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BIOMECHANICAL CONSIDERATIONS IN IMPLANT-SUPPORTED FIXED AND REMOVABLE RESTORATIONS PROSTHODONTICS: A REVIEW

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Abstract

Objectives. The aim of this narrative review was to evaluate the current evidence regarding the biomechanical principles governing implant-supported fixed and removable restorations and their influence on treatment outcomes, peri-implant tissue preservation, and prosthetic longevity. **Materials and Methods.** A structured literature search was conducted in PubMed/MEDLINE, PubMed Central, Scopus, and Web of Science. Systematic reviews, meta-analyses, randomized controlled trials, clinical studies, and finite element analyses published between 2000 and 2025 were included. The review focused on biomechanical factors affecting implant-supported fixed prostheses and removable overdentures, including load distribution, implant number and position, implant angulation, cantilever design, prosthetic materials, attachment systems, stress transmission, marginal bone loss, and prosthetic complications. Due to methodological heterogeneity, data were synthesized narratively. **Results.** Biomechanical performance of implant-supported restorations is strongly influenced by prosthetic design, implant configuration, and occlusal loading conditions. Fixed restorations generally provide favorable load distribution and reduced prosthetic movement, whereas removable implant-supported overdentures offer functional and economic advantages but may generate increased stresses around attachment systems and supporting implants. Factors such as excessive cantilever length, non-axial loading, inadequate implant distribution, and unfavorable crown-to-implant ratios are associated with increased peri-implant stress concentrations, marginal bone loss, and mechanical complications. Advances in digital planning, CAD/CAM technologies, and finite element modeling have improved the understanding and optimization of biomechanical behavior in implant prosthodontics. **Conclusions.** Biomechanical considerations play a critical role in the long-term success of implant-supported fixed and removable restorations. Individualized treatment planning based on biomechanical principles is essential for minimizing biological and mechanical complications, preserving peri-implant tissues, and enhancing the predictability and longevity of implant prosthetic rehabilitation.

Keywords: *prosthetic rehabilitation; risk factors; systemic disease; medically compromised patients.*

INTRODUCTION

In contemporary oral implantology practice, clinicians frequently face the need to provide prosthetic and surgical treatments that ensure both functional stability and long-term biological integration [1]. Although dental implants have become a predictable therapeutic solution for partial and complete edentulism, their success depends largely on the understanding and control of the biomechanical factors involved. Occlusal forces, stress distribution at the level of the alveolar bone, the type of prosthetic loading, and implant design are all essential

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elements influencing osseointegration and the longevity of treatment outcomes [2,3].

The study of oral implant biomechanics represents a modern research direction capable of explaining the underlying causes of complications such as marginal bone loss, implant fracture, and prosthetic failure, while also offering solutions for optimizing treatment planning. Computational, analytical, and experimental models — including finite element analysis (FEA), photoelasticity, and strain gauge measurements — have been employed to evaluate the biomechanics of implant-supported fixed prosthetic restorations [4,5].

Research groups are working to optimize the accuracy of simulated clinical models and to correlate FEA findings with data reported by clinical studies assessing implant survival rates and the longevity of implant-supported fixed restorations. FEA research have advanced the understanding of how masticatory forces are transferred to peri-implant bone tissues, by investigating the magnitude and distribution of these forces under conditions simulating real clinical scenarios. This is particularly relevant given that one of the most significant causes of implant failure is bone resorption at the interface between the implant neck and the surrounding osseous tissue [6]. FEA studies are especially valuable in this context because direct clinical evaluation of the biomechanical behavior of implant and peri-implant bone structures is not feasible, owing to inherent methodological and design limitations, potential ethical concerns, and the extended timeframes required to complete such investigations [7].

MATERIALS AND METHODS

Search Strategy

The identification of relevant studies was carried out by consulting the electronic databases PubMed/MEDLINE, PubMed Central (PMC), Scopus, and Web of Science.

The literature search was performed using combinations of keywords and MeSH terms such as: "dental implants", „biomechanics”, „fixed implant-supported restorations” „removable implant-supported restorations” "implant-supported overdenture", „implant-supported hybrid restorations”, "implant survival rate", "implant success rate", "implant failure", "prosthetic rehabilitation", "marginal bone loss", "systemic disease", "implant-supported overdenture". Search terms were used both individually and in Boolean combinations (AND/OR) to maximize retrieval of relevant records. Priority was given to studies available in full text via PMC Open Access, in order to ensure complete data extraction.

Selection Criteria

Studies were considered eligible when they met the following criteria: original manuscripts — including randomized controlled trials, prospective and retrospective observational studies, and finite element analysis investigations — examining the biomechanical behavior of dental implants and implant-supported prosthetic restorations; systematic reviews and meta-analyses addressing stress distribution, load transfer mechanisms, marginal bone loss, and mechanical complications in implant-supported rehabilitations; narrative reviews from well-known textbooks in the fields of

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implantology, prosthodontics, and oral biomechanics; and original studies reporting quantitative biomechanical outcomes such as stress and strain distribution patterns, implant survival rates, prosthetic complication rates, and marginal bone loss values determined over specified follow-up periods.

