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BIOMECHANICAL EVALUATION OF OCCLUSAL LOAD DISTRIBUTION IN FIXED PROSTHODONTIC RESTORATIONS

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Abstract: The biomechanical behavior of fixed prosthodontic restorations under occlusal loading is critical for long-term success, structural integrity, and patient comfort. This study investigates occlusal load distribution patterns in various fixed prosthetic designs, including single crowns, multi-unit bridges, and implant-supported prostheses, using finite element analysis, strain gauge measurements, and clinical evaluation. Emphasis is placed on the effects of restoration material, marginal design, connector dimensions, cantilever length, and occlusal scheme on stress distribution within the prosthesis and supporting structures. Findings indicate that optimal load distribution reduces the risk of mechanical complications, including fracture, debonding, and connector failure, while maintaining periodontal stability and minimizing bone resorption. Both clinical and computational results underscore the necessity of customized occlusal design and precise prosthesis fabrication to achieve favorable biomechanical performance. The study also highlights the importance of integrating digital planning and material selection to enhance the longevity and predictability of fixed restorations. Evidence-based strategies for occlusal load management are critical to achieving functional efficiency, patient satisfaction, and preservation of supporting tissues.

Keywords: Biomechanics, Occlusal load distribution, Fixed prosthodontics, Single crowns, Bridges, Implant-supported prostheses, Finite element analysis, Stress analysis, Connector design, Periodontal stability

Introduction: Fixed prosthodontic restorations restore masticatory function, esthetics, and occlusal harmony but are subjected to complex occlusal forces that can compromise structural integrity over time. Occlusal load distribution is influenced by prosthesis design, material properties, tooth preparation, antagonist characteristics, and occlusal scheme. Improper load distribution may lead to crown or bridge fracture, cement failure, tooth mobility, bone resorption, or temporomandibular joint disorders. Finite element analysis and strain gauge studies provide insight into stress concentration points, guiding modifications in connector design, occlusal morphology, and material selection. Implant-supported restorations present additional biomechanical considerations due to the absence of periodontal ligament damping and potential bone remodeling in response to load. Understanding these biomechanical principles enables clinicians to optimize prosthetic design, reduce complication rates, and ensure the functional longevity of fixed restorations while preserving periodontal and peri-implant tissue health.

Materials and Methods: The study integrates computational modeling, in vitro testing, and clinical evaluation. Finite element models of single crowns, three-unit bridges, and implant-supported fixed partial dentures were constructed with varying material properties, connector dimensions, marginal designs, and occlusal schemes. Load application simulated masticatory forces of 150–300 N at axial, oblique, and lateral directions. Strain gauges attached to abutment teeth and implant analogs measured deformation under load. Clinical evaluation included assessment of occlusal contacts using articulating paper, wear pattern analysis, and follow-up radiographs to evaluate bone response and periodontal health. Statistical analysis compared stress distribution patterns, deformation values, and incidence of mechanical complications among restoration designs and materials. The integration of digital scanning, CAD/CAM design, and 3D printing facilitated accurate modeling of occlusal morphology and connector geometry.

Materials: 1. Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) blocks used for prosthesis fabrication, providing high flexural strength (900–1200 MPa) and fracture toughness (9–10 MPa·m½); stored in dry, temperature-controlled conditions to prevent hydrothermal degradation. 2. Lithium disilicate glass-ceramic (LS2) blocks offering esthetic translucency, moderate flexural strength (360–400 MPa), and favorable occlusal wear characteristics; kept in sealed containers to maintain chemical stability. 3. Resin-modified glass ionomer cement providing chemical adhesion, marginal sealing, fluoride release, and periodontal protection; stored at recommended room temperature to prevent premature setting. 4. Adhesive resin cement ensuring high bond strength, low microleakage, and excellent marginal adaptation; refrigeration recommended to maintain viscosity and polymerization efficiency. 5. Implant analogs for biomechanical simulation of load transfer; metallic components stored in clean, dry conditions to preserve surface integrity. 6. Strain gauges for in vitro load measurement, capable of detecting microstrain variations across prosthesis and supporting structures; calibrated and stored in protective casing. 7. Finite element modeling software for simulation of stress distribution under variable loading conditions; project files backed up and stored securely. 8. High-speed diamond burs for standardized tooth preparation with controlled reduction and rounded line angles; sterilized and stored in dry containers. 9. Articulating paper and occlusal indicator films for clinical assessment of contact points; protected from moisture and light to maintain color integrity. 10. CAD/CAM milling machines to fabricate zirconia and lithium disilicate restorations; machine parameters regularly maintained and files stored securely to ensure precision and reproducibility.

Results: Finite element analysis revealed that occlusal load is concentrated at connector regions in multi-unit bridges and at axial walls in single crowns, with maximum stress observed under oblique loading. Monolithic zirconia crowns demonstrated higher resistance to stress concentration compared with veneered restorations. Implant-supported prostheses showed stress concentration at the crestal bone, with cantilever extensions significantly increasing mechanical load and deformation. Strain gauge data corroborated computational findings, indicating minimal deformation in crowns with optimized occlusal morphology and proper axial alignment. Clinical follow-up revealed low incidence of fracture or chipping in restorations with controlled occlusal contacts, proper connector dimensions, and balanced occlusal scheme. Periodontal parameters remained stable across tooth-supported prostheses, with minimal probing depth changes and no significant attachment loss. Restoration materials and occlusal design influenced stress distribution, highlighting the importance of material selection and occlusal adjustment for long-term biomechanical stability.

Discussion: The study emphasizes that occlusal load distribution is critical for preventing mechanical failures and ensuring the longevity of fixed prosthodontic restorations. Proper connector design, cantilever management, and occlusal morphology minimize stress concentration, reducing risk of fracture, cement debonding, and abutment tooth overload. Material choice affects deformation behavior, with zirconia exhibiting superior mechanical performance compared to lithium disilicate, especially in posterior loadbearing areas. Implant-supported prostheses require meticulous occlusal adjustment to prevent crestal bone overloading and peri-implant tissue complications. Integration of digital workflow, including CAD/CAM design and finite element simulation, enhances restoration accuracy and predicts biomechanical behavior. Clinicians must consider patient-specific occlusal patterns, parafunctional habits, and antagonist material to tailor restorations for optimal load distribution and tissue preservation. Preventive strategies, such as occlusal splints for bruxism and regular follow-up, further enhance restoration longevity.

Conclusion: Biomechanical evaluation demonstrates that occlusal load distribution significantly influences the structural integrity, functional performance, and tissue response of fixed prosthodontic restorations. Optimized restoration design, appropriate material selection, precise connector dimensions, and controlled occlusal morphology reduce stress concentration, minimize mechanical complications, and preserve periodontal and peri-implant health. Monolithic zirconia exhibits superior resistance to fracture, while veneered ceramics require careful occlusal adjustment to prevent chipping. Implant-supported prostheses demand careful load management to avoid crestal bone stress. Digital planning and finite element analysis provide valuable predictive tools for customizing prosthetic rehabilitation. Clinical integration of these biomechanical principles enhances restoration longevity, patient satisfaction, and overall treatment predictability, supporting evidence-based strategies for fixed prosthodontic practice.

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