CASE REPORT/CLINICAL TECHNIQUES

Impacted Maxillary Canine with Curved Apex: Three-Dimensional Guided Protocol for Autotransplantation

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ABSTRACT

Introduction: Maxillary canines play a crucial role in dental and facial aspect, arch expansion, and efficient occlusion. When surgical exposure measures cannot be executed or the patient does not agree to take the treatment, autotransplantation should be considered. The aim of this case report was to describe a novel surgical technique using virtually planned three-dimensional (3D)-printed templates for guided apicoectomy and guided drilling of the recipient site for autotransplantation of an impacted maxillary canine with a curved apex. **Methods:** A 42-year-old man complaining of pain and increased mobility in the maxillary left primary canine came to the clinic. Autotransplantation of the impacted canine was completed using altered methods from guided implant surgery to manufacture 3D-printed templates. After a full-thickness mucoperiosteal flap elevation, the surgical template for the guided osteotomy and apicoectomy was inserted. This 3D-printed guide allowed the clinician to perform a quick and precise removal of the curved apex, providing an atraumatic extraction of the impacted canine throughout the cyst. Three further 3D surgical guides for implant burs and a 3D replica tooth were printed to modify the recipient socket. After the final position, the tooth was semi-rigid splinted to the adjacent teeth. **Results:** Follow-up at 2 years showed complete regeneration of the palatal defect and remodeling of the bone surrounding the maxillary canine. **Conclusions:** Digitally planned procedures can facilitate the complex execution of an autotransplantation, reducing the treatment chair time and the morbidity for the patient as well as increasing the predictability of the result. *(J Endod 2022;48:379–387.)*

KEY WORDS

Digital dentistry; guided tooth autotransplantation; impacted maxillary canine; interdisciplinary treatment; mature donor teeth; surgically created sockets

SIGNIFICANCE

The incorporation of digital workflow in dentistry has improved both diagnosis and treatment planning. The combination of virtually planned surgical procedures minimizes the possibility of clinical errors, making complex autotransplantation cases more efficient, predictable, and minimally invasive.

Canine impaction, a major challenge in orthodontic clinical practice, is detrimental to good facial appearance, lip support, arch development, dental esthetics, functional occlusion, and phonetics[1]. After the third molar, the maxillary canine is the second most frequently impacted tooth in the permanent dentition[1,2], with a reported prevalence ranging from 0.92% to 6.81%[3–6]. Eighty-five percent of these impacted canines are palatally impacted, and 15% are labially impacted[7]. In contrast, the frequency of impacted mandibular canines does not surpass 0.5%[8]. Untreated maxillary canine impaction causes severe clinical problems, including malocclusion, worse facial profiles, shorter dental arches, and a greater possibility of follicular cyst development[2,9]. However, thanks to improved diagnostic techniques, more and more patients with impacted canines receive a timely diagnosis and prompt treatment, meeting their needs for oral health care.

The main treatment options available for impacted canines include expectant management, interception, surgical exposure, possibly coupled with orthodontic alignment, autotransplantation, and extraction[10].The 2 most common systems used to take impacted canines into occlusion consist of surgically uncovering the tooth and allowing it to erupt naturally during early or late mixed dentition or surgically uncovering the tooth and bonding an attachment to move the tooth orthodontically[11,12]. Hence, only with a prompt diagnosis and timely interdisciplinary interception can orthodontic extrusion of impacted maxillary canines be successful[13]. Many adult patients are too old to receive effective orthodontic treatment before the retained maxillary deciduous canine is exfoliated. In addition,

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orthodontic treatment may be risky or unfeasible, especially when impacted maxillary canines are positioned obliquely/horizontally[14]. In such cases, if there is sufficient space for the transplanted tooth, autotransplantation might offer an alternative treatment choice[10].

