Case Report

Guided autotransplant of a first premolar to replace a maxillary ankylosed incisor using a custom-designed osteotome

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ABSTRACT

Background. Autotransplantation is a highly successful technique to replace ankylosed teeth. The authors propose a modified therapeutic approach to guide the autotransplant of an immature maxillary premolar using a tooth-shaped osteotome.

Case Description. A 9-year-old boy reported an avulsion of his maxillary permanent left central incisor with a delayed replantation. An autotransplant of the immature maxillary right first premolar into the position of the affected tooth was planned. A surgical 3-dimensional guiding template and a tooth-shaped osteotome were manufactured to prepare the neo-alveolus (referring to the creation or modification of an alveolus to house the tooth) modification. Although the donor tooth was placed in the recipient socket with the buccal side of the root fully exposed, the transplant outcome was successful.

Practical Implications. The use of 3-dimensionally designed surgical osteotome could improve accuracy and surgical handling of a donor tooth autotransplant, even with substantial bone defects in the recipient site.

Key Words. Autotransplanted tooth; cone beam computed tomography; digital planning; guided implant surgery; tooth-shaped osteotome.

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Tooth avulsion, the most severe form of trauma to permanent teeth, is described as the complete displacement of a tooth from its alveolar socket.[1] The treatment of choice to maintain the viability of the periodontal ligament (PDL) cells demands an immediate replantation into the socket.[2] The presence of vital PDL cells on the root surface of the replanted tooth safeguards replacement root resorption, which is one of the most critical complications.[3,4] Therefore, it is essential to reduce the time lapse between avulsion and tooth replantation.[5] When immediate replantation is not possible after avulsion, the clinician should preserve these cells on the root surface by storing the avulsed tooth in an appropriate solution.[6,7] The ideal storage media suggested for avulsed teeth include tap water, saliva, and saline serum, but Hank's balanced salt solution, milk, modified Eagle medium, and ViaSpan (DuPont) have been shown to yield the best outcomes.[8,9] However, the frequent delay in replantation means the tooth is stored in an unsuitable medium, or it experiences extensive drying before replantation.[8,10] In such situations, the root surface may have an unlimited damaged area, leading to an inflammatory process in the periodontal tissues, after which the new attachment apparatus reorganizes itself.[11] Osteoclasts from the adjacent alveolar bone repopulate the affected area and over time cause gradual ankylosis and replacement resorption. The result is the fusion of the alveolar bone with the root surface.

Ankylosis is first observed by a high percussion sound, followed by reduced mobility and evident infraposition of the affected tooth in growing patients.[12] An ankylosed root is resorbed constantly and substituted by bone, finally resulting in resorption of the entire root. This situation is gradual, and to date there has been no evidence that this course can be arrested or reversed.

When this progression is left untreated in growing patients, the eruption of the replanted tooth is disrupted, leading to infrapositioning of the tooth, tilting of the adjacent teeth, disorder in the growth of the alveolar bone, and an unesthetic appearance.[13-16] Autotransplantation is a highly successful technique used to replace irreversibly damaged teeth and is particularly indicated when crowding permits extraction of an immature premolar.[17] To reach revascularization of the pulp and positive periodontal healing, the perfect root should develop to three-fourths of the entire length of the donor tooth.[18] Different methods, incorporating 3-dimensional (3D) design and 3D printing technologies, have been proposed to update and help achieve higher success rates for autotransplants.[19] However, these approaches still need free-hand preparation of the recipient socket. In 2017, Anssari Moin and colleagues[20] described a method of computer-assisted template-guided autotransplant with custom 3D-designed and -printed surgical tools that possibly may offer a relatively precise alternative for the existing treatment methods.

Theoretically, horizontal and vertical bone regeneration can be stimulated at the recipient site after autotransplant when the PDL cells of the donor tooth root are conserved.[21,22] However, to our knowledge, there have been no reports in the literature of tooth autotransplants involving a donor tooth placed in the recipient socket with the buccal side of the root fully exposed and no surrounding bone. The affected tooth in our case report had a highly advanced degree of replacement root resorption, which produced severe bone atrophy. The aim of this case report is to report a successful guided autotransplant of an immature maxillary premolar using a tooth-shaped osteotome.

CASE PRESENTATION

A 9-year-old boy was referred to us, having experienced a maxillofacial trauma 8 months previously, with an avulsion of his maxillary left permanent central incisor (tooth no. 9) and a delayed replantation. Clinical examination revealed a severe infraocclusion of tooth no. 9 and a metallic sound to percussion test. The maxillary dental midline had deviated 1 mm to the left in relation to the mandibular dental midline (Figure 1). Radiographic image examination showed an absence of periodontal space surrounding the affected tooth, making it impossible to differentiate the alveolar bone from the root surface (Figure 2, A and B). A cone-beam computed tomographic (CBCT) scan (8.0 mA and 90 kV, 5 × 5 cms) (CS 9300; Carestream Health) showed that the residual bone ridge in tooth no. 9 was thin, and there was no vertical development of the surrounding alveolar process (Figure 3). The scan also revealed a bone resorption of the buccal cortical plate, although the palatal bone was not affected (Figure 3, A and B).

