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Review Article

Advancements in Tooth Transplantation and Reimplantation Techniques. A Review

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ABSTRACT

Introduction: The evolution of tooth transplantation and reimplantation has been significantly influenced by technological advancements, including cone-beam computed tomography (CBCT), advanced biomaterials, and digital planning. These innovations have enhanced procedural precision, improved success rates, and increased patient satisfaction. However, despite these advancements, challenges remain in optimizing long-term clinical outcomes and standardizing treatment protocols. **Aim:** This study aims to comprehensively assess and analyze the latest advancements in tooth transplantation and reimplantation techniques, evaluating their impact on clinical success and patient outcomes. **Materials and Methods:** A systematic search was conducted using MEDLINE, Google Scholar, and PubMed to identify peer-reviewed articles, reviews, and clinical studies published between 2007 and 2024. The inclusion criteria focused on studies investigating the role of CBCT imaging, digital planning, and biomaterials in enhancing transplantation and reimplantation procedures. **Results:** The findings reveal a transformative shift from conventional techniques to technology-driven approaches, leading to increased precision in case selection, surgical planning, and post-operative management. The integration of CBCT imaging has significantly improved pre-operative assessment, while digital workflows have optimized procedural accuracy and predictability. Moreover, using advanced biomaterials has enhanced graft integration and long-term success rates. **Conclusion:** The incorporation of CBCT, digital planning, and biomaterials has revolutionized tooth transplantation and reimplantation, improving clinical outcomes and patient satisfaction. However, further research is needed to establish standardized protocols and long-term efficacy, ensuring consistent success across diverse clinical settings.

Keywords: Auto-transplantation, avulsed tooth, extraction, reimplantation, transplant, transplantation

Introduction

The ancient dental surgical practice of tooth transplantation and reimplantation was the cornerstone of modern dentistry. Still, due to the host of challenges, their success rate and patient satisfaction outcomes were not so good. This was the main approach, completely depending on the skills and experience of the surgeon.[1] Very little equipment was used for these operations. The lack of precise imaging carried forward the procedure, where both the choice of donor's tooth and the preparation of the recipient site were based on estimations rather than measurements.[2] These challenges were caused by the absence of exact measurements, therefore resulting in poor overlapping with adjacent teeth, a bad fit into the jawbone, and complications such as tooth mobility, misalignment, or even rejection of the transplanted tooth. The precise evaluation of the recipient site bone quality and density is a crucial factor that causes the same problems with implantation and increases the risk of failure of implantation.[3] This limitation highlights the importance of developing both the tools and procedures that could be used to make the most of tooth transplantation and reimplantation, given that the advantages offered by this procedure can only be attained through the application of advanced methods.[4,5]

Due to the inappropriate biomaterials and the lack of necessary techniques for integration, the newly implanted teeth could be unsuccessful in fusing properly with the surrounding bones and soft tissues, thus, as a result,[6,7] the root resorption and ankylosis which are the pathological fusion of the alveolar which is the

bone that grows around the tooth roots with the teeth cementum may occur and cause restriction in the times these challenges were encountered in actual surgeries involved tooth transplantation or reimplantation,[8] these deficiencies became more apparent and necessitated the entry of innovations such as imaging, medicated and multidisciplinary approach that is the current dentistry practice.[6,9]

The technology breakthroughs in tooth transplantation and reimplantation have been dramatically altered by several technological innovations. These advances, rather than only tackling the majority of the disadvantages of the previous methods, but also raise new opportunities in research and clinical practice.

Currently, cone beam computed tomography (CBCT) plays a crucial role in dental imaging, transforming how clinicians plan and perform tooth transplantation and reimplantation procedures.[8,10] CBCT boasts a complete 3D contrasting view that goes a step further than conventional two-dimensional imaging to give an articulate picture of every intricacy of the dental and the neighboring structures with astonishing precision.[11,12]

Materials and Methods

The review encompasses a comprehensive search and analysis of relevant information on tooth transplantation and reimplantation techniques from diverse sources without a specific physical or clinical setting. Literature sources include scholarly databases, such as PubMed, Web of Science, and other reputable repositories, to gather peer-reviewed articles, reviews, and clinical studies. The review focuses on publications in the English language between 2007 and 2024, ensuring the inclusion of recent advances, historical context, and emerging trends in tooth transplantation and reimplantation techniques.

