NARRATIVE REVIEW

Three-dimensional Assisted Autotransplantation of Teeth: Essentials, Outcomes, and Future Implications: A Narrative Review

Fizzah Ikram[1], Wajiha Maqsood[2], Leelan Kanwal[3], Rashna Hoshang Sukhia[4]

Abstract

Missing teeth is one of the most commonly encountered problems in dental offices globally. With the passage of time, clinicians have developed several methods of treatment for missing teeth. Some of these methods include dental implants, fixed or removable prostheses, and autotransplantation of tooth to the recipient site. Treatment modalities such as prostheses and implants are suitable options for adults because of the presence of mature bone. However, autotransplantation is more favourable for young patients because of continual jaw growth that would accommodate the erupting teeth. Three-dimensional-assisted autotransplantation is one such treatment modality which has significantly surpassed the success and survival rates of conventional autotransplantation while improving ease of handling and simplifying the complex technique sensitive procedure along with better selection of the donor tooth, better pre-operative planning and guided recipient site preparation, decrease in extralveolar time of the donor tooth and decrease in the number of fitting attempts that further limits damage to periodontal cells. In future, robotics and guided surgical methods may help in introduction of minimally invasive procedures.

Keywords: Autotransplantation, Missing teeth, 3D technology, Orthodontics.

DOI: https://doi.org/10.47391/JPMA.AKU-10Surg-19

Introduction

Missing teeth is one of the most encountered problems in dental offices globally. In addition to caries-associated tooth loss, which is one of the most prevalent cause of missing teeth among all age groups, trauma (particularly in children and adolescent males), periodontal disease, congenital absence (maxillary lateral incisors and mandibular premolars), ectopic eruptions, pathological lesions, and iatrogenic treatment failures, are other important reasons for the presenting complain.[1-3] Teeth have important physiological functions in mouth and their absence may lead to multiple problems like compromised mastication, maintenance of alveolar bone height and vertical jaw dimensions, soft tissue preservation, adequate occlusal relationships, and aesthetics.[4-7] Hence, it is imperative for a lost tooth to be replaced immediately.

With the passage of time, clinicians have developed several methods of treatment for missing teeth. Some of them include dental implants, fixed or removable prostheses, and autotransplantation of tooth to the recipient site. Treatment modalities such as prostheses and implants are suitable options for adults because of the presence of mature bone. However, autotransplantation is more favorable for young patients because of continual jaw growth that would accommodate the erupting teeth.[8-10]

Autotransplantation is defined as surgical transposition of an erupted, unerupted, or partially erupted tooth from one position (donor site) to another (recipient site) in the same individual.[11,12] The procedure is highly technique-sensitive and involves placement of a donor tooth, which is atraumatically extracted from its socket, and placed in a new surgically prepared recipient site. These teeth have shown to exhibit many beneficial outcomes relative to implants and fixed prosthesis, including better periodontal adaptation, bone induction and soft tissue preservation, natural eruption patterns and occlusal relationship relative to adjacent teeth, physiological mobility, improved aesthetics, more resistance to occlusal loading, and a normal response to orthodontic forces.

However, there are several anatomical and clinical factors that are crucial for the overall success of the procedure. Anatomical aspects affecting outcomes include the developmental stage of donor tooth and its root configuration; the mesio-distal width, root length, root volume and apical surface, buccal and lingual bone plate at the recipient site, cervical approximation between bone and transplanted tooth roots, and recipient socket length, width and height. Similarly, the clinical determining factors include the competency of the

[1,3,4]Department of Surgery, The Aga Khan University Hospital, [2]Karachi Medical And Dental College, Allama Shabbir Usmani Road, Karachi, Pakistan
Correspondence: Rashna Hoshang Sukhia. **Email:** rashna.aga@aku.edu
ORCID ID: 0000-0001-9210-6432

surgeon, trauma during extraction and donor tooth manipulation in the recipient site, number of fitting attempts, extralveolar time of the donor tooth, and distance between root of the donor tooth and neo-alveolus.

Advances in digital technologies during the last decade has revolutionized the contemporary treatment approaches in dentistry for the better. Three-dimensional-assisted autotransplantation is one such treatment modality which has significantly surpassed the success and survival rates of conventional autotransplantation while improving ease of handling and simplifying the complex technique sensitive procedure. The computer-aided autotransplantation involves using digital diagnostic tools like cone-beam-computed-tomography (CBCT) and computed tomography (CT) scans to evaluate the donor tooth prior extraction and formulating a digital replica through 3D CAD/CAM (computer-aided design/computer-aided manufacturing) softwares. This replica of donor tooth is then fabricated into donor tooth replicas by rapid prototyping through various digital printing techniques (such as stereolithography (STL), fused deposition modelling (FDM), PolyJet models, etc.) which serve as three-dimensional printed guiding templates for preparation of recipient site.[12-14] This significantly reduces the extralveolar time of the donor tooth and the number of fitting attempts in the neo-alveolus, which saves vulnerable periodontal ligament cells from damage and facilitates their regeneration after implantation. Moreover, the fabrication of additional guiding templates like occlusal splints, arch bars, and connecting bars further facilitate better three-dimensional positioning and orientation of the donor tooth in the recipient site further improving the outcome of the procedure than through conventional means.

Clinical studies have shown that 3D-assisted autotransplantation achieves success rates of 80–91% and survival rates of 95–100%, compared with 79–100% and 57–100% for conventional techniques, respectively.[15,16] Recent investigations by Verweij et al.[12], Babiuc et al.[15] , and Abella et al.[17] , further support these findings, reporting high clinical predictability and reduced extra-alveolar time when CBCT-based planning and 3D-printed donor replicas are used. This consistency across studies reinforces the reliability of digitally guided autotransplantation and its growing value in clinical dentistry.

This narrative review aims to determine the essentials and clinical significance of three-dimensional assisted autotransplantation and how they surmounted the barriers encountered with conventional manual method. Moreover, the review also discusses any gaps in current knowledge and future perspectives pertinent to the treatment approach that need more research and critical evaluation.

Essentials of Planning of Computer-aided Autotransplantation with Guided Surgical Templates:

Computer-aided tooth autotransplantation has shown promising results in terms of tooth success and survival, as reported in recent studies using 3D donor tooth replicas and surgical guides (Figure 1).[4,15,16,18,19] Initially, it was hypothesized that autotransplantation is only successful when performed in teeth with open apices, with at least 50%-75% root formation complete.[20-21] This stage radiographically corresponds to an open apex of minimum one mm which facilitates revascularization of pulp and impending bone growth.[4,15] However, evidences from specific case reports and clinical studies, including Abella et al.[17], Babiuc et al.[15], and Verweij et al.[22], suggested clinical success of the procedure even in mature teeth with fully formed roots, provided the donor teeth undergo endodontic therapy either before transplantation or within 2 weeks of transplantation to exterminate the incitement of inflammatory root resorption. Abella et al.[17], along with recent reports[4,15,] proved this concept in his clinical study with mature third molars transplanted through three-dimensionally-printed guiding templates and donor tooth replicas, among which 22 teeth were a success rate of 91.7%. Out of 24 teeth, 2 showed severe mobility and inflammation and were extracted.

Conversely, this study further widens the successful application horizon of the procedure in adults with mature bone and teeth, and the possibility of a promising treatment alternative in addition to implants and prosthesis. Hence, with careful planning and manipulation of determining anatomical and clinical factors through 3D technology, the outcomes can be improved significantly. The process of computer-aided autotransplantation involves three crucial planning components which determine its prognosis i.e assessment of the donor tooth and recipient site through 3D diagnostic tools, and fabrication of the donor tooth replica through rapid prototyping and 3D printing techniques.

Assessment of the donor tooth: Before planning an autotransplantation, the first step is to select an appropriate donor tooth that is to replace the tooth at the recipient site. Various diagnostic aids are used for this

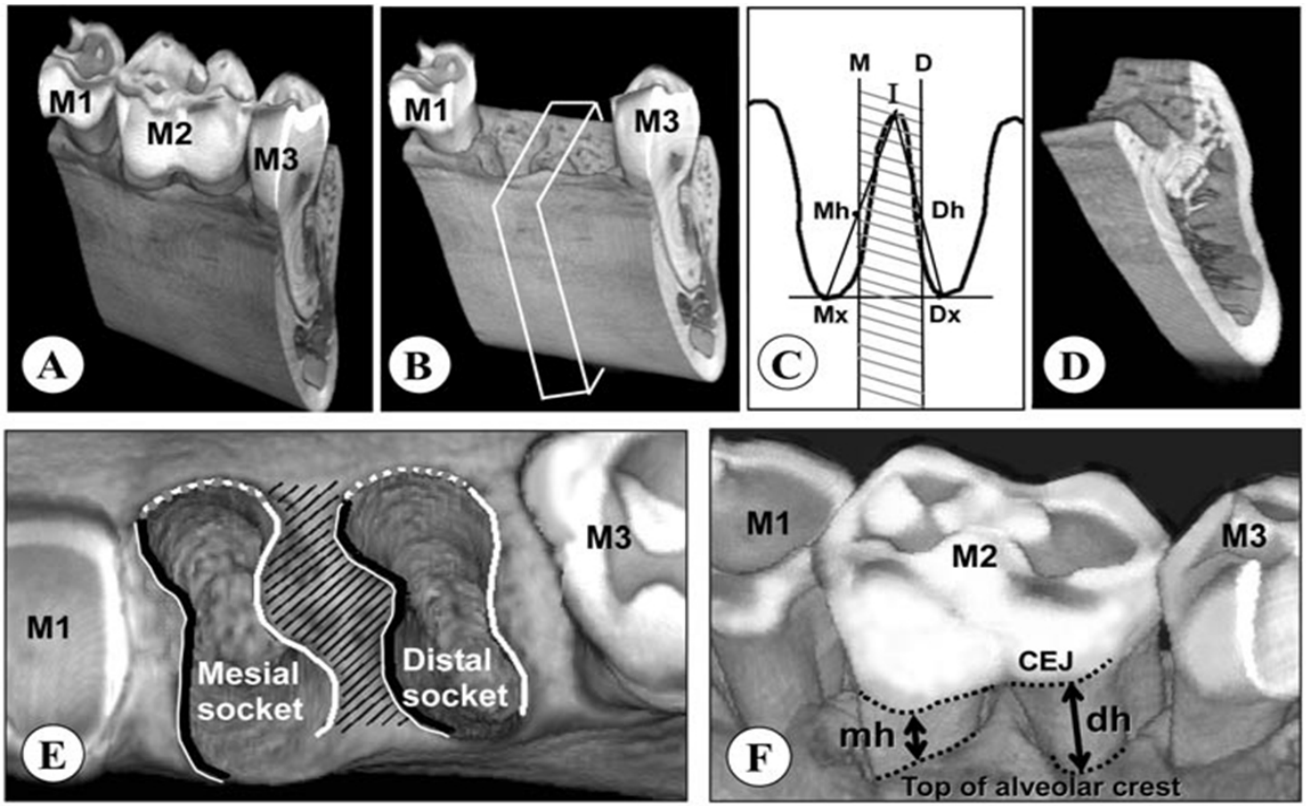

Figure-1: 3D Assessment of Donor and Recipient Site.

assessment, including the conventional periapical and panoramic radiographs to assess the clinical, physiological, and developmental stage of the selected donor tooth. These traditional radiographs are supplemented with 3-dimensional diagnostic tools, like cone-beam-computed-tomography (CBCT) majorly and computed-tomography (CT) scans to formulate a 3D image of the donor tooth through digital softwares that may aid in effective planning.

The scans are converted to Digital imaging and Communications in Medicine (DICOM) format and are transferred to implant planning softwares where all the anatomical considerations are evaluated for a successful surgery. They include crown length, crown-to-root ratio, developmental stage of root, cervical dimensions relative to the recipient socket, distance of the root apex from the neo-alveolus, inferior alveolar nerve and maxillary sinus.[18] All these parameters are gauged for selection of the appropriate tooth for autotransplantation, often aided by AI-integrated digital workflows that enhance guide design accuracy and pre-surgical assessment.[18,23,24]

As mentioned previously, the developmental stage and root configuration; the mesio-distal and bucco-lingual dimensions, root length, root apex and root surface, are important determinant factors that must match that of the replaced tooth. Moreover, as per the protocol, in case of immature tooth, the root apex should be between stage 4 and 5 as suggested by Mores i.e., root should be 50-75% complete. CBCT images are carefully interpreted to study the developmental stage of the donor tooth and appropriate surgery time is devised for the patient. In case three of the case series presented by Ong et al[5], maxillary left second premolar was selected to undergo autotransplantation at the place of a traumatized maxillary left central incisor in a 12-year-old patient, but surgery was delayed till appropriate developmental stage for transplantation. Previous studies have used CBCT images to critically assess donor tooth selection and applied DICOM data, digital planning software, and 3D printing—particularly stereolithography—to fabricate donor tooth replicas with high anatomical accuracy.[21,22,25,26-31]

Assessment of the recipient site: For any tooth to be transplanted, the recipient site must be prepared which requires essential information such as the available mesio-distal and bucco-lingual width and length of the alveolar socket (Figure1). Digital software quantifies these factors and provides the clinician with the accurate

Figure-2: 3D Replica of Donor Teeth to be Transplanted.

values required for successful transplant of tooth. CBCT imaging is used for this purpose as well and they are later juxtaposed with digital softwares with the donor tooth digital scans to assess the optimal orientation, position, and location of the donor tooth in the socket. These softwares provide accurate virtual imaging of donor tooth in the socket relative to the adjacent and contralateral teeth and surgical occlusal splints are used for these purposes which are also fabricated digitally.

According to the extracted data, the recipient site is prepared prior to extraction of the donor tooth with the help of donor tooth replica as a guiding template. The preparation may be done through a surgical round bur in a slow speed handpiece with copious irrigation as in the clinical case study by Abella et al.[17], Srivastava et al.[27], and Verweij et al.[22]. The recipient socket is usually prepared a little larger than the donor tooth in order to accommodate the ±0.25mm size variations in the donor tooth replica and natural donor tooth and for the fact that a narrow socket is more attributable to failed autotransplantation than slightly wide one. Therefore, intra-alveolar septa were removed to adjust some of the teeth which had to be readjusted through bone graft materials between bone walls and roots of transplanted teeth that served as an unnecessary complication.[22]

In some cases, recipient site preparation may also involve vertical ridge osteotomy for augmentation of alveolar bone growth when investigation shows signs of atrophic changes in alveolar bone. Moreover, another case report introduced preparation of the recipient site including use of milled, sleeveless, multi-drilling axial surgical stent including implant drilling sequence. Later, soft speed handpieces with round bur was used to eliminate irregularities. The case report proposed this approach with the intent to subject the recipient site with minimal preparation trauma through mechanical and heat stimulus which would ensure clot stabilization in the socket and better periodontal regeneration. Although the 3D guided autotransplanted teeth were a success through this method, one of the ten teeth needed additional preparation and adjustment of the stent that may highlight the potential contradiction to the rationale of minimizing mechanical trauma to the socket. Hence, further research is required for assessing the clinical relevance of this technique.

3D Assisted Guidance for Donor Teeth: Since the idea of computer-aided autotransplantation was introduced, three dimensionally printed donor tooth replicas (rapid prototyping) (Figure 2) received much critical evaluation to determine their accuracy in mediating the transplantation procedure. For our review, we extracted six in vitro studies which focussed on quantifying the accuracy of these fabricated models in mimicking the donor tooth to be replaced and their significance in the planning process. Khalil et al.[33] evaluated the fabrication of donor tooth replicas using different 3D printing technologies from CBCT images and found all techniques to produce models within ±0.25mm of the natural tooth, indicating surgical accuracy. Sans et al.[31] assessed CAD-CAM guided tooth replicas and confirmed high fidelity suitable for clinical transplantation. Moin et al.[34] investigated computer-assisted template-guided autotransplantation and demonstrated precise donor tooth reproduction with custom 3D tooling. Similarly, Verweij et al.[22] evaluated multiple 3D printing techniques and found them to produce accurate donor tooth replicas Hence, these in vitro studies proved that dimensionally and surgically accurate replicas fabricated through all these techniques would therefore lead to adequate preparation of the recipient site for a more straightforward and accurate autotransplantation process than the conventional manual method.

Among the three 3D printing techniques, STL is most common and was used in all clinical studies. In all these studies, the donor tooth replicas adequately mimicked

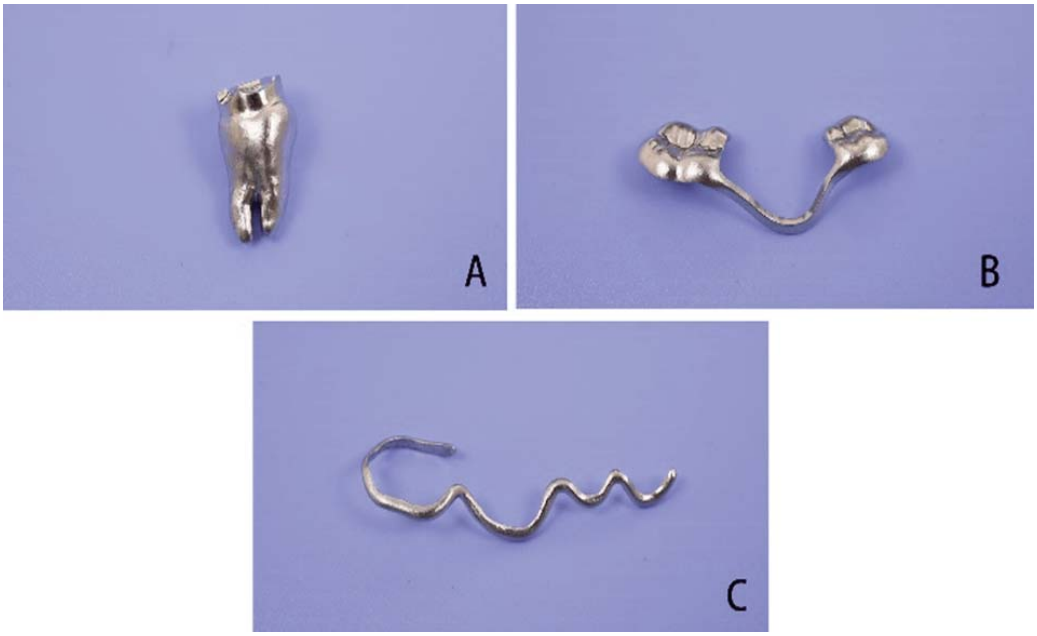

Figure-3: Surgical guides including 3D Printed Guiding Templates.

the original donor tooth and facilitated as a surgical guiding template in preparation of the recipient site before donor tooth extraction. They significantly reduced the extralveolar time of the donor tooth to generally less than 18 min, which is considered crucial for normal periodontal healing post operatively. Besides, they also limited the number of fitting attempts of the donor tooth facilitating a straightforward operation and limited trauma to fragile periodontal cells of donor tooth and clot and bone progenitor cells of recipient site. Moreover, they also served as an adequate guide for optimal orientation location and position of donor tooth in the socket improving the ease and control of the procedure in addition to providing adequate occlusal relationships with adjacent teeth.

Additional Surgical Guides: Other than donor tooth replicas, 3D printed guiding templates are also used for authentic transplantation of donor teeth into their desired positions. (Figure 3) These guiding templates are designed over occlusal surfaces of adjacent teeth via virtual assessment of tooth positions. Guides are attached to the donor tooth replica to determine their final position during surgical procedure. These guides can either be connected through buccal or lingual surface of adjacent teeth covering the donor tooth. Fabrication of surgical guide templates considers the surface of the opposing tooth to ensure the production of a guide that ensures adequate bite for optimum auto transplantation of donor tooth. In some instances, individual arch bars are also constructed along with surgical template guides. These arch bars increase the post-surgical stability of donor tooth in their new position. Once designed, they are sent forward to 3D printing software for their printing. The material commonly used for fabrication of such guides and donor teeth is resin biocompatible.

For the autotransplantation to be successful, presurgical planning for the donor tooth to be implanted at an accurate position, location, and orientation in the recipient socket as such to replicate the orientation of the tooth replaced should be performed. This maintains optimum occlusal relationships and eruption patterns relative to the adjacent and contralateral teeth. Moin et al34 assessed the accuracy of planning of computer-aided autotransplantation and found that even after adequate homework the transplanted donor tooth showed a rotation of 3.1° later. They also quantified average cervical and apical deviations of 1.25mm and 0.89mm, respectively, from the planned positions. These findings highlight the importance that the use of donor tooth replicas might still not be the solution for a three-dimensional accurate positioning to achieve. Hence, future studies proposed the use of modified surgical guides like occlusal splits, connecting bars, and arch bars to achieve a more harmonious occlusal relationships of the autotransplanted teeth with adjacent and contralateral teeth and minimize the need for any additional intervention to correct to asserted defects.

Recent studies have used surgically guided occlusal splits designed via 3D software to accurately orient the donor

tooth in the recipient socket relative to occlusal contacts and adjacent teeth.[29,30-34] The guides are designed through 3D softwares virtually and aimed to orient the donor tooth in correct position in the socket relative to occlusal contacts and relationships with adjacent and contralateral teeth. He W et al[29], in addition to occlusal splits also designed an individual arch bar surgical template for proper stabilization of the oriented donor tooth in the planned position and hence, achieved smooth and successful autotransplantation surgery without any pathological findings. Moreover, the surgical guides promoted easy stabilization of the donor tooth at the recipient site without manipulation hurdle as they were small in size, easy to handle and did not hinder vision during socket preparation and stabilization of the donor tooth. Additionally, they were believed to be the reason for attaining desired accuracy and stability post operatively.[30]

Outcomes: 3D assisted autotransplantation is a revolutionary treatment modality for management of missing teeth not only in preadolescents and adolescents, but also in adults with a precise approach and adequate candidate selection. Wu H et al[32] conducted a case-controlled study where 24 premolars were autotransplanted in each group with 3D technology and conventional methods respectively. Out of 24 teeth, 22 in 3D assisted group were deemed successful with no signs of pathology both clinically and radiographically, whereas rest of the 2 teeth showed signs of ankylosis and apical infection. Among the control group, 4 teeth showed ankylosis and 2 showed signs of inflammatory root resorption. The study showed the success and survival rates of 80%-91% and 95%-100%, respectively, hence, a clear indication of the improvement in the success and survival rates with the use of 3D tooth replicas. Moreover, the use of 3D replicas also reduced extralveolar time to ≥ 1 minute in comparison to the 3-10 minute extralveolar time in the conventional method. Hence significantly improving periodontal healing at the recipient socket and the overall success rate.[12]

Verweij et al[22] conducted a clinical study where 5 premolars with open apices were transplanted with the help of 3D titanium donor teeth replicas. He attributed the reduced extra-alveolar time as the reason for hundred percent success and survival rates as the donor tooth was an immediate fit and did not need any further modification of recipient site. He concluded that decreased extralveolar time and manipulation of recipient site is directly proportional to the ease of procedure and short procedural time. Abella et al[17] also used 3D donor tooth replicas and other surgical guides for carrying out the autotransplantation of mandibular third molars at the position of first molar teeth. Only 2 teeth showed signs of inflammation and hypermobility. The study validated the 91.7% success rate with 3D assisted procedure. Similarly, Srivastava et al[27] in his case report autotransplanted right lower third molar in place of first molar with 3D tooth replicas and guiding templates. The extralveolar time in this case was 12 minutes that was below the standard 18 minutes attributed to healthy periodontal regeneration. The case report endorsed the use of donor tooth replicas and surgical guides with accurate positioning and orientation at the recipient site and decreased number of fitting attempts which are directly proportional to the success rate.

He W et al[29] conducted a clinical study where 8 mandibular third molars with complete root formation were autotransplanted in 8 adult patients. They utilized donor tooth replicas, guided occlusal splits, and connecting arch bars as surgical guides which gave an 87.5% success rate with ankylosis seen in only one patient, however, extralveolar time was not specified. Similarly, Lucas-Taulé et al28 in his study performed computer-aided autotransplantation of molars and premolars with multi-drilling axial surgical stent and found successful results.

All these studies prove that the increase in the success and survival rates of autotransplantation with the aid of 3D technology is attributed to the following advantages:

1. Better selection of the donor tooth
2. Better pre-operative planning and guided recipient site preparation
3. Decrease extralveolar time of the donor tooth
4. Decrease in the number of fitting attempts that further limits damage to periodontal cells.
5. Proper orientation and positioning at the recipient site through surgical guides which decrease procedural time and increase ease of manipulation.

Future Implications: With continuous advancements in technology and modifications of procedures for better outcomes, 3D assisted autotransplantation can help in virtual treatment planning of missing teeth in both young and adult patients. Technology assisted autotransplantation will aid in accurate donor tooth selection, simulation of the surgical procedure beforehand and assessment of location via 3D bone width examination. In future, robotics and guided surgical methods may help in introduction of minimally

invasive procedures.[35] Use of bioprinting for structures that aid in surgical procedure and healing process may result in quicker regeneration of supporting structures. Moreover, integration of 3D assisted autotransplantation with different softwares used in dentistry and orthodontics may enhance treatment efficiency.

Conclusion

3D-assisted autotransplantation has significantly improved the outcomes and procedural complications of conventional autotransplantation. It is now an attractive treatment approach for managing missing teeth in both young and adult patients provided satisfactory medical history, indications, and patient compliance needs are met. The overall success and survival rates are high with more favourable benefits of natural periodontum regeneration, hard and soft tissue preservation, healthy gingival conformation, better aesthetics, along with better occlusal resistance, proprioception, and normal response to orthodontic forces. Using fast prototyping and CBCT to create customized tooth models, the risk of iatrogenic periodontal damage is significantly reduced. Nonetheless, our review proclaims a generally low quality of evidence and high risk of bias. Further research is therefore required to establish clinically relevant benefits, outcomes, and implications of 3D autotransplantation with donor tooth replicas and surgical guiding templates.

Disclaimer: None.

Conflict of Interest: None.

Source of Funding: None.

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