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Malka Ashkenazi

Computerized three-dimensional design for accurate orienting and dimensioning artificial dental socket for tooth autotransplantation

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Objective: To present an improved, accurate, and efficient method for planning and preparing an artificial socket for autotransplantation, by using a three-dimensional (3D) surgical guide and a replica of the transplanted donor tooth. The guide and the tooth replica were fabricated using a computerized 3D simulation. A case treated with this approach is presented. **Method and Materials:** Cone beam computed tomography (CBCT) and computerized 3D simulations (Simplant plus registration as stereolithography) were used for planning the optimal artificial socket position and dimensions, within the limitations of the alveolar bone borders and the adjacent teeth roots, and for producing a metal replica of the transplanted tooth. The replica was used to assure the correct socket preparation and orientation before extraction and replantation of the donor premolar. **Results:** The entire procedure time for autotransplantation of a permanent second premolar to the incisor site without the buccal plate was about 45 minutes. At 15 months' follow up, clinical examination of the transplanted tooth demonstrated both normal mobility and no sensitivity to cold stimulation. A radiographic examination revealed continuous root development and pulp obliteration. The adjacent teeth maintained their vitality with no pathologic signs. **Conclusion:** We present an improved technique for autotransplantation based on computerized 3D simulations and guidance for accurate dimensioning and optimal locating of the artificial socket relative to the alveolar bone borders and the adjacent teeth roots. This technique may significantly simplify the autotransplantation procedure and will probably also increase its success rate and use in young patients, even in cases with absence of a buccal plate.

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Key words: 3D printed template, dental socket, guided autotransplantation, modern autotransplantation, surgical template

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Figs 1a and 1b Clinical preoperative view of anterior teeth. Note the maxillary right central incisor in a buccal inclination and in a severe infraocclusion, with almost a complete loss of the buccal plate. Space loss was caused by proximal movement and inclination of the adjacent incisors. The tooth was splinted temporarily until initiation of the orthodontic treatment.



Fig 2 Preoperative panoramic radiograph taken upon acceptance of the patient.

Tooth autotransplantation is a surgical transposition of a donor tooth from its original site to a recipient site within the same individual. The donor tooth is transplanted into an extraction site or into a surgically prepared artificial socket at the recipient site.[1]

The pulp healing of the transplanted tooth is directly correlated with a younger age of root formation and with the diameter of its apical foramen.[2-6] However, root growth following replantation is impaired or arrested in 55% to 65% and 14% to 19% of the cases, respectively.[7,8] In addition, future orthodontic treatment may induce further shortening of root length.[9-11] Therefore, the optimal timing recommended for autotransplantation is when the root reaches maximum length and width but the walls of the apical foramen of the transplanted tooth are inverted or at least parallel.[3,7] One of the key factors for a successful autotransplantation is the correct preparation of the recipient socket. To that end, the dimensions of the artificial socket should be only slightly wider and longer than those of the donor tooth, in order to prevent pressure and subsequent damage to the periodontal ligament cells (PDLc) and the Hertwig epithelial root sheath (HERS), and simultaneously to ensure a continuous blood supply to the PDLc and the pulp of the transplanted tooth. The second key factor for a successful replantation is to minimize the number of fitting attempts of the donor tooth during the procedure, as every fitting attempt further increases the risk of trauma to the PDL and prolongs the extra-alveolar time.[12-14] The third key factor in addition to size and depth is angulation, ie, achieving an optimal location of the artificial socket, in relation to three planes: to the alveolar bone borders, in order to minimize the risk of perforating the buccal plate (especially in cases with atrophic alveolar process); to the adjacent roots in order to prevent their damage during the preparations; and to the occlusal plane.[15-21]

There have been several suggestions to measure/model the artificial socket using a fabricated tooth replica as a guide, in order to minimize manipulation of the donor tooth during the procedure.[22-25] Rounded surgical templates that resembled different sizes of premolar roots have been produced.[12] Others proposed fabricating several sizes of premolar metal templates