Ever since 1954 when M. L. Hale[15] first accurately described, step by step, an autogenous tooth transplantation, the main principles of the technique have remained valid. Autotransplantation has progressed because of, in part, advances in digital technology such as cone-beam computed tomography (CBCT) and computer-aided design/computer-aided manufacturing (CAD/CAM) systems[16]. Obtaining Digital Imaging and Communications in Medicine (DICOM) files from a CBCT scan and using three-dimensional (3D) design software, the clinician can select the most suitable donor tooth according to its dimensions, visualize the most favorable 3D position, and calculate or even modify digitally the dimensions of the recipient socket[17]. In addition, prototype models of both the donor tooth (3D replicas) and the recipient area can be created to facilitate the entire surgical procedure[18,19]. These developments have been corroborated by the elevated success rates described over the past decade[20–22].

Autotransplantation of a maxillary canine entails carefully removing it from its impacted or ectopic site. A socket is then generated or modified, after which the tooth is reimplanted into the correct 3D position within the alveolus. Factors that can influence the prognosis for autotransplanted teeth include patient age and sex, root development and anatomy of the donor tooth, sufficient alveolar bone support, atraumatic surgical technique, adaptation to the recipient site, stabilization method, and postoperative care[21,23]. However, the most crucial factor for long-term success is healthy and viable maintenance of the periodontal ligament (PDL) cells on the root surface[24]. Successful PDL healing is probable when the donor tooth is extracted with insignificant mechanical injury to the PDL and is kept in ideal extraoral conditions until the end of the procedure[25]. The aim of this case report was to demonstrate a novel surgical technique using virtually planned 3D-printed templates for guided apicoectomy and guided drilling of the recipient site for autotransplantation of an impacted maxillary canine with a curved apex.

CLINICAL CASE

A 42-year-old man came to the clinic with the chief complaint of pain in the vicinity of the maxillary left lateral incisor (tooth #10) and maxillary left primary canine (tooth #48) (Fig. 1*A*). At the first appointment, the patient's medical history revealed no systemic diseases, infectious diseases, or allergies, and that he was not being prescribed medication. The pretreatment records showed standard vertical facial proportions, a straight profile, suitable facial symmetry, moderate oral hygiene, and well-maintained dentition. Clinical examination revealed an increased mobility in the maxillary left primary canine with pain on both palpation and percussion. According to the periapical radiograph, the maxillary left canine (tooth #11) was obliquely impacted, producing no apparent root resorption in the adjacent teeth (Fig. 1*B*).

It was decided to perform a 3D radiographic examination to plan a detailed treatment, rule out resorption of the root of tooth #10, ascertain the exact position of the permanent canine, and whether autotransplantation of the impacted tooth was viable for primary canine replacement. Limited CBCT images were taken with ProMax 3Ds (Planmeca OY, Helsinki, Finland) with a small field of view (5 $\times$ 8 cm) and a 0.2-mm voxel size. Operating parameters were set at 8.5 mA and 90 kV with a 12-second exposure time. After assessing coronal, axial, and sagittal CBCT slices, it was observed that the maxillary left canine, associated with an extensive follicular cyst, was palatally impacted and obliquely positioned between the roots of the maxillary left lateral incisor and the maxillary left first premolar without producing any type of resorption (Fig. 1*C*).

After discussing the risks, advantages, and possibilities with the patient, the clinician opted for a guided autotransplantation of the maxillary left canine into the primary canine site. Because orthodontic treatment would have been prolonged and not entirely reliable, the surgical exposure technique followed by orthodontic traction was ruled out because of the patient's age. The patient was fully informed that if the autotransplantation was unsuccessful, the definitive treatment would consist of either an implant or a fixed dental prosthesis.

The CBCT scan provided a 3D view of the area of interest, the crown and root length of the impacted canine, as well as the height and width of the recipient alveolar socket. The CBCT data (DICOM files) were then uploaded to surgical planning software (Blue Sky Plan 3; Blue Sky Bio, LLC, Grayslake, IL). Both the impacted maxillary left canine and the primary canine were segmented by using the DICOM files and then saved to a stereolithographic (STL) file format (Fig. 1*D*). Similar to virtual planning for implant placement, the precise 3D position of the donor tooth was chosen, taking into account the existing anatomic space and adjacent structures. After virtually adjusting the donor tooth to check its optimal fit, it was observed that the alveolus would have to be surgically modified in height and width.

