

# A dual composite resin injection molding technique with 3D-printed flexible indices for biomimetic replacement of a missing mandibular lateral incisor

Keiichiro Watanabe <sup>a</sup>, Eiji Tanaka <sup>a</sup>, Kohei Kamoi <sup>b</sup>, Antonin Tichy <sup>c</sup>, Takahiko Shiba <sup>d,e</sup>, Kazuhide Yonerakura <sup>f,g</sup>, Masatoshi Nakajima <sup>f</sup>, Ruonan Han <sup>h</sup>, Keiichi Hosaka <sup>f,g,i,j,\*</sup>

<sup>a</sup> Department of Orthodontics and Dentofacial Orthopedics, Tokushima University Graduate School of Biomedical Sciences, Tokushima, Japan, <sup>b</sup> Department of Dental Laboratory, Tokushima University Hospital, Tokushima, Japan, <sup>c</sup> Institute of Dental Medicine, First Faculty of Medicine of the Charles University and General University Hospital in Prague, Prague, Czech Republic, <sup>d</sup> Department of Periodontology, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, Tokyo, Japan, <sup>e</sup> Department of Oral Medicine, Injection, and Immunity, Harvard School of Dental Medicine, Boston, USA, <sup>f</sup> Department of Regenerative Dental Medicine, Tokushima University Graduate School of Biomedical Sciences, Tokushima, Japan, <sup>g</sup> Division of Interdisciplinary Research for Medicine and Photonics, Institute of Post-LED Photonics, Tokushima University, Tokushima, Japan, <sup>h</sup> Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, USA, <sup>i</sup> The Research Laboratory of Electronics at Massachusetts Institute of Technology, Cambridge, USA, <sup>j</sup> Department of Mineralized Tissue Biology, The ADA Forsyth Institute, Cambridge, USA

## Abstract

**Patients:** This case report presents a minimally invasive approach to replace a missing mandibular lateral incisor using a dual-injection molding technique with flowable composite resins. Integrated with a comprehensive digital workflow, this method achieves a structurally and esthetically biomimetic, bi-layered prosthetic solution. A 34-year-old woman with congenital absence of a mandibular lateral incisor was successfully rehabilitated using a direct composite resin-bonded fixed partial denture (RBFPD).

**Discussion:** Two specialized three-dimensional (3D)-printed flexible indices stabilized by a custom-designed 3D-printed rigid holder were employed to ensure the meticulous injection molding of flowable composite resins formulated to emulate the inherent chromatic gradations between dentin and enamel. The inherent flexibility of the indices, combined with the holder, facilitated accurate and seamless adaptation to the complex morphological features of the dental arch, thereby mitigating the challenges commonly associated with rigid 3D-printed resin indices.

**Conclusions:** The bilayered direct composite RBFPD using 3D printed flexible indices prepared with a full digital workflow has several advantages over other dental prosthetic solutions, including noninvasiveness, cost-effectiveness, biomimetic esthetics, reparability, and shortened treatment times. Although the initial results are promising, further longitudinal studies with larger patient cohorts are required to confirm the long-term efficacy of this approach.

**Keywords:** Missing lateral incisor, Direct composite resin-bonded fixed partial denture, Injection molding technique, Bi-layered restoration, Digital workflow

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## 1. Introduction

Restoring congenitally missing incisors poses a complex challenge, necessitating a delicate balance between esthetics and functionality[1,2]. Although generally effective, traditional treatment options, such as dental implants and fixed dental prostheses, are associated with limitations, including surgical invasiveness,

financial burden, and prolonged treatment timelines. More recently,

### WHAT IS ALREADY KNOWN ABOUT THE TOPIC?

» Traditional anterior tooth replacements are invasive and expensive, whereas cantilever and fiber-reinforced direct composite resin-bonded fixed partial dentures (RBFPDs) offer less invasive yet technique-sensitive alternatives. The injection technique, improved by digital workflows, partly relies on manual processes, such as creating silicone indices from 3D-printed models.