Studies were excluded if they fulfilled one or more of the following criteria: non-human studies without translational relevance; articles published before 2000; studies not directly addressing the biomechanical behavior of dental implants or implant-supported prostheses; investigations examining material properties of prosthetic components and biomaterials without reporting relevant biomechanical outcome measures; studies focused exclusively on implant surface characteristics, biomaterials, or osseointegration without biomechanical outcome data; publications not available in English.

Data Extraction and Quality Assessment

Two independent reviewers systematically extracted data from each included article. The following variables were documented for every study: (1) study design and level of evidence; (2) sample size in terms of number of patients, implants, or computational models; (3) implant characteristics, including number, position, diameter, length, and angulation; (4) type of prosthetic rehabilitation performed; (5) loading conditions and occlusal scheme; (6) follow-up length; and (7) biomechanical outcome measures reported, including stress and strain distribution patterns, marginal bone loss (MBL), implant survival rate (ISR), and prosthetic complication rates. For finite element analysis studies, model specifications, boundary conditions, material properties, and stress-analysis parameters were also recorded. Statistical measures, were extracted wherever available.

LITERATURE REVIEW

1.General context

Biomechanics of oral implants is at the core of modern dental research, given the need to thoroughly understand how masticatory forces interact with implant structures in order to ensure clinical success. The integration of implants into the maxilla or mandible depends on numerous biomechanical factors, such as the dimensions, shape, and material composition of the implant itself, as well as the quality and quantity of the recipient bone [8].

The biomechanical response of peri-implant bone influences both the primary stability and subsequent osseointegration of a dental implant [9]. The implantology field is further complicated by the sheer diversity of available implant systems, each differing in insertion characteristics and thread design, and by the relatively limited number of robust clinical studies — a combination that makes implant system selection according to individual clinical and biological parameters an ongoing challenge for practitioners [10]. Excessive or poorly distributed loading can trigger bone resorption and ultimately lead to implant failure, whereas a well-balanced load distribution supports bone maintenance and may even promote bone apposition around the implant over time [11]. Stress distribution around oral implants is a critical determinant of long-term treatment

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outcomes. When stresses exceed physiological thresholds — whether due to unfavorable prosthetic design or suboptimal surgical technique — bone microfractures and osseointegration failure can result. The implant material itself also plays a significant role in how stresses are transmitted and dissipated; modern materials such as titanium and its alloys have been specifically engineered to optimize stress distribution and improve overall implant survival rates [12].

Finite element analysis (FEA) has emerged as a particularly valuable tool, enabling detailed computational simulation of force distribution across implant structures and surrounding bone under a variety of loading conditions [13,14]. Stress magnitude and distribution are shaped by multiple interacting variables, including surface properties, subtle geometric variations, and the complexity of implant–prosthetic assemblies. FEA studies are especially well suited to investigating these interactions, as they can incorporate the full range of parameters that are difficult or impossible to isolate in clinical settings [15]. The magnitude of masticatory forces transmitted to implant-supported fixed restorations varies widely, from a few tens of Newtons to approximately 2000 N depending on the individual and the region of the arch [16]. Functional loading of dental implants occurs for an estimated average of 30 minutes per day, at a masticatory cycle frequency of 48 to 112 cycles per minute [17]. When multiple implants are used to support fixed or removable prostheses in the context of complex oral rehabilitations, the biomechanical picture becomes considerably more intricate. The interactions among implants, the prosthetic superstructure, and the surrounding hard and soft tissues must all be carefully considered and optimized if complications are to be avoided [18,19].

2. Biomechanics of Implant-Supported Fixed Prosthetic Restorations

The success of implant-prosthetic therapy is dependent on the entire capacity of osseointegration, which is defined as the direct structural and functional connection between peri-implant bone tissues with titanium alloys without the presence of fibrous tissue interposition [20]. Bone tissues respond positively to implant transmission that involves combined tissue resistance within bone and proper mechanical alignment of accentuated distributed loading stress throughout peri-implant osseous tissues, thereby sustaining the long-term maintenance of functional implant-supported fixed prosthetic restorations. The level and orientation of peri-implant bone resorption are influenced by the following factors [20]:

- type of loading;
- material properties of the implants and prosthetic restorations;
- implant design;
- volume of peri-implant bone tissues;
- density of peri-implant bone tissues;
- characteristics of the implant–peri-implant tissue interface.

