pISSN 2394-6032 | eISSN 2394-6040

DOI: https://dx.doi.org/10.18203/2394-6040.ijcmph20250071

Review Article

Influence of occlusal loading on the longevity of dental bridges

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Received: 02 January 2025
Accepted: 22 January 2025

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ABSTRACT

Dental bridges are a cornerstone in restorative dentistry, offering functional and aesthetic solutions for patients with missing teeth. Their longevity is influenced by a complex interplay of biomechanical, material, and clinical factors. Occlusal loading, the force exerted during mastication and other functional activities, plays a critical role in determining the durability of these prostheses. Excessive or uneven occlusal forces can lead to mechanical failures such as fractures, debonding, or material fatigue. Advances in materials, particularly high-strength ceramics like zirconia, have improved the ability of bridges to withstand these stresses, providing enhanced resistance to wear and fracture. Design considerations, including connector dimensions and the use of computer-aided design and computer-aided manufacturing (CAD/CAM) technology, ensure more precise stress distribution, minimizing the risk of localized mechanical failures. Finite element analysis and digital occlusal analysis have further refined the understanding of stress patterns, enabling personalized approaches tailored to individual patient needs. Clinical studies have highlighted the importance of maintenance strategies, such as regular follow-ups and early repair of minor defects, in extending the lifespan of dental bridges. Patient-specific factors, such as parafunctional habits and periodontal health, significantly influence outcomes and necessitate individualized treatment planning. Emerging technologies, combined with material innovations, have shifted the focus toward optimizing the biomechanical performance of dental bridges. Trends reveal that integrating robust materials with advanced design techniques results in improved longevity and reduced failure rates. The interplay between clinical, material, and mechanical factors continues to evolve, offering new insights into enhancing the reliability and success of dental bridges over time.

Keywords: Dental bridges, Occlusal loading, Zirconia, CAD/CAM technology, Prosthesis longevity

INTRODUCTION

Dental bridges are one of the cornerstone restorative options in modern dentistry, providing both functional and aesthetic rehabilitation for patients with missing teeth. They play a vital role in restoring occlusion, masticatory efficiency, and facial harmony.[1] However, their longevity is a subject of significant clinical interest, as failure rates can vary based on a multitude of factors. Among these, occlusal loading stands out as a primary determinant of a bridge's durability and overall success. Occlusal loading encompasses the forces exerted on dental bridges during functions such as mastication, clenching, and parafunctional activities like bruxism. These forces have both direct and indirect effects on the mechanical, material, and biological aspects of the dental bridge and surrounding tissues.

Occlusal forces vary in magnitude and direction depending on individual occlusal schemes, dietary habits, and parafunctional behaviors. When these forces exceed the material's or tooth structure's threshold, they can lead to complications such as fractures, debonding, or damage to abutment teeth.[2] Studies have shown that improper occlusal loading is one of the leading causes of prosthetic failure, highlighting the need for precise occlusal management in bridge design and placement. For instance, bridges exposed to uneven forces are prone to fatigue, leading to microfractures that compromise the structural integrity over time.[3] Conversely, well-distributed occlusal forces can enhance the stability and longevity of these restorations.

Material selection plays a crucial role in withstanding occlusal loading. Advances in restorative materials, particularly in ceramics and high-strength alloys, have significantly improved the durability and resistance of dental bridges to occlusal stress. Finite element analysis (FEA) studies have demonstrated that materials such as zirconia and lithium disilicate are particularly effective at dissipating occlusal forces, reducing stress concentration in critical areas like connectors and abutments.[4] Furthermore, surface treatments and the use of high-quality adhesives have been shown to enhance the bond strength between abutment teeth and the prosthesis, reducing the risk of mechanical failure under repeated loading.

Bridge design also influences the response to occlusal forces. Designs with wide connectors and symmetrical stress distribution have proven more resilient to the cyclic forces of mastication. In contrast, cantilever designs and bridges with inadequate connector dimensions are more susceptible to stress fractures.[5] This understanding underscores the importance of applying biomechanical principles during treatment planning. Notably, the inclusion of digital tools like computer-aided design (CAD) and computer-aided manufacturing (CAM) has revolutionized the fabrication of bridges, enabling precise customization to match individual occlusal demands. Beyond mechanical factors, biological considerations such as periodontal health and abutment vitality also mediate the effects of occlusal loading. Excessive forces can exacerbate periodontal inflammation or lead to mobility of abutment teeth, further compromising the stability of the prosthesis. Clinicians must therefore adopt a holistic approach that integrates material science, occlusal management, and periodontal care to maximize the success of dental bridges.