### WHAT THIS STUDY ADDS?

» This study introduces a bi-layered RBFPD using a dual composite resin injection molding technique and a fully digital workflow. Utilizing two unique 3D printed indices, it offers a standardized, noninvasive, and cost-effective solution for replacing mandibular lateral incisors.

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\*Corresponding author: Keiichi Hosaka, Department of Regenerative Dental Medicine, Tokushima University Graduate School of Biomedical Sciences, 3-18-15 Kuramoto-cho, Tokushima city, 770-8504, Japan; Division of Interdisciplinary Research for Medicine and Photonics, Institute of Post-LED Photonics, Tokushima University, 2-1 Minamijosanjima-cho, Tokushima 770-8506, Japan; The Research Laboratory of Electronics at Massachusetts Institute of Technology, 60 Vassar Street, Building 39, Cambridge, MA 02139, USA; Department of Mineralized Tissue Biology, The ADA Forsyth Institute, 245 First Street, Cambridge, MA, 02142, USA.

E-mail address: [hosaka@tokushima-u.ac.jp](mailto:hosaka@tokushima-u.ac.jp) [khosaka@mit.edu](mailto:khosaka@mit.edu) [khosaka@forsyth.org](mailto:khosaka@forsyth.org)

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less-invasive zirconia cantilever resin-bonded fixed partial dentures (RBFDPs) have emerged as a noteworthy alternative; however, they require tooth preparation and intricate laboratory procedures, incurring significant costs[3,4].

Direct composite RBFDPs reinforced with fibers have become viable alternatives because of their minimal invasiveness and cost-effectiveness[5–7]. While they can serve as definitive restorations[5–7], their longevity is contingent upon meticulous handling and they are susceptible to internal hydrolysis and material degradation over time[7,8]. Unreinforced variants, primarily used as interim solutions, have specific applicability in anterior regions and benefit from less intense masticatory forces and durable enamel bonding[9–12].

Modern dentistry has been transformed by recent advancements in digital technologies, including computer-aided design (CAD), digital impressions, and three-dimensional (3D)-printing technologies, which hold significant promise for enhancing indirect and direct restorative techniques. Notably, the injection molding technique, initially conceptualized by Terry[13–15], relies on a clear index (mold), prefabricated from materials such as polyvinyl siloxane or 3D-printed resin, which replicates a digital wax-up, facilitating the accurate injection of highly filled flowable composite resin intraorally[10,16–23]. This markedly minimizes procedural inconsistencies during the clinical and laboratory stages, especially when 3D-printed indices are utilized[23,24].

However, the inherent rigidity and high tear resistance of conventional 3D-printed resins pose challenges, particularly when negotiating dental undercuts, which lead to complicated index separation procedures[22]. Flexible 3D-printed resins have recently been developed to mitigate these limitations[23], offering potential reductions in technical sensitivity.

While the efficacy of the injection molding technique with dual polyvinyl siloxane-based indices for creating esthetically and structurally robust layers of dentin and enamel in a direct composite RBFDP has been demonstrated[10], literature regarding the application of flexible 3D-printed resin-based indices remains sparse.

Hence, this case report aimed to elucidate a dual composite resin injection molding technique for restoring a congenitally absent mandibular lateral incisor by leveraging 3D-printed flexible indices for both dentin and enamel layers anchored by a custom-designed rigid stabilizing holder for accurate intraoral application. This technique synergizes chair-side operations with laboratory protocols, optimally exploits digital technological advancements, and offers a promising avenue for achieving esthetic and functional restoration without requiring invasive or financially prohibitive approaches.

