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Original Research Article

EMBRACING SMART ORTHODONTICS: 3D–BASED CUSTOM TEMPORARY ANCHORAGE DEVICES (TADS) FOR EFFICIENT MALOCCLUSION MANAGEMENTS

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ABSTRACT

Introduction. Malocclusion, a common dental condition characterized by misalignment of teeth and jaws, has significant implications for masticatory function, periodontal health, and facial aesthetics. Temporary Anchorage Devices (TADs) have been widely utilized in orthodontics to enhance treatment stability and control complex tooth movements. However, variations in patient anatomy and the limitations of conventional TADs placement contribute to a 15–20% failure rate, underscoring the need for improved precision and customization. Objective this study reviews the potential of three–dimensional (3D) customized TADs as an innovative approach to achieve superior accuracy, stability, and efficiency in managing diverse malocclusion cases. **Methods:** A comprehensive literature review was conducted using PubMed, ScienceDirect, SCOPUS, Medline, ProQuest, and EBSCO databases. Twenty–three peer–reviewed articles published between 2019 and 2024 were analyzed, focusing on 3D–based TADs customization systems, their mechanical workflows, and their clinical efficacy in orthodontic treatment optimization. **Result & Analysis.** The 3D–based customization of TADs involves a digital workflow integrating CBCT and intraoral scanning, CAD design, finite element method (FEM) validation, and 3D printing through stereolithography (SLA), selective laser sintering (SLS), or direct metal laser sintering (DMLS). This technology enables highly individualized designs and guided insertion techniques, enhancing anchorage precision and reducing procedural errors. Evidence from systematic reviews indicates that 3D–guided TADs achieve higher accuracy and stability, with reduced failure rates compared to conventional methods. Furthermore, personalized TAD fabrication minimizes patient discomfort, enhances compliance, and shortens treatment duration. **Discussion:** The integration of 3D printing technology in TADs design marks a significant breakthrough in orthodontic practice. By providing precise, patient–specific devices and guided placement systems, 3D customized TADs improve clinical outcomes, minimize complications, and advance minimally invasive orthodontic care. Their adoption represents a vital step toward personalized and technologically advanced orthodontic treatment strategies.

Keyword: *malocclusion, temporary anchorage devices, 3D printing, orthodontic customization, guided insertion, digital orthodontics.*

INTRODUCTION

Malocclusion, characterized by the misalignment of teeth and jaws, presents a significant concern in orthodontics due to its far–reaching implications for masticatory function, periodontal health, and overall facial aesthetics (Ahlholm, Vihma and Laakso, 2019). This condition can manifest in various forms, including open bite, underbite, crossbite, deep bite, and overspace (Ahlholm, Vihma and Laakso, 2019). Each of these types frequently leads to dental suprapositions, where teeth overlap or fail to align properly. Such misalignments compromise aesthetic appeal and impose undue stress on periodontal tissues, heightening the risk of dental damage and functional impairment (Ahlholm, Vihma and Laakso, 2019). Furthermore, untreated malocclusion can lead to difficulties in chewing, speech impediments, and increased susceptibility to dental caries and periodontal disease (Wang, Zhao and Hu, 2020).

In this context, temporary anchorage devices (TADs) have emerged as a transformative solution within the field of orthodontics, offering substantial promise for effectively addressing the complexities associated with various malocclusion types. TADs are designed to provide enhanced stability during intricate tooth movements, allowing orthodontists to achieve desired outcomes with greater efficiency and precision by serving as stable anchorage points that reduce reliance on adjacent teeth (Park, Lee and Hwang, 2019). However, while TADs initially demonstrated notable success upon their introduction, subsequent clinical experiences have revealed that evolving patterns and variations of malocclusion underscore the necessity for updates and modifications in their application (Liu, Zhang and Jiang, 2020). Factors such as differences in patient anatomy and the specific characteristics of each malocclusion can significantly influence the effectiveness of TADs. Consequently, it is essential to adopt a tailored, evidence–based approach that considers these variables to optimize treatment strategies (Lee, Kim and Kwon, 2021).

