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Stress Generated On Surrounding Bone In Implant Supported Cantilever Fixed Dental Prosthesis A Systematic Review

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Abstract

Purpose: This systematic review aims to identify, evaluate, and interpret in-vitro studies that utilize the Finite Element Analysis Method to analyze stress distribution patterns in implant supported cantilever fixed partial dentures, specifically within mandibular posterior region models.

Materials and Methods: A systematic search was conducted across multiple electronic databases, including MEDLINE, Pub Med, and Web of Science, for English-language studies published between January 2000 and October 2022. The search focused on in-vitro simulations of posterior cantilever fixed partial dentures using Finite Element Analysis Method Following the PRISMA guidelines, 10 high quality studies were selected for qualitative synthesis based on strict inclusion and exclusion criteria. Data extraction focused on model geometry, implant characteristics, loading conditions, and resulting von Mises stress values.

Results: The synthesis revealed that while cantilever designs introduce a Class I lever mechanism that increases stress at the bone implant interface, the levels generally remain below the yielding limit of cortical bone under physiological loads. Key findings indicate that mesial cantilevers provide a more favorable stress distribution than distal cantilevers. Furthermore, Morse taper connections demonstrated superior biomechanical performance compared to external hexagon designs. Oblique loading was found to be more critical than axial loading, producing higher peak stresses at the cervical region of the primary implant.

Conclusion: Implant-supported cantilever fixed partial dentures are a viable clinical alternative when anatomical constraints prevent multiple implant placement. Success

depends on meticulous planning of the cantilever length, implant connection type, and position. To minimize the risk of mechanical failure, mesial cantilevers and Morse taper connections are recommended.

Keywords: Cantilever, Implant-supported, Fixed Partial Denture, Finite Element Analysis, Mandible, von Mises Stress.

Introduction

Oral health is defined as “a comfortable and functional dentition which allows individuals to continue in their desired social role”[1]. However, oral and dental health typically deteriorates with age, cumulatively resulting in partial or complete edentulism. Missing teeth create significant hurdles in fundamental functions such as mastication and speech, while the resulting esthetic concerns often affect the psychological and mental well-being of the individual[2]. Because oral health is often a "mirror" of general health, edentulism can compromise systemic wellness by affecting dietary functions.

To address these conditions, several replacement modalities—including removable/fixed partial dentures (FPDs) and dental implants—have been developed. Recent surveys indicate that while the majority of the population is aware of traditional dentures, awareness of dental implants remains lower, despite a strong preference for fixed prostheses[3]. Ideally, an FPD requires two abutments for support (one at each end). However, clinical scenarios often necessitate a cantilever design, where the pontic is attached to an abutment at only one end[4].

The primary challenge of a cantilever design is its biomechanical nature; it creates a class I lever system when vertical or oblique forces are directed at the pontic. This system generates stress forces generally higher than those in a conventional three-element FPD, transferring much greater forces to the abutment and surrounding bone[5]. When dental implants serve as abutments, they revolutionize treatment options for edentulous patients, particularly in cases where anatomical limitations or severe ridge resorption prevent the placement of multiple implants[6,7].

Unlike natural teeth, which possess a flexible periodontal ligament-alveolar bone interface that absorbs stress[8,9], the bone-implant interface is virtually non-flexible. Consequently, masticatory forces induce direct stress gradients across the interface[10,11]. In an implant-supported cantilever FPD, these forces are particularly concentrated in the cervical region of the implants and can exceed the applied stresses[15]. Such stress overload may result in bone resorption, mobility, or fracture of the prosthesis framework[16]. These mechanical complications are primary determinants of peri-implantitis—a progressive disease of the surrounding tissues that often leads to implant failure.

