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CASE REPORT

Removable space maintainers fabricated using a CAD-CAM system for tooth loss: two pediatric case reports

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Abstract

Background: In pediatric dentistry, multiple dental caries, trauma, and congenital anomalies often necessitate prosthetic rehabilitation. A removable space maintainer (RSM) is the only device capable of providing both proximal and vertical retention, serving as an effective prosthetic and functional solution. Advances in digital technology have established computer-aided design/computer-aided manufacturing (CAD-CAM) systems as reliable tools in pediatric dental treatment; however, their application in the fabrication of RSMs and pediatric dentures remains limited. **Cases**: We describe the cases of two pediatric patients in which RSMs were fabricated using subtractive manufacturing via a CAD-CAM system. The first patient was a boy with partial edentulous mandibular anterior teeth, whereas the other patient was a girl with a missing maxillary right lateral central incisor due to trauma. In both patients, the RSMs were successfully placed without requiring intraoral adjustments, and an excellent fit was achieved. **Conclusions**: The use of subtractive manufacturing for RSM fabrication offers several advantages, including clinical fit, efficiency, visualization, and esthetics. Nonetheless, further technical refinements are required to enhance fit accuracy.

Keywords

Children; CAD-CAM; Removable space maintainer

1. Introduction

In pediatric dentistry, prosthetic treatment is often required for multiple missing teeth resulting from severe dental caries, trauma, or congenital tooth agenesis. The premature loss of primary teeth may lead to various complications, such as tilting or drifting of adjacent teeth, loss of eruption space for permanent successors, overeruption of opposing teeth, disturbances in mastication and speech, esthetic problems, and malocclusion. Removable space maintainers (RSMs) are the only devices capable of preserving both mesiodistal and vertical dimensions, thereby serving as effective prosthetic and functional solutions.

Conventional methods for fabricating RSMs have long relied on the technical skill of the operator, often resulting in variability in the accuracy and amount of adjustment required, thereby raising concerns regarding human error. In addition, limitations in dimensional accuracy due to changes during impression taking and stone pouring, as well as the complexity of the fabrication process, have been identified as key challenges. Although conventional methods involving the brush-dip technique are prone to air bubble entrapment and material inhomogeneity, the fabrication of RSMs using CAD-CAM technology can overcome these issues by ensuring consistent material properties. With recent advancements in digital technologies, such as computer-aided design/manufacturing (CAD-CAM) systems, increasingly reliable dental treatments have been introduced across multiple fields. Although the use of digital technology in pediatric dentistry has been reported for the fabrication of crowns and fixed space maintainers [1–6], its application to RSM [7] and pediatric dentures [8] remains limited.

In this report, we evaluated the accuracy and reproducibility of RSMs fabricated using CAD-CAM technology with a view towards clinical application, and examined a streamlined fabrication process aimed at simplifying the workflow. The clinical significance of this report lies in evaluating, through an actual clinical case, the feasibility of intraoral placement, fit, and comfort of an RSM fabricated using a CAD-CAM system, thereby demonstrating its potential and usefulness for clinical application. The accuracy of digitally designed RSM was examined in a previous study. Herein, we present clinical cases of two pediatric patients in which RSMs were fabricated by subtractive manufacturing using a CAD-CAM system and subsequently applied. The first patient was a boy with partial anodontia in the anterior mandibular region. Meanwhile, the second patient was a girl who had lost a primary maxillary central incisor due to trauma. In both cases, the chief complaints were related to the esthetics, speech, and psychosocial concerns due to anterior tooth loss. Written informed consent was obtained from the patients' guardians.

2. Case report

2.1 Patient 1

Patient: Male, 4 years and 11 months.

Chief complaint: Request for denture fabrication.

Medical history: Tooth number abnormalities were identified during health checkups at 1.5 and 3 years of age. The patient was referred for the fabrication of an RSM.

Patient's medical condition: No notable findings.

Clinical findings: Intraoral examination revealed the dental formula "EDCA┴ACDE" and "EDC┬CDE", indicating partial anodontia involving the bilateral mandibular lateral incisors and maxillary right central and lateral incisors (Fig. 1).