The factors influencing stress magnitude and distribution within peri-implant bone tissues are the following [20]:

- type of forces (horizontal, vertical, oblique) loading the dental implants;
- type of bone–implant interface;
- implant dimensional parameters;
- macroscopic design;
- type of prosthetic restoration;

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- volume and quality of peri-implant bone tissues.

Excessive forces along the implant axis or paraaxial forces must be avoided in order to prevent peri-implant bone resorption [20]. Vertical forces ensure uniform stress distribution along the implant–bone interface, whereas oblique forces are associated with shear forces and bending moments, leading to stress concentration at the implant neck and at the bone contact area [21].

Data from the literature demonstrate the influence of microdesign on the degree of peri-implant bone resorption. Implants with a rough microsurface and microthreads exhibit the lowest peri-implant resorption values: a mean of 0.1 mm at the end of the healing period, 0.5 mm (range 0–2.1 mm) at two years, and 0.7 mm (range 0–2.3 mm) at five years [22]. Dental implants with a rough surface and rough microthreads have the lowest peri-implant bone resorption values at 5 years post-loading (0.61 ± 0.32 mm), followed by rough-surface implants without microthreads (0.99 ± 0.38 mm) [23]. Implants with a rough microsurface incorporating microthreads have the lowest peri-implant bone resorption, with a mean value of 0.18 mm (±0.16 mm) at twelve months post-loading [24]. Post-loading alveolar bone resorption may be reduced by the addition of microthreads to rough microsurface implants [25].

Regarding implant dimensional parameters, the height and width of the edentulous ridge (prosthetic space) determine the selection of implant length and diameter. In implant sites with severe bone resorption, bone augmentation procedures are required to ensure favorable biomechanical conditions [21, 26]. At implant sites reconstructed through guided bone regeneration techniques, the stress distribution surface area is considerably reduced compared to the pre-treatment state; the bone is anisotropic, and the level of integration varies along the bone–implant interface. Research groups have reported a direct relationship between stress fields in bone tissues and the degree of occlusal loading, as well as implant design and length [20, 21, 26].

With regard to the relationship between implant macroscopic design and biomechanical behavior, design features can influence the implant–peri-implant bone connection and the manner in which forces at this interface are dispersed — either homogeneously or heterogeneously [20].

Implant design is a major determinant of the primary stability of dental implants, through its influence on peri-implant stress magnitude and distribution [27].

3. Biomechanics of Implant-Supported Hybrid Prosthetic Restorations

Biomechanics of Implant-Retained Overdentures with Special Attachment Systems

In hybrid prosthetic rehabilitation through implant-supported overdentures at the mandibular arch, two to four implants are regularly placed in the anterior region (at the canines or canines and second premolars) according to the desired stability and patient anatomy [28, 29]. Implants are usually placed in the anterior mandible where bone quality is superior and to avoid important anatomical structures such as the mandibular nerve. Implant placement at the

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premolar sites is performed less routinely and in selective cases — for example, when additional stability is required or when sufficient bone volume exists at the premolar sites to support a more uniform masticatory load distribution. Thus, the standard option for implant-supported removable prosthetics at the mandibular level usually consists of two implants in the anterior region; however, additional implants may be used depending on both the clinical situation and patient requirements, including placement in the premolar zone. For implant-supported overdentures, the choice between mixed support (both implant and mucosal) and exclusively implant-borne support — particularly in cases with implants at the canine and second premolar sites — is influenced by the prosthesis type and the specific clinical case [28, 29].

With mixed support (implants and mucosa), the removable prosthesis maintains direct contact with and distributes a portion of the masticatory forces to both the implants and the alveolar mucosal tissue. In this configuration, no space exists between the prosthetic saddle and the mucosa, meaning that part of the masticatory pressure is borne by the soft tissue [28, 29].

In the case of an overdenture supported by four implants (placed at the canine and second premolar sites), exclusively implant-borne support is generally the preferred option, particularly in modern solutions such as All-on-4 systems. This approach provides superior stability and long-term comfort, avoiding complications associated with bone resorption and mucosal irritation. Mixed support may be employed in specific cases — for instance, when available bone does not allow for sufficiently stable implants — but over the long term, exclusively implant-supported prostheses are generally more reliable and more comfortable for the patient [28, 29].