Results

As with tooth transplantation and reimplantation, the process is only possible through the use of a multidisciplinary approach that combines the expertise of oral surgeons, orthodontists, periodontists, and radiologists. This cooperative model guarantees coherent operational processes from pre-operative planning to the post-operative care and rehabilitation services. The interventions of different specialists are aimed at providing a complete treatment plan that has not only the technical and the organic but also the functional and esthetic aspects in view. Multidisciplinary teams spread out the whole range of clinical applications of the latest technology, guaranteeing that every patient is treated according to the top standards in the clinical field and with personalized treatment options that reflect the specific requirements of one's health.[1,13] The employment of these advanced technologies and the switching toward multidisciplinary care altogether helped to increase the range, suitability, and solidity of tooth transplantation and reimplantation techniques, which therefore forms a new standard in dental and oral health care.

Tooth transplant and reimplantation operations from traditional to technically advanced techniques with the aid of modern technology have made a huge difference in terms of success and turnout of the patient. This part brings up an in-depth comparison of the traditional and the contemporary methods of auto-transplantation of teeth, gives the survival rates and benefits of the original teeth, describes the esthetical outcomes and patient satisfaction, and ends with the case studies that highlight these main points. Regarding the traditional approach of transplantation and re-implantation of teeth as a radical discovery at that time, it has been noticed to be associated with such challenges as precision in surgery and the length of time the transplanted teeth will live.[14] In addition, the methods that are present, supported by the development of imaging, biomaterials, and surgical approaches, have displayed high levels of elevated rates in achieving success rates. For example, the new CBCT technology that is used allows transplantation accuracy nowadays, which is much higher and, therefore, dictates a significant reduction of the complications that could be related to previous operations. However, the emerging 3D printing technology with a higher precision of the biomaterials and scaffolds has encouraged the growth speed of lost body parts (and not only) and has allowed for reconstruction of the cosmetic appearance of the reconstructed body part [Figure 1].[8,15]

Survival rates of auto-transplanted teeth and their functional benefits the survival rates of auto-transplant teeth have seen a substantial increase with the application of modern techniques.

Because auto-transplanted teeth have been demonstrated to survive at rates similar to those of implants using present-day protocols when followed for comparable periods,[7,16] research is now focused on improving bone regeneration in areas where regeneration appears