Subsequently, a digital impression (Trios; 3Shape Dental Systems, Copenhagen, Denmark) of the upper arch was performed and merged with the CBCT DICOM file by using the same implant planning software (Blue Sky Plan 3; Blue Sky Bio). The root of the impacted canine showed a mature root formation with an apical abrupt curvature, making it challenging to extract atraumatically. Thus, a 3D surgical template was designed to perform a guided osteotomy and apicoectomy of the last 5 mm of the impacted root by using a trephine (Fig. 2*A*). A guide port with 7 mm of depth was designed to accommodate a 6-mm outer diameter trephine (Meisinger, Dusseldorf, Germany) according to depth of penetration, angulation, and the site of root-end resection. The STL file generated was then exported to a Digital Light Processing printer (NextDent 5100 3D printer; 3D Systems, Rock Hill, SC). The 3D surgical guide was printed (Nexdent SG; 3D Systems), and printed cast was used to confirm a snug fit. The goal of this 3D-printed guide was to perform a quick and precise removal of the curved apex, avoid perforating the maxillary sinus membrane, and atraumatically extract the tooth through the cyst. Three further 3D surgical guides for implant burs (Camlog Biotechnologies, Winsheim, Germany) were designed and printed to modify the recipient socket according to the dimensions of the canine without the apical curvature (Fig. 2*B*). In addition, a 3D-printed replica of the maxillary canine without its apex was used to reduce intraoperative fitting attempts of the donor tooth in the neo-alveolus without damaging the PDL.

Surgery was performed under local anesthesia using 3D-printed surgical templates to ensure a guided procedure (Fig. 2*C* and *D*). Initially, the primary canine was removed cautiously so as not to damage the buccal cortical plate at any time. A full-thickness mucoperiosteal flap was then elevated, and the surgical template for the guided osteotomy and apicoectomy was inserted (Fig. 3*A*). A trephine bur with side venting, constantly and copiously irrigated, was gently pecked to perform the osteotomy without excessive heat generation. Afterward, the trephine was removed, and a cylinder-shaped segment of bone and root-end was extracted (Fig. 3*B*). The entire root surface was inspected at high magnification with the operating microscope to rule out fractures or