In FEA simulations for implant-supported overdentures at the mandibular level, several force types are applied to evaluate the biomechanical behavior of the prosthetic restoration. The most frequently simulated forces include vertical occlusal forces, lateral (transverse) forces, oblique forces, torsional forces, and retentive (dislodging) forces. Vertical occlusal forces represent the masticatory forces generated during chewing and occlusion, applied perpendicular to the occlusal surface of the prosthesis [30]. They reflect the normal pressure exerted on the teeth or prosthetic restorations and are important for evaluating how the prosthesis and implants withstand masticatory loads. Lateral (transverse) forces act laterally on the prosthesis, simulating lateral displacement movements during mastication or the lateral forces arising during the chewing process. These forces can produce shear effects and are important for assessing prosthetic stability and the risk of implant overloading or fracture. Oblique forces combine a vertical and a lateral component and are frequently simulated because, during mastication, forces are rarely purely vertical or lateral. They are applied at an angle to the implants and prosthesis, simulating real masticatory conditions or irregular occlusal contact. Torsional forces arise when rotational or twisting movements of the prosthesis occur around the implants. They are essential for evaluating the stability of the prosthesis–

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implant assembly and for determining the resistance of the retention systems, such as clips or ball attachments. Retentive (dislodging) forces are applied to evaluate prosthetic retention and the behavior of the attachment systems (clip, ball, magnets), simulating situations in which the patient applies pressure to detach the prosthesis from the implants. The application of these forces in FEA simulations allows determination of the stress distribution and deformations occurring in the prosthesis, implants, and surrounding bone structures. In FEA simulations for overdentures on two or four mandibular implants, it is important to consider both unilateral and bilateral forces, thereby ensuring a comprehensive assessment of the biomechanical behavior of the prosthetic restoration. Unilateral forces simulate mastication on one side of the mandible, which is a very common real-life scenario. These forces can create uneven stress distributions between the implants and surrounding bone structures, and their simulation is essential for evaluating the risk of overloading on specific implants and the possibility of fractures in restoration materials or implant damage. Bilateral forces simulate simultaneous mastication on both sides of the mandible and are useful for understanding how the load is distributed when the patient applies more balanced masticatory forces. Although bilateral mastication is less frequent, these forces are necessary to evaluate stress distribution between the implants and the prosthesis under uniform loading conditions. Applying only unilateral forces could underestimate the stress distributed across structures when the prosthesis is subjected to bilateral loading, particularly in scenarios of intensive use such as simultaneous bilateral mastication. Ideally, simulations should incorporate both force types [28, 29, 35].

The choice of attachment system influences stress distribution. A research grpoup highlight that the gradual loss of retention of various dental attachment systems is a critical consideration when selecting the appropriate attachment.

A research group designed and three-dimensionally printed an implant-supported overdenture, evaluating both initial retention and the rate of retention loss over time for three different attachment systems following simulation of five years of use. Two implants were placed using a fully computer-designed surgical guide, following a prosthodontically driven implant placement protocol. A digitally designed metal mesh with tissue stops, containing the geometric center, was integrated into the attachment-bearing surface of the prosthesis. Forty-eight metal-reinforced, 3D-printed prostheses were divided into four groups of twelve. Retention loss was measured using two Locator attachments (twelve pairs of Locator R-TX and twelve pairs of Locator F-TX with medium and low retention settings) and compared with twelve pairs of traditional ball-and-socket attachments. Each group underwent a series of insertion and removal tests simulating five years of patient use. A universal testing machine recorded retention values. The Locator F-TX attachments with medium and low retention settings showed significant retention losses of 91.93% and 92.91%, respectively, after simulations equivalent to two and three years of use. Ball-and-socket and Locator R-TX attachments showed

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retention losses of 19.87% and 26.31%, respectively, after a simulated period equivalent to five years of use [31]. Two studies favored the ball attachment over the bar-clip attachment system when stress posterior to the implants was evaluated. Due to the limited number of studies and conflicting results, no definitive conclusions could be drawn regarding differences in stress concentration between ball, magnetic/equator, and locator attachment systems. The variability in results across studies may be attributed to the diversity of attachment systems and study designs employed. Locator attachments offer a more favorable stress distribution around peri-implant bone compared to other attachment systems [32]. A research group evaluated stress distribution in cortical bone around the implant neck and at the bone–implant interface in hybrid prosthetic restorations equipped with different attachment types, using three-dimensional finite element analysis. Static bilateral and unilateral vertical and oblique occlusal loads of 100 N were applied. Results showed that oblique loads induced greater principal stresses compared to vertical loads across all models. The highest principal stress levels were observed around the mesial aspect of the contralateral implant, while the lowest values were noted around the distal aspect of the ipsilateral implant under unilateral vertical loading. These stress patterns reversed under oblique loading conditions. Models with ball attachments exhibited lower von Mises stress values compared to locator attachment models across all loading scenarios. Stress distribution remained consistent in models with identical and different bone heights, suggesting that alveoloplasty procedures to remove alveolar ridge irregularities may not be biomechanically necessary. These findings may assist clinicians in better designing mandibular overdentures, particularly in cases with varying bone heights. A research group analyzed six randomized controlled trials (RCTs) including 294 mandibular overdentures, while studies on maxillary overdentures did not meet the inclusion criteria. In the short term, the need for retreatment (repair of the attachment system) was more frequent with ball attachments (RR 3.11; 130 participants; 2 studies), while no significant differences in retreatment through attachment system replacement were observed between the two systems (RR 1.18; 130 participants; 2 studies). Between ball and magnetic attachments, no differences were found in medium-term prosthetic success (RR 0.84; 69 participants; 1 study) or in the need for medium-term retreatment (RR 1.75; 69 participants; 1 study). However, prosthetic maintenance costs after five years were higher when magnetic attachments were used (69 participants; 1 study). A study comparing ball and telescopic attachments reported no significant differences in short-term maintenance activities such as matrix replacement, matrix activation, or overdenture rehabilitation (RR 1.75–11.00; 22 participants). It remains uncertain whether a difference exists in short-term prosthetic maintenance when ball attachments are compared to telescopic attachments. The same research group concluded that the evidence is insufficient to determine the relative efficacy of different attachment systems for mandibular overdentures with regard to