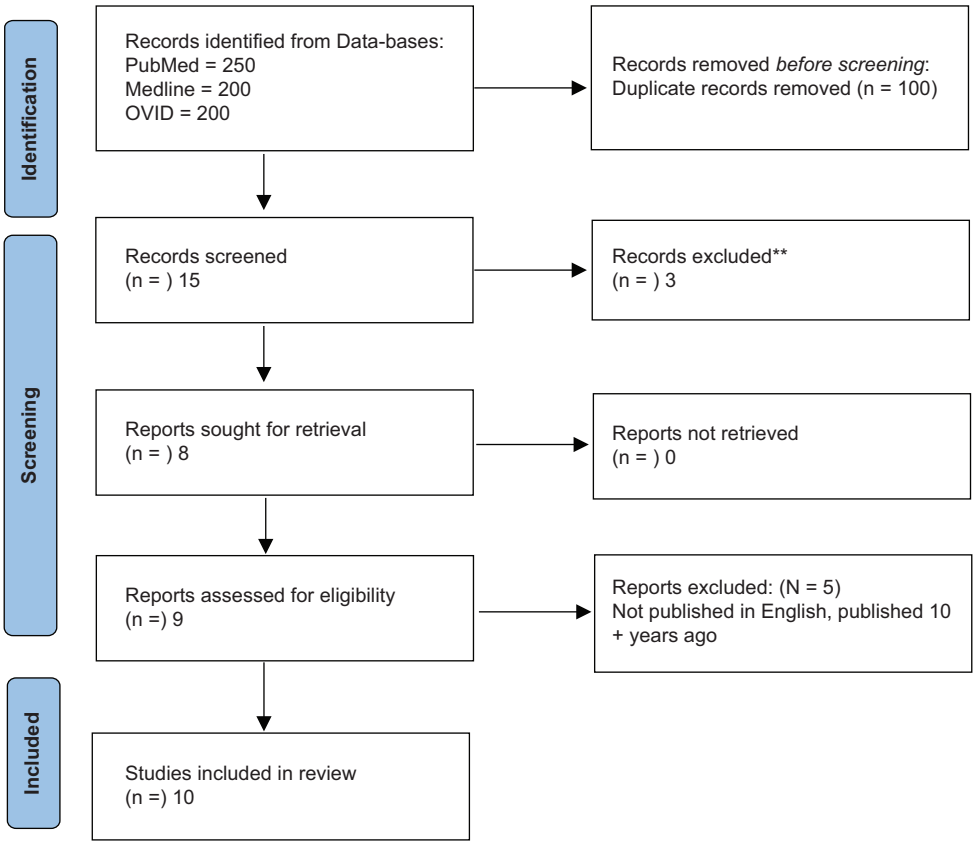

Figure 1: Prisma flowchart

to be incomplete. The functional advantages of auto-transplantation beyond the restoration of masticatory function range from alveolar bone preservation to the sharing of natural feelings through the tooth structures, which are great facets of patients' oral health and well-being.[13]

Esthetic outcomes and patient satisfaction: Among the most significant variables when determining the success of tooth transplantation and reimplantation are both esthetic outcome and patient satisfaction. The emergence of technology for planning and prototyping has been instrumental in amplifying the individualism characteristic of treatment choices by a patient's desire for beauty. Computer-aided design (CAD) and computer-aided manufacturing (CAM) technology used by dental professionals in treatment planning leads to the development of treatment plans that are very purposefully tailored to the specific requirements and desires of each patient, resulting in satisfaction for those who receive the treatment. In addition, the interactive displays and the demonstration of treatment results digitally provide patients with an environment in which they can be involved in their well-being. Hence, they develop trust in the dental care providers. Therefore, patients not only enjoy an increased sense of happiness from the appearance change but also the overall medical treatment.[17,18]

The amalgamation of virtual planning, biomaterial advancement, and patient-centered care has attained significantly improved esthetics and patient satisfaction in tooth retransplanting and reimplanting procedures. This integration of technology with personalized care represents a significant shift in dental practice, combining high functionality with a compassionate, patient-centered approach.[1,17] Surveys and questionnaires, including follow-up studies that are used to gauge patient satisfaction, continually report high levels of patient satisfaction with the cosmetic results and functional benefits of modern transplantation techniques.[18]

Case studies or clinical examples illustrating key points, illustrative case studies, and demonstrating the efficacy of modern tooth transplant and reimplantation methods. For instance, a case of auto-transplantation of a premolar where it is replaced by a missing anterior tooth, needing

CBCT for pre-surgical planning and 3D printing of a surgical guide, also showed successful integration with excellent esthetic and functional results at a 1-year follow-up.[19] This study explores another case, where having a fully biodegradable scaffold helps in the regeneration of periodontal tissues after the tooth reimplantation is carried out, which results in a significant betterment of the health of the tissues and the stability of the reimplanted tooth.[2] These cases are evidence of how developments in technology and methodology are altering the field so rapidly, showing a high success rate, more functional benefits, and the best possible esthetic outcome.

The use of stem cells in tooth reimplantation was showcased. This led to a faster healing and integration of a tooth that was knocked out. By utilizing their own adipose tissue-derived stem cells, scientists on this particular occasion focused on having the cells applied to the root surface of a tooth that was avulsed during an accident.[14]

The biomimetic approach was discovered by stem cells in the treated tooth, which promoted regeneration of the periodontal ligament, and a fast healing process. Bone density scan, X-ray, and radiograph analysis on a 6-month follow-up not only proved the integration of the tooth but also showed a substantially restored periodontal tissue layer. This shows the possibility of stem cell therapy in dental restoration operations.[3]

Digital workflow in complex transplantation, for instance, the case explores the complex procedure of tissue-engineered techniques in which many teeth were affected by trauma. The fully contrived digital situation was utilized, which combined CBCT for detailed anatomical analysis and software tools for the planning of multiple tooth transplantation.[20] Then the CAD/CAM technology was used to process the surgical guides for each site where the transplantation was going to be placed, for a perfect affixation. Thus, the method gave way to the procedure, both shortened in time and precise with a higher degree of integrity. In the long term, the patient demonstrated a complete recovery in function and the target esthetic features that this digital plan was capable of providing. This underscores the fact that the digital integration of technology can be instrumental in complex dental procedures.[21]