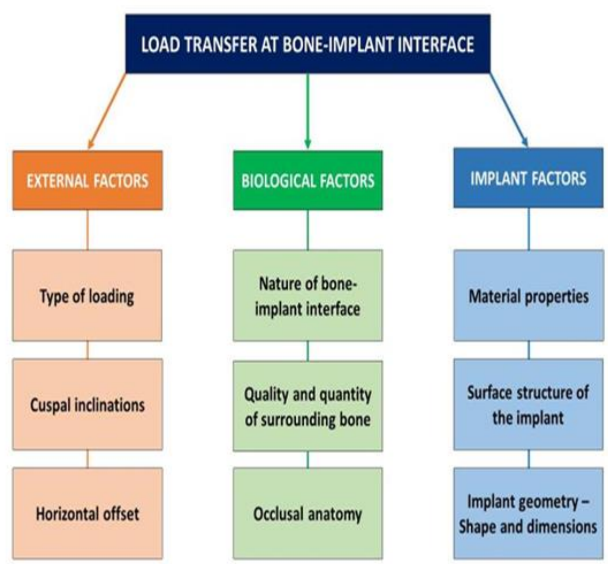

Figure 1: Factors affecting the load transfer at the bone-implant interface

Therefore, it is imperative to study stress distribution within tolerable limits to optimize the biomechanics of implant-supported cantilever designs. Analyzing load transmission and the direction of forces allows clinicians to determine appropriate implant placement and prosthetic design to increase the longevity of the restoration[17-19]. Engineering techniques, specifically the Finite Element Analysis Method (FEAM), have emerged as vital tools for analyzing these stress patterns in vitro[2-23]. FEAM allows for the identification of critical areas by breaking down complex structures into mathematically discrete elements connected by nodes[24]. This systematic review aims to identify and interpret studies utilizing FEAM to analyze stress patterns on implant-supported cantilever fixed prostheses in mandibular posterior region models.

Materials and Methods

The methodology for this systematic review was rigorously structured to identify and analyze high-quality in-vitro studies focusing on the biomechanical behaviour of implant-supported cantilever fixed partial dentures (FPDs). The process followed a standardized protocol to ensure a comprehensive, transparent, and unbiased collection of data.

Search Strategy and Information Sources

A systematic search was executed to identify relevant literature published in the English language between January 2000 and October 2022. The search utilized a wide array of high impact electronic databases, including MEDLINE (Ovid), PubMed, PubMed Central, Web of Science (Science Citation Index Expanded), Google Scholar, EMBASE, HINARI, Science Direct, EBSCO host, and Wiley databases.

The search employed complex Boolean strings to maximize retrieval. The Primary Strategy targeted specific MeSH terms: “Cantilever" AND (“Implant-supported” OR “Implant”) AND "Fixed Partial Denture." A Secondary Strategy was used to capture studies using alternative terminology, such as “Cantilever” AND “Implant” AND “Prosthesis.” Furthermore, the reference lists of all identified primary studies were manually scanned (cross referencing) to ensure that no seminal engineering or dental studies were overlooked.

Selection and Exclusion Criteria

To maintain a strict focus on biomechanical stress analysis via computational engineering, the study selection was governed by specific eligibility criteria based on the PICOS (Population, Intervention, Comparison, Outcome, and Study Design) framework

Inclusion Criteria: The review included in vitro studies utilizing the Finite Element Analysis Method (FEAM) to evaluate stress distribution in the bone and prosthetic components of implant-supported cantilever FPDs. The scope was limited to simulations of the posterior region of the jaws and full-arch prostheses.

Exclusion Criteria: Studies involving in-vivo clinical trials, animal models, case reports, and systematic reviews were excluded. Additionally, simulations involving the anterior region, removable partial dentures, or complete dentures were omitted to ensure data homogeneity.

Study Selection and Data Extraction

As illustrated in the PRISMA flow chart, the initial search yielded a significant pool of records (including 187 from cross-references). After removing duplicates and screening 165 titles and abstracts, 35 full-text articles were assessed for eligibility. Ultimately, 10 articles met all criteria for final qualitative synthesis.