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prosthetic success, prosthetic maintenance, patient satisfaction, patient preference, or costs, and noted that it was not possible to identify a preferred attachment system for implant-supported mandibular overdentures [33]. A research group evaluated and compared the intensity and pattern of peri-implant bone stress in two-implant mandibular overdentures, considering different implant positions. Two intraosseous implants equipped with ball attachment systems were positioned in the interforaminal region. The overdenture was supported by these implants and subjected to bilateral and unilateral vertical masticatory loads (100 N total). Eight distinct model types were developed, varying in implant locations, attachment heights, and angulations: MI (implants at lateral incisor locations), MC (canine locations), MP (premolar locations), MI-Hi (increased attachment height), MC-M (mesial inclination of canine implants), MC-D (distal inclination of canine implants), MC-B (buccal inclination of canine implants), and MC-L (lingual inclination of canine implants). Overdentures supported by implants at the lateral incisor positions demonstrated the lowest peri-implant bone stress levels and the most efficient stress distribution. The MI-Hi model exhibited higher stress levels and reduced distribution efficiency. Implant inclination led to increased stress levels and diminished distribution efficiency. Among the inclined implant models, MC-B showed the lowest stress levels and the most efficient stress distribution. Optimal stress minimization and implant stability in two-implant mandibular overdentures were achieved with implants placed at the lateral incisor positions, using shorter attachments aligned parallel to the longitudinal axes of the teeth [34]. Patil et al. [36] conducted a literature review on the biomechanical behavior of overdentures with different attachment types. A comparative analysis between ball and low-profile attachments in two studies indicated similar peri-implant tissue health, although differences in crestal bone level changes were reported. Another study comparing ball and telescopic attachments found comparable results regarding crestal bone level changes and peri-implant tissue health parameters [35]. A research group analyzed stress distribution in peri-implant bone and the attachments of small-diameter implant-supported mandibular overdentures, and examined the influence of implant placement on prosthetic stability. Using finite element analysis, four models were constructed: three two-implant mandibular overdenture (IOD) models and one conventional complete denture (CD) model. The IOD models included one with implants in both canine zones, one with implants in both lateral incisor zones, and one with one implant in the canine zone and one in the lateral incisor zone. Each model was subjected to three loading types: a vertical force of 100 N, an oblique force applied at the left first molar, and a vertical force of 100 N applied at the lower incisors. The study evaluated stress distribution in peri-implant bone, attachment systems, and the biomechanical responses of the implant-supported overdentures. Across all models and loading conditions, maximum peri-implant bone stress values remained within safe physiological limits. The IOD model with dispersed implant placement (one implant in the canine zone and one in the lateral incisor zone) recorded the highest

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maximum stress in peri-implant bone (822.8 με) and attachments (275 MPa). The CD model showed the highest peak mucosal pressure under all three loading conditions (0.8188 MPa). By comparison, the contact area between the prosthesis and mucosa was smaller in the conventional acrylic denture model than in the IOD models under molar loading, but larger under anterior loading. Contact areas under anterior loading across all models were significantly smaller than those under molar loading. IOD models demonstrated considerably less rotational movement compared to the complete denture, with implant placement having a minimal effect on this outcome. IOD models — particularly with canine zone implants — showed greater maximum stress in peri-implant bone and attachments, and increased stability with reduced rotational movement. The most intense stress concentration was observed around the neck of the small-diameter implants rather than at the abutment. Two-implant overdentures provided better stability than conventional complete dentures [36].