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Figs 3a to 3c Clinical views of *(a)* the patient's anterior teeth immediately after orthodontic space was regained, *(b)* extraction of the avulsed tooth, and *(c)* maintaining the space with an acrylic removable appliance.

and to use the one with the most suitable dimensions.[22] The use of computed tomography (CT) or cone beam computed tomography (CBCT) has been suggested for fabricating a plastic or metal replica of the donor tooth, and to assess its fit in the socket before transplantation.[23-29] In a recent review, several printing techniques, including solid-based forced metal deposition (FMD), Polyjet modeling, stereolithographic (SLA), and Simplant Pro 12.1, were found to produce models that were well within the clinically acceptable level of accuracy (0.25 mm in comparison with the original tooth).[30]

Recently, several reports have suggested utilizing CBCT to assist the surgeon in planning the ideal artificial socket location for autotransplantation.[13,23,25,28,31,32] In these reports several consecutive burs with increasing diameters were used to drill the socket holes. However, the shape of the root of the transplanted tooth is never a perfect cylinder with parallel borders, thus a stage of trial and error is inevitable, which increases the risks of a prolonged surgery or a mismatch between the transplanted tooth and the socket.

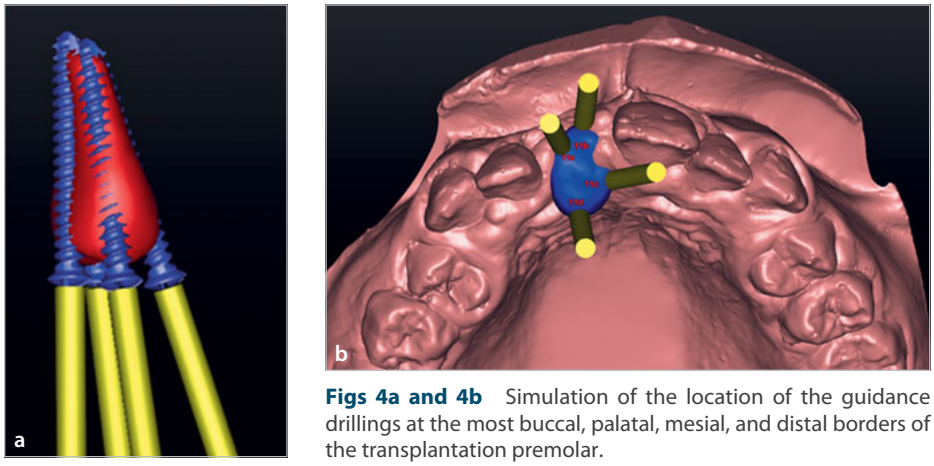
The aim of this report was to suggest an accurate and efficient method for planning and facilitating the surgical procedure, by preparing an artificial socket using computerized 3D simulations in combination with a surgical guide and a replica of the transplanted donor tooth. A case treated with this approach is presented.

CASE PRESENTATION

An 11-year-old girl was referred to the clinic for consultation in December 2015. Eighteen months previously she had suffered a traumatic injury to her face, with a subsequent avulsion of her maxillary right central incisor and underwent a delayed tooth re-implantation. Clinical and radiographic examinations revealed progressive root resorption of the re-implanted tooth with class II mobility. The tooth was in severe infra-occlusion, with an almost complete loss of the buccal plate, and space loss caused by proximal inclination and movement of the adjacent incisors (Fig 1). The patient's panoramic radiograph revealed that her maxillary premolars' roots were at ¾ of their maximal length (Fig 2). The orthodontic treatment plan included performing an autotransplantation of the maxillary left second premolar into the site of the lost incisor, followed by additional orthodontic treatment to close the donor site and achieve harmonious occlusion. After the parents signed informed consent, the patient was referred for dental treatment entailing extraction of the maxillary left first and second primary molars, in order to accelerate the eruption of the maxillary premolars. Then orthodontic treatment was initiated to regain the lost space of the incisor. At this stage the avulsed tooth was maintained in position for esthetic reasons.