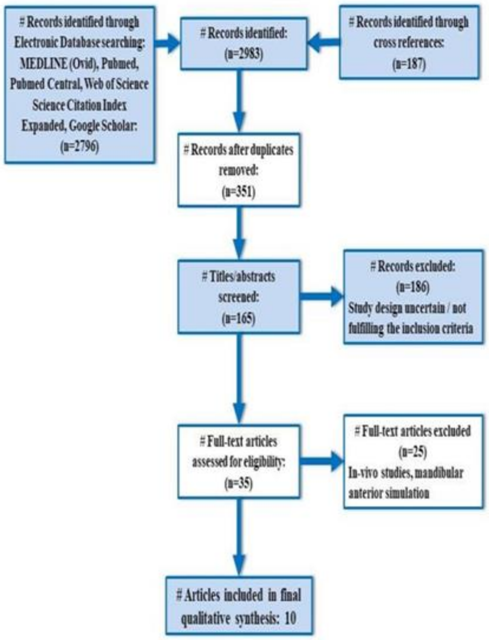

Figure 2: PRISMA Chart indicating the selection process of articles for final qualitative synthesis in the present systematic review

To eliminate the risk of bias during quality assessment, the authors were divided into two independent groups for screening and data extraction. Data were recorded into standardized MS Excel sheets and included

1. Study Characteristics: Author, year of publication, and software used (e.g., Pro/Engineer, Sap2000, Mimics).
2. Model Details: The region of the bone model (e.g., Mandible), the size of the simulated segment, and the specific design of the block used as a bone model.
3. Prosthetic Variables: Characteristics of the implants, materials used for coping, and the nature of the occlusal surfaces.
4. Loading and Outcomes: The type and magnitude of forces applied (e.g., 1-point vs. 3 point occlusal load) and the resulting von Mises stress values across the bone-implant interface.
5. This rigorous methodological framework provided a solid foundation for interpreting how various design parameters influence the structural integrity and longevity of cantilevered implant restorations.

Results

The systematic review included 10 in-vitro studies published between 2002 and 2018, all of which utilized Finite Element Analysis (FEA) to evaluate the biomechanical behavior of posterior implant-supported cantilever fixed partial dentures (FPDs). The results are categorized based on model parameters, implant characteristics, and loading outcomes.

Technical Parameters and Modeling

Most studies simulated the mandibular posterior region (8 out of 10), typically modeling the area from the premolars to the molars. Advanced engineering software was employed to design these three-dimensional models, with Ansys (Versions 11.0 to 14.0) and Solid Works being the most frequently used platforms. The bone segments were generally modeled as Type 2 bone (dense cortical bone surrounding a core of cancellous bone).

Impact of Loading Locations and Vectors

The magnitude of axial (vertical) forces applied across the studies ranged from 50N to 500N, with most authors using a standard static load of 300N to simulate molar masticatory forces.

Point of Contact: Eskitascioglu et al. (2004) demonstrated that loading at two or three locations on the occlusal surface distributed stress more evenly within the bone compared to a single-point load, which concentrated stress at the implant-bone interface.

Force Direction: Oblique (angled) loads consistently produced higher peak stress values than axial loads. Alencar et al. (2015) found that 45° oblique loads concentrated stress at the bone crest of the implant closest to the cantilever, regardless of whether the prosthesis was screwed or cemented.

Biomechanical Performance of Design Variations

Several key design variables were identified as critical factors in stress distribution

Mesial vs. Distal Cantilevers: Studies by De Souza Batista (2017) and Coutinho Bastos (2018) highlighted that distal cantilevers (molar position) induce significantly higher cortical compression and unfavorable biomechanical behavior compared to mesial cantilevers.

Implant Connection Types: The Morse taper connection showed superior performance over the external hexagon (EH) connection. EH connections were associated with higher cortical compression and increased stress on prosthetic and abutment screws.

Prosthetic Material: Zirconia was found to support maximum bite forces effectively in both molar and premolar designs, whereas titanium frameworks required larger connector areas (fillets) to withstand the same loads.

Implant Design: Koka et al. (2011) observed that one-piece implants distributed stress better than two-piece designs, where stress tended to concentrate at the junction of the abutment and the fixture.

Misfit and Failure Factors: Kunavisarut et al. (2002) noted that a prosthesis misfit (a gap between the implant and framework) significantly amplified stress by 43% to 85% in cantilever models. In all studies, the maximum stress peak was consistently located at the cervical bone (the "neck" of the implant) in contact with the first few threads of the primary implant.

In summary, the most favorable clinical configuration for rehabilitating the posterior mandible—based on minimizing stress concentration—was identified as a Morse taper implant connection combined with a mesial cantilever.