Radiographic examination confirmed the congenital absence of teeth #52, #62, #71, #72, #81, and #82 along with the lack of successive permanent teeth (#12, #21, #31, #32, #41, and #42). Additionally, the possible absence of other permanent teeth (#15, #17, #25, #27, #35, and #45) was indicated (Fig. 2).

Treatment: The RSM was fabricated following conventional impression-taking and bite registration procedures. After impressions were recorded, a dental stone (NEW PLASTONE II, GC) was poured into the impressions to create a working model. The undercut area of the model was blocked and coated with a resin separator (NEW ACROSEP, GC). The autopolymerizing resin (Metafast #2, Sunmedical CO, Siga, Japan) was then applied using the brush-dip technique. After the autopolymerizing resin was built up, the RSM was immersed in water for 1 h. Final morphological adjustments and polishing were subsequently performed (Fig. 3).

Simultaneously, the working model was scanned using a laboratory scanner (D2000, 3Shape, Copenhagen, Denmark), and a digital design was performed using CAD software (S-WAVE, ver. 2019, 3Shape A/S, Copenhagen, Denmark). The design process involved determining the insertion path, adjusting undercuts, arranging the dentition, and shaping the polished surface (Fig. 4). The resulting standard tessellation language (STL) data were transferred to CAM software (Go2Dental, V6, Go2cam, Lyon, France), where support positions and disk placement were configured. Milling was carried out using a five-axis milling machine (Roland DWX-50, DGSHAPE, Shizuoka, Japan) and poly (methyl methacrylate) (PMMA) resin disks (M-PM-Disc, Shofu, Kyoto, Japan). Two types of RSMs were fabricated from the A1-colored and transparent PMMA disks (Fig. 5).

Outcome: The milled RSM was inserted without the need for adjustment and demonstrated a good intraoral fit. The patient reported a slightly looser fit compared with the conventional RSM. The transparent RSM allowed for visualization of the underlying mucosa during pressure application but was aesthetically inferior to the single-color RSM (Fig. 6). After intraoral insertion of the RSMs fabricated by both conventional and CAD-CAM techniques, a follow-up examination was conducted on day 7. No abnormal findings, such as mucosal erythema, were noted. The patient and guardian were instructed to alternate between the two devices, and a subsequent evaluation was performed one month later. No mucosal abnormalities were noted at that time, and the patient was able to independently insert and remove the devices. Due to esthetic concerns, the conventional RSM was used more frequently, while the CAD-CAM-fabricated RSM was used only at home. A follow-up examination at 3 months post-insertion also revealed no mucosal abnormalities (Fig. 7). By around 4 months, the patient discontinued the use of the CAD-CAM-fabricated RSM and opted for continued use of the conventional RSM. The reason for this preference was the superior esthetics of the conventionally fabricated device. Subsequently, the patient continued to use the conventional

FIGURE 1. Intraoral photograph at the initial visit. Dental formula: "EDCA┴ACDE" and "EDC┬CDE"; Missing teeth: B┴B and BA┬AB.

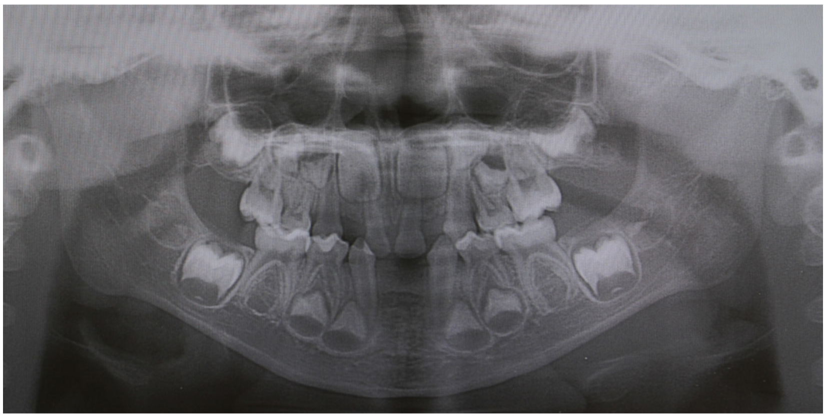

FIGURE 2. Panoramic radiograph taken at the initial visit.

FIGURE 3. Intraoral photograph of the RSM fabricated using the brush-dip technique. Missing teeth: BA┬AB.

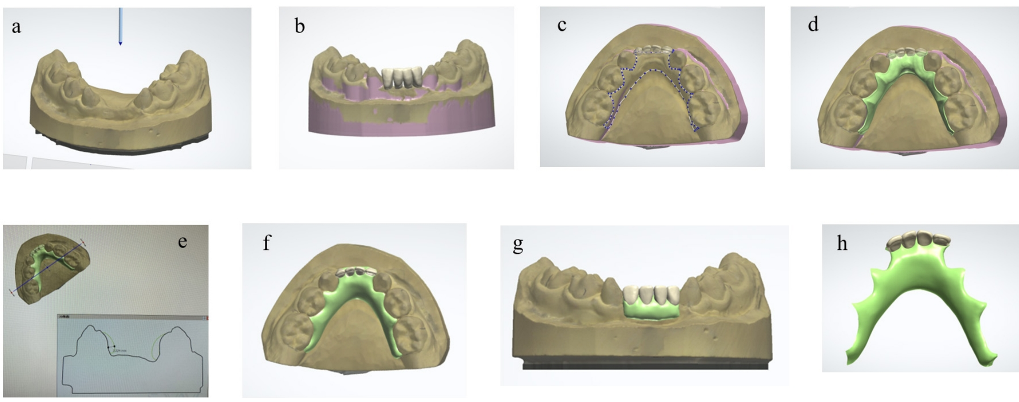

FIGURE 4. RSM design using computer-aided design software. (a) Attachment and removal direction determination. (b) Artificial tooth arrangement. (c) RSM outline configuration. (d) A 0.2-mm wax-up applied to the outline. (e) Confirmation of thickness. (f–h) Completed RSM design.

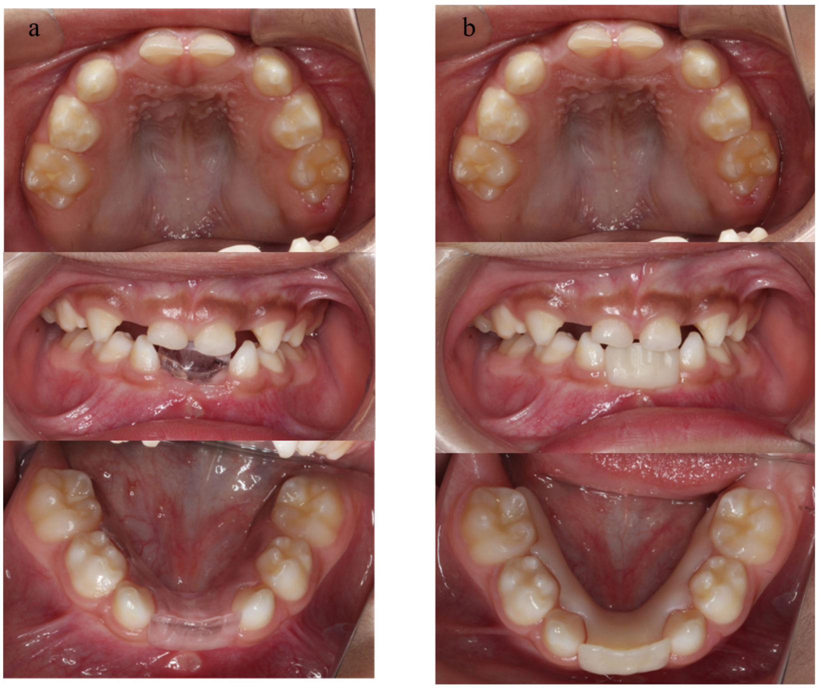

FIGURE 5. Intraoral photograph of the RSM fabricated using the CAD-CAM system. (a) RSM fabricated from a transparent disk. (b) RSM fabricated from an A1-colored disk.

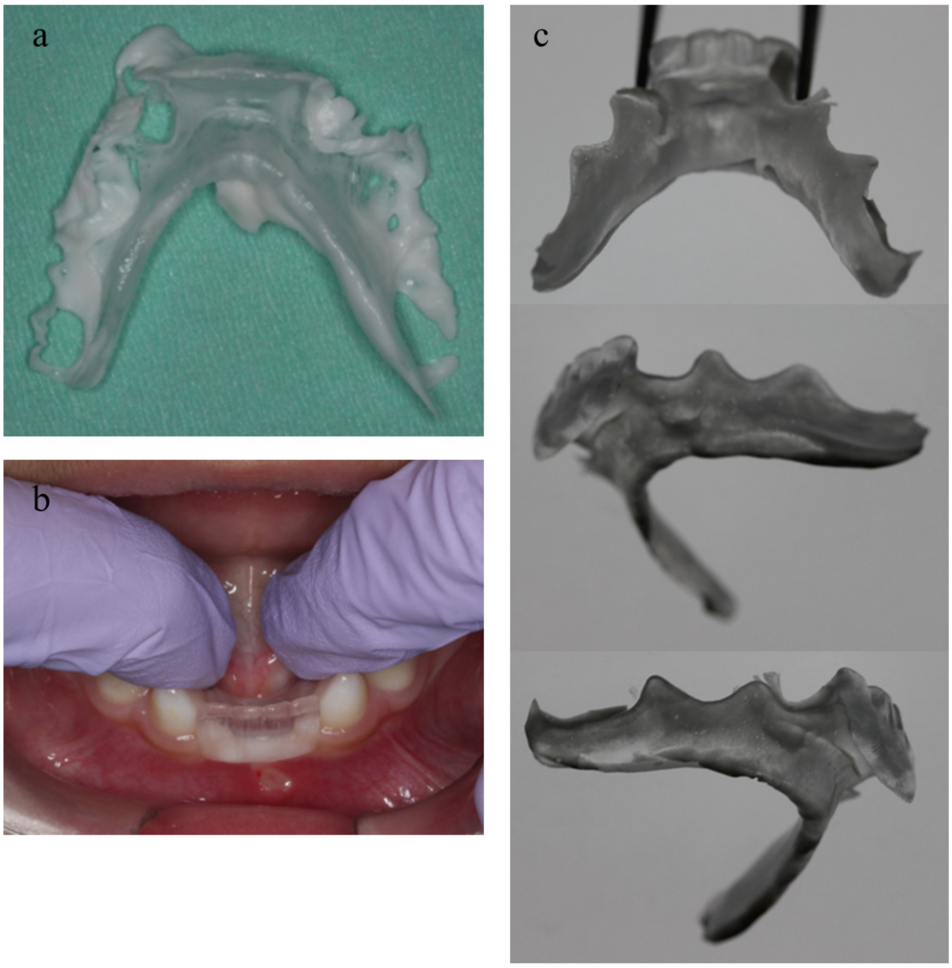

FIGURE 6. RSM fitting verification. (a) Fit assessment using fit test materials (FIT CHECKER; GC, Tokyo, Japan). (b) Fitting evaluation under finger pressure. (c) Permeability assessment of fit test materials.

FIGURE 7. Intraoral photograph taken 3 months after RSM placement.

RSM for 2 years and 8 months. After losing the device, a new RSM with a retentive component was fabricated using the conventional technique (Fig. 8). During use, the patient reported looseness of the RSM due to jaw growth, and relining was performed accordingly.

2.2 Patient 2

Patient: Female, 3 years and 11 months.

Chief complaint: Request for denture fabrication.

Medical history: The patient experienced dental trauma at 1.5 years of age, resulting in a crown-root fracture of tooth #51, which was subsequently extracted at a local dental clinic. Regular follow-up was maintained, and the patient was later referred for RSM fabrication.

Clinical findings: Intraoral examination revealed a dental formula of "EDCB┴ABCDE" and "EDCBA┬ABCDE", with the absence of tooth #51 and the presence of fused teeth (#82 and #83) (Fig. 9).

Treatment: Owing to limited patient cooperation, multiple behavior management visits were required prior to RSM placement at the age of 4 years and 8 months. Initially, an RSM fabricated using the brush-dip technique was fitted, following the same procedure described in patient 1 (Fig. 10).

Subsequently, an RSM fabricated using a CAD-CAM system was attached. The working and opposing models and occlusal records were digitized using a laboratory scanner, and the design process followed the same protocol as in patient 1 (Fig. 11). To improve esthetics, the prosthesis was designed with distinct color tones for the artificial teeth and denture base. A male-female interface was shaped at the junction between the two components. Artificial teeth (A1-colored) and the transparent denture base were milled separately from different PMMA disks and bonded using a self-curing resin (UNIFAST III; GC, Tokyo, Japan) (Fig. 12).

Outcome: The CAD-CAM-fabricated RSM was successfully worn without the need for adjustment and exhibited a good intraoral fit (Fig. 13). The RSMs fabricated using CAD-CAM technology required no adjustments and demonstrated significantly shorter chairside time for placement. Compared with conventional methods, they exhibited superior efficiency during the insertion procedure. No discernible difference in fit was observed compared with the conventionally fabricated RSM. The transparent base allowed visualization of mucosal pressure during wear, and the use of contrasting color tones contributed to improved esthetic appearance. A follow-up examination was conducted on day 8 after the intraoral insertion of the RSMs fabricated using both conventional and CAD-CAM techniques. No abnormal findings, such as mucosal erythema, were observed. The patient and guardian were instructed to alternate between the two devices, and a reevaluation was conducted 1 month later. No mucosal abnormalities were observed, and the patient was able to independently insert and remove the devices. Furthermore, a follow-up examination performed 3 months after insertion revealed no mucosal abnormalities (Fig. 14). By approximately 6 months post-insertion, the patient had discontinued the use of the CAD-CAM-fabricated RSM and opted to use the conventionally fabricated RSM. The reason cited for this choice was the superior retention and stability provided by the conventional RSM. Owing to maxillary growth, the retention and stability of the CAD-CAM-fabricated RSM had presumably decreased compared with that of the conventional RSM. Thereafter, the patient continued to use the conventional RSM for 1 year and 10 months. During this period, repairs were required due to incidents, such as fracture of the artificial teeth. As the eruption of the succedaneous permanent tooth approached, use of the RSM was discontinued (Fig. 15).

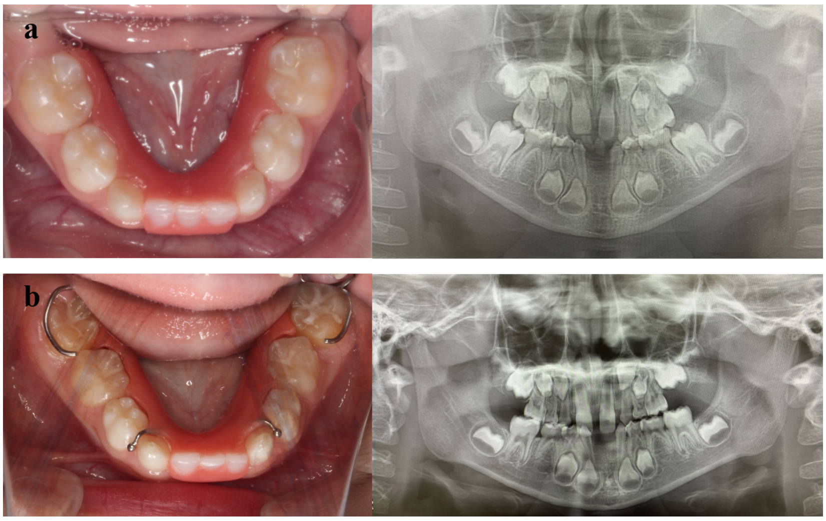

FIGURE 8. Follow-up panoramic radiographs. (a) Intraoral photograph and panoramic radiograph at 7 years and 1 month of age. (b) Intraoral photograph and panoramic radiograph at 8 years and 1 month of age.

FIGURE 9. Intraoral photograph and radiograph at the initial visit.

FIGURE 10. Intraoral photograph of the RSM fabricated using the brush-dip technique.

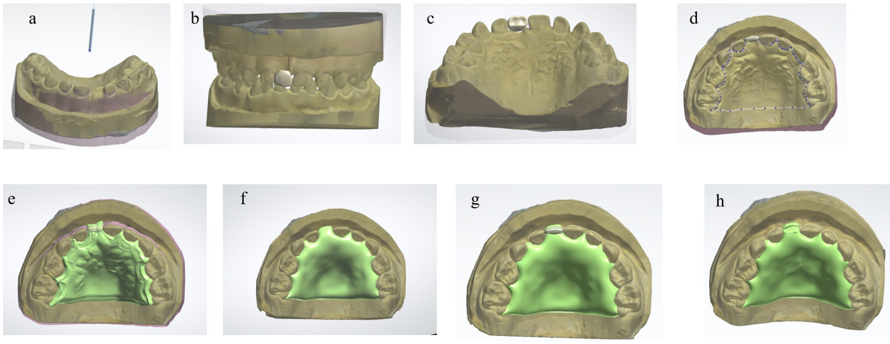

FIGURE 11. RSM design using computer-aided design software. (a) Attachment and removal direction determination. (b,c) Artificial tooth arrangement. (d) Outline configuration of the RSM. (e) A 0.2-mm wax-up applied to the outline. (f) Final design of the denture base. (g) Completed RSM design. (h) Final design of the denture plate incorporating the female component.

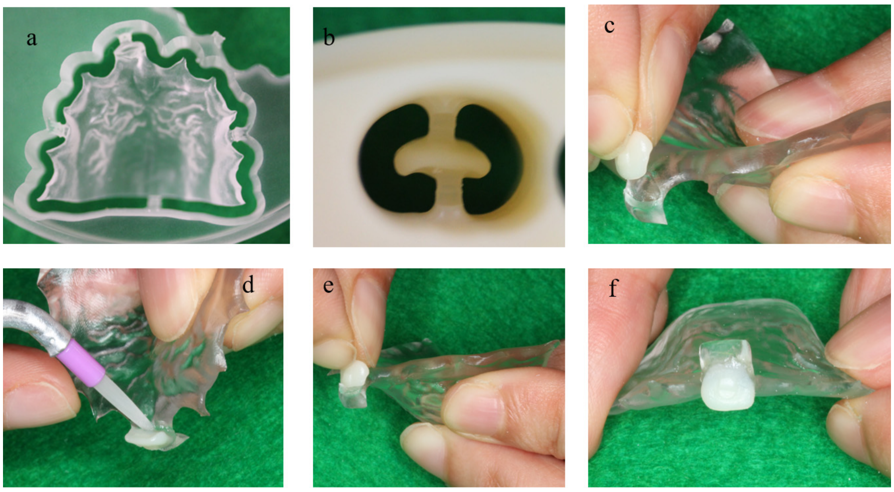

FIGURE 12. Bonding of artificial teeth to the denture plate. (a) Denture plate fabrication via subtractive manufacturing. (b) Artificial teeth fabrication via subtractive manufacturing. (c) Fit confirmation of the artificial teeth and denture plate. (d) Application of self-curing resin (UNIFAST III, GC, Tokyo, Japan) to the denture base. (e) Bonding of the denture plate and artificial teeth. (f) Final bonded denture assembly.

FIGURE 13. Intraoral photograph of the RSM fabricated using the CAD-CAM system.

FIGURE 14. Intraoral photograph and radiograph taken 3 months after RSM placement.

FIGURE 15. Dental radiograph 1 year and 10 months after RSM placement.

3. Discussion

In the present study, RSMs fabricated using both the conventional brush-dip technique and CAD-CAM milling technology were applied in two pediatric patients. Clinical fit, esthetics, procedural efficiency, and patient comfort were evaluated.

The CAD-CAM-fabricated RSMs were successfully inserted intraorally without the need for adjustment, demonstrating an excellent clinical fit. This favorable outcome may be attributed to the high reproducibility achieved through digital impression-making and design, highlighting the clinical potential of digital workflows in pediatric prosthodontics. However, in patient 1, the patