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Digital Twin Dentures Adapting Occlusion Based on Chewing Behavior Collected Through Embedded Sensors

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ABSTRACT

Digital twin dentures represent an emerging advancement in prosthodontics by combining digital modeling, embedded sensor technology, and artificial intelligence to create adaptive removable prostheses capable of responding to an individual's chewing behavior. Unlike conventional dentures, these smart prostheses continuously collect functional data such as bite force, chewing frequency, occlusal contacts, and mandibular movement through integrated microsensors. The acquired information is transmitted to a virtual digital twin that replicates the clinical performance of the denture, enabling continuous assessment of occlusal function and personalized treatment planning. Advanced data analytics facilitate the identification of functional imbalances, excessive loading, and parafunctional habits, allowing clinicians to optimize occlusion and improve prosthesis performance over time. This adaptive approach has the potential to enhance masticatory efficiency, patient comfort, prosthesis stability, and long-term durability while supporting preventive maintenance and reducing the frequency of manual adjustments. Furthermore, integration with cloud-based monitoring systems and digital dentistry workflows may enable remote follow-up and evidence-based clinical decision-making. Although challenges remain regarding sensor reliability, data security, manufacturing complexity, and clinical validation, digital twin dentures offer a promising direction for personalized prosthodontic care by transforming static prostheses into intelligent systems capable of continuous functional adaptation and improved patient-centered outcomes.

INTRODUCTION

Digital transformation in dentistry has increasingly enabled the integration of computerized diagnostics, artificial intelligence, sensor technologies, and virtual modeling into patient-specific treatment. In prosthodontics, these developments provide opportunities to move beyond conventional static dentures toward intelligent prostheses capable of monitoring and responding to individual functional demands. Artificial intelligence can support the analysis of complex clinical information and facilitate personalized decision-making, providing an important foundation for digitally assisted prosthetic rehabilitation (Bagde, 2021).

Occlusion is a critical determinant of denture stability, masticatory efficiency, comfort, and the long-term mechanical performance of removable prostheses. Computerized occlusal analysis provides a means of obtaining objective information regarding occlusal contacts and functional loading, thereby complementing conventional clinical assessment (Radke, 2020). Similarly, restorative approaches that emphasize conservative preservation of tooth structure demonstrate the broader importance of individualized biomechanical management in maintaining oral function (Singh, 2020). Understanding how mechanical forces influence oral structures is also relevant to prosthetic design, particularly because excessive or uneven loading may contribute to structural complications and reduced longevity (Chandra et al., 2021).

The concept of a digital twin denture extends these developments by creating a virtual representation of the physical prosthesis that can be updated using real-time chewing and occlusal data. Embedded sensors could monitor bite forces, chewing frequency, occlusal patterns, and functional changes, while sensor-based oral devices have already demonstrated the feasibility of detecting bite-related mechanical activity (Hou et al., 2022). Furthermore, wireless biofeedback systems have shown potential for monitoring and modifying parafunctional behaviors such as sleep bruxism (Gu et al., 2014). Collectively, these technologies provide a foundation for developing dentures capable of continuously assessing chewing behavior and supporting individualized occlusal adaptation.

Digital Twin Denture Architecture and Adaptive Occlusion

A digital twin denture can be conceptualized as a digitally connected prosthetic system in which the physical denture is continuously represented by a virtual model that receives functional information from embedded sensors. The architecture integrates sensor acquisition, wireless data transmission, digital modeling, data analysis, and clinician-guided occlusal optimization. Artificial intelligence can support the interpretation of complex oral-function data and identify individualized patterns of chewing, loading, and occlusal contact (Bagde, 2021).

Embedded pressure, strain, or force-sensitive sensors can record variations in bite intensity, chewing frequency, contact distribution, and functional loading. Developments in sensor-enabled oral devices demonstrate the feasibility of detecting bite-related mechanical activity and converting it into useful digital signals for responsive applications (Hou et al., 2022). Such measurements can be synchronized with the digital twin, allowing the virtual denture to simulate functional behavior and identify areas of excessive or uneven loading. Computerized occlusal analysis provides an important technological foundation for interpreting these dynamic occlusal relationships (Radke, 2020).