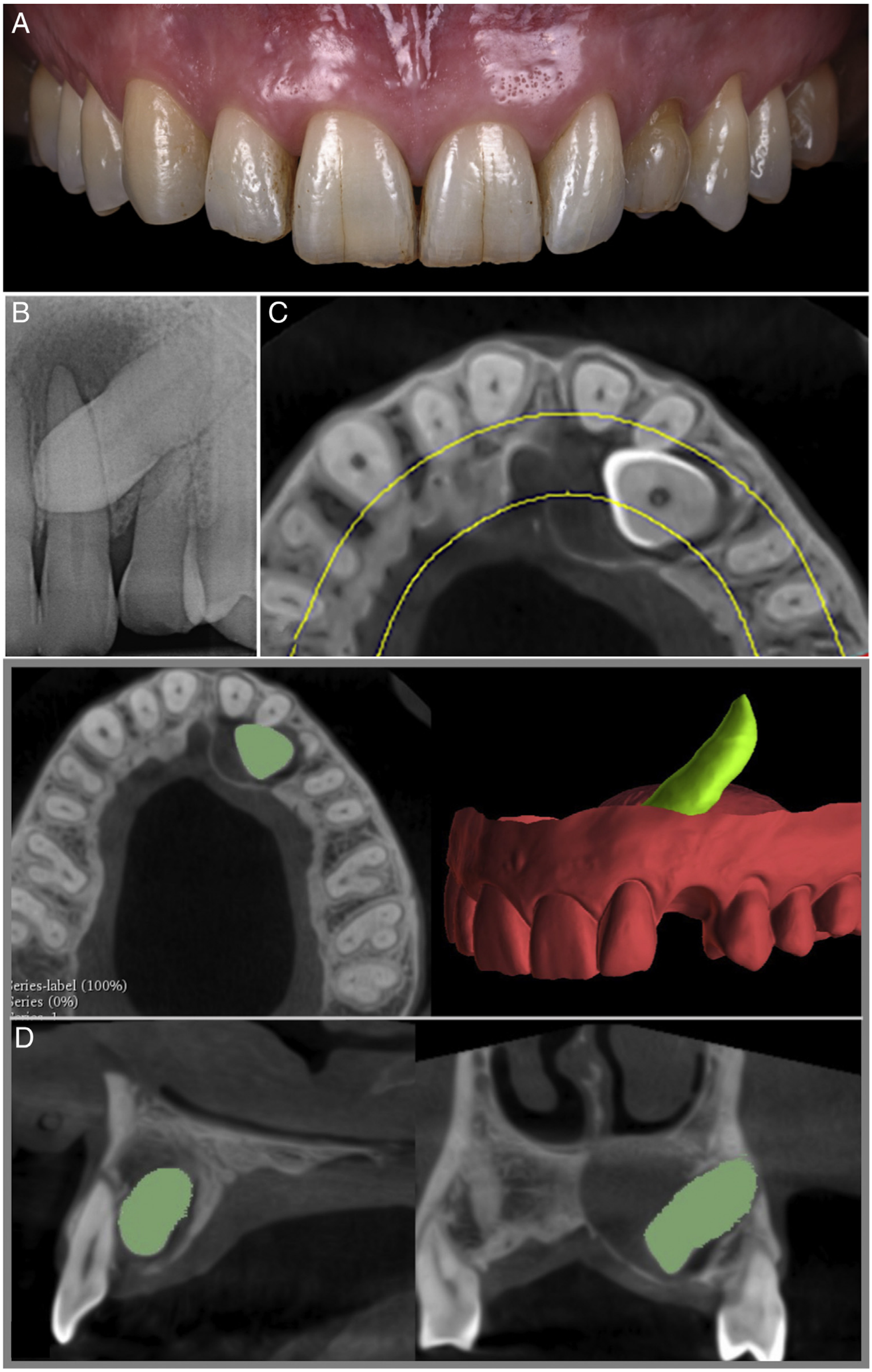

FIGURE 1 – (*A*) Preoperative view showing maxillary left primary canine (tooth #48). (*B*) Periapical radiograph revealing maxillary left canine (tooth #11) obliquely impacted without any apparent root resorption in the adjacent teeth. (*C*) Axial view of the CBCT image of the palatal position of the maxillary left primary associated with an extensive follicular cyst. (*D*) DICOM files from the 3D radiologic examination were uploaded into surgical planning software (Blue Sky Plan 3; Blue Sky Bio, LLC). In the segmentation mode, the crown and root of the impacted maxillary canine were visualized virtually.

other signs of root damage. After the combined osteotomy and apicoectomy, the palatine bone around the impacted tooth was steadily delimited with a piezoelectric handpiece under copious water-cooling irrigation until a thin coat of bone was left close to cyst. The bone was gently elevated with an excavator to avoid damaging the healthy PDL remnants on the root. After removal of

