Asian Journal of Periodontics and Orthodontics
2023, Volume 3, Page No: 44-52
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Available online at: www.tsdp.net

ISSN: 3062-3499

Original Article

Innovative Use of 3D-Printed Metal Appliances for Orthodontic Treatment of Palatally Impacted Maxillary Canines

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Received: 02 May 2023; **Revised:** 29 August 2023; **Accepted:** 09 September 2023

ABSTRACT

This study describes the creation and application of a digitally designed and 3D-printed metallic appliance used for the surgical exposure and orthodontic alignment of maxillary palatally impacted canines. Two patients with palatally impacted canines underwent Cone-Beam Computed Tomography (CBCT) and intraoral scanning to accurately determine the tooth position. Using the digital data, a custom guide supported by teeth and mucosa was designed to assist the surgeon in uncovering the canine crown and to provide the orthodontist with a reliable direction for traction. The appliance was 3D-printed using a biocompatible dental alloy and fitted in the oral cavity. Following exposure, a gold chain was bonded to each canine crown and connected to the device's metallic projection via an elastic chain. After 3 months of traction, the crowns of the impacted canines emerged on the palate at the expected positions. A digitally planned and 3D-fabricated metallic guide, constructed from CBCT and intraoral scan data, can thus be effectively utilized for both exposure and traction of palatally impacted canines.

Keywords: Impacted canine, Cone-beam computed tomography, Intraoral scanning, Additive manufacturing

How to Cite This Article: Stoev AN, Pavlova Z, Vasileva IM. Innovative Use of 3D-Printed Metal Appliances for Orthodontic Treatment of Palatally Impacted Maxillary Canines. Asian J Periodont Orthodont. 2023;3:44-52. https://doi.org/10.51847/T0fTuJw29g

Introduction

The prevalence of unerupted maxillary canines is reported between 0.8% and 2% in the general population [1], with approximately 85% positioned palatally [2]. The etiology may involve local obstructions, pathological conditions, or genetic predisposition associated with anomalies or absence of lateral incisors [3]. However, some authors consider the genetic link uncertain [4], while others emphasize the influence of environmental and epigenetic factors on the phenotype [5]. In addition, skeletal anomalies—such as Sella turcica bridging (SB), ponticulus posticus (PP), atlas posterior arch deficiency (APAD), and elongated pterygopalatine fissure—have been correlated with maxillary canine impaction [6, 7]. Because of their complexity, impacted canines require well-established and predictable treatment approaches.

Two main surgical strategies are commonly employed: the open-eruption and closed-eruption techniques [8]. In the open approach, the overlying mucosa and bone are removed and a surgical dressing is placed; whereas, in the closed approach, a mucoperiosteal flap is elevated, bone is removed to expose the tooth, and a chain attachment is bonded to the crown before repositioning and suturing the flap. The chain is then activated via fixed orthodontic appliances. The closed method has been reported to yield superior periodontal outcomes once the tooth is properly aligned [9]. Nevertheless, other investigations suggest there is no significant difference in overall surgical or periodontal results between the two methods [10, 11], while some indicate the open technique may reduce treatment time and the likelihood of ankylosis [12].

Traditional two-dimensional imaging—including panoramic, periapical, and bitewing radiographs—has

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long been used to evaluate impacted canines. Ericson and Kurol [2] proposed a panoramic-based classification that assesses crown position sectors, distance from the occlusal plane, and inclination to the midline. The diagnostic value of cephalometric records was also highlighted by Quinzi *et al*. [13]. However, the advent of cone-beam computed tomography (CBCT) has enabled precise three-dimensional localization of impacted canines [14, 15]. Compared with 2D imaging, CBCT provides superior detection of adjacent incisor root resorption [16, 17] and root dilaceration [18].

Three-dimensional visualization (sagittal, coronal, and axial planes) assists clinicians in determining the ideal direction of traction, avoiding damage to adjacent structures, and improving surgical access [19]. Nevertheless, radiation exposure remains a concern, and patient dose depends on parameters such as field of view (FOV), exposure time, number of projections, and milliampere-seconds (mAs) [20].