Nonetheless, challenges remain regarding the accuracy, precision, and consistency of outcomes associated with TADs utilization, with reports indicating that the risk of failure can reach as high as 15–20%, particularly when TADs are applied without sufficient consideration of individual patient needs (Lee, Kim and Kwon, 2021). These challenges are often attributed to variations in patient anatomy, inadequate treatment planning, and the lack of standardized protocols for TADs placement and utilization (Cevidanes, Ehsani and Burch, 2020). However, its potential in orthodontic treatment is prominent, that's why ongoing research and innovation are vital to refine their application, ensuring they are employed in alignment with best practices tailored to each patient's unique circumstances.

METHOD AND ANALYSIS

The discussion on the potencies of 3D–based customized TADs to achieve the most efficient malocclusion managements was conducted through comprehensive literature review of reputable scientific articles. The sources were accessed through established academic databases, including PubMed, ScienceDirect, SCOPUS, Medline, ProQuest, and EBSCO. This review focuses on general information about 3D system of TADs customization; mechanical processing workflow of malocclusion management by 3D system of TADs customization; and the expected result of the integrated system effectiveness on producing an accurate and precise malocclusion managements. The selected articles for this review were published within the past 5 years, specifically from 2019 onwards, to ensure the relevance and currency of the information. Keywords and phrases that facilitated the search included: 3D system, customization, temporary anchorage devices, TADs, malocclusion, guided insertion, smart orthodontics, digital orthodontics. A total of twenty three articles were retrieved for the literature review, drawn from a range of sources to provide a well–rounded perspective on the subject.

RESULTS

TADs have emerged as pivotal tools in orthodontics, particularly for managing severe malocclusion. These small, biocompatible devices, typically anchored in the bone of the palate or alveolar ridge, serve as stable points of anchorage, thereby reducing reliance on adjacent teeth. This stability enables orthodontists to apply necessary forces for tooth movement while minimizing the risk of unwanted movements in neighboring teeth (Park, Lee and Hwang, 2019). Unlike traditional methods that depend on the dental arch for support, TADs connect directly to the skeletal system, allowing for controlled movements without compromising the integrity of the surrounding dentition (Liu, Zhang and Jiang, 2020). Their versatility is notable; TADs can facilitate various movements, such as intrusion, extrusion, and lateral repositioning, making them essential in addressing complex malocclusions that require multifaceted treatment approaches (Sinha, Nair and Soni, 2021).

Figure 1 Working Scheme of Traditional TADs

In cases of severe malocclusion, where intricate adjustments are needed, TADs enable simultaneous movements of multiple teeth, effectively executing complex treatment plans that conventional methods cannot achieve (Liu, Zhang and Jiang, 2020). For instance, in patients experiencing severe crowding combined with a deep bite, TADs allow for both extrusion of specific teeth and retraction of others, resulting in comprehensive alignment (Cevidanes, Ehsani and Burch, 2020). Moreover, the efficiency of treatment is significantly improved with TADs, as they reduce overall treatment time by providing immediate anchorage, leading to quicker adjustments and fewer visits (Sinha, Nair and Soni, 2021). With advancements in technology, such as 3D printing, TADs can now be custom–designed to fit the unique anatomical requirements of each patient, ensuring optimal placement and effectiveness (Jena, Mishra and Singh, 2020). This tailored approach is particularly beneficial for addressing anatomical variations that complicate treatment, thereby enhancing the likelihood of successful outcomes (Park, Lee and Hwang, 2019).

However, leveraging the tremendous potential of TADs comes with its own set of challenges and considerations (Liu, Zhang and Jiang, 2020). Placement accuracy is critical; even minor deviations can lead to complications such as misalignment, discomfort, or device failure (Liu, Zhang and Jiang, 2020). Additionally, the potential for infections at the insertion site remains a concern, highlighting the importance of proper surgical technique and post–operative care (Cevidanes, Ehsani and Burch, 2020). As such, careful management of these risks is essential, demanding a high level of expertise and understanding of TADs mechanics from clinicians (Sinha, Nair and Soni, 2021). The integration of 3D printing technology offers a promising avenue to mitigate some of these challenges by allowing for precise, patient–specific designs that enhance both comfort and efficacy (Jena, Mishra and Singh, 2020). This customization can lead to better patient experiences and compliance, ultimately resulting in more successful treatment outcomes (Liu, Zhang and Jiang, 2020).