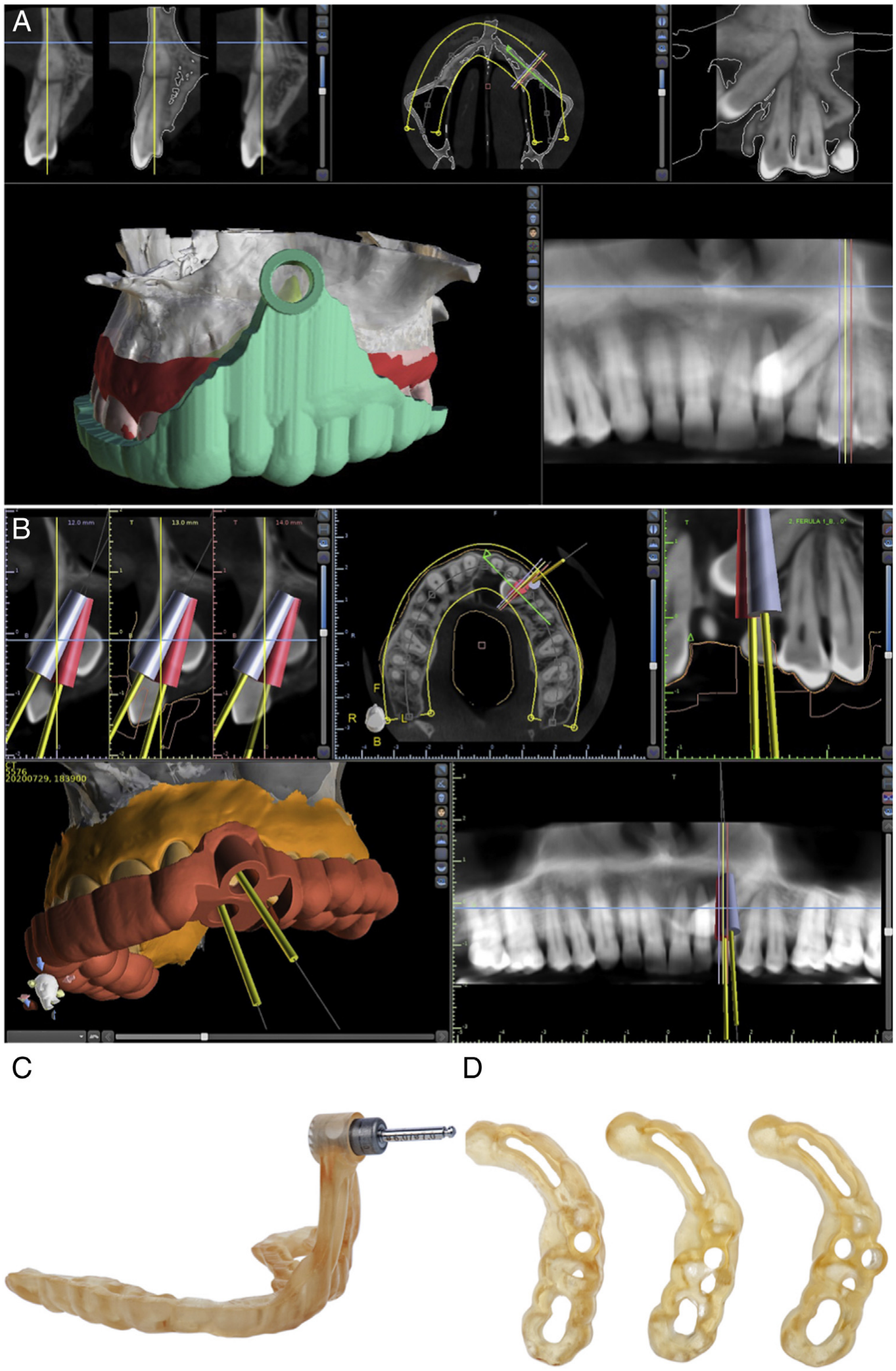

FIGURE 2 – (*A*) A stereolithographic (STL) file of the upper jaw superimposed with DICOM data for the design of a 3D surgical template for a guided osteotomy and apicoectomy. (*B*) Template for guided drilling procedure of the recipient site for use with guided implant drills. (*C*) Printed 3D surgical guide with a custom fit trephine. (*D*) Three 3D surgical guides for implant burs (Camlog Biotechnologies) for drilling the recipient site.

sufficient bone, the impacted canine was extracted atraumatically with forceps at the same time that the entire cyst was removed (Fig. 3*C*). Finally, the extracted tooth was placed immediately in saline solution for later transplantation (Fig. 3*D*).

The recipient socket was performed using the previously printed surgical guides according to the implant drilling system (Camlog Biotechnologies) planned with the implant software (Fig. 3*E*). An additional alveoloplasty was performed using a tungsten

FIGURE 3 – (*A*) 3D surgical guide with trephine inserted in the guided port. (*B*) Trephine osteotomy of the buccal cortical plate and the resected curved root-end. (*C*) Surgical exposure of the maxillary left permanent canine. (*D*) Atraumatic extraction of the maxillary impacted canine. (*E*) Guided preparation of the recipient socket to receive the donor tooth. (*F*) Donor tooth and 3D-printed tooth replica. (*G*) Try-in of the 3D-printed replica. (*H*) Donor tooth coated with enamel matrix proteins before placement in the recipient socket. (*I*) Donor tooth placement. (*J*) Guided bone regeneration with human allograft bone and a resorbable membrane in the palatal defect.

