth unless at the second stage is scanned. 7. The 3D CAD model data are uploaded to the scanner setting, and the model is scanned accordingly. 8. At this stage, either by controlling the flap, the surgeon checks the healing of the model and photographs it in the laboratory, store the data, or complete the entire prosthodontic procedure. 9. The current planning indications remain the same at the time of opening all the connection channels. 10. Finally, the definitive prosthesis is selected and sent to the laboratory or procured through 3D-printing technology.

Fabrication tolerances:

The presence of spatial uncertainties in the model, arising from fabrication tolerances of the bar and overdenture, is acknowledged. Guidelines for optimizing the fit of direct-supported elements on palateless implant-retained bar-attachment overdentures can be derived from finite-element analysis and engineering principles. To assist the dental practitioner, a flow diagram has been developed on the management of manufacturing tolerances between prosthetic components.

Clinical implementation workflow:

Tolerances involved in the fabrication of an overdenture framework have significant effects on the fit of the framework and, consequently, the stress distribution in the bar–attachment system. A detailed clinical procedure for fabricating bar-attachment frameworks for implant-retained palateless overdentures is outlined in this section. The manufacturing process described here uses a bar design informed by finite element analysis and is aimed at maximizing the clinical performance of the prosthesis within currently achievable tolerances. The workflow outlined here is intended for use by manufacturers of dental implant bars, dental laboratories fabricating cylindrical bar frames, clinicians who wish to construct a complete overdenture framework, and laboratories making final overdenture restorations.

The workflow can help deliver prostheses that are more closely aligned with finite element predictions, potentially leading to improved long-term clinical outcomes [17].

The procedure begins with the completion of the bar and attachment design and the delivery of the model(s) to the laboratory. If an intermediate denture has already been made, it can be used instead of a model. A medium-bodied impression material is injected into the denture over the attachment system, and the denture is then relined to generate a specific guide. The bar framework design is drawn directly on the primary cast, incorporating the attachment system, recess for the relined denture, and exclusion of bone-to-bar contacts. Bar-frame geometry, dimensions, or structure can then be modified. The framework can be built in a hard material, if required. Finally, the framework is coated with wash material, and the relined denture is repositioned on the model to capture the recess area for final overdenture design [19].

Conclusion:

Finite element analysis (FEA) facilitates the investigation of stress distribution in bar-attached bar-overdentures retained by four implants in the maxilla. For dynamic study purposes, the non-linear behaviour typically observed with soft tissue support was simulated with pre-calculated loading scenarios. Stress analysis focused on Von Mises and principal stress quantities. Under vertical and oblique loading, high-stress concentrations were identified at the bar and attachment interfaces. The occlusal load was transmitted effectively to the implants with lateral loading, generating considerable tensile and compressive stresses in the palatal area of the overdenture, particularly near the first molar region.

Angulating the implants distally diminished concentration stresses on the bridge, while maintaining a parallel arrangement with a 10 mm centre distance reduced peak stresses at the attachments. The latter configuration is expected to distribute the occlusal loads efficiently, optimise the overdenture base–mucosa interfacial pressure, and favour congruity with individualised mucosal shape. Modelling muco-supported over-dentures should therefore consider a wider inter-implant distance and distal angulation.

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