Several treatment choices were considered, including buildup, surgical repositioning, bone distraction by means of a piezoelectric osteotomy of the segment, decoronation, and autotransplant.[12-15] After discussing the benefits of each treatment option and possible long-term success rate, as well as its possible complications, duration, function, esthetics, and treatment cost, the patient's parents consented to a tooth autotransplant. At the same time, the patient was referred to an orthodontist, who planned a bilateral tooth extraction of maxillary and mandibular first premolars to correct the malocclusion. After this interdisciplinary consultation, a decision was made to perform an autotransplant of the immature maxillary right first premolar (tooth no. 5) into the position of tooth no. 9, followed by an esthetic restoration and orthodontics.

The CBCT scan was exported to Digital Imaging and Communications in Medicine files, which were uploaded to surgical planning software specifically designed for guided implant surgery (NemoScan, Nemotec). The donor tooth (tooth no. 5) was segmented using the Digital Imaging and Communications in Medicine files and then saved as a standard tessellation language file. The digitally segmented donor tooth was transplanted virtually into the socket of tooth no. 9, taking into account the nasopalatine foramen position and the adjacent dental structures, as well as the optimal esthetic and functional requirements (Figure 4A).

An analogous root (donor tooth—shaped osteotome) was custom designed according to the virtual position of the donor tooth and the shape of the recipient site (Figure 4B). This design allowed for the fabrication of an osteotome shaped like the buccal surface of the donor tooth. Then, a surgical 3D guiding template was prepared for neo-alveolus modification, thus improving the accuracy of the donor tooth transplant. The surgical template design consisted of an occlusal reference fixed to 3 adjacent teeth for good stability (Figure 5A). The 3D guiding template, the segmented donor tooth (3D replica), and the design of the root-shaped osteotome were exported as

ABBREVIATION KEY

3D: 3-dimensional.
CBCT: Cone-beam computed tomography.
PDL: Periodontal ligament.

Figure 1. Preoperative view of a 9-year-old boy with an ankylosed mandibular left central incisor (tooth no. 9). Note the severe infraposition of tooth no. 9 and the tilting of the adjacent teeth 8 months after avulsion and delayed replantation.

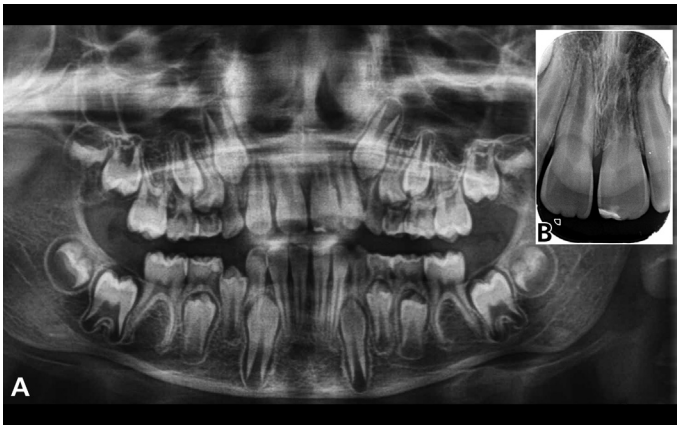

Figure 2. The previously replanted maxillary left central incisor showing an extensive replacement root resorption. **A.** Preoperative panoramic view. **B.** Tooth no. 9 was ankylosed in an infraoccluded position.

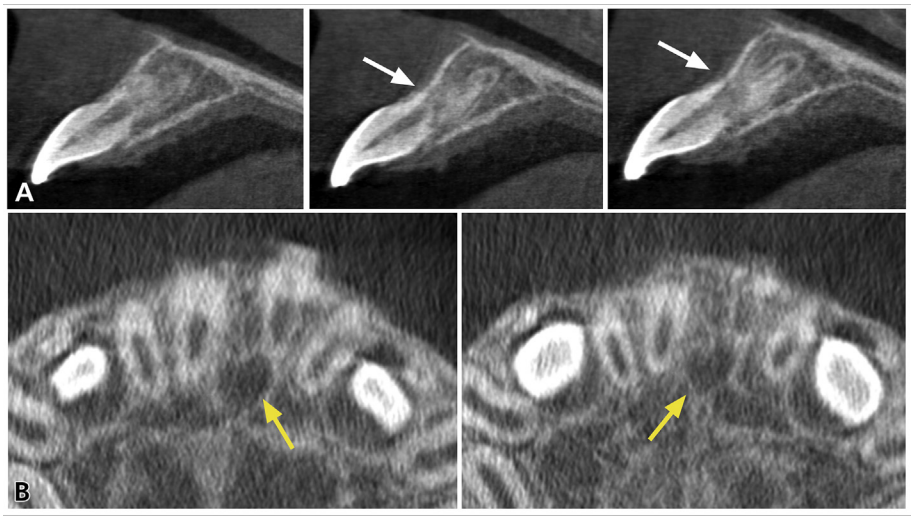

Figure 3. A cone-beam computed tomographic scan showing a thin residual bone ridge in tooth no. 9 and no vertical development of the surrounding alveolar process. **A.** Sagittal slices of the gradual bone replacement of the root (white arrows) preventing it from a normal eruption. **B.** Axial slices also revealing a bone resorption of the buccal cortical plate but not the palatal cortical plate. Yellow arrows indicate the nasopalatine foramen position.