Despite advancements in material technology and bridge design, gaps remain in fully understanding the multifactorial nature of occlusal loading and its long-term implications for bridge longevity. Innovations such as digital occlusal analysis and advanced imaging modalities offer promising avenues for further research, paving the way for more predictable and durable restorative outcomes. This review aims to explore the intricate relationship between occlusal loading and the longevity of dental bridges, focusing on biomechanical, material, and clinical considerations to inform evidence-based practice.

REVIEW

The impact of occlusal loading on the longevity of dental bridges is multifaceted, involving mechanical, biological, and material considerations. Proper stress distribution is critical to maintaining the structural integrity of a dental bridge. Excessive or uneven occlusal forces can lead to complications such as microcracks in the material, debonding, or failure of the abutment teeth. Research indicates that the preparation of abutments and the design of the connectors significantly affect stress distribution and, consequently, the durability of the bridge. A study by Lüthy et al highlighted that optimized connector dimensions and the use of advanced ceramic materials like zirconia improve resistance to occlusal stresses, mitigating the risk of fractures and enhancing longevity.[6]

The choice of restorative materials also plays a pivotal role in managing occlusal forces. Schroeder et al demonstrated that the preparation design and material properties directly influence the stress distribution within the restoration under occlusal loading.[7] For instance, high-strength ceramics with superior flexural strength can withstand greater loads, making them ideal for bridges subjected to heavy occlusal forces. However, patient-specific factors such as occlusal schemes and parafunctional habits must also be considered to optimize outcomes. Overall, a biomechanically sound approach tailored to individual patient needs is essential for ensuring long-term success.

Biomechanics of occlusal loading

Occlusal loading plays a central role in the biomechanical performance of dental bridges, influencing their structural integrity and clinical longevity. When masticatory forces are applied to these prostheses, a complex interplay of stress distribution occurs within the bridge structure, surrounding abutments, and periodontal tissues. These forces, depending on their magnitude, direction, and frequency, can have varying effects on the stability and functionality of the restoration. The distribution of stresses within a dental bridge is primarily dictated by its design and the materials used. A study by Mously et al explored the impact of connector dimensions on micromotion and displacement in tooth-supported bridges.[8] It revealed that larger connector cross-sections improve the ability of bridges to withstand higher occlusal loads by minimizing micromotion at the interface. The study highlighted the importance of optimizing design parameters to ensure the even distribution of occlusal forces, thus reducing the risk of mechanical failure.

Dynamic loading conditions add another layer of complexity. Research by Benaissa et al analyzed the effects of dynamic occlusal forces on the biomechanical behavior of human teeth and their prosthetic replacements.[9] The study utilized advanced simulation techniques to demonstrate that cyclic loading induces stress concentrations at specific points, such as the pontic and connectors. These localized stresses can lead to fatigue and eventual material failure, emphasizing the necessity for robust material properties and precise fabrication techniques. Material selection is equally critical in managing occlusal forces. Noh et al conducted a biomechanical analysis of implant-supported bridges subjected to occlusal loads.[10] The findings showed that high-strength ceramics, such as zirconia, are effective at reducing stress concentrations in areas susceptible to failure. Additionally, the study underlined that the combination of material properties and appropriate loading direction significantly enhances the durability of prosthetic structures.

Patient-specific factors also influence the biomechanical response of dental bridges to occlusal loading. Kuroshima et al explored the role of bone quality and implant alignment in supporting fixed prostheses.[11] They observed that poor-quality alveolar bone subjected to uneven occlusal forces is more prone to fatigue failures. This underscores the need for customized treatment planning that considers the unique anatomical and functional characteristics of each patient. The integration of digital tools in modern dentistry has improved the accuracy of biomechanical assessments. Advanced FEA models have allowed researchers to simulate and predict the behavior of dental bridges under various loading conditions. For example, studies using FEA have demonstrated how specific connector designs and material properties influence stress distribution and deformation patterns.[12] These findings have practical implications, guiding clinicians in selecting designs and materials tailored to individual occlusal requirements. Understanding the biomechanical principles underlying occlusal loading is essential for improving the performance and longevity of dental bridges. This requires a multidisciplinary approach, integrating material science, engineering, and clinical expertise to address the diverse challenges posed by occlusal forces.