## 2. Outline of the case

### 2.1. Clinical findings

A 34-year-old woman with a congenitally missing mandibular lateral incisor was referred from an orthodontic clinic to a restorative dentistry clinic (**Fig. 1**). She had used a temporary acrylic resin pontic for 16 years following orthodontic treatment from 14 to 17 years of age. Dissatisfied with the esthetic limitations and frequent loss of retention of the temporary acrylic pontic, the patient sought a more durable and esthetically pleasing solution. The patient expected a minimally invasive approach to preserve the adjacent teeth. Clinical



**Fig. 1.** Preoperative situation. (A, B) Frontal view with maxillary dentition. (C) Lingual view. The orthodontic fixed retainer remained.

examination revealed that the neighboring teeth were intact with no bleeding on probing, normal sulcular depths, and no mobility. An orthodontic fixed metal retainer was bonded to teeth #31, #32, and #41.

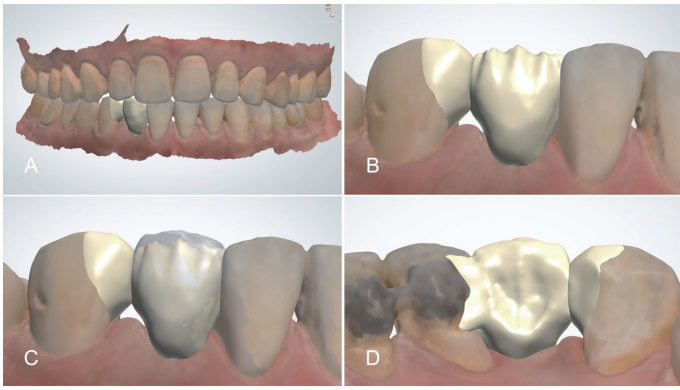
### 2.2. Laboratory preparation

After obtaining informed consent, digital impressions were captured using an intraoral scanner (iTero Elements, AZ, USA). Subsequently, CAD software (Dental Systems, 3Shape, Copenhagen, Denmark) was used to design the digital wax-ups for the inner and outer enamel layers (**Fig. 2**).

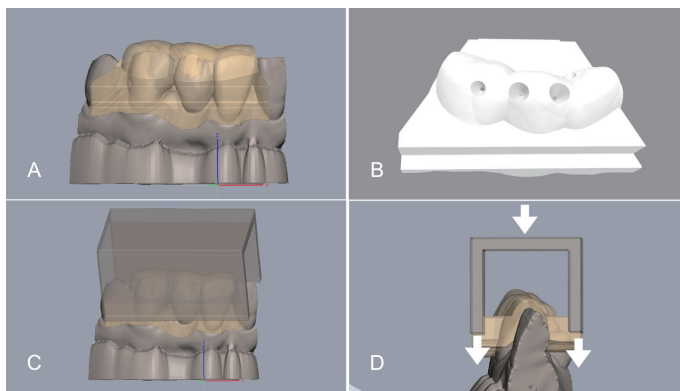
Considering the patient's 16-year interval since orthodontic treatment completion and the poor occlusal contact and guidance, a deliberate decision was made to design and restore the canine abutment tooth form simultaneously. This decision aimed to rectify inadequate contact and guidance and reduce the space available for designing the pontic, ultimately optimizing the patient's functional outcome.

The pontic was meticulously designed to be bonded to the neighboring mesial and distal teeth to mitigate the risk of complete debonding, providing a simplified design without reinforcing fibers. Subsequently, dentin and enamel 3D-printed indices were created as negative molds for wax-ups (**Fig. 3A**). These indices have several specialized features for optimizing the injection molding processes. They included three outwardly flaring incisal openings, each 0.5 mm in diameter at the interior and expanding outward at a 30-degree angle, to enable easy removal of the nob, ensure smooth composite resin flow, and prevent air entrapment. Buccolingual extensions were designed to prevent overflow at the mesial and distal connections and labial/lingual steps in the gingival area for stabilization holder integration, ensuring consistent pressure during index application (**Figs. 3B, C, and D**)[23].