Upon eruption of the permanent maxillary left second premolar, the orthodontic splint was removed, the avulsed tooth was extracted, its socket was debrided, and the space was maintained by an acrylic removable appliance (Fig 3). This allowed performance of a CBCT scan (without brackets) and complete soft tissue healing before the transplantation. A plaster model of the patient's maxilla was poured and scanned, and she was referred to a low-dose CBCT scan of the maxilla. Ten

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Figs 4a and 4b Simulation of the location of the guidance drillings at the most buccal, palatal, mesial, and distal borders of the transplantation premolar.

months later the autotransplantation of the permanent maxillary left second premolar into the place of the extracted maxillary right central incisor was performed.

Surgical guide system fabrication

The CBCT scan and the scanned plaster model were converted to DICOM files to obtain computerized 3D models. To start the stereolithography (STL) registration over the DICOM, three points were selected. Then the full synchronization (ie, registration) was checked for all the common points in the DICOM and the STL.[28]

A change between the STL registration over the DICOM was observed only in the erupted permanent maxillary left second premolar. Segmentation and masking of the DICOM model of the maxillary arch and the tooth to be transplanted were performed using Simplant plus registration as STL. Virtual autotransplantation of the tooth (as STL) was then performed using the "optical module" in Simplant. The exact 3D position of the donor permanent maxillary left second premolar in the recipient site was determined in the mesial/distal direction, in relation to the locations of the incisive canal and the adjacent roots of the right lateral and left central teeth; and in the buccal/palatal direction, in relation to the alveolar ridge borders. Once the optimal position of the transplanted tooth was determined virtually, a surgical guide (Simplant Guide Production Unit, Dentsply Implants) was designed and fabricated to facilitate the preparation of an artificial socket identical to the shape of the root of the transplanted tooth. Four guidance drillings of 2.00 mm diameter were planned in the most buccal, lingual, mesial, and distal locations (Fig 4). Each of the drillings were parallel to the planned root surface of the autotransplanted tooth, and angulated accordingly, thus achieving a correct spatial form. The outer borders of the drills were placed at a distance of 1 mm from the planned border of the donor tooth, in order to achieve an optimal size artificial socket, slightly larger than the donor tooth. The lengths of the tubes were about 1 mm longer than the tooth in an attempt to avoid as much damage as possible to the HERS. Additionally, a replica from chrome cobalt of the permanent maxillary left second premolar was fabricated according to the STL digital imaging by laser sintering, to confirm the proper depth, size, and angulation of the newly prepared socket, before extracting and transplanting the donor tooth. The accuracy of the replica was confirmed immediately after extraction of the maxillary premolar and was found to be identical.

Surgical technique

The surgical procedure was performed under sedation using Midazolam (10 mg orally diluted with 10 mL of ibuprofen syrup [100 mg/5 mL] in conjunction with nitrous oxide/oxygen inhalation [5 L/min, 50% N_2O, and

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Fig 5 Clinical view of the surgical guide seated on the occlusal surfaces of the maxillary teeth. The accuracy of the guide was verified by the fenestration.





Figs 6a and 6b Simulation of *(a)* the autotransplantation of the metal replica of the premolar and *(b)* autotransplantation of the premolar into the location of missing incisor immediately afterward.

50% O_2]). Immediately before surgery, the teeth and the surgical area were scrubbed with chlorhexidine (0.2%) solution. The guiding template was placed and found to have an accurate fit according to the designed fenestration (Fig 5). A mucoperiosteal flap was elevated in the recipient site, and the socket was then prepared by using the surgical guide. The proper size, depth, and angulation of the newly prepared socket were verified by placing the metal replica in the newly formed socket (Fig 6). Only then, the permanent maxillary left second premolar was extracted and immediately re-implanted in the new location without further manipulation of the donor tooth or adjustment of the recipient socket, while restricting the extra-alveolar time to several seconds (Fig 6).