A variety of mechanical systems have been proposed to guide the orthodontic traction of impacted canines. Jacoby [21] introduced the ballista spring using twisted round wires (0.014–0.018 inch) for energy storage. Oppenhuizen [22] later developed a prefabricated extrusion spring for palatal impactions, while Bowman and Carano [23] presented the Kilroy I and II systems for palatal and buccal impactions, respectively. Additional innovations include elastic traction from bonded eyelets [24], miniscrew-assisted force systems [25], adjustable auxiliary struts with coiled eyelets [26], and magnetic force appliances [27]. Nakandakari *et al*. [28] used a modified transpalatal arch (TPA) featuring an extended arm for traction.

The optimal extrusion force has been reported to range from 0.3 to 0.4 N [29], with continuous and light forces being essential for effective biological response and reduced tissue trauma. Consequently, understanding the applied force system is vital for achieving efficient and predictable results [30, 31].

Tepedino *et al*. [32] designed a cantilever mechanism welded to a transpalatal bar to provide physiological force during extrusion, while Peng *et al*. [33] developed a composite appliance combining a Nance arch, traction hook, M bracket, and molar bands, adaptable for canine traction.

With the accessibility of digital imaging and 3D printing technologies, clinical management of impacted canines has become more precise and less invasive [34]. The present article introduces a digitally engineered and 3D-printed metallic device, guided by CBCT and intraoral scans, which enables accurate localization of the canine crown during surgery and controlled directional traction in the early treatment phase—facilitating repositioning before buccal movement.

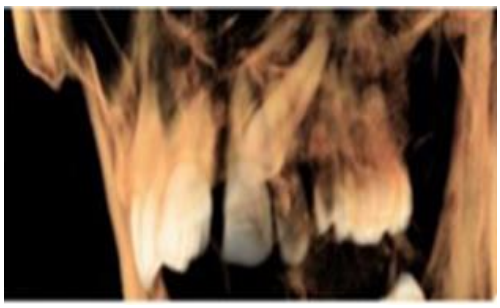
Materials and Methods

A 23-year-old woman (patient 1) and a 14-year-old boy (patient 2) were referred for management of palatally impacted canines—tooth 23 and 13, respectively. Both canines were found adjacent to the lateral incisor roots (sector 5 and sector 3, respectively, as defined by Ericson and Kurol [2]), requiring careful control of the traction vector. The clinical plan involved first repositioning each canine toward a more favorable palatal orientation, followed by labial movement. These treatment criteria justified the use of a newly designed 3D-printed metallic guide, bonded to the maxillary dentition in conjunction with conventional fixed orthodontic appliances. Written consent was obtained from both patients (or guardians) after full explanation of the procedures.

Following diagnostic evaluation, fixed appliances were installed in the upper arch to gain sufficient space for tooth eruption. Besides a panoramic radiograph, a cone-beam computed tomography (CBCT) scan was performed using the Planmeca ProMax® CBCT system (Planmeca Oy, Helsinki, Finland; parameters = 90 kVp, 4–10 mA, voxel size 200–400 μm) to determine the exact position of the impacted canines **(Figure 1)**.



a1



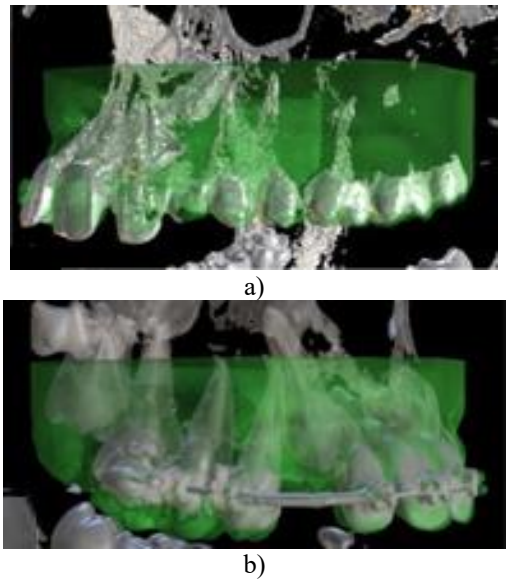
a2



b1 b2

Figure 1. Panoramic and CBCT images of both cases showing palatal canine impaction ((a1,a2): patient 1; (b1,b2): patient 2).