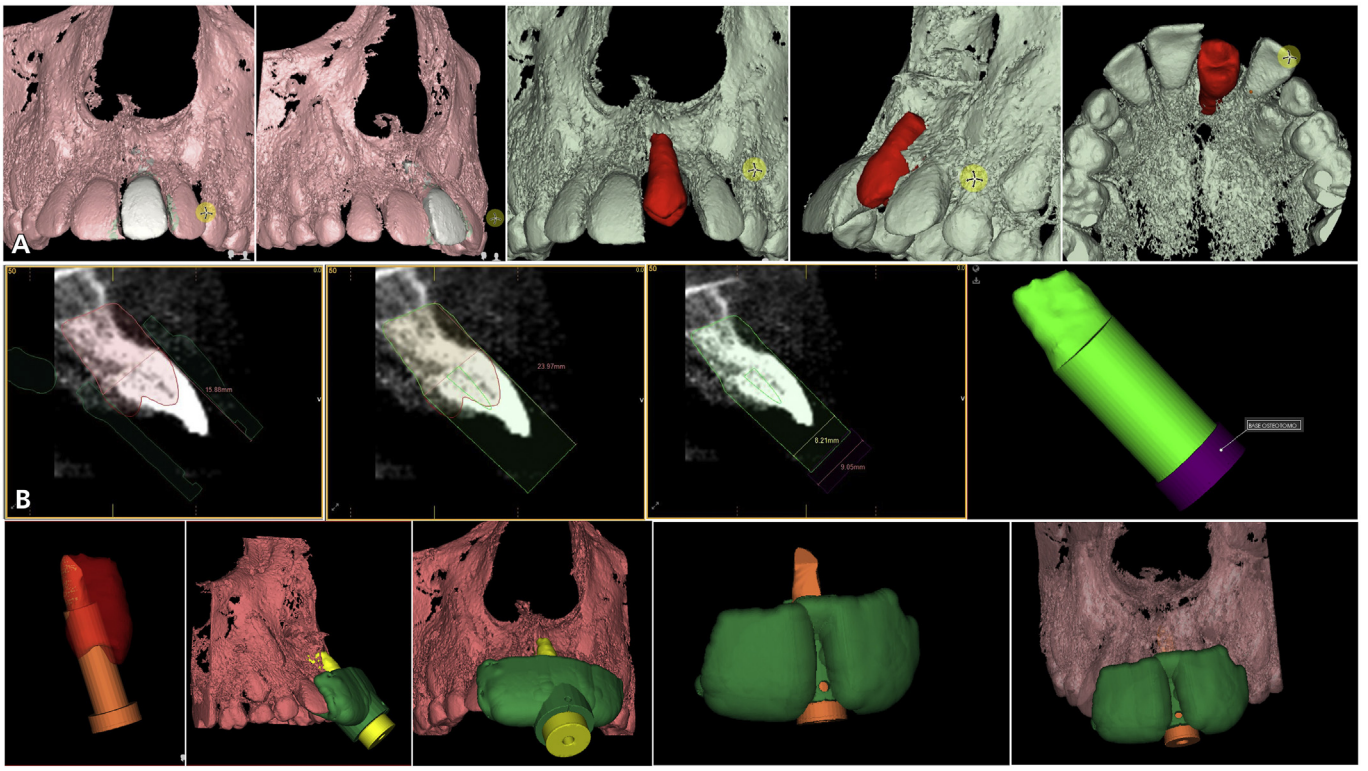

Figure 4. Digital planning sequence: immediate premolar autotransplant. **A.** The digitally segmented donor tooth was virtually transplanted into the recipient socket. **B.** An analogous root (donor tooth-shaped osteotome) was custom designed according to the virtual position of the donor tooth and the shape of the recipient site. Note the osteotome shaped like the buccal surface of the donor tooth. A surgical 3 dimensional guiding template was also designed for neo-alveolus modification.

Figure 5. Manufacture and use of the custom 3-dimensional (3D) designed tools. **A.** Detail of the root-shaped osteotome, the 3D guiding template, and the segmented donor tooth (3D replica). **B.** Placement of the 3D guiding template and the custom osteotome. Note how the tooth replica was inserted into the recipient site to verify the final preparation.

standard tesselation language files and printed in biocompatible resin (Dental LT clear resin) with a stereolithography 3D printer (Form 3B, Formlabs). Finally, the printed root-shaped osteotome was converted into a cobalt-chrome tool using a traditional cast method based on the lost wax process (Figure 5A).