The donor tooth was stabilized with a resorbable suture and splinted by metal wire and composite material (Fig 7). To prevent occlusal interference, composite material was placed on the mandibular second primary molars to increase the vertical dimension of occlusion. The crown of the implanted tooth was reshaped to an incisor form using a composite material with minimal manipulation. The duration of the entire procedure was approximately 45 minutes.

Postoperative examination

Clinical and radiographic examinations were performed at 2 weeks, and 1, 4, 8, and 15 months postoperatively. At 15 months' follow-up, clinical examination of the transplanted tooth demonstrated both normal mobility and no sensitivity to cold stimulation. The radiographic examination revealed continuous root development and pulp obliteration (Fig 8). The adjacent teeth maintained their vitality with no pathologic signs. A slight recession of the buccal plate of the transplanted tooth resulted, mainly from bone loss associated with infraocclusion of the extracted traumatized tooth and from presence of an excessive buccal bulge in the transplanted tooth (Fig 9).

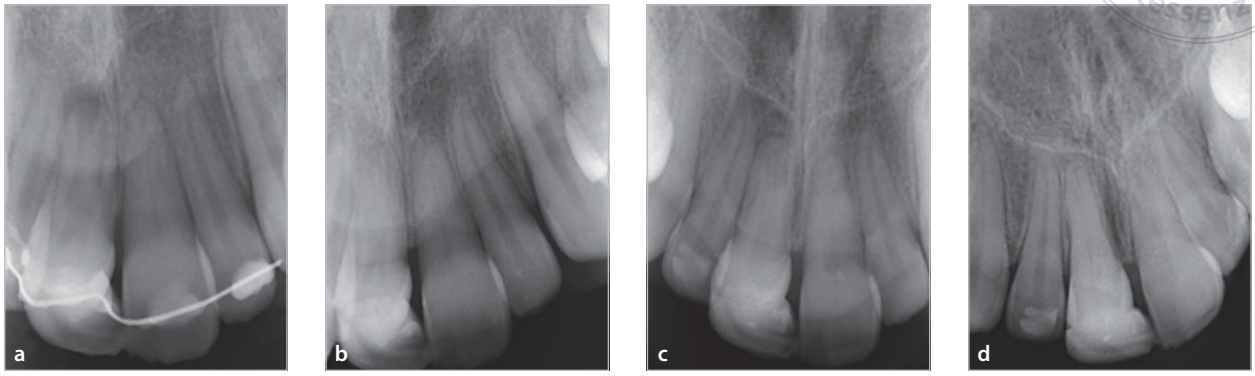


Fig 7 Clinical view of the patient's anterior teeth immediately after autotransplantation and splinting.

DISCUSSION

The ideal treatment for missing maxillary permanent anterior teeth in a young pediatric patient is autotransplantation of a premolar, when available.[31-34] Such treatment provides both immediate and permanent esthetic rehabilitation and induces continuous local alveolar bone growth, as well as regeneration of bone

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Figs 8a to 8d Serial periapical radiographs of the transplanted tooth taken at the following times. *(a)* Immediately postoperatively: the apex of the tooth is open. Note that the preparation is longer than the actual root length of the autotransplanted tooth. *(b)* 4 months postoperatively: the apex is closed, with no periapical radiolucency. *(c)* 8 months postoperatively: obliteration of the pulp is evident. *(d)* 15 months postoperatively: healthy lamina dura is evident around the root surface.

defects caused by the negative consequences of the preceding trauma.[31,33,34] Nonetheless, it entails the risk of several complications, including root resorption, ankylosis, loss of the autotransplanted tooth, and fracture during extraction.[26]