Each patient's maxilla was then digitally scanned with the CS 3600 intraoral scanner (Carestream Dental, LLC, Atlanta, GA, USA). After consultation with the oral surgeon, an open-eruption technique was selected for both cases. The DICOM datasets from CBCT and the .STL files from the scans were imported into Blue Sky Plan® software (v 4.9.4, Blue Sky Bio LLC, Libertyville, IL, USA)—an open-source program that enables analysis and manipulation of tomographic data. Both datasets were aligned using reference points to produce a 3D virtual model visualizing teeth, bone, mucosa, and roots concurrently **(Figure 2)**.

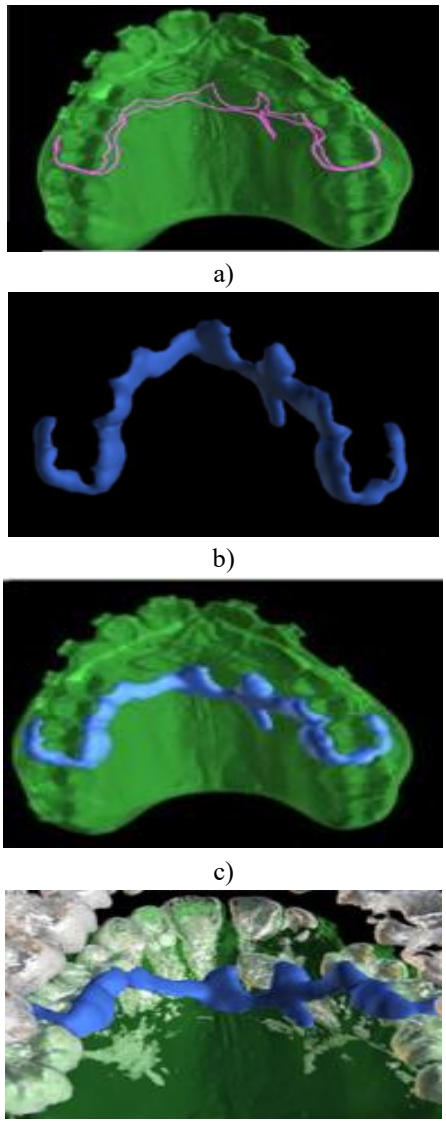


a)

b)

Figure 2. Digitally reconstructed maxillary models derived from merged DICOM and .STL files (green region) (a) patient 1; b) patient 2).

A custom guide was then digitally designed to indicate the palatal region requiring tissue removal. The guide rested on the buccal and palatal aspects of the first molar (or second premolar) and extended over the palatal mucosa **(Figure 3)**. Its semi-circular framework marked both the approximate crown location of the impacted tooth and the precise bonding site for the chain eyelet. These parameters were extracted directly from the CBCT images. The appliance thus functioned as a surgical navigation aid, directing the surgeon to remove only the necessary mucosa and bone to uncover the canine crown. It also included a metallic arm designed to hold an elastic chain, allowing the desired traction pathway to be established.



a)