After the digital planning was done, the autotransplant surgery was performed. The patient was prescribed antibiotic (875 mg of amoxicillin and 125 mg of clavulanic acid) every 12 hours for 7

days beginning the day before the surgery. First, the affected tooth (tooth no. 9) was extracted carefully so as not to further damage the remaining buccal cortical plate. Visual inspection of the alveolus confirmed that the buccal cortical plate had disappeared completely, leaving a dehiscence of 8 mm. Then, the recipient site was modified slightly with surgical round burs at low speed and cooled with a solution of physiological saline. All the while, the entire palatal cortical plate was carefully preserved to avoid damaging the nasopalatine foramen. Subsequently, the 3D guiding template was positioned, and the recipient site was definitively shaped by gently tapping the custom osteotome with a hammer through the template (Figure 5B). The replica was inserted into the recipient site to verify the final preparation (Figure 5B).

Successively, the donor tooth was extracted atraumatically (Figure 6A) and immediately transplanted into the neo-alveolus at the recipient site (Figure 6B). The position of the donor tooth exactly matched the position of the digital planning guide and that of the 3D tooth replica. The buccal root surface of the transplanted tooth was covered using a porcine pericardium collagen membrane (Jason; Bottis) fixed by 2 tenting screws (Master-Pin-Control Fixation System, Osteogenics Biomedical) between the root and the raised flap (Figure 6, C and D). Primary instability of the transplanted tooth was overcome by splinting it to the adjacent teeth with a 0.012 double segment nickel-titanium wire and composite resin for 21 days (Figure 6E). The extra-alveolar time between tooth extraction and transplant of the maxillary premolar in the neo-alveolus took no more than 1 minute. The occlusion was adjusted to ensure there was no occlusal interference (Figure 6F). A composite restoration (Enamel plus HRi-Function, Micerium) was placed in the transplanted tooth to adjust the occlusion and give the crown an esthetic appearance.

The patient was scheduled for follow-up appointments at 6, 12, and 18 months to evaluate the transplant outcome (Figure 7). Because the donor tooth was immature and Hertwig epithelial sheath was preserved around the apex, continued root development and partial canal obliteration were observed at the 3 follow-ups. Clinical and radiographic image examinations at 20 months revealed no signs or symptoms, and the transplanted tooth remained functional (Figure 8A). The transplanted tooth retained its esthetic appearance and continued to erupt according to the patient's growth stage. Periapical follow-up radiography showed evidence of root development and no signs of root resorption (Figure 8B).

DISCUSSION

Most dental avulsions occur in people aged 8 through 12 years during the development of the jaws and alveolar processes,[19] accounting for 1% through 16% of all traumatic injuries of the permanent dentition.[23] Immediate extraction of an irreversible ankylosed tooth is not usually a good treatment choice as it leads to bone attachment loss, particularly the thin buccal plate of the maxilla, and subsequently a defect both in the horizontal and vertical dimensions.[24] In addition, the tooth frequently may be preserved for a few more years, giving the patient a temporary esthetic and efficient solution.[16] The underdeveloped growth of the bone around the ankylosed tooth is often complemented by a tilting of the adjacent teeth, produced by the interdental fibers between the ankylosed tooth and neighboring teeth.[25,26]

The 2 most predictable techniques for preserving the alveolar ridge in children and adolescents with an ankylosed tooth are decoronation or autologous transplant.[12,17] In 1984, Malmgren and colleagues[15] established the concept of decoronation, with the idea that by means of keeping the resorbing root, the labial contours of the socket could be conserved. It appears that a thin layer of bone apposition grows over the affected root, probably owing to the interdental fibers interacting between the adjacent teeth and the dentoperiosteal fibers.[24] Although the treatment of an ankylosed permanent incisor by means of decoronation can maintain the width of the alveolar bone ridge, the final step is to place an implant in a young patient.[16]

Compared with resin-bonded restorations, conventional fixed bridgework, and removable partial dentures, dental implants are used more widely to offer better esthetic outcomes.[27] Implantation is considered an excellent treatment option, but it is highly contraindicated in growing patients because implants do not erupt or move with neighboring teeth, which can lead to infraocclusion with functional and esthetic complications.[28] Moreover, implant survival rate in young patients is lower than that described for adult and older adult patients.[29]

In complex cases of growing patients with missing anterior teeth, only an autotransplant of an appropriate donor tooth can offer a functional and esthetic therapy. This approach supports