round bur to burnish any roughness in the alveolar socket. Once the suitability of the donor tooth replica was checked in the recipient site, the permanent canine was accommodated in its new alveolus in less than a minute (Fig. 3*F* and *G*). Before placement, the clinician coated the donor tooth in enamel matrix proteins (Straumann Emdogain; Straumann, Basel, Switzerland) to facilitate regeneration of possible damaged periodontal tissue (Fig. 3*H*). After final positioning and checking stability and occlusion of the transplant (Fig. 3*I*), the clinician splinted the tooth semi-rigidly to the adjacent teeth with a combination of a glass prepreg fiber (Tender Fiber Quattro; Micerium, Avegno, Italy) and a flowable resin composite (Tetric Flow; Ivoclar Vivadent AG, Schaan Fürstentum, Liechtenstein).

The palatal affected area was regenerated with human allograft bone (MinerOss; BioHorizons, Birmingham, AL) and a resorbable membrane (Mem-Lok Pliable 15 × 20 mm; BioHorizons) (Fig. 3*J*). Finally, a milled nightguard was placed to avoid any occlusal interference of the recently transplanted tooth. The stent was digitally designed using CAD-CAM software (Exocad DentalCAD, Darmstadt, Germany), allowing for more space than necessary for the future transplanted canine (Fig. 4*A* and *B*). To ensure the long-term stability of the material, the nightguard was milled (Ceramill-Motion 2, Amann Girrbach, Austria) rather than printed. Endodontic treatment was conducted at 2 weeks to avoid infection-related resorption.