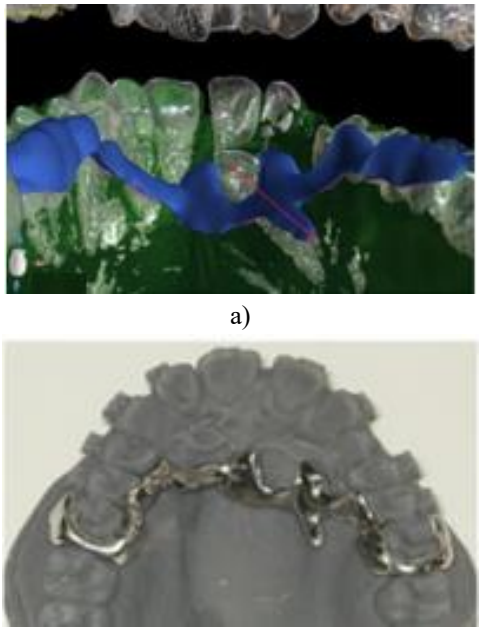
b)

c)

d)

Figure 3. a, b) CAD design (purple) and .STL model (blue) of the guide; c, d) position of the device on the digital model (patient 1).

The model was manufactured via Selective Laser Melting (SLM) using a biocompatible cobalt–chromium alloy (composition: Co 61%, Cr 28.1%, M 5.3%, W 5%; supplier: Audental Biomaterial Co., Ltd., Shenzhen, China) **(Figure 4)**.



a)

b)

Figure 4. a) Visualization of the appliance (blue) showing the canine crown position and traction direction (purple arrow); b) 3D-printed alloy device.

Before the surgical phase, the metallic guide was cemented to the maxillary teeth using G-CEM LinkAce self-adhesive resin cement (GC Corporation, Tokyo, Japan). Under local anesthesia (3% mepivacaine), the overlying soft tissues and bone were gently removed to expose the impacted crown, to which a gold chain was attached. The surgical field was protected with a Coe-Pak® dressing (GC, Tokyo, Japan) for approximately one week **(Figure 5)**.



a)



b)



c)

Figure 5. a) Device positioned intraorally; b) surgical exposure of the impacted canine; c) bonded gold chain and protective dressing (patient 1).

After removal of the pack, the bonded chain was linked to an elastic chain fixed on the device's projection, initiating orthodontic traction that generated the planned mechanical forces and moments **(Figures 6 and 7)**.



a)



b)

Figure 6. Connection of the gold chain to the appliance via elastic chain (a) patient 1; b) patient 2).

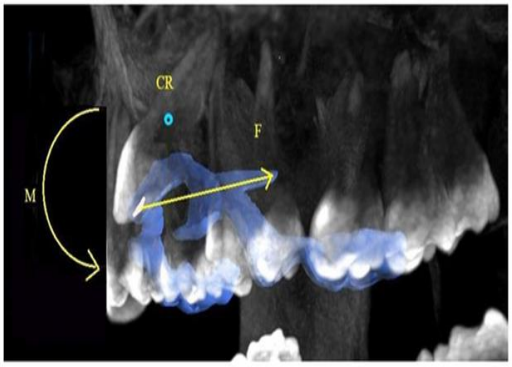
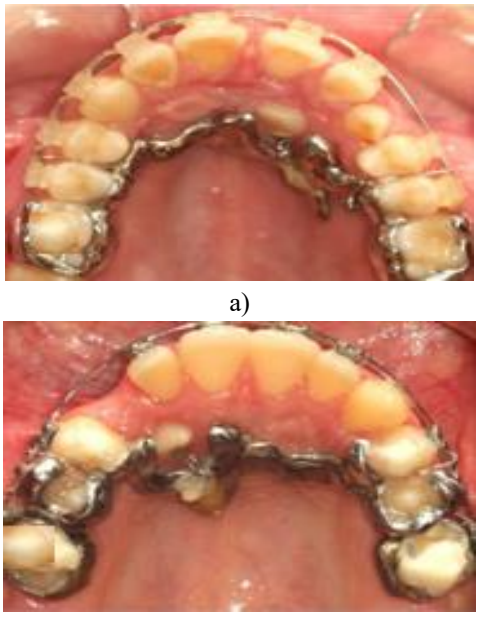


Figure 7. Diagram illustrating the applied force (F) and the resulting moment (M) due to the vertical offset between the point of force application and the center of resistance (CR) of the canine.