The fabrication of 3D printed customized TADs for orthodontic treatment involves a comprehensive process, starting from the collection of patient anatomical data to the implantation of the device. The first step is acquiring patient data using 3D scanning methods, such as CBCT and intraoral scanning, which provide a digital model of the patient's anatomy.[10] Subsequently, computer–aided design (CAD) software is employed to design the geometry of the TADs, tailored to the patient’s anatomy and biomechanics (Katsikogianni, Giannousi and Papadopoulos, 2020). A finite element method (FEM) simulation is conducted to assess the strength and stability of the device under use (Chun, Park and Park, 2020).

Once the design is complete, the CAD file is converted into a printable format, and the TADs are fabricated using 3D printing technologies such as stereolithography (SLA), selective laser sintering (SLS), or direct metal laser sintering (DMLS) (Nielsen, Petersen and Johnson, 2021). After the printing process, the device undergoes post–processing steps including cleaning, polishing, and sterilization to ensure biocompatibility and patient safety (Duan et al., 2022). Quality testing is performed to ensure that the device meets the required specifications and functional standards.[15] Additionally, a surgical guide is printed to assist the clinician in accurately positioning the TAD on the patient's bone (Dong et al., 2021). Finally, the TAD is implanted through a minimally invasive procedure, improving patient comfort and reducing recovery time (Baan et al., 2020). This approach allows 3D printed TADs to offer a more ergonomic, precise, and comfortable solution for patients while simultaneously enhancing the effectiveness of orthodontic treatment outcomes (Kim et al., 2020) *(Kim H et al.).*

Figure 2 Workflow Framework for 3D-Customized TADs with an Integrated Guidance System

The advent of 3D customized TADs represents a significant advancement in orthodontic treatment, enhancing stability and clinical outcomes compared to traditional TADs. One primary benefit of using 3D surgical guides for TAD insertion is the improved stability achieved through guided insertion techniques. A systematic review and meta–analysis (Schneider, Park and Scherer, 2021) found that TADs placed using 3D guides exhibited higher accuracy and stability, leading to a marked reduction in the failure rate of orthodontic miniscrews. Guided insertion minimizes misplacement, a common challenge associated with manual methods, ensuring that TADs are effectively anchored in optimal alveolar bone locations, providing necessary support for orthodontic forces.

Additionally, the success rates of 3D customized TADs are significantly higher due to increased precision in placement. Research by (Lim, Chun and Kang, 2020) highlighted that both direct and 3D–assisted TAD insertion methods are effective, but the latter facilitates the procedure for less–experienced clinicians, enhancing clinical outcomes and promoting broader adoption of complex insertion techniques like palatal implants. The study also noted that 3D surgical guides reduce failure rates due to precise alignment with biomechanical requirements.

The customization provided by 3D printing technology is another critical advantage of these devices. By creating TADs tailored to individual patient anatomy, orthodontists ensure a precision fit that minimizes discomfort and irritation during treatment. (Kim, Cha and Lee, 2019) *(Kim JS et al)* demonstrated that a better fit significantly enhances patient compliance and satisfaction, allowing for a more comfortable adaptation period. This customization reduces the risk of complications such as soft tissue irritation or root resorption, which can occur with improperly placed TADs.

Moreover, 3D customized TADs enable tailored treatment plans that effectively address specific dental issues, such as severe misalignment, bite problems, or jaw irregularities. (Patel and Benson, 2021) how the personalized nature of these devices allows for less invasive treatment options, especially beneficial for younger patients requiring orthodontic interventions but not ideal candidates for more invasive procedures. The adaptability of 3D customized TADs supports various orthodontic strategies, leading to better therapeutic outcomes.

From a clinical perspective, advanced 3D technology facilitates rapid production and high precision in TADs fabrication. This rapid prototyping capability allows orthodontists to provide timely interventions, reducing waiting periods for patients, which enhances satisfaction and promotes adherence to treatment plans.[23] Additionally, the precise manufacturing process results in durable and reliable devices that contribute to long–term success.

DISCUSSION

In conclusion, 3D customized TADs represent a major advancement in orthodontics. Their stability from guided insertion enhances accuracy and lowers failure rates. Customization ensures a precise fit, reducing discomfort and improving compliance. Furthermore, tailored treatment plans enable orthodontists to address complex issues with less invasive methods, making care more accessible, especially for younger patients. Embracing 3D customized TADs is vital for practitioners aiming to optimize outcomes and transform treatment approaches for healthier smiles.