The adaptive component involves comparing observed chewing behavior with the intended occlusal design. Artificial intelligence algorithms could identify recurring deviations and recommend modifications to denture tooth position, contact relationships, or occlusal surfaces. This individualized approach is particularly relevant because prosthetic function must account for patient-specific mechanical and behavioral factors. Material integrity and resistance to functional loading are also important considerations when developing adaptive prostheses (Chandra et al., 2021).

Additionally, sensor-based feedback could help identify parafunctional activities such as excessive clenching or bruxism, supporting preventive intervention and behavioral modification (Gu et al., 2014). Overall, the architecture combines continuous sensing with digital modeling to move denture therapy from static fabrication toward personalized, data-informed occlusal management (Singh, 2020; Bagde, 2021).

Clinical Applications, Benefits, and Challenges

Digital twin dentures could provide a patient-specific platform for monitoring and optimizing removable prosthesis function. Embedded sensors may record bite force, chewing frequency, occlusal contacts, and functional loading, allowing the virtual denture model to identify deviations from the intended occlusal scheme. Computerized occlusal analysis can support objective assessment of occlusal relationships and complement conventional clinical diagnostic methods (Radke, 2020). The incorporation of artificial intelligence may further facilitate interpretation of large volumes of sensor-generated data and support individualized prosthetic adjustments (Bagde, 2021).

A major clinical application is the detection of asymmetric or excessive occlusal loading that may contribute to denture instability, discomfort, or premature material deterioration. Sensor-based bite monitoring is supported by developments in interactive oral devices, including mechanoluminescence-powered optical-fibre sensors capable of detecting bite-related mechanical activity (Hou et al., 2022). Similar monitoring could potentially identify parafunctional behaviors such as bruxism, for which wireless biofeedback approaches have demonstrated clinical potential (Gu et al., 2014). Continuous assessment could therefore enable earlier intervention and more personalized maintenance.

The principal benefits include improved occlusal optimization, enhanced masticatory comfort, better prosthesis stability, and potentially increased functional longevity. Monitoring mechanical loading may also provide useful information for evaluating the durability of denture components, particularly because excessive functional stresses can influence fracture and material performance (Chandra et al., 2021). Conservative restorative principles further emphasize the value of preserving healthy oral structures while optimizing function (Singh, 2020).

However, several challenges remain, including sensor miniaturization, calibration, power supply, biocompatibility, data transmission, privacy, and the need for clinical validation. Reliable interpretation of individual chewing patterns is also essential to prevent inappropriate automated adjustments. Thus, digital twin dentures should initially function as clinician-guided decision-support systems rather than completely autonomous prostheses.

FUTURE PERSPECTIVES

Future development of digital twin dentures is likely to focus on increasingly intelligent, miniaturized, and patient-specific systems capable of continuously monitoring and interpreting chewing behavior. Integration of embedded force, pressure, and motion sensors with artificial intelligence could allow virtual denture models to identify abnormal occlusal loading, chewing asymmetry, and parafunctional activity, supporting more precise occlusal optimization (Bagde, 2021; Radke, 2020). Sensor technologies capable of detecting bite-related mechanical events demonstrate the feasibility of incorporating functional monitoring into oral appliances (Hou et al., 2022). Combining these systems with wireless communication and biofeedback could also support early recognition and management of excessive loading or bruxism-related behaviors (Gu et al., 2014). Future platforms may further integrate digital scanning, computer-aided design and manufacturing, and predictive analytics to facilitate individualized denture modification and maintenance. However, clinical translation will require improvements in sensor durability, calibration, power management, biocompatibility, data security, and validation across diverse patient populations. Attention should also be given to ensuring that technological modifications preserve structural integrity and functional reliability of prosthetic components (Chandra et al., 2021).

CONCLUSION

Digital twin dentures represent a promising transition from conventional static prostheses toward intelligent, data-driven removable dental appliances. By combining real-time chewing data with virtual modeling and computerized occlusal analysis, these systems could enable more personalized assessment and optimization of denture function (Radke, 2020). Their potential to incorporate adaptive monitoring and biofeedback may further improve patient comfort, stability, and functional outcomes (Gu et al., 2014). Ultimately, integration of artificial intelligence and sensor-based technologies into prosthodontics may establish a more responsive and preventive approach to denture care, while maintaining the conservative and patient-centered principles emphasized in contemporary restorative dentistry (Singh, 2020; Bagde, 2021).

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