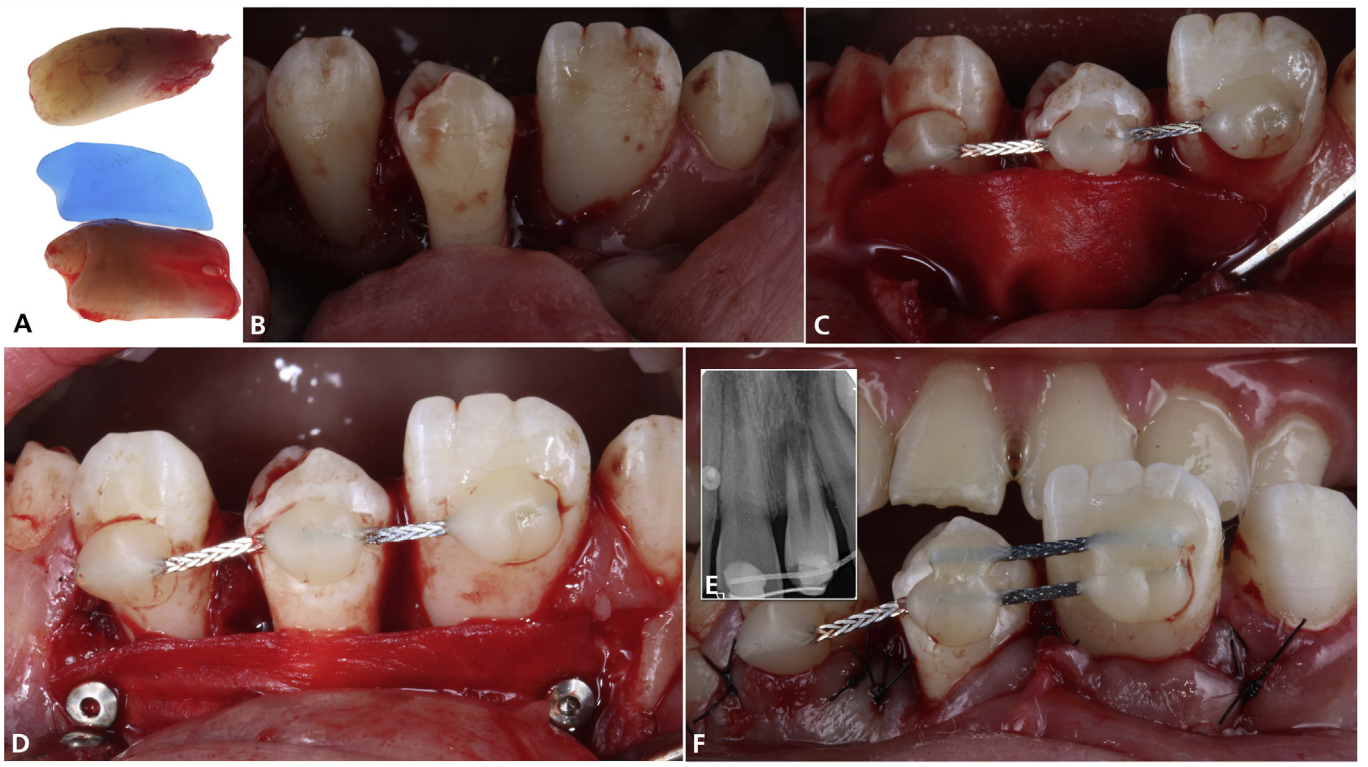

Figure 6. Autotransplant surgical procedure. **A.** Atraumatic extraction of both the ankylosed tooth and the donor tooth. Comparison between the 3 dimensional tooth replica and the donor tooth. **B.** Immediate transplant into the neo-alveolus. **C** and **D.** The buccal root surface of the transplanted tooth was covered with a porcine pericardium collagen membrane fixed by 2 tenting screws. **E.** Periapical radiograph showing the final position of the donor tooth within the recipient socket. **F.** Double splinting to ensure adequate primary stability.

continuing skeletal and dentoalveolar growth without compromising the remaining dentition.[30] Tooth transplants can be performed at an early age, when frequency of trauma is elevated, providing tooth survival rates of up to 90% as well as hard and soft tissue comparable to that of natural maxillary incisors.[31] Almpani and colleagues[18] found that teeth with immature apexes were less likely to be lost as the possibility of extraction decreased by 70% compared with teeth with mature apexes. Thus, the root development stage may be a crucial factor in autotransplants.

The biological principles and wound healing of autotransplanted teeth are similar to those of avulsed teeth after they are replantated. Thus, mechanical damages during extraction or traumatic press-fit placement in the recipient socket and biochemical aspects due to lengthy extra-alveolar period may damage dental structures, specifically the PDL, leading to progressive root resorption.[20,32] The methods used to minimize these negative influences are based on CBCT and intraoral scanners, as well as additive manufacturing technology. Strbac and colleagues[19] and Verweij and colleagues,[33,34] among others, have shown that autotransplants combined with 3D technology could improve the clinical outcome thanks to a decrease in extraoral time and intraoperative fitting attempts.

Different methods have been proposed to update and simplify the surgical technique to achieve higher success rates for autotransplants.[35-37] However, it was not until the report by Anssari Moint and colleagues[20] that a method was used without the need for free-hand preparation. They introduced a method of performing computer-assisted template-guided autotransplants with custom 3D-printed surgical tooling. The novelty of our case report is that the donor tooth was placed in a recipient socket with the buccal side of the root fully exposed and no surrounding bone. A custom-printed osteotome shaped like the buccal surface of the immature maxillary right first premolar was used to perform a minimally invasive intervention and simplify surgical handling.