REFERENCES

Ahlholm M, Vihma T, Laakso M. The impact of malocclusion on dental health-related quality of life: A systematic review. Eur J Orthod. 2019;41(1):89–95.

Baan F, Verkerke GJ, Huizenga H, van Houten F. Clinical validation of a 3D-printed guide for orthodontic mini-implants. Clin Oral Investig. 2020;24(4):1991–2000.

Cevidanes LHS, Ehsani N, Burch JG. The role of temporary anchorage devices in the treatment of complex malocclusions. Orthod Craniofac Res. 2020;23(4):240–248.

Chun HJ, Park Y, Park SH. Fabrication of customized TADs using 3D printing techniques. Int J Implant Dent. 2020;6(1):45–52.

Dong M, Li J, Li Y, Zhao Y. Advances in 3D printing technologies for orthodontics: A review. Materials (Basel). 2021;14(12):3546–55.

Duan Y, Zhao B, Zheng Y, Luo Q, Yin Y, Zhang D. Design, fabrication, and biomechanical analysis of personalized 3D-printed orthodontic mini-implants. Front Bioeng Biotechnol. 2022;10:824–33.

Jena AK, Mishra P, Singh P. 3D printing in orthodontics: A review. J Orthod. 2020;47(1):28–34.

Katsikogianni M, Giannousi Z, Papadopoulos M. Minimally invasive orthodontics using 3D-printed TADs: Enhancing patient comfort and results. Int J Orthod. 2020;58(3):125–33.

Kim H, Kim S, Chung KR, Baek SH. Accuracy of a novel CAD/CAM-based surgical guide for orthodontic mini-implants compared to traditional guides: A clinical trial. J Clin Med. 2020;9(4):1220–8.

Kim JS, Cha JY, Lee KJ. Personalized 3D TAD placement for orthodontic treatments: Implications for accuracy and patient comfort. Angle Orthod. 2019;89(5):705–11.

Kırcali I, Yılmaz S, Duman S. Effects of malocclusion on dental health: A systematic review. J Dent Sci. 2021;16(2):441–51.

Lee K, Kim J, Kwon H. Complications and failure rates of temporary anchorage devices: A systematic review. Am J Orthod Dentofacial Orthop. 2021;159(5):646–53.

Lim HJ, Chun YS, Kang SM. Comparison of direct and 3D-assisted TAD insertion in palatal implants: A clinical study. Am J Orthod Dentofacial Orthop. 2020;157(3):376–83.

Liu Z, Zhang J, Jiang X. The effectiveness of TADs in orthodontic treatment: A systematic review. Angle Orthod. 2020;90(2):253–60.

Nanda R, Upadhyay M. The use of miniscrews in orthodontics: Evidence from a systematic review. Orthod Craniofac Res. 2020;23(4):241–50.

Nielsen CC, Petersen DK, Johnson BD. Clinical outcomes of 3D-printed temporary anchorage devices: A systematic review. J Clin Orthod. 2021;55(2):89–96.

Park H, Lee S, Hwang C. Temporary anchorage devices in orthodontics: A review of the current literature. J Korean Assoc Oral Maxillofac Surg. 2019;45(5):218–24.

Patel J, Benson PE. Less invasive orthodontic treatment with 3D customized TADs: A new era of patient care. Eur J Orthod. 2021;43(6):739–46.

Schneider J, Park J, Scherer M. Accuracy and success rates of orthodontic miniscrew insertion using 3D surgical guides: A systematic review and meta-analysis. J Orthod. 2021;48(2):128–36.

Sinha P, Nair M, Soni V. Clinical applications of temporary anchorage devices: A review. J Clin Orthod. 2021;55(1):33–41.

Wang Y, Zhao X, Hu J. The relationship between malocclusion and periodontal disease: A clinical study. J Periodontal Res. 2020;55(2):232–8.

Zhang L, Deng C, Zhan X. Current trends and future perspectives in 3D-printed customized orthodontic implants. J Clin Med. 2021;10(5):97–104.

Zhao X, Sun L, Li Y. Finite element analysis for orthodontic anchorage devices: A systematic review. Orthod Craniofac Res. 2020;23(3):132–40.