Regenerative techniques in periodontal tissue repair. The significance of a case study is revealed by a technique that was applied in regenerative medicine to repair periodontal tissues injured during a tooth graft. A bioengineered mesh, filled with growth hormone, was implanted together with the transplanting tooth. These scaffolds allowed the generation of new tissues, which in turn helped restore the periodontal loss at the transplantation location. Periodontal health observations following the transplant showed not only the integration of the grafted tooth but also highlighted the regenerative properties of the biomaterials used, as they significantly improved the health and integrity of surrounding periodontal tissues.[4,22]

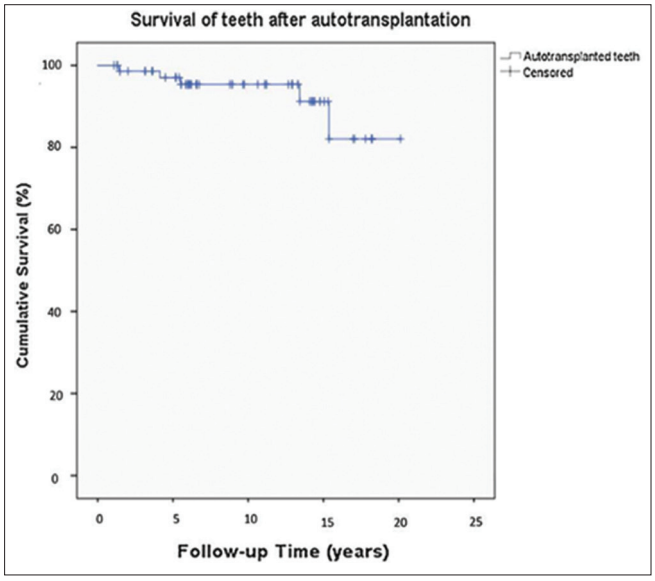

Figure 2: Survival rates

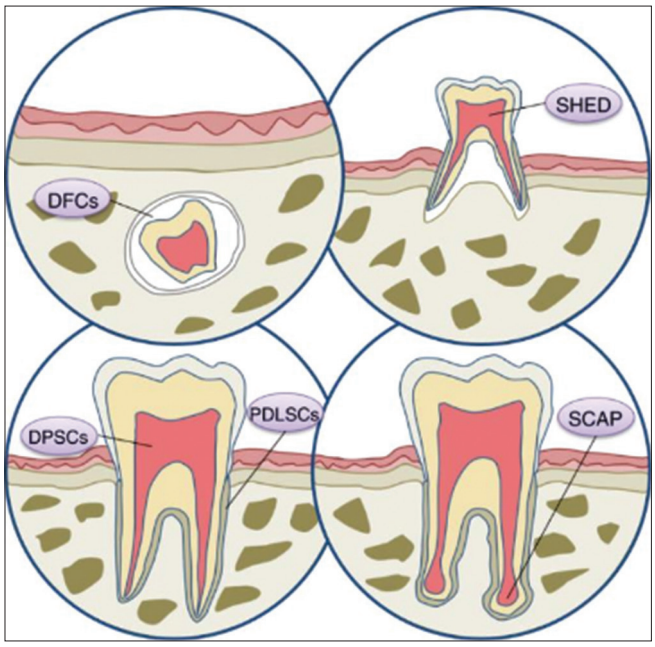

Figure 3: Stem cell sources

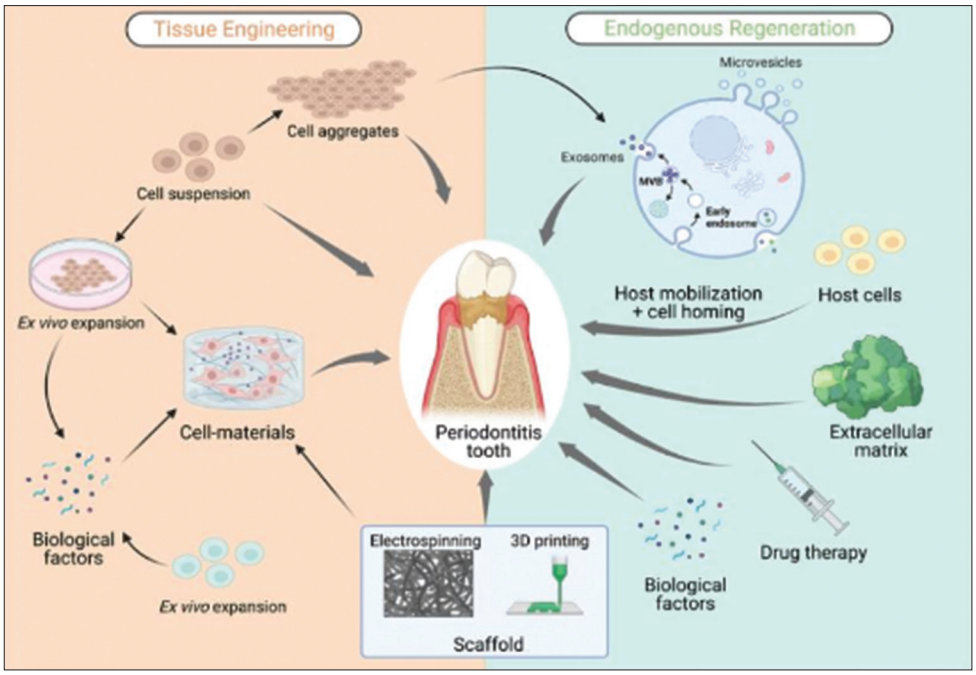

Figure 4: Periodontal regeneration, diagram

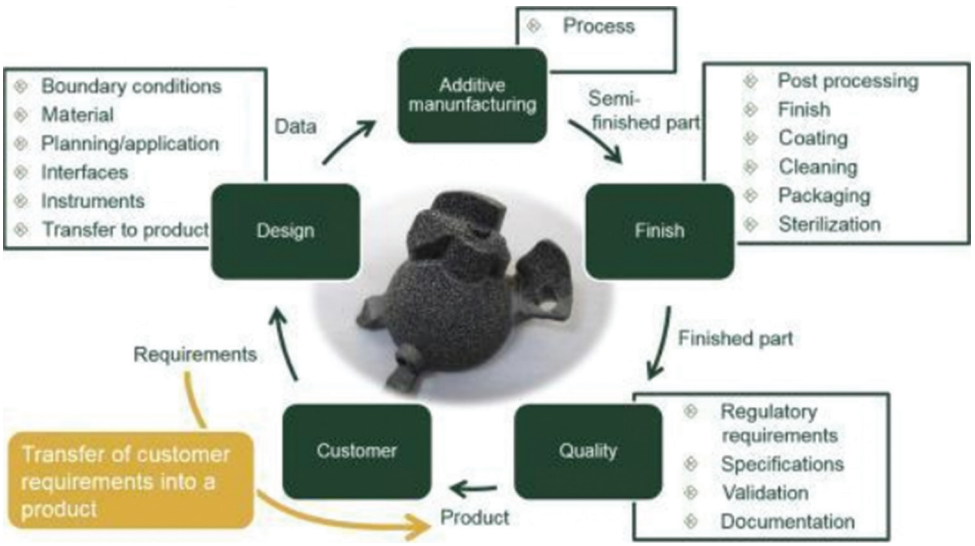

Figure 5: Personalized services diagram

Personalized prosthodontics post-transplantation: In an instance where personalized prosthodontics post-tooth transplantation acts as the main character, the patient received an artificial crown that was fabricated to match the transplanted molar's specific characteristics by CAD/CAM tech. The crown was custom-made with occlusal and esthetical details that exactly matched those of the patient.[23] This individualized approach not only provided the patient with chewing function but also ensured a natural look. Thus, the patient's satisfaction with the treatment outcome was significantly improved [Figures 2-4]. Employing digital design and manufacturing technologies to create custom-made prosthetics after transplantation represents a great advancement in the assurance of full treatment success, which implies not only functional restoration but also esthetic appeal [Figure 5].[10]

A detailed assessment of treatment success rate, dentofacial and esthetical consequences, and clinical case scenarios shows that contemporary approaches to tooth transplantation and reimplantation offer far better results in comparison with the traditional methods, leading to better results for the patient and higher levels of satisfaction.

Many studies summarized some of the challenges and considerations along with the developments in the surgery of tooth transplantation and reimplantation that contribute to the enhancement in the success rate and the patient outcomes; however, there are some issues and considerations. Such considerations comprise appropriate candidate selection and analysis of biological factors that influence final results, as well as the socio-economic aspect for patients, particularly in low and middle-income countries.