Several articles have suggested that autotransplants of developing teeth may be a feasible option for treating local bone growth defects.[21,22] Kim and colleagues[22] report 2 cases with significant vertical bone growth after autotransplants. Our case report indicated rapid healing owing to the

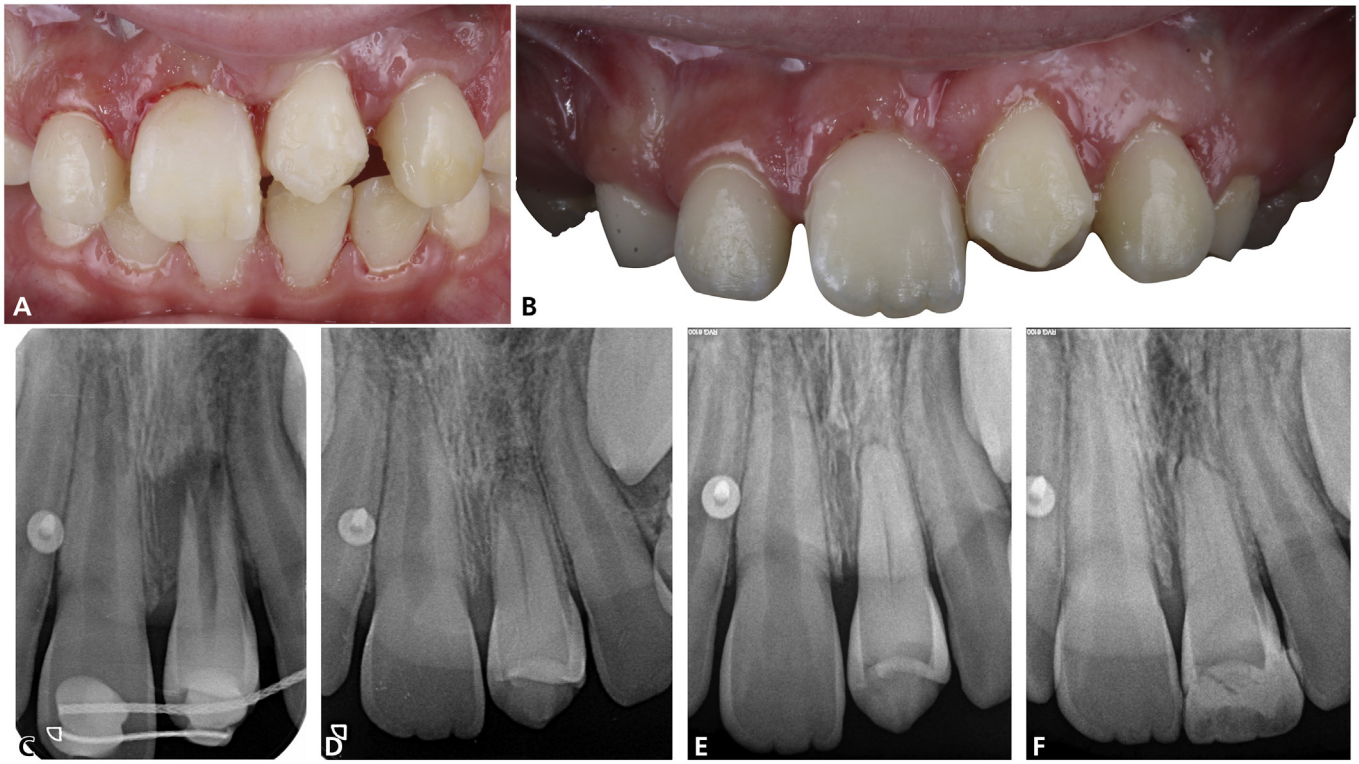

Figure 7. Follow-up appointments. **A** and **B.** After removal of the splinting at 3 weeks. **C-F.** Radiographic follow-ups at 6, 12, and 18 months showing continued root development and partial pulp canal obliteration.

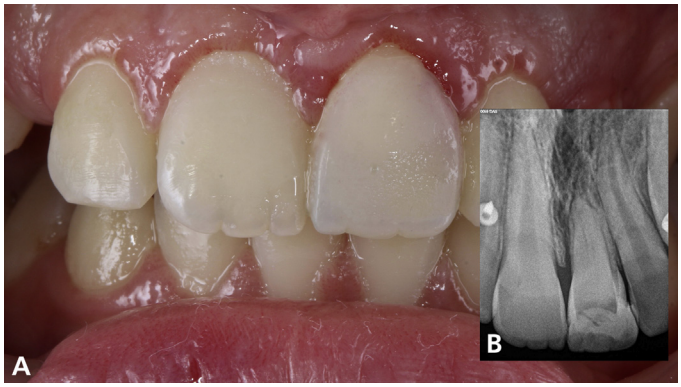

Figure 8. Twenty months after the transplant of the maxillary right first premolar. **A.** Clinical examination showing a normal eruption of the transplanted tooth. **B.** Normal root development was evident.