Biomechanics of Implant-Supported Bar-Retained Overdentures

Implant-supported bar-retained removable prosthetic restorations represent an effective option for completely edentulous patients. This type of restoration consists of a metal framework anchored to several implants, which supports the removable prosthesis. The biomechanical aspects include force distribution, stability, and the capacity to reduce the rate of bone resorption. The bar allows distribution of occlusal forces along the dental arches, reducing stress concentration at the implants and supporting bone. Owing to the rigid connection between implants and bar, these overdentures provide superior stability and retention compared to traditional fully removable prostheses. Adequate bone stimulation through the transmission of masticatory forces to the bone helps prevent long-term bone resorption. A research group evaluated stress distribution in the peri-implant bone of a mandibular overdenture with asymmetric implant placement relative to the midline. Two internally connected implants were inserted perpendicular to the occlusal plane at the right canine and left lateral incisor sites. Two attachment types were used (bar and ball). Loading was applied anteriorly (at the central incisors) and bilaterally posteriorly (at the premolars and molars) to simulate real clinical conditions. Stress distribution was examined through finite element analysis (FEA). Under anterior loading conditions, the implant at the lateral incisor position experienced the highest maximum principal stress (approximately 33 MPa) in both models. Conversely, under posterior loading conditions, higher stress values (approximately 22 MPa) were recorded at the canine-positioned implant in both models. In mandibular overdentures supported by implants placed asymmetrically relative to the midline, one implant tends to act as a fulcrum, bearing a greater occlusal load. The study found that the bar attachment system did not provide superior stress distribution compared to the ball attachment system [38].

In a literature review on the clinical performance of implant-supported overdentures with bar versus ball attachment systems, short-term retreatment

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(repair of the attachment system) was more frequent with ball attachments (RR = 3.11; 95% CI: 1.68 to 5.75); however, no difference was found regarding attachment system replacement between the two retention designs (RR = 1.18; 95% CI: 0.38 to 3.71) [39]. A research group evaluated through FEA the biomechanical characteristics of overdentures supported by four implants using locator and bar-clip attachment systems under various mechanical loading conditions. Different mechanical loads were applied to each model: a vertical load of 100 N at the central incisor, vertical or oblique loads of 100 N at the canine, and vertical or oblique loads of 100 N at the mandibular first molar. Stress distribution was measured at the implant level, in peri-implant bone, and at the mucosal level to compare the effect of different attachment systems on biomechanical behavior. Results indicated that stress concentrations in the implants were located predominantly at the implant neck, and in peri-implant bone at the cortical bone level, across all attachment types and loading conditions. Mucosal stress was consistently lower than that recorded in the implants and cortical bone. Peak stress at the bone–implant interface under lateral loading exceeded that observed during vertical loading, regardless of loading position (canine or mandibular first molar). The locator model demonstrated lower stress in the implants and cortical bone (maximum von Mises stress values of 79.5 and 22.3 MPa, respectively) compared to the bar-clip model (maximum von Mises stress values of 110.3 and 28.7 MPa, respectively); however, maximum compressive stress in the mucosa was slightly higher in the locator model (0.198 MPa) than in the bar-clip model (0.137 MPa). Clinically, lateral forces applied to implant-supported overdentures should be minimized to prevent complications caused by pathological loading. Under identical loading conditions, overdentures with locator attachments exhibited more dispersed stress distributions, improving the long-term stability of the implants [40].

CONCLUSIONS

Biomechanical performance of implant-prosthetic systems is governed by an intricate and interdependent constellation of factors, each having the potential to affect stress propagation, marginal bone preservation, and long-term prosthetic stability. Treatment predictability is largely determined by the careful optimization of implant number and spatial configuration, prosthetic material selection, occlusal scheme design, and attachment system choice, rather than by any single isolated parameter. Unfavorable biomechanical conditions — arising from excessive cantilever length, insufficient implant distribution, or mismatched crown-to-implant ratios — translate directly into increased rates of marginal bone loss, screw loosening, framework fracture, and prosthetic failure. Standardization of biomechanical outcome reporting, longer follow-up periods, and prospective comparative studies across diverse prosthetic designs and loading conditions are requested to refine evidence-based protocols and establish clinically applicable thresholds for the key biomechanical parameters that determine the success of implant-supported rehabilitations.