The role of ongoing technological advancements in improving clinical outcomes among the major activities happening in the sphere of dental transplantation and reimplantation, technical growth is a key drive. Innovations such as advanced imaging techniques, which also include the CBCT, further refinements, and an integration of artificial intelligence (AI) for improved planning, will certainly be another aspect that is expected to add precision to these procedures and therefore improve their success rates.[24,25] In addition, the constant development of digital and robotic surgical devices offering high accuracy and performance leads to shortening the operational periods, and consequently improving the surgical interventions, the patient's experiences, and outcomes.[4,10] As the technologies advance, they carry the ability to make the substitution and transplantation of teeth more affordable and accessible to a larger number of people, thus making more admissions into the class of those who can enjoy dental treatments.

Discussion

The evolution of dental transplantation and reimplantation techniques over the years highlights the transformative role of technological advancements in enhancing clinical outcomes. As outlined in the results, innovations such as CBCT, AI, and CAD/CAM technologies have revolutionized the precision, efficiency, and accessibility of these procedures. These technologies not only enable accurate pre-surgical planning but also significantly improve the predictability of outcomes. For instance, CBCT allows for detailed 3D visualization of the surgical site, facilitating precise diagnosis and treatment planning.[24,25] When coupled with AI algorithms, it further enhances the ability to predict outcomes and tailor treatments to individual patient needs. Such advancements have the potential to increase success rates and reduce complications, as observed in recent clinical studies.

Patient-centered care has become a cornerstone of modern dentistry, with an increasing emphasis on esthetic outcomes and patient satisfaction. The integration of CAD/CAM technology in treatment planning exemplifies this shift. By creating custom surgical guides and prosthetics, clinicians can address not only the functional requirements of patients but also their esthetic preferences. The use of interactive digital displays during consultations empowers patients to actively participate in their treatment planning, fostering trust and improving satisfaction levels.[17,18] This approach underscores the emotional dimension of dental care, where patient satisfaction extends beyond clinical success to include psychological well-being.

Moreover, the incorporation of regenerative techniques, such as the use of biodegradable scaffolds and stem cell therapies, has opened new frontiers in periodontal tissue repair and tooth restoration. These methods have demonstrated significant success in promoting faster healing, enhancing tissue integration, and restoring functionality. For example, stem cell-based therapies have shown promise in regenerating periodontal ligaments and bone, as evidenced by clinical follow-ups highlighting improved stability and health of reimplanted teeth.[3] These findings emphasize the importance of biomimetic approaches in achieving long-term success in dental procedures.

However, despite these advancements, challenges persist. Socioeconomic factors remain a significant barrier to widespread adoption, particularly in low- and middle-income countries where access to advanced dental technologies is limited. In addition, patient selection and biological factors, such as bone quality and healing capacity, continue to influence outcomes.[4,10] Addressing these challenges requires a multifaceted approach, including training clinicians in new technologies, developing cost-effective solutions, and increasing awareness about the benefits of modern dental transplantation techniques.

Beyond technical and socioeconomic challenges, ethical considerations also play a crucial role in shaping the future of dental transplantation. The use of AI-driven diagnostics and regenerative therapies raises concerns about patient consent, data privacy, and the potential for unequal access to cutting-edge treatments.[26] Ethical frameworks must evolve alongside technological advancements to ensure that innovations benefit a broad spectrum of patients rather than exacerbating existing healthcare disparities. Engaging patients in shared decision-making and maintaining transparency

in treatment options are essential steps toward building ethical and equitable dental care practices.

Looking ahead, the continued integration of digital dentistry, AI, and regenerative medicine holds promise for transforming the landscape of dental transplantation. Collaboration between researchers, clinicians, and policymakers will be vital in overcoming existing barriers and advancing these technologies. Future studies should focus on long-term clinical outcomes, cost-effectiveness, and patient-reported experiences to refine and optimize treatment protocols. As dental transplantation techniques evolve, a patient-centric approach must remain at the core of innovation, ensuring that advancements translate into meaningful improvements in clinical success and patient quality of life.

Conclusion

The integration of cutting-edge technologies with patient-centered care has undeniably improved the field of tooth transplantation and reimplantation. From enhanced pre-surgical planning to personalized prosthetics and regenerative therapies, these advancements are reshaping the landscape of dental care. Moving forward, research should focus on bridging the gap between innovation and accessibility to ensure that these benefits are universally available.

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Data Availability Statement

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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