viable PDL, even in cases in which a large bone defect is present in the recipient site.[28] Garcia and Saffar[38] observed that PDL preservation promoted bone growth around the transplanted tooth root. PDL cells are a heterogeneous cell population that can be divided into fibroblasts, cementoblasts, and osteoblasts.[39] In contrast, the absence of viable PDL cells encourages a fast migration of the soft tissues, which in turn produces a long junctional epithelium attachment.[40]

CONCLUSIONS

Ankylosis or replacement resorption after tooth injuries in children and adolescents not only leads to loss of the affected teeth but also might interfere with adjacent alveolar bone growth. Guided autotransplants appear to be an excellent treatment option, particularly when crowding indicates

extraction of a premolar. This approach helps decrease extra-alveolar time and insertion attempts of the tooth destined for a transplant. Future studies could focus on evaluating the accuracy of guided autotransplants using custom-printed osteotomes. ■

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1. Andersson L, Andreasen JO, Day P, et al. International Association of Dental Traumatology guidelines for the management of traumatic dental injuries, 2: avulsion of permanent teeth. *Dent Traumatol*. 2012;28(2):88-96.

2. Coste SC, Silva EFE, Santos LCM, et al. Survival of replanted permanent teeth after traumatic avulsion. *J Endod*. 2020;46(3):370-375.

3. Souza BDM, Dutra KL, Kuntze MM, et al. Incidence of root resorption after replantation of avulsed teeth: a meta-analysis. *J Endod*. 2018;44(8):1216-1227.

4. Lauridsen E, Andreasen JO, Bouaziz O, Andersson L. Risk of ankylosis of 400 avulsed and replanted human teeth in relation to length of dry storage: a re-evaluation of a long-term clinical study. *Dent Traumatol*. 2020;36(2):108-116.

5. Pohl Y, Filippi A, Kirschener H. Results after replantation of avulsed permanent teeth, II: periodontal healing and the role of physiologic storage and antiresorptive-regenerative therapy. *Dent Traumatol*. 2005;21:93-101.

6. Panzarini SR, Gulinelli JL, Poi WR, Sonoda CK, Pedrini D, Brandini DA. Treatment of root surface in delayed tooth replantation: a review of literature. *Dent Traumatol*. 2008;24(3):277-282.

7. Schwartz O, Andreasen FM, Andreasen JO. Effects of temperature, storage time and media on periodontal and pulpal healing after replantation of incisors in monkeys. *Dent Traumatol*. 2002;18(4):190-195.

8. Osmanovic A, Halilovic S, Kurtovic-Kozaric A, Hadziabdic N. Evaluation of periodontal ligament cell viability in different storage media based on human PDL cell culture experiments: a systematic review. *Dent Traumatol*. 2018;34(6):384-393.

9. Souza BDM, Garcia LFR, Bortoluzzi EA, Felippe WT, Felippe MCS. Effects of several storage media on viability and proliferation capacity of periodontal ligament cells. *Eur Arch Paediatr Dent*. 2020;21(1):53-59.

10. Hecova H, Tzigkounakis V, Merglova V, Netolicky J. A retrospective study of 889 injured permanent teeth. *Dent Traumatol*. 2010;26(6):466-475.

11. Fuss Z, Tsesis I, Lin S. Root resorption: diagnosis, classification and treatment choices based on simulation factors. *Dent Traumatol*. 2003;19(4):175-182.

12. Malmgren B. Ridge preservation/decoronation. *Pediatr Dent*. 2013;35(2):164-169.

13. Malmgren O, Malmgren B, Goldson L. Orthodontic management of the traumatized dentition. In: Andreasen JO, Andreasen FM, eds. *Textbook and Color Atlas of Traumatic Injuries to the Teeth*. 3rd ed. Munksgaard; 1994:383-425.

14. Sigurdsson A. Decoronation as an approach to treat ankylosis in growing children. *Pediatr Dent*. 2009;31(2):123-128.

15. Malmgren B, Cvek M, Lundberg M, Frykholm A. Surgical treatment of ankylosed and infrapositioned reimplanted incisors in adolescents. *Scand J Dent Res*. 1984;92(5):391-399.

16. Lin S, Schwarz-Arad D, Ashkenazi M. Alveolar bone width preservation after decoronation of ankylosed anterior incisors. *J Endod*. 2013;39(12):1542-1544.

17. Stange KM, Lindsten R, Bjerklin K. Autotransplantation of premolars to maxillary incisor region: a long-term follow-up of 12-22 years. *Eur J Orthod*. 2016;38(5):508-515.

18. Almpani K, Papageorgiou SN, Papadopoulos MA. Autotransplantation of teeth in humans: a systematic review and meta-analysis. *Clin Oral Investig*. 2015;19(6):1157-1179.