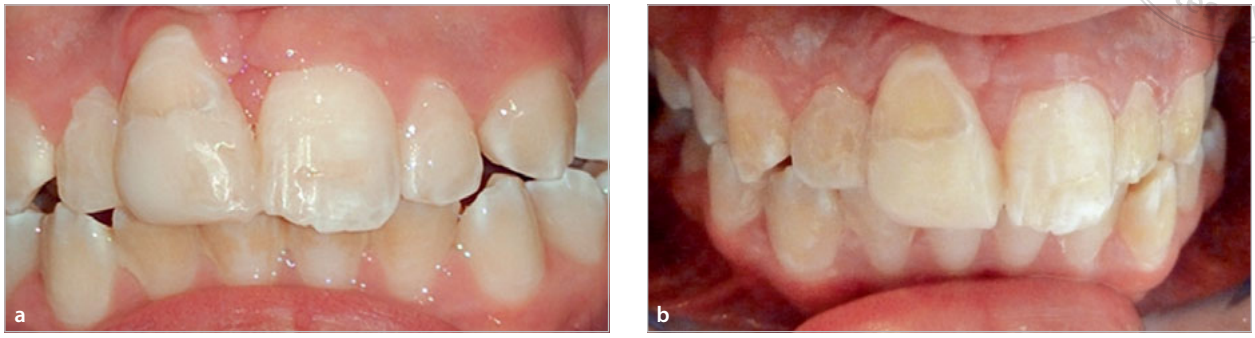
The key factor for a successful clinical outcome of an autotransplantation procedure is the preservation of PDL vitality of the transplanted tooth during the surgical procedure. This can be achieved mainly by avoiding the application of high pressure on the donor tooth and reducing the extra-alveolar time of the tooth during transplantation.[15-21] A specified maximum distance between the adjacent teeth and the border of the newly prepared socket has not yet been confirmed in the published literature. Nonetheless, it seems reasonable to prepare the recipient alveolar bone area with a cut 1 to 2 mm wider and deeper than the perimeter of the donor root, to both preserve the PDL and to enable an optimal blood supply to the PDLc, thus leading to further improved success rates of autotransplantations.[11,14]

Importantly, damage to the roots of the adjacent teeth is considered one of the more severe risks of autotransplantation. This is especially true in cases when the autotransplantation is not performed immediately after a traumatic avulsion, but rather several months later, following proximal movement of the adjacent teeth.

The approach suggested herein for fabricating a computerized surgical guide by virtual preoperative planning, may increase the safety of the procedure by enabling accurate and optimal sizing and orientation of the artificial socket. The advantages of the current procedure over those previously suggested include creating the shape and size of the socket more accurately by using four guiding holes instead of one.[13,27,32] Moreover, the location of the drilled holes, 1 mm wider and longer than the transplanted tooth, ensures the preservation during surgery of the PDL and the HERS of the young developing transplanted tooth. A recent report has shown that the status of the alveolar bone at the recipient site, at the time of surgery, is significantly related to periodontal healing outcome of the transplanted tooth.[3] The method described herein may enhance the prognosis of PDL healing, even after severe bone loss at the recipient site. In the current case presentation, periodontal healing, defined as newly formed periodontal space surrounding the root periphery, was confirmed on the successive periapical radiographs. Additionally, evidence of pulp vitality was clinically and radiographically confirmed by signs of pulp canal obliteration.

Moreover, by marking the most mesial and distal borders of the preparation, this approach may decrease the risk of damaging the incisive canal nerve, the buccal plate, and/or the PDL of the adjacent incisor roots.

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Figs 9a and 9b Clinical view of the patient's anterior teeth *(a)* 3 months and *(b)* 15 months following autotransplantation. The yellow patch on the cervical surface of the crown results from the gradual grinding of the buccal bulge of the transplanted premolar to obtain a self-cleansing anatomy and to enable buccal migration of the gingiva.