Both the indices and stabilization holder were 3D-printed using a Cara Print 4.0 Pro 3D printer (Kulzer, Hanau, Germany), utilizing flexible (dima Print Soft Splint ink, Kulzer) and rigid (dima Print Splint clear, Kulzer) resins, respectively. After 3D printing, an ethanol-based separator (Washable SEP; Sun Medical Corp., Shiga, Japan) was applied to the inner surfaces of the indices and dried.



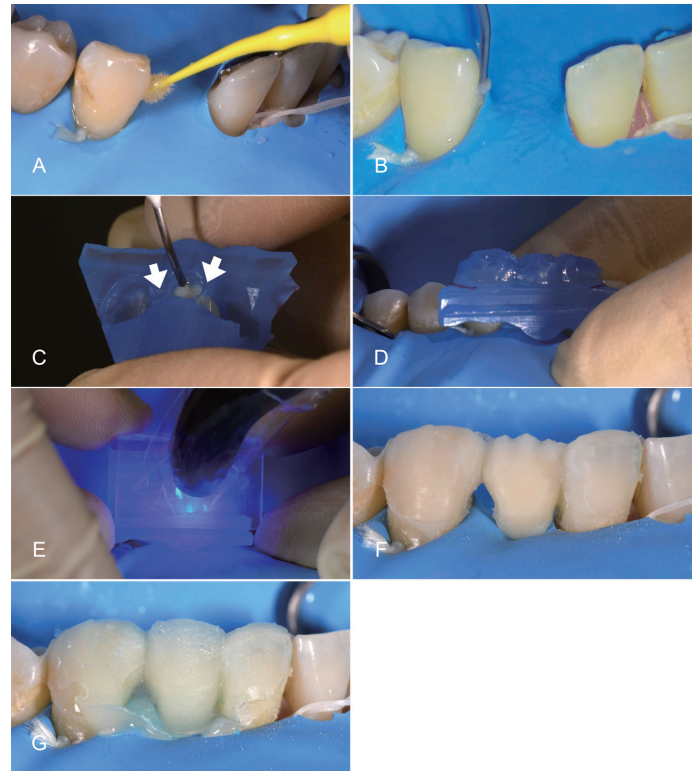
**Fig. 2.** Digital wax-up. (A) Frontal view of the digital final wax-up. (B) Digital wax-up of dentin. (C) Digital wax-up of enamel over dentin. (D) Lingual view of the wax-up.



**Fig. 3.** Digital wax-ups of index and stabilization holder. (A) Digital index design on the simulated final dental form (B) The cone-shaped openings in the index were designed. (C) Digital design of the stabilization holder. (D) The holder bucco-lingually stabilizes the index firmly in place. Simultaneously, manual pressure applied to the occlusal surface improves the adaptation of the index to the dentition (indicated by white arrows).

### 2.3. Restorative procedure

In the operative setting, the bonding surfaces of the adjacent teeth were prepared by acid etching with a 37% phosphoric acid gel (K-etchant Gel Syringe, Kuraray Noritake Dental Corp., Tokyo, Japan). A two-step self-etching adhesive system (Clearfil SE Bond 2, Kuraray Noritake Dental Corp.) was used (**Fig. 4A**). A small amount of flowable composite resin was placed on the bonding surfaces and light-cured (**Fig. 4B**). An opaque-shaded injectable composite resin (Estelite Universal Flow, OA1 shade, Tokuyama Dental Corp., Tokyo, Japan) was injected into the dentin index (**Fig. 4C**), stabilized using a custom-designed holder (**Fig. 4D**), and light-cured for 20 s (Pencure 2000, J. Morita Corp., Tokyo, Japan) (**Fig. 4E**). Following the removal of the index and holder, an additional 20-s light cure was performed (**Fig. 4F**). A translucent enamel-shaded flowable composite resin (Estelite Universal Flow, CE shade, Tokuyama Dental Corp.) was similarly injected into the enamel 3D-printed index and light-cured (**Fig. 4G**). The excess composite was removed, and a final 20-s light cure was conducted. The restoration was adjusted for proper occlusion and polished with shortened chair time (**Figs. 5A–C**).