19. Strbac GD, Schnappauf A, Giannis K, Bert MH, Moritz A, Ulm C. Guided autotransplantation of teeth: a novel method using virtually planned 3-dimensional templates. *J Endod*. 2016;42(12):1844-1850.

20. Anssari Moin D, Verweij JP, Waars H, van Merkesteyn R, Wismeijer D. Accuracy of computer-assisted template-guided autotransplantation of teeth with custom three-dimensional designed/printed surgical tooling: a cadaveric study. *J Oral Maxillofac Surg*. 2017;75(5):925.e1-925.e7.

21. Plakwicz P, Czochrowska EM, Milczarek A, Zadurska M. Vertical bone growth following autotransplantation of the developing maxillary third molar to replace a retained mandibular permanent molar: a case report. *Int J Periodontics Restorative Dent*. 2014;34(5):667-671.

22. Kim S, Lee SJ, Shin Y, Kim E. Vertical bone growth after autotransplantation of mature third molars: 2 case reports with long-term follow-up. *J Endod*. 2015;41(8):1371-1374.

23. Lin S, Zuckerman O, Fuss Z, Ashkenazi M. American Association of Endodontists; International Association of Dental Traumatology; Royal College of Surgeons of England. *Dent Traumatol*. 2007;23(5):297-303.

24. Malmgren B, Malmgren O, Andreasen JO. Alveolar bone development after decoronation of ankylosed teeth. *Endodontic Topics*. 2006;14:35-40.

25. Becker A, Karnei-R'em RM. The effects of infraocclusion, part 1, tilting of the adjacent teeth and local space loss. *Am J Orthod Dentofacial Orthop*. 1992;102(3):256-264.

26. Becker A, Karnei-R'em RM. The effects of infraocclusion: part 2, the type of movement of the adjacent teeth and their vertical development. *Am J Orthod Dentofacial Orthop*. 1992;102(4):302-309.

27. Mainkar A. A systematic review of the survival of teeth intentionally replanted with a modern technique and cost-effectiveness compared with single-tooth implants. *J Endod*. 2017;43(12):1963-1968.

28. Tsukiboshi M, Yamauchi N, Tsukiboshi Y. Long-term outcomes of autotransplantation of teeth: a case series. *Dent Traumatol*. 2019;35(6):358-367.

29. Bohner L, Hanisch M, Kleinheinz J, Jung S. Dental implants in growing patients: a systematic review. *Br J Oral Maxillofac Surg*. 2019;57(5):397-406.

30. Plotino G, Abella Sans F, Duggal MS, et al. Clinical procedures and outcome of surgical extrusion, intentional replantation and tooth autotransplantation: a narrative review. *Int Endod J*. 2020;53(12):1636-1652.

31. Machado LA, do Nascimento RR, Ferreira DM, Mattos CT, Vilella OV. Long-term prognosis of tooth autotransplantation: a systematic review and meta-analysis. *Int J Oral Maxillofac Surg*. 2016;45(5):610-617.

32. Jang Y, Choi YJ, Lee SJ, Roh BD, Park SH, Kim E. Prognostic factors for clinical outcomes in autotransplantation of teeth with complete root formation: survival analysis for up to 12 Years. *J Endod*. 2016;42(2):198-205.

33. Verweij JP, Anssari Moin D, Wismeijer D, van Merkesteyn JPR. Replacing heavily damaged teeth by third molar autotransplantation with the use of cone-beam computed tomography and rapid prototyping. *J Oral Maxillofac Surg*. 2017;75(9):1809-1816.

34. Verweij JP, van Westerveld KJH, Anssari Moin D, Mensink G, van Merkesteyn JPR. Autotransplantation with a 3-dimensionally printed replica of the donor tooth minimizes extra-alveolar time and intraoperative fitting attemps: a multicenter prospective study of 100 transplanted teeth. *J Oral Maxillofac Surg*. 2020;78(1):35-43.

35. Lee SJ. Clinical application of computer-aided rapid prototyping for tooth transplantation. *Aust Endod J*. 2004;30(1):29-31.

36. Lee SJ, Jung IY, Lee CY, Choi SY, Kum KY. Clinical application of computer-aided rapid prototyping for tooth transplantation. *Dent Traumatol*. 2001;17(3):114-119.

37. Zufía J, Abella F, Trebol I, Gómez-Meda R. Autotransplantation of mandibular third molar with buccal cortical plate to replace vertically fractured mandibular second molar: a novel technique. *J Endod*. 2017;43(9):1574-1578.

38. Garcia A, Saffar JL. Bone reactions around transplanted roots: a 5-month quantitative study in dogs. *J Clin Periodontol*. 1990;17(4):211-216.

39. Lekic P, Rojas J, Birek C, Tenenbaum H, McCulloch CA. Phenotypic comparison of periodontal ligament cells in vivo and in vitro. *J Periodontal Res*. 2001;36(2):71-79.

40. Dahlin C, Linde A, Gottlow J, Nyman S. Healing of bone defects by guided tissue regeneration. *Plast Reconstr Surg*. 1988;81(5):672-676.