Material and design factors

The mechanical performance of dental bridges under occlusal loading is largely determined by the materials used and the design configurations of the restoration. As the field of prosthodontics advances, the focus has shifted towards creating restorations that are not only functional and esthetically pleasing but also capable of withstanding the complex forces generated during mastication. Materials used in dental bridges have evolved significantly, with modern innovations emphasizing durability, flexibility, and biocompatibility. Additively manufactured resins, as highlighted by Paranna et al have gained prominence due to their ability to be customized for individual cases.[13] These materials, created through advanced 3D printing techniques, demonstrate excellent tensile strength and resistance to fracture. The study emphasized that these properties are influenced by the layering process during fabrication, which allows for tailored stress distribution within the restoration. Such advancements ensure that the prostheses remain stable under the dynamic forces of daily use. In resin-bonded bridges, the interplay between adhesive systems and material properties becomes particularly important. Research by Jaoued et al indicated that the success of these bridges depends on the precise balance between adhesive thickness and the strength of the material.[14] Mismanagement of these factors can lead to debonding or material failure under repeated loading. The findings underscore the critical role of material selection in achieving both durability and reliable performance in clinical settings.

The design of dental bridges also influences their biomechanical behavior, particularly in managing stress concentrations. Mourouzis and Tolidis explored how CAD/CAM systems revolutionized the design of dental restorations.[15] Their work revealed that digitally designed bridges could achieve superior load distribution by optimizing connector dimensions and creating geometrically consistent restorations. With CAD/CAM technology, precision becomes a critical factor, as inaccuracies in the design can lead to uneven stress distribution, increasing the likelihood of material fatigue or failure. FEA has further illuminated the importance of design considerations in dental bridges. Younesi et al conducted FEA simulations to analyze stress distribution in tooth-implant-supported bridges, revealing that wider connectors reduced localized stress significantly.[16] The study also demonstrated that implant alignment and the number of abutments used impact the stress-bearing capacity of the bridge. These insights help clinicians make evidence-based decisions regarding the optimal design parameters for bridges subjected to heavy occlusal forces.

Material innovation is continually pushing the boundaries of what is possible in dental bridge fabrication. Punia and Garg demonstrated the mechanical benefits of incorporating stainless steel nanoparticles into 3D-printable resin matrices.[17] Their findings showed enhanced fracture resistance and increased load tolerance, suggesting that hybrid materials could address the challenges posed by complex occlusal loads. This integration of nanotechnology with traditional dental materials offers promising possibilities for creating highly resilient prostheses. Beyond the physical properties of materials and structural design, patient-specific factors, such as occlusal force direction, bite alignment, and parafunctional habits, must be considered during the planning phase. Modern diagnostic tools, including digital occlusal analysis, enable clinicians to assess these variables accurately. Integrating these insights into the material selection and design process ensures that restorations are tailored to the unique biomechanical environment of each patient.

The synergistic relationship between material properties and bridge design is crucial in managing the stresses imposed during mastication. Materials must have sufficient flexural strength to absorb forces while maintaining the esthetic and functional characteristics required for patient satisfaction. Meanwhile, design precision must ensure that these forces are evenly distributed to prevent localized stress concentrations that could lead to failure over time. Advancements in both materials and digital design technologies continue to refine the ability of dental bridges to endure the complex biomechanical demands of the oral environment. These developments represent a paradigm shift in how prosthodontic restorations are approached, focusing on integrating robust materials with cutting-edge design principles to achieve optimal outcomes.