Results and Discussion

After approximately three months of traction application to the canines, the crown surfaced on the palatal side in the expected region for each patient **(Figure 8)**.

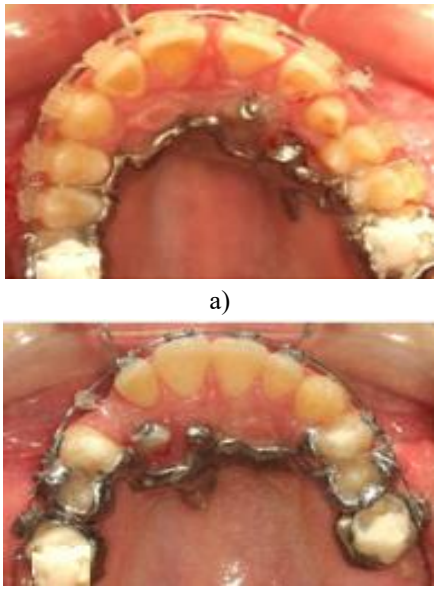


a)

b)

Figure 8. Palatal emergence of the canine crown after three months (a) patient 1, b) patient 2).

Following the detachment of the traction chain, an orthodontic button was secured to the labial aspect of the crown, and a new elastic chain was used to pull the tooth toward the labial direction **(Figure 9)**.



a)

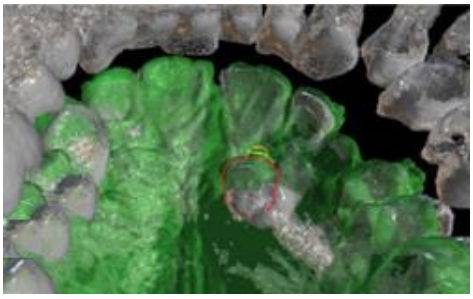
b)

Figure 9. Movement of the canine toward the labial side (a) patient 1, b) patient 2).

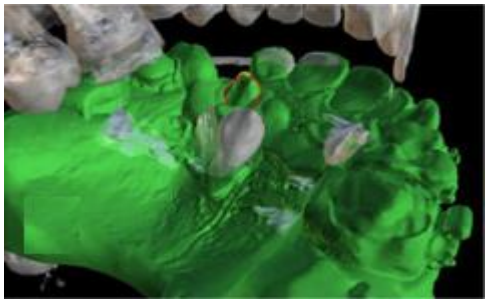
At this phase, the metallic appliance was taken out from the oral cavity **(Figure 10)**. The initial palatal-directed traction, achieved through the custom device, allowed for a controlled and safe final repositioning of the canines within the dental arch **(Figure 11)**.



Figure 10. Image taken immediately after device removal showing slight mucosal irritation on the palate (patient 1).



a)



b)

Figure 11. Superimposed view of Cone-Beam Computed Tomography (CBCT) and stereolithography (STL) data obtained after four months (three months of palatal traction followed by one month of labial traction). Green: .STL from intraoral scanning after four months; red contour: final canine crown outline; yellow mark: bonded component. The canine progresses into its designated arch position (a) patient 1, b) patient 2).

Bishara [30] identified several localized causes of canine impaction, such as space deficiency within the arch, persistence of primary teeth, alveolar clefts, or cystic lesions. Jacoby [35] also noted that around 85% of palatally impacted canines actually have sufficient eruption space, a situation often due to surplus maxillary volume resulting from factors like missing lateral incisors, early eruption of nearby teeth, or localized bone overdevelopment. In this study, the first case involved prolonged retention of a primary canine, while the second displayed transverse maxillary deficiency.

Research findings have questioned the clinical importance of CBCT in deciding between open and closed exposure techniques. Alqerban *et al*. [19] observed no substantial distinction between 2D and 3D imaging concerning surgical selection—whether to expose the tooth with or without an attachment or to extract it—and concluded that the surgeon's judgment and background largely guide the approach. Similarly, Wriedt *et al*. [18] reported that treatment recommendations for impacted canines do not significantly vary when using 2D instead of 3D imaging.