Discussion

An implant-supported fixed partial denture (FPD) must possess adequate structural integrity to resist masticatory forces. Mechanical failure occurs when stresses exceed the von Mises yielding limit of the materials used[32,3]. In cantilever designs, the "Class I lever mechanism" accentuates forces at the interfaces, often leading to prosthetic screw loosening— one of the most common complications in clinical practice[34,35].

Finite Element Analysis (FEA) serves as a vital numerical method for discretizing these complex structures into finite elements connected by nodes to approximate actual stress and deformation[36]. Studies using software like Ansys and Solid Works enable the simulation of realistic loading patterns, allowing clinicians to optimize designs before fabrication[5,37]. While maximal biting forces in the molar region range from 300N to 500N, research by Meric et al. found that generated stresses at the bone-implant interface (approx. 64.9 MPa) typically remain below the cortical bone's yielding threshold of 130 Mpa[15,38].

The location of occlusal contact is a critical factor. Although "organic occlusion" suggests 3-point contact, Eskitascioglu et al. demonstrated that while 3-point contact increases local occlusal stress, the forces transferred to the supporting bone are comparable to 1- or 2-point contact scenarios[26]. However, the direction of force is paramount; oblique loads generate significantly higher stress values than axial loads due to the introduction of a "shearing" component[30].

Under buccolingual loading, the cantilever pontic not only tilts the prosthesis but also induces horizontal rotation[5]. Biomechanical performance varies significantly between mesial and distal cantilevers. Mesial cantilevers distribute stress more homogeneously within the peri-implant bone[30,31]. Conversely, distal cantilevers often experience higher loads because molars have a wider occlusal table that attracts more surface contact [30]. Caution is advised for distal cantilevers in patients with parafunctional habits, and it is generally recommended that the cantilever extension does not exceed the mesiodistal dimension of a premolar[27,41].

Furthermore, implant configuration and design influence longevity. Systems with three implants show lower stress values than two implant configurations[31]. In the "All-on Four" approach, tilting posterior implants reduces cantilever length and improves cortical anchorage[44]. Connection types also matter; Morse taper designs provide superior stress distribution compared to external hexagon connections[16]. Regarding fixation, screwed prostheses generally exhibit lower stress peaks under oblique loads than cemented ones, as they have a lower tendency to bend[30]. Material choice is equally influential. Zirconia frameworks can support masticatory loads with smaller connector areas (approx. 5.28 mm^2), whereas titanium requires broader connectors (over 9.05 mm^2) or the introduction of fillets to keep stresses below the yielding strength[5]. Finally, it is essential to note that in-vitro FEA models assume a 100% osseointegrated, isotropic environment. In clinical reality, the absence of a periodontal ligament (PDL) and the parallel orientation of collagen fibers around implants—compared to the perpendicular attachment in natural teeth—results in a diminished capacity to absorb stress[53,54]. Therefore, while cantilever FPDs are a viable treatment option, clinicians must account for host factors like bone quality and opposing occlusion to ensure long-term success.

Conclusion

Implant-supported cantilever fixed partial dentures (FPDs) can definitely be considered a viable treatment option in clinical cases that do not permit the placement of multiple implants or where extensive surgical procedures are contraindicated.

While these designs are subject to certain biomechanical limitations, they can be utilized safely in most posterior region scenarios when properly engineered.

The inherent "Class I lever mechanism" created by the cantilever design inevitably places the primary implant and the surrounding peri implant bone under additional stresses that are often greater in magnitude than the actual occlusal load applied.

The efficiency of load transfers to the abutment, pontic, and cortical bone is governed by a complex interplay of patient-related, implant-related, and prosthesis related factors. To ensure long-term clinical success, these variables must be carefully assessed before meticulously planning a cantilever FPD with an optimal functional design. In ideal scenarios where bone volume and financial factors allow for one implant per missing tooth, the use of a cantilever—particularly a distal cantilever—should be avoided due to its unfavorable biomechanical behavior, which increases the risk of mechanical or biological treatment failure. Nevertheless, when used judiciously, implant supported cantilever FPDs remain a highly effective treatment modality. They provide a stable, fixed solution for patients in clinical situations that do not allow for the generous placement of multiple implants or the fabrication of conventional, fully-supported fixed prostheses.

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