**Fig. 4.** Operative procedures. (A) Application of adhesive to the enamel of adjacent teeth after phosphoric acid etching. (B) A small amount of flowable material was placed and polymerized on the connecting enamel surfaces of the adjacent teeth. (C) Injection of the flowable composite resin inside the remaining buccolingual extensions (white arrows). (D) Placing index in dentition. (E) Light curing is performed using a three-dimensional (3D)-printed index with a stabilization holder. (F) Polymerized dentin-shaded composite resin (G). The enamel shade composite resin is then polymerized.

### 2.4. Maintenance plan

A comprehensive maintenance plan is integral for the success of restorative and orthodontic treatments. This plan encompasses regular follow-up visits to monitor the treatment progress and ensure longevity. Personalized oral hygiene guidance, coupled with specific periodontal care instructions, is a crucial part of patient care. Additionally, we leverage advanced 3D-printing technology to promptly address any repair needs while maintaining the restoration's functionality and esthetics.

At the one-year follow-up, the patient showed excellent treatment outcomes, including maintenance of oral hygiene and complete satisfaction with the results (**Fig. 5D**). Strategic placement of fixed wires in the lower anterior teeth, which is essential for optimal dental alignment, has been carefully managed to positively contribute to restoration stability. Regular assessments during orthodontic follow-up ensured the continued success of our treatment approach.

## 3. Discussion

Restoring missing teeth, especially in the anterior region, requires a delicate balance between esthetics and functionality. Traditional prosthodontic restorations, such as dental implants and fixed partial dentures, often have limitations such as invasiveness,





**Fig. 5.** Post-operative views after the restoration. (A, B) Frontal views. (C) Lingual view. (D) Post-operative view after one year.

extended treatment duration, financial burden, and the need to alter existing teeth.

Recent advancements in prosthodontics have led to the development of zirconia cantilever resin-bonded fixed partial dentures (RBFPDs) and fiber-reinforced direct composite RBFPDs. Zirconia cantilever RBFPDs offer a conservative alternative by limiting enamel preparation to the palatal surfaces[25–28], excelling in esthetics, mechanical strength, and durability, but at a higher cost. In contrast, fiber-reinforced direct-composite RBFPDs present a more affordable option and require an exact application technique[5–7]. These variants, while cost-effective, slightly compromise esthetics and durability. Interestingly, both types avoid the need for lingual extension preparation in abutment teeth, which can interfere with tongue movement, indicating a potential role for nonreinforced direct composite RBFPDs in mandibular incisor replacement.

The digital revolution in dentistry, which encompasses CAD, digital impressions, and 3D-printing technologies, has significantly transformed the process of direct composite resin restorations. This enhances the accuracy and predictability of direct composite resin injection molding techniques[10]. Conventionally reliant on Manual placement of resin composites often results in inconsistent restoration forms. The integration of digital technologies with direct composite resin restoration techniques has created an opportunity to achieve ideal restoration morphology with a shortened chair time. This represents a seamless combination of direct and indirect restoration methods.

In this study, a dual-injection molding technique utilizing two distinct 3D-printed clear indices was employed. This approach replicates internal dental anatomical structures, such as dental mamelons, using an opaque composite resin, followed by an overlay of a translucent enamel-shaded composite for a bi-layered biomimetic restoration. The composite resin contained spherical silica zirconia nanoparticles and prepolymerized fillers comprising an organic polymerizable resin with a high load of silica-zirconia nanoparticles, potentially imparting resistance to external stresses and stability during water storage and thermocycling. However, it is important to note that this approach may have limitations in enhancing the longevity and durability of the restoration when compared to a direct composite RBFPD using a short-fiber reinforced flowable composite resin inside the dentinal structure[10].