REFERENCES

1. Xi D, Wong L. Titanium and implantology: a review in dentistry. *J Biol Regul Homeost Agents*. 2021 Jan-Feb;35(1 Suppl. 1):63-72.
2. Mojaver S, Patel N, Sarmiento H, Fiorellini JP. Under pressure: Unraveling the impact of occlusal overload on peri-implant health — A systematic review. *J Prosthodont*. 2025 Oct;34(8):784-795.
3. Bertolini MM, Del Bel Cury AA, Pizzoloto L, Acapa IRH, Shibli JA, Bordin D. Does traumatic occlusal forces lead to peri-implant bone loss? A systematic review. *Braz Oral Res*. 2019 Sep 30;33(suppl 1):e069. doi: 10.1590/1807-3107bor-2019.vol33.0069.
4. Qiu P, Cao R, Li Z, Fan Z. A comprehensive biomechanical evaluation of length and diameter of dental implants using finite element analyses: A systematic review. *Heliyon*. 2024 Feb 22;10(5):e26876. doi: 10.1016/j.heliyon.2024.e26876.
5. Maminskas J, Puisys A, Kuoppala R, Raustia A, Juodzbalys G. The Prosthetic Influence and Biomechanics on Peri-Implant Strain: a Systematic Literature Review of Finite Element Studies. *J Oral Maxillofac Res*. 2016 Sep 9;7(3):e4. doi: 10.5037/jomr.2016.7304.
6. Kishen A, Murthy V, Devi L, Jayachandran B, Sadish SS. Clinical and biomechanical determinants of immediate, early, progressive, and delayed implant loading: a comprehensive narrative review. *Saudi Dent J*. 2026;38(4):47. doi: 10.1007/44445-026-00122-6.
7. Rasoolzadeh R, Jafari M. Short Dental Implants: A Review of Literature. *J Long Term Eff Med Implants*. 2019;29(4):261-271.
8. Singh R, Desai SR, Manjunath RGS. Influence of implant design and length on stress distribution in immediately loaded implants in posterior maxilla — A two-dimensional finite element analysis. *J Indian Soc Periodontol*. 2023 Nov-Dec;27(6):600-606.
9. Misch CE. Dental implant prosthetics. Elsevier Health Sciences, St. Louis, Missouri. 2015.
10. Oshida Y, Tuna EB, Aktören O, Gençay K. Dental implant systems. *Int J Mol Sci*. 2010 Apr 12;11(4):1580-678.
11. Sheng-Lei L, Xin X, Kui-feng Y, Qing-guo L, Xiao-peng T, Ying L. Angular immediate loading: three-dimensional finite element analysis. *J Craniofac Surg*. 2014 May;25(3):1072-5.
12. Mosavar A, Ziaei A, Kadkhodaei M. The effect of implant thread design on stress distribution in anisotropic bone with different osseointegration conditions: a finite element analysis. *Int J Oral Maxillofac Implants*. 2015 Nov-Dec;30(6):1317-26.
13. Barão VA, Delben JA, Lima J, Cabral T, Assunção WG. Comparison of different designs of implant-retained overdentures and fixed full-arch implant-supported prosthesis on stress distribution in edentulous mandible — a computed tomography-based three-dimensional finite element analysis. *J Biomech*. 2013 Apr 26;46(7):1312-20.
14. Anitua E, Tapia R, Luzuriaga F, Orive G. Influence of implant length, diameter, and geometry on stress distribution: a finite element analysis. *Int J Periodontics Restorative Dent*. 2010 Feb;30(1):89-95.
15. Mitra D, Gurav P, Rodrigues S, Khobragade B, Mahajan A. Evaluation of stress distribution in and around dental implants using three different implant-abutment interfaces with platform-switched and non-platform-switched abutments: A three-dimensional finite element analysis. *J Dent Res Dent Clin Dent Prospects*. 2023 Fall;17(4):256-264.
16. Akbas O, Greuling A, Stiesch M. The effects of different grading approaches in additively manufactured dental implants on peri-implant bone stress: A finite element analysis. *J Mech Behav Biomed Mater*. 2024 Jun;154:106530. doi: 10.1016/j.jmbbm.2024.106530.