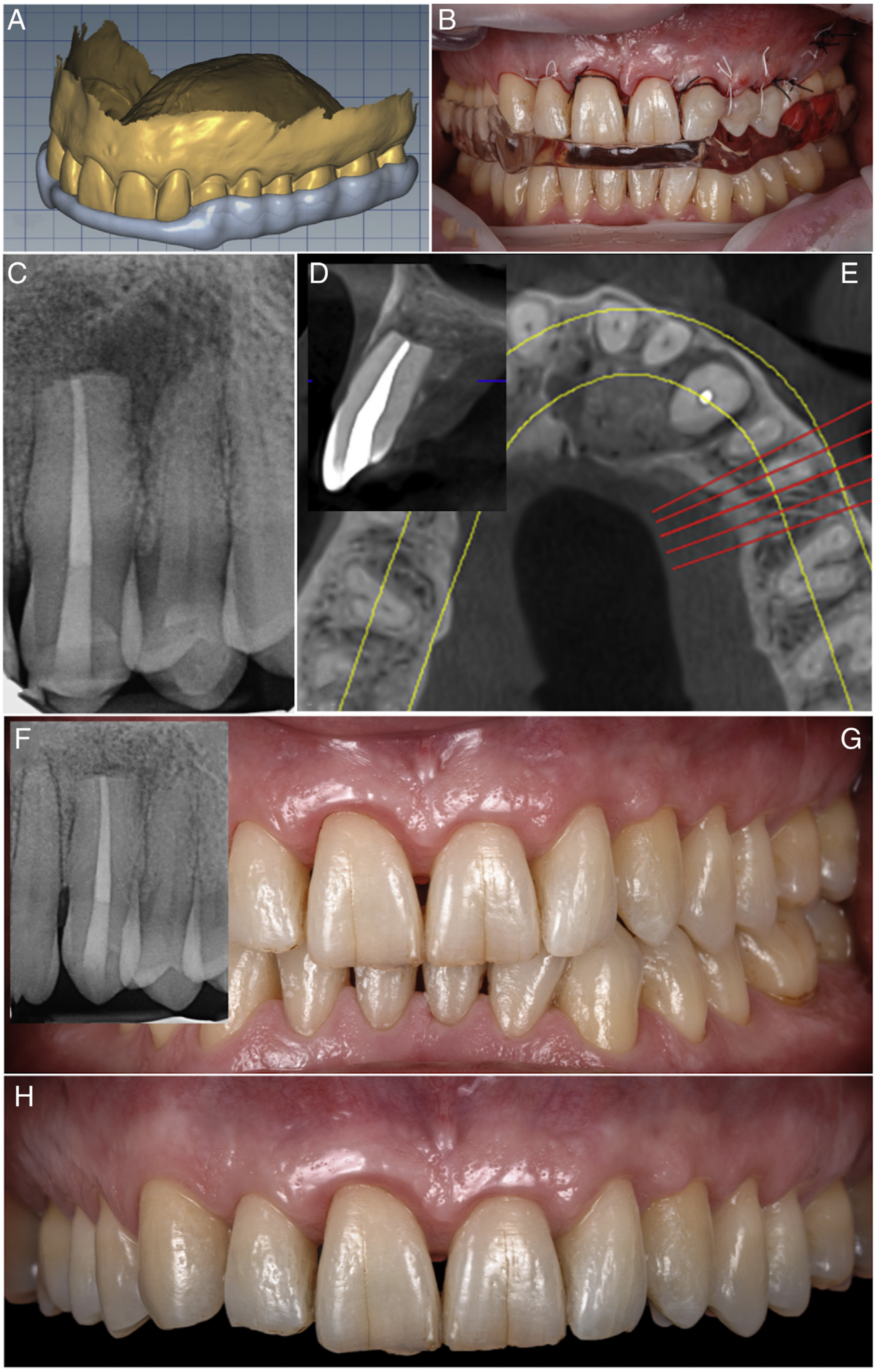

FIGURE 4 – (*A*) Digital design of a nightguard using CAD-CAM software (Exocad DentalCAD). (*B*) Final position of the autotransplanted tooth with the milled nightguard and a semi-rigid composite splint. (*C*) Endodontic treatment of the transplanted tooth. (*D* and *E*) 3D radiologic evaluation 1 year after canine autotransplantation. (*F*) Periapical radiograph 2 years after transplantation showing a continuous periodontal space with no signs of apical periodontitis and root resorptions. (*G* and *H*) Clinical view of the patient 2 years after autotransplantation.

The root canal was instrumented with ProTaper Gold files (Dentsply Sirona, Maillefer, Ballaigues, Switzerland) alternatingly irrigated with 5% sodium hypochlorite (NaOCl) and 17% EDTA and filled with a Guttacore obturator (Dentsply Tulsa Dental, Tulsa, OK) and AH-Plus cement (Dentsply DeTrey GmbH, Konstanz, Germany).

The semi-rigid composite splint was removed at 4 weeks after surgery, and the patient was followed up every month. At 6 months after surgery a periapical radiograph and a CBCT scan taken of the area showed no signs of complications (Fig. 4*C*–*E*). Follow-up at 2 years showed complete regeneration of the palatal defect and remodeling of the bone surrounding the maxillary canine (Fig. 4*F*–*H*). The soft tissue level was stable, and a periapical radiograph showed an almost natural shape of the alveolar crest around the permanent canine. No signs of swelling or bleeding were detected.

DISCUSSION

Advances in digital technology have radically changed the way many dental procedures are performed, offering great opportunities to improve treatment planning and successful outcomes in all disciplines of dentistry. This technology is based on a combination of CBCT imaging, CAD/CAM milling or printing methods, and haptic simulators[26,27]. In 1991, Duret and Preston[28] demonstrated the first dental application of CAD/CAM technology by introducing a subtractive manufacturing milling for fixed restorations. Since then, the number of applications has expanded exponentially, and endodontics has been one of the main beneficiaries[29]. All CAD/CAM applications entail 3 steps: digital data acquisition from an intraoral scanner and/or CBCT scan, data processing and design within a software application, and manufacturing by milling or printing[30,31]. 3D printing is especially suited to cases for which subtractive manufacturing is impractical[32].