We observed that the flexible 3D-printed indices, which are advantageous for accommodating dental undercuts, demonstrated slower shape recovery after deformation than conventional polyvinyl siloxane clear silicone materials. To overcome this problem and preserve the accuracy of the restoration, particularly in terms of marginal fit, we developed an intraorally approved rigid 3D-printed stabilization holder[23]. This holder horizontally stabilized the index, minimizing the deformation from the resin flexibility. The minimized flash observed in the first injection technique demonstrates this, although the second injection still resulted in some flashes, indicating room for improvement. Future developments in flexible 3D printable resins tailored for injection molding techniques could eliminate the need for such holders. Additionally, design features, such as buccolingual extensions and multiple flared openings, were incorporated to minimize resin overflow and attenuate the risk of gingival inflammation. Despite these advances, the occurrence of flash in flowable composites has been managed through meticulous finishing and polishing procedures.

Preliminary data suggest that the colored flexible 3D-printed resin exhibits light transmittance comparable to 50–60% of clear polyvinyl siloxane materials such as Exaclear (GC, Tokyo, Japan). These promising findings are yet to be clinically validated for broader applications.

Although a fully digital workflow significantly enhances the procedural precision of direct composite RBFPDs, the absence of reinforcing fibers is a notable limitation that affects fracture resistance[7,24]. These fibers improve their strength but are technique-sensitive and susceptible to long-term degradation[7,8,29]. This challenge could be partially addressed through “Super Enamel formation,” a mechanically and chemically reinforced enamel bonding interface[12,30,31]. Despite their growing popularity, directly placed composite resin materials are generally less rigid and more prone to wear than ceramic alternatives, emphasizing the clinical importance of case selection. Future research could explore the potential of nondestructive detection sensors to monitor the structural integrity of these direct composite RBFPDs, contributing to the emerging field of smart dentistry and enhancing long-term maintenance and prognosis.

## 4. Conclusions

In conclusion, the dual-composite resin injection molding technique, augmented by a comprehensive digital workflow and 3D-printed indices, presents a minimally invasive and precise solution for restoring a congenitally missing mandibular anterior tooth. The method, promising in its initial esthetic and functional results, requires future research to validate its long-term efficacy and broad applicability. This study contributes to the ongoing exploration of innovative and patient-centered restorative solutions.

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## Conflict of interest

The authors declare no financial interest in any of the companies or products mentioned in this article.