This method also simplifies the chairside procedure, allowing the surgeon to operate with more accuracy and confidence, minimizing the guesswork involved and reducing the duration of the procedure. Additionally, the prefabrication of the donor tooth's metal replica may decrease the traumatic handling and the extraoral time of the donor tooth, reducing the risk of bacterial contamination, which is a critical factor for success in tooth autotransplantation.[15-21]

Computer-aided design has been widely applied to design and manufacturing of surgical templates for dental implant positioning. The accuracy of CAD/CAM (computer-aided design/computer-assisted manufacture) guiding systems in implant dentistry has been confirmed by a recent systematic review.[35,36]

Currently, the reliability of computer-guided systems is insufficient for performing "blind" implantations because deviations in horizontal and vertical planes and angulation are not clinically acceptable when a small deviation can be detrimental (eg, damage to anatomical structures). Thus, the diagnostic and surgical procedures require constant verification after each step. This is also the case in autotransplantation; the procedure should not be done flapless, and visual control of each step is critical for ensuring the reliability of the surgical template. Furthermore, since all guides in this procedure are tooth-supported, better accuracy is expected.[3,37] Although, performing postoperative intraoral scans and matching them with preoperative plans could provide some information about the methods' accuracy, it would further expose the patient to radiation.

Several factors should be taken into consideration when applying the approach described herein to the treatment of a young patient:

- The timing of the procedure in a young child. It was found that the positions of erupting teeth change quite rapidly in children at the age of mixed dentition. Therefore, acquiring the plaster model and the CT scan on the same day, if possible, can be recommended.
- When an ankylotic tooth is diagnosed in a child undergoing a growth spurt, it is recommended to perform a decoronation procedure, as soon as possible, to preserve the alveolar bone width and height and to prevent proximal movement of the adjacent teeth,[38-41] which would otherwise increase the cost and complexity of further treatment due to a preliminary orthodontic treatment to regain the lost space.
- It should be mentioned that orthodontic treatment prior to autotransplantation may nonetheless be required in cases of crowded anterior dentition to prevent damage to the PDLc of the adjacent teeth.

In the present case, the maxillary premolar was chosen for autotransplantation of the missing anterior tooth, as the future orthodontic treatment of this patient was

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considered. The patient had mild Class II division 1 malocclusion, and extraction of the maxillary premolar and space closure was considered to be a treatment alternative for the original malocclusion presented. The mandibular premolar would have been preferable for the autotransplantation, because of the shape of its root and crown; however, in the present patient extraction of the mandibular premolar would either have led to a prolonged and more complex future orthodontic treatment or have necessitated maintaining until adulthood the mandibular premolar space for a future implant.

In the current patient, the buccal recession of the transplanted tooth probably resulted from the preoperative infraoccluded position of the traumatized incisor. As the child is still growing, improvement is expected in the buccal bone with time. Retrospectively, it might have been beneficial to graft the buccal plate. Moreover, at 12 years old, the patient has not yet started her definitive orthodontic treatment. Therefore the transplanted tooth is not yet in its correct vertical position. It is expected that during her future orthodontic treatment the gingival margins will be matched, and the occlusion will be consolidated to Class I. This treatment should be completed approximately 2 years from its initiation.

It could be argued that this procedure has some limitations, such as increased exposure to radiation and a relatively higher cost due to the use of CBCT, 3D guiding templates, and dental laboratory services. Notwithstanding, in some children this procedure may actually decrease the amount of radiation exposure and the cost of treatment by reducing postoperative complications. Moreover, simplifying and shortening the procedure's duration reduces the need for general anesthesia, thus further lowering the cost of treatment.

CONCLUSIONS

An improved technique is presented for autotransplantation based on computerized 3D simulations and guidance, and enables accurate dimensioning and optimal localization of the artificial socket relative to the alveolar bone borders and the adjacent teeth roots. This technique may significantly simplify the autotransplantation procedure and will likely increase its success rates and use in young patients.

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REFERENCES

1. Natiella JR, Armitage JE, Greene GW. The replantation and transplantation of teeth: a review. Oral Surg Oral Med Oral Pathol Oral Radiol 1970;29:397–419.
2. Kristerson L. Autotransplantation of human premolars: a clinical and radiographic study of 100 teeth. Int J Oral Surg 1985;14:200–213.
3. Kafourou V, Tong HJ, Day P, et al. Outcomes and prognostic factors that influence the success of tooth autotransplantation in children and adolescents. Dent Traumatol 2017;33:393–399.
4. Kallu R, Vinckier F, Politis C, et al. Tooth transplantations: a descriptive retrospective study. Int J Oral Maxillofac Surg 2005;34:745–755.
5. Mendoza-Mendoza A, Solano-Reina E, Iglesias-Linares A, et al. Retrospective long-term evaluation of autotransplantation of premolars to the central incisor region. Int Endod J 2012;45:88–97.
6. Andreasen JO, Paulsen HU, Yu Z, et al. A long-term study of 370 autotransplanted premolars. Part II. Tooth survival and pulp healing subsequent to transplantation. Eur J Orthod 1990;12:14–24.
7. Paulsen HU, Andreasen JO. Eruption of premolars subsequent to autotransplantation. A longitudinal radiographic study. Eur J Orthod 1998;20:45–55.
8. Andreasen JO, Paulsen HU, Yu Z, et al. A long-term study of 370 autotransplanted premolars. Part IV. Root development subsequent to transplantation. Eur J Orthod 1990;12:38–50.
9. Andreasen JO, Paulsen HU, Yu Z, et al. A long-term study of 370 autotransplanted premolars. Part III. Periodontal healing subsequent to transplantation. Eur J Orthod 1990;12:25–37.
10. Paulsen HU, Andreasen JO, Schwartz O. Pulp and periodontal healing, root development and root resorption subsequent to transplantation and orthodontic rotation: a long-term study of autotransplanted premolars. Am J Orthod Dentofac Orthop 1995;108:630–640.
11. Andreasen JO, Paulsen HU, Yu Z, et al. A long-term study of 370 autotransplanted premolars. Part I. Surgical procedures and standardized techniques for monitoring healing. Eur J Orthod 1990;12:3–13.
12. Day PF, Lewis BRK, Spencer RJ, et al. The design and development of surgical templates for premolar transplants in adolescents. Int Endod J 2012;45:1042–1052.
13. Moin DA, Derksen W, Verweij JP, et al. A novel approach for computer-assisted template-guided autotransplantation of teeth with custom 3D designed/printed surgical tooling. An ex vivo proof of concept. J Oral Maxillofac Surg 2016;74:895–902.
14. Kim E, Jung JY, Cha IH, et al. Evaluation of the prognosis and causes of failure in 182 cases of autogenous tooth transplantation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;100:112–119.
15. Czochrowska EM, Stenvik A, Bjercke B, et al. Outcome of tooth transplantation: survival and success rates 17-41 years posttreatment. Am J Orthod Dentofac Orthop 2002;121:110–119.
16. Tsukiboshi M. Autotransplantation of teeth: requirements for predictable success. Dent Traumatol 2002;18:157–180.
17. Mensink G, Van Merkesteyn R. Autotransplantation of premolars. Br Dent J 2010;208:109.

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18. Hupp JG, Mesaros S V, Aukhil I, et al. Periodontal ligament vitality and histologic healing of teeth stored for extended periods before transplantation. Dent Traumatol 1998;14:79–83.
19. Andreasen JO. Interrelation between alveolar bone and periodontal ligament repair after replantation of mature permanent incisors in monkeys. J Periodontal Res 1981;16:228–235.
20. Nethander G. Oral restoration with fixed partial dentures on transplanted abutment teeth. Int J Prosthodont 1995;8:517–526.
21. Schwartz O, Bergmann P, Klausen B. Autotransplantation of human teeth: a life-table analysis of prognostic factors. Int J Oral Surg 1985;14:245–258.
22. Ashkenazi M, Levin L. Metal tooth-like surgical templates for tooth autotransplantation in adolescents. Dent Traumatol 2014;30:81–84.
23. Shahbazian M, Jacobs R, Wyatt J, et al. Validation of the cone beam computed tomography-based stereolithographic surgical guide aiding autotransplantation of teeth: clinical case-control study. Oral Surg Oral Med Oral Pathol Oral Radiol 2013;115:667–675.
24. Honda M, Uehara H, Uehara T, et al. Use of a replica graft tooth for evaluation before autotransplantation of a tooth. A CAD/CAM model produced using dental-cone-beam computed tomography. Int J Oral Maxillofac Surg 2010;39:1016–1019.
25. Keightley AJ, Cross DL, McKerlie RA, et al. Autotransplantation of an immature premolar, with the aid of cone beam CT and computer-aided prototyping: a case report. Dent Traumatol 2010;26:195–199.
26. Clokie CML, Yau DM, Chano L. Autogenous tooth transplantation: an alternative to dental implant placement? J Can Dent Assoc 2001;67:92–96.
27. Cousley RRJ, Gibbons A, Nayler J. A 3D printed surgical analogue to reduce donor tooth trauma during autotransplantation. J Orthod 2017;44:287–293.
28. Strbac GD, Schnappauf A, Giannis K, et al. Guided autotransplantation of teeth: a novel method using virtually planned 3-dimensional templates. J Endod 2016;42:1844–1850.
29. Shahbazian M, Jacobs R, Wyatt J, et al. Accuracy and surgical feasibility of a CBCT-based stereolithographic surgical guide aiding autotransplantation of teeth: in vitro validation. J Oral Rehabil 2010;37:854–859.
30. Verweij JP, Jongkees FA, Anssari Moin D, et al. Autotransplantation of teeth using computer-aided rapid prototyping of a three-dimensional replica of the donor tooth: a systematic literature review. Int J Oral Maxillofac Surg 2017;46:1466–1474.
31. Lee SJ, Jung IY, Lee CY, et al. Clinical application of computer-aided rapid prototyping for tooth transplantation. Dent Traumatol 2001;17:114–119.
32. van der Meer WJ, Jansma J, Delli K, et al. Computer-aided planning and surgical guiding system fabrication in premolar autotransplantation: a 12-month follow up. Dent Traumatol 2016;32:336–340.
33. Andreasen JO, Schwartz O, Kofoed T, et al. Transplantation of premolars as an approach for replacing avulsed teeth. Pediatr Dent 2009;31:129–132.
34. Díaz JA, Almeida AM, Benavente AA. Tooth transplantation after dental injury sequelae in children. Dent Traumatol 2008;24:320–327.
35. Schneider D, Marquardt P, Zwahlen M, et al. A systematic review on the accuracy and the clinical outcome of computer-guided template-based implant dentistry. Clin Oral Implants Res 2009;20:73–86.
36. Van Assche N, Vercruyssen M, Coucke W, et al. Accuracy of computer-aided implant placement. Clin Oral Implants Res 2012;23:112–123.
37. Tahmaseb A, Wismeijer D, Coucke W, et al. Computer technology applications in surgical implant dentistry: a systematic review. Int J Oral Maxillofac Implants 2014;29:25–42.
38. Filippi A, Pohl Y, Von Arx T. Decoronation of an ankylosed tooth for preservation of alveolar bone prior to implant placement. Dent Traumatol 2001;17:93–95.
39. Malmgren B, Cvek M, Lundeberg M, et al. Surgical treatment of ankylosed and infrapositioned reimplanted incisors in adolescents. Eur J Oral Sci 1984;92:391–399.
40. Malmgren B, Malmgren O. Rate of infraposition of reimplanted ankylosed incisors related to age and growth in children and adolescents. Dent Traumatol 2002;18:28–36.
41. Malmgren B. Decoronation: how, why, and when? J Calif Dent Assoc 2000;28:846–854.