Manufacturing of printed or milled 3D objects allows for simple and accurate treatment using minimally invasive techniques, which is more comfortable for the patient and needs less chair time[29]. 3D printed guides are used in endodontics for a conservative access cavity, location of calcified or missing canals, and precise osteotomies in apicoectomies. Strbac et al[33] and Verweij et al[34,35] have shown that autotransplantation with 3D technology could also see an improvement in the clinical outcome of this technique because of a reduction in extraoral time and intraoperative fitting attempts. Present evidence highlights the importance of 3D-printed donor tooth replicas to reduce complications linked with damage to the PDL[18]. Numerous studies have focused on decreasing the extraoral time of the donor tooth[18,25,34,35], yet it is also important to consider accurate osteotomy and minimal surgical trauma during the donor-tooth extraction. A decisive stage for a successful autotransplantation, especially in surgically or modified created sockets, mainly rests on an atraumatic extraction minimizing damage to the cementoblast layer[36]. The novelty of this impacted canine autotransplantation is that the virtual planning allowed a guided apicoectomy for the atraumatically extracted donor tooth while preparing the modified surgically socket precisely without excessive heat of the bone. The preoperative CBCT and intraoral scans made possible to calculate all these parameters, segment the donor tooth, and manufacture different 3D-guiding templates. However, there are no reports with long-term follow-ups exhibiting better results with this digital method than with the conventional procedure.

The main benefits of the autotransplantation technique include PDL and the alveolar bone preservation, its suitability for pediatric patients or those who are still growing, as well as adult patients, and its ability to preserve the shape of the attached gingiva, resulting in adequate function and good aesthetics[37]. In addition, the transplanted tooth can be moved through orthodontic treatment if necessary[21]. Thus, autotransplantation is a viable alternative to implants, fixed bridges, resin-bonded restorations, and even removable partial dentures. However, the technique is not without certain disadvantages or complications because it involves rather more aggressive and complex surgery than a conventional extraction[38]. To minimize traumatic extraction, the procedure used guided trephination for root-end resection, which was developed by different authors[39–41]. Giacomino et al[40] concluded that trephine burs guided by 3D-printed surgical templates provide efficient targeted osteotomies with a predictable site, angulation, and profundity of preparation. Still, it should be noted that in some cases, the outcome of treatment may be difficult to predict, and likely complications such as inflammatory root resorption, replacement root resorption, or clinical attachment level loss may occur, which may result in tooth loss[42].

In most autotransplantations involving a donor tooth with a fully developed root, as in this case, the clinician should perform an endodontic treatment[43]. This treatment, which would be carried out mainly to prevent external inflammatory resorption, can be performed before, during, or at 15 days after transplantation, depending on the position of the donor tooth and its root anatomic complexity[44]. By contrast, in the transplantation of immature teeth, only a small necrosis occurs in the most apical part of the pulp tissue; therefore, most cases would show a revascularization of the pulp tissue, making endodontic treatment unnecessary[45]. Marques-Ferreira et al[46] stated that revascularization can be accomplished when the root is shorter than 8.07 mm and the width of the apical foramen is longer than >1 mm, as also explained by Andreasen et al[47] and Gaviño Orduña et al[48]. However, these results remain controversial. In this case, because the donor tooth did not respond to the thermal sensitivity tests at 2 weeks after surgery, an endodontic treatment was performed, avoiding any damage to the guided bone regeneration of the palatal area.

Provided the case is properly selected, autotransplantation is a sufficiently predictable treatment with 70%–97 % success rates[21,23,42]. Indeed, the clinician's skill and experience are factors that must also be considered when discussing the success and survival of autotransplanted teeth. A recent systematic review on autotransplantation of maxillary canines concluded that there is a dearth of well-designed studies on this topic[49]. In a prospective split-mouth study, Grisar et al[50] demonstrated clinically acceptable results with maxillary canine autotransplantation compared with results with the contralateral canine outcomes at between 1 and 3 years of follow-up. However, further high-quality observational studies are needed on indications, prognostic factors, clinical success considerations, surgical instruments and techniques, 3D virtual planning, aesthetic results, and patient approval of maxillary canine autotransplantation.

CONCLUSIONS

In a favorable clinical situation, autotransplantation may be considered a predictable therapeutic alternative to a conventional prosthesis or implant. The combination of virtually planned surgical procedures minimizes the possibility of clinical errors, making complex clinical cases more efficient and predictable, as shown in this article. Thus, complex surgeries can be transformed nowadays into minimally invasive procedures, helping the clinician implement these daily workflows.

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