## References

- [1] Naoum S, Allan Z, Yeap CK, Razza JM, Murray K, Turlach B, *et al.* Trends in orthodontic management strategies for patients with congenitally missing lateral incisors and premolars. *Angle Orthod.* 2021;91:477–83. <https://doi.org/10.2319/092320-809.1>, PMID:33657211
- [2] Kokich VO, Jr., Kinzer GA, Janakievski J. Congenitally missing maxillary lateral incisors: restorative replacement. *Counterpoint. Am J Orthod Dentofacial Orthop* 2011;139:435, 7, 9 *passim*. <https://doi.org/10.1016/j.ajodo.2011.02.004>
- [3] Mourshed B, Samran A, Alfagih A, Samran A, Abdulrab S, Kern M. Anterior cantilever resin-bonded fixed dental prostheses: A review of the literature. *J Prosthodont.* 2018;27:266–75. <https://doi.org/10.1111/jopr.12555>, PMID:29522288
- [4] Tezulas E, Yildiz C, Evren B, Ozkan Y. Clinical procedures, designs, and survival rates of all-ceramic resin-bonded fixed dental prostheses in the anterior region: A systematic review. *J Esthet Restor Dent.* 2018;30:307–18. <https://doi.org/10.1111/jerd.12389>, PMID:30113136
- [5] Wolff D, Wohlrab T, Saure D, Krisam J, Frese C. Fiber-reinforced composite fixed dental prostheses: A 4-year prospective clinical trial evaluating survival, quality, and effects on surrounding periodontal tissues. *J Prosthet Dent.* 2018;119:47–52. <https://doi.org/10.1016/j.prosdent.2017.02.008>, PMID:28506655
- [6] Frese C, Schiller P, Staehle HJ, Wolff D. Fiber-reinforced composite fixed dental prostheses in the anterior area: A 4.5-year follow-up. *J Prosthet Dent.* 2014;112:143–9. <https://doi.org/10.1016/j.prosdent.2013.10.019>, PMID:24529838
- [7] Perrin P, Meyer-Lueckel H, Wierichs RJ. Longevity of immediate rehabilitation with direct fiber reinforced composite fixed partial dentures after up to 9 years. *J Dent.* 2020;100:103438. <https://doi.org/10.1016/j.jdent.2020.103438>, PMID:32736081
- [8] Wierichs RJ, Weilenmann W, Jeganathan S, Perrin P. Longevity of immediate rehabilitation with direct metal-wire reinforced composite fixed partial dentures. *Dent Mater.* 2022;38:e257–65. <https://doi.org/10.1016/j.dental.2022.06.008>, PMID:35718596
- [9] Staehle HJ. A new restorative method for the closure of single-tooth gaps - technique description and case series. *J Adhes Dent.* 2019;21:239–45. <https://doi.org/10.3290/j.jad.a42522>, PMID:31093621
- [10] Hosaka K, Tichy A, Hasegawa Y, Motoyama Y, Kanazawa M, Tagami J, *et al.* Replacing mandibular central incisors with a direct resin-bonded fixed dental prosthesis by using a bilayering composite resin injection technique with a digital workflow: A dental technique. *J Prosthet Dent.* 2021;126:150–4. <https://doi.org/10.1016/j.prosdent.2020.05.007>, PMID:32800576
- [11] Hosaka K, Tashiro H, Takahashi M, Kishikawa R, Nakajima M, Otsuki M, *et al.* The simplified posterior direct flowable composite bridge restoration without reinforcing fibers: A case report. *Jpn J Conserv Dent.* 2019;62:47–53. <https://doi.org/10.11471/shikahozon.62.47>
- [12] Nikaido T, Takagaki T, Sato T, Burrow MF, Tagami J. The concept of super enamel formation—relationship between chemical interaction and enamel acid-base resistant zone at the self-etch adhesive/enamel interface. *Dent Mater J.* 2020;39:534–8. <https://doi.org/10.4012/dmj.2020-165>, PMID:32624553
- [13] Terry DA, Powers JM, Mehta D, Babu V. A predictable resin composite injection technique, part 2. *Dent Today.* 2014;33:12. PMID:25174193
- [14] Terry DA, Powers JM. A predictable resin composite injection technique, Part I. *Dent Today.* 2014;33:96, 98–101. PMID:24791292
- [15] Terry DA. *Restoring with flowables*. 1st ed. Michigan: Quintessence Publishing Co; 2017.
- [16] Geštakovski D. The injectable composite resin technique: biocopy of a natural tooth - advantages of digital planning. *Int J Esthet Dent.* 2021;16:280–99. PMID:34319664
- [17] Ammannato R, Rondoni D, Ferraris F. Update on the 'index technique' in worn dentition: a no-prep restorative approach with a digital workflow. *Int J Esthet Dent.* 2018;13:516–37. PMID:30302440
- [18] Revilla-León M, Besné-Torre A, Sánchez-Rubio JL, Fábrega JJ, Özcan M. Digital tools and 3D printing technologies integrated into the workflow of restorative treatment: A clinical report. *J Prosthet Dent.* 2019;121:3–8. <https://doi.org/10.1016/j.prosdent.2018.02.020>, PMID:30093121
- [19] Coachman C, De Arbeloa L, Mahn G, Sulaiman TA, Mahn E. An improved direct injection technique with flowable composites. A digital workflow case report. *Oper Dent.* 2020;45:235–42. <https://doi.org/10.2341/18-151-T>, PMID:32101498
- [20] Hosaka K, Tichy A, Motoyama Y, Mizutani K, Lai WJ, Kanno Z, *et al.* Post-orthodontic recontouring of anterior teeth using composite injection technique with a digital workflow. *J Esthet Restor Dent.* 2020;32:638–44. <https://doi.org/10.1111/jerd.12619>, PMID:32603555
- [21] Hosaka K, Tichy A, Yamauti M, Watanabe K, Kamoi K, Yonekura K, *et al.* Digitally guided direct composite injection technique with a bi-layered clear mini-index for the management of extensive occlusal caries in a pediatric patient: a case report. *J Adhes Dent.* 2023;25:211–8. <https://doi.org/10.3290/j.jad.b4515527>, PMID:37843503
- [22] Zhang Y, Zhang J, Fan L, Yu H. Closing post-orthodontic spaces between anterior teeth using sequential 3D-printed direct composite injection guides. *Oper Dent.* 2022;47:612–9. <https://doi.org/10.2341/21-183-T>, PMID:36279322
- [23] Watanabe K, Tichy A, Kamoi K, Hiasa M, Yonekura K, Tanaka E, *et al.* Restoration of a microdont using the resin composite injection technique with a fully digital workflow: A flexible 3D-printed index with a stabilization holder. *Oper Dent.* 2023;48:483–9. <https://doi.org/10.2341/23-007>, PMID:37503684
- [24] Chen J, Cai H, Suo L, Xue Y, Wang J, Wan Q. A systematic review of the survival and complication rates of inlay-retained fixed dental prostheses. *J Dent.* 2017;59:2–10. <https://doi.org/10.1016/j.jdent.2017.02.006>, PMID:28212978
- [25] Sasse M, Eschbach S, Kern M. Randomized clinical trial on single retainer all-ceramic resin-bonded fixed partial dentures: influence of the bonding system after up to 55 months. *J Dent.* 2012;40:783–6. <https://doi.org/10.1016/j.jdent.2012.05.009>, PMID:22659339
- [26] Rosentritt M, Kolbeck C, Ries S, Gross M, Behr M, Handel G. Zirconia resin-bonded fixed partial dentures in the anterior maxilla. *Quintessence Int.* 2008;39:313–9. PMID:19081900
- [27] Rosentritt M, Ries S, Kolbeck C, Westphal M, Richter EJ, Handel G. Fracture characteristics of anterior resin-bonded zirconia-fixed partial dentures. *Clin Oral Investig.* 2009;13:453–7. <https://doi.org/10.1007/s00784-009-0254-8>, PMID:19221810
- [28] Al-Wahadni A, Dkmak MSF, Almohammed S, Hatamleh MM, Tabanjah A. Fracture strength of anterior cantilever resin-bonded fixed partial dentures fabricated from high translucency zirconia with different intaglio surface treatments. *J Prosthodont; Online ahead of print.* 2023. <https://doi.org/10.1111/jopr.13694>, PMID:37114526
- [29] Komada W, Inagaki T, Ueda Y, Omori S, Hosaka K, Tagami J, *et al.* Influence of water immersion on the mechanical properties of fiber posts. *J Prosthodont Res.* 2017;61:73–80. <https://doi.org/10.1016/j.jpor.2016.05.005>, PMID:27324293
- [30] Sato K, Hosaka K, Takahashi M, Ikeda M, Tian F, Komada W, *et al.* Dentin bonding durability of two-step self-etch adhesives with improved degree of conversion of adhesive resins. *J Adhes Dent.* 2017;19:31–7. <https://doi.org/10.3290/j.jad.a37726>, PMID:28195277
- [31] Hosaka K, Tichy A, Ikeda M, Nakagawa K, Sadr A, Tagami J, *et al.* Ultra-high-speed videography of resin-dentin interface failure dynamics under tensile load. *Dent Mater.* 2019;35:e153–61. <https://doi.org/10.1016/j.dental.2019.04.006>, PMID:31078308



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