Clinical longevity trends

The durability of dental bridges is an essential consideration in restorative dentistry, reflecting the success of both material science advancements and clinical techniques. As clinical practices and patient demands evolve, understanding trends in bridge longevity allows for a more tailored approach to treatment planning and improvements in prosthesis design. One of the most significant advancements influencing clinical longevity is the adoption of zirconia as a core material for dental bridges. Datewas et al demonstrated that zirconia bridges exhibit greater resistance to fracture and wear compared to traditional porcelain-fused-to-metal (PFM) restorations.[18] The study particularly emphasized zirconia's performance in long-span bridges, attributing its success to the material's high fracture toughness and excellent wear resistance. These characteristics make zirconia an ideal choice for high-stress areas, especially for patients with heavy occlusal loads or parafunctional habits such as bruxism.

Another key factor affecting longevity is the design of the prosthesis, including the optimization of connector dimensions and load distribution. Bridges designed using CAD/CAM technologies show enhanced stress distribution and fewer failures related to mechanical fatigue.[19] CAD/CAM precision ensures that the forces exerted during mastication are evenly distributed across the prosthesis, reducing localized stress that could lead to fractures or debonding. The role of maintenance and regular follow-ups in extending the lifespan of dental bridges has also been a focus of research. Lynne Miller et al investigated the impact of routine dental check-ups on bridge longevity, finding that patients who adhered to regular maintenance schedules experienced fewer complications, such as periodontal issues, marginal leakage, or mechanical failures.[20] The study underscored that proactive management of plaque control, as well as early detection and repair of minor defects, can significantly delay the need for replacement or extensive repairs.

Material-specific trends further reveal differences in clinical longevity. Morimoto et al conducted a systematic review and meta-analysis comparing the survival rates of resin-based and ceramic-based dental restorations.[21] Their findings indicated that ceramic-based materials consistently outperformed resin composites in terms of longevity and structural reliability, particularly under occlusal stresses. Resin-based composites, while offering lower initial costs and acceptable aesthetics, were found to degrade faster under cyclic loading, leading to higher repair and replacement rates. This emphasizes the importance of matching the material to the patient's functional needs and willingness to maintain the prosthesis over time. For patients with parafunctional habits such as bruxism, material choice becomes even more critical. Asaad et al examined the influence of bruxism on the longevity of dental restorations, including bridges, and found that parafunctional behaviors significantly impact the lifespan of restorative materials.[22] Their research revealed that bruxism leads to increased mechanical stress, contributing to microfractures, material fatigue, and eventual failure. Strategies such as using high-strength materials like zirconia and incorporating protective measures, such as occlusal guards, were recommended to mitigate these effects and enhance bridge durability.

Patient-specific factors, including occlusal alignment, periodontal health, and systemic conditions, also influence clinical outcomes. Proper occlusal analysis and adjustment are necessary to prevent uneven loading, which can lead to premature failure. Studies suggest that tailoring treatment to individual needs—such as selecting materials and designs suited to the patient's occlusal environment and lifestyle—can enhance bridge longevity. For instance, patients with poor periodontal health benefit from shorter-span bridges or implant-supported designs, as these reduce the load on compromised abutment teeth.

Emerging diagnostic technologies, such as digital occlusal analysis tools, have further improved the clinician's ability to predict and manage factors influencing bridge longevity. These tools provide real-time insights into occlusal force patterns, enabling precise adjustments during placement and follow-up visits. The integration of such technologies into clinical workflows represents a growing trend toward evidence-based personalization of dental restorations. In the context of restorative dentistry, the continuous evaluation of clinical outcomes is vital for identifying patterns and improving future interventions. The trends in bridge longevity highlight the intersection of material innovation, design optimization, and proactive maintenance as cornerstones of successful long-term outcomes.

CONCLUSION

The longevity of dental bridges is determined by a combination of material properties, precise design, and proactive maintenance strategies. Innovations such as zirconia-based materials and CAD/CAM technologies have significantly improved durability and performance under occlusal loading. Regular follow-ups and personalized treatment plans further enhance outcomes by addressing patient-specific factors. Continued research and technological advancements are essential to optimize restorative solutions and ensure long-term success.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: Not required

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Cite this article as: Aqely MA, Faraj MI, Alnafisi AA, Ayoub MN, Diqini IM, Majrashi NM, et al. Influence of occlusal loading on the longevity of dental bridges. Int J Community Med Public Health 2025;12:1074-8.