However, CBCT remains advantageous for identifying the precise point for placing the traction eyelet and determining the pull direction, offering better precision than panoramic imaging [14, 15]. The 3D visualization from CBCT enhances diagnostic certainty by revealing the canine's spatial relationship to adjacent roots and detecting any resorption, improving surgical predictability [18, 19]. For these cases, CBCT was employed to accurately locate the impacted teeth in accordance with prior evidence-based guidelines [34].

The imaging data were complemented with intraoral .STL scans, which improve treatment assessment and planning in orthodontics [36, 37]. Using dedicated planning software (Blue Sky Plan®, Version 4.9.4, Blue Sky Bio, LLC, Libertyville, IL 60048, Illinois, USA), a customized apparatus was virtually designed for both exposure and traction of the canine.

Special cantilever springs have been introduced as versatile tools in orthodontic applications [38], particularly for managing palatally impacted canines. These springs may be inserted into the buccal auxiliary tubes of molar bands [39] or positioned in the lingual sheath [40] and connected to the impacted canine. Despite their effectiveness, their intricate configuration often complicates fabrication, and the numerous loops included in their structure can be challenging to manipulate clinically—relying heavily on the practitioner's or technician's skill. Adjusting or activating such appliances is frequently carried out directly within the oral cavity, which may cause discomfort or potential risk to the patient. Additionally, minimizing wire diameter to better regulate the applied force [32] can compromise the device's strength, increasing the chance of fracture. Improper placement of the springs may irritate the tongue or cheeks, and accidental detachment of the chain's eyelet could result in an urgent clinical issue. Nevertheless, even complex impactions can be effectively managed using conventional methods such as the double-arch approach [41], which employs a carefully formed stainless-steel auxiliary arch in combination with a main stainless-steel archwire to deliver controlled traction to the canine.

Conversely, computer-aided and 3D-printed systems—developed through the integration of CBCT imaging, intraoral scanning, CAD modeling, and additive manufacturing—offer several benefits, including greater precision, shorter operative times, fewer procedural errors, and enhanced predictability of results [42]. Reports also indicate that such techniques can make surgical interventions quicker and less invasive [43].

This digital workflow yields a lightweight, uniform, and well-adapted appliance that fits accurately to the teeth and mucosal surfaces, as demonstrated in the present cases. Its design facilitates hygiene maintenance and improves patient comfort. The semi-circular component of the device precisely identifies the palatal mucosal point where flap elevation should begin. Utilizing the underlying CBCT data, once the overlying tissues are removed, the exact site on the canine crown for bonding the chain's eyelet becomes visible. Additionally, the device includes a small

projection for attaching the elastic chain used during traction. The contour, thickness, and proportions of both the semi-circular portion and the projection are digitally adjusted after assessing the optimal traction pathway, ensuring the canine is guided correctly in the early stage of treatment.

Regarding the material selection, the 3D-printed cobalt–chromium (Co–Cr) alloy, produced using Selective Laser Melting (SLM)—a direct metal printing process that fuses fine metal powder with a high-energy laser—has shown superior electrochemical stability, enhanced polarization resistance, and greater corrosion and pitting resistance compared with traditional manufacturing methods [44, 45].

A possible drawback of the proposed design is irritation of the palatal mucosa due to direct contact with the soft tissue **(Figure 10)**. Therefore, meticulous hygiene of the appliance—through appropriate interdental brushes, mouth rinses, and possibly adjunctive measures such as photodynamic therapy (PDT) [46]—is highly recommended. Regular clinical monitoring and correct activation of the device remain crucial. Future investigations should aim to digitally map the trajectory of orthodontic traction for impacted canines and develop 3D-printed systems for its implementation.

Conclusion

The effective exposure and traction of palatally impacted canines can be greatly enhanced by computer-aided, additively manufactured appliances. Incorporating digital diagnostic tools, including CBCT and intraoral scanning, significantly contributes to the precision and efficiency of such treatments.

Acknowledgments: None

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

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