17. Han J, Sun Y, Wang C. Effect of Integration Patterns Around Implant Neck on Stress Distribution in Peri-Implant Bone: A Finite Element Analysis. *J Prosthodont*. 2017 Aug;26(6):549-558.
18. Sayed AJ, Mohsin SF, Garg KK, Agwan MAS, Tareen SUK, Alruthea MS, Mohan S. Finite Element Analysis (FEA) for Influence of Variation in Dental Implant Dimensions (Length and Diameter) on Peri-implant Bone Stress/Strain Distribution: A Systematic Review. *Pak J Med Sci*. 2025 Jan;41(1):318-330.
19. Öztürk H, Muğlalı M, Çankaya RTA. Influence of different implant designs on stress distributions in all-on-four concept: A finite element analysis. *J Craniomaxillofac Surg*. 2025 Jul;53(7):911-920.
20. Dundar S, Tolga T, Murat YS, Ferhan Y, Yusuf A, Arif S, Fatih A, Omer C. Finite element analysis of the stress distributions in peri-implant bone in modified and standard-threaded dental implants. *Biotechnology & Biotechnological Equipment*. 2016;30(1):127-133.
21. Zhang G, Yuan H, Chen X, Wang W, Chen J, Liang J, Zhang P. A three-dimensional finite element study on the biomechanical simulation of various structured dental implants and their surrounding bone tissues. *International Journal of Dentistry*. 2016;1(9):82-86.
22. Nickenig HJ, Wichmann M, Happe A, Zöller JE, Eitner S. A 5-year prospective radiographic evaluation of marginal bone levels adjacent to parallel-screw cylinder machined-neck implants and rough-surfaced microthreaded implants using digitized panoramic radiographs. *J Craniomaxillofac Surg*. 2013 Oct;41(7):564-8.
23. Lee SY, Koak JY, Kim SK, Rhyu IC, Ku Y, Heo SJ, Han CH. A Long-Term Prospective Evaluation of Marginal Bone Level Change Around Different Implant Systems. *Int J Oral Maxillofac Implants*. 2016 May-Jun;31(3):657-64.
24. Shin YK, Han CH, Heo SJ, Kim S, Chun HJ. Radiographic evaluation of marginal bone level around implants with different neck designs after 1 year. *Int J Oral Maxillofac Implants*. 2006 Sep-Oct;21(5):789-94.
25. Bateli M, Att W, Strub JR. Implant neck configurations for preservation of marginal bone level: a systematic review. *Int J Oral Maxillofac Implants*. 2011 Mar-Apr;26(2):290-303.
26. Bhat VS, Premkumar P, Shenoy KK. Stress Distribution Around Single Short Dental Implants: A Finite Element Study. *J Indian Prosthodont Soc*. 2014;14(1):161-167.
27. Abuhussein H, Pagni G, Rebaudi A, Wang HL. The effect of thread pattern upon implant osseointegration. *Clin Oral Implants Res*. 2010;21:129-36.
28. Luo S, Fu C, Wei H, Zhao B. Study on Overdenture of Immediate Implant Placement and Function. *J Craniofac Surg*. 2023 Mar-Apr;34(2):e134-e138.
29. Ter Gunne LP, Dikkes B, Wismeijer D, Hassan B. Immediate and Early Loading of Two-Implant-Supported Mandibular Overdentures: Three-Year Report of Loading Results of a Single-Center Prospective Randomized Controlled Clinical Trial. *Int J Oral Maxillofac Implants*. 2016 Sep-Oct;31(5):1110-6.
30. Hasan I, Madarlis C, Keilig L, Dirk C, Weber A, Bourauel C, Heinemann F. Changes in biting forces with implant-supported overdenture in the lower jaw: A comparison between conventional and mini implants in a pilot study. *Ann Anat*. 2016 Nov;208:116-122.
31. Abdelaziz MS, Fawzy AM, Ghali RM, Nassar HI. Retention of Different Attachment Systems for Digitally Designed Mandibular Implant Overdenture. *J Prosthodont*. 2023 Feb;32(2):162-169.
32. Bhattacharjee B, Saneja R, Singh A, Dubey PK, Bhatnagar A. Peri-implant stress distribution assessment of various attachment systems for implant supported overdenture prosthesis by finite element analysis — A systematic review. *J Oral Biol Craniofac Res*. 2022;12(6):802-808.
33. Payne AG, Alsabeeha NH, Atieh MA, Esposito M, Ma S, Anas El-Wegoud M. Interventions for replacing missing teeth: attachment systems for implant overdentures in edentulous jaws. *Cochrane Database Syst Rev*. 2018 Oct 11;10(10):CD008001. doi: 10.1002/14651858.CD008001.pub2.
34. Hong HR, Pae A, Kim Y, Paek J, Kim HS, Kwon KR. Effect of implant position, angulation, and attachment height on peri-implant bone stress associated with mandibular two-implant overdentures: a finite element analysis. *Int J Oral Maxillofac Implants*. 2012;27(5):e69-76.
35. Patil PG, Seow LL, Kweh TJ, Nimbalkar S. Unsplinted Attachment Systems and Peri-implant Outcomes in Two-implant-retained Mandibular Overdentures: A Systematic Review of Randomized Controlled Trials. *J Contemp Dent Pract*. 2021 Nov 1;22(11):1346-1354.

36. Liao X, Cao R, Zhong J, Chen C, Pan S. Influence of implant distribution on the biomechanical behaviors of mandibular implant-retained overdentures: a three-dimensional finite element analysis. *BMC Oral Health*. 2024 Mar 30;24(1):405. doi: 10.1186/s12903-024-04146-4.
37. Aalaei S, Sheikhi A, Mehdian P, Taghavi F, Salimian S, Taghavi-Damghani F. Assessment of peri-implant bone stress distribution with the effect of attachment type and implant location using finite element analysis. *J Dent Res Dent Clin Dent Prospects*. 2023 Fall;17(4):222-226.
38. Stafford GL. The effectiveness of different attachment systems maxillary and mandibular implant overdentures. *Evid Based Dent*. 2019 Mar;20(1):26-27.
39. Jiang MY, Wen J, Xu SS, Liu TS, Sun HQ. Three-dimensional finite element analysis of four-implants supported mandibular overdentures using two different attachments. *Zhonghua Kou Qiang Yi Xue Za Zhi*. 2019 Jan 9;54(1):41-45.
40. Assunção WG, Tabata LF, Barão VA, Rocha EP. Comparison of stress distribution between complete denture and implant-retained overdenture — 2D FEA. *J Oral Rehabil*. 2008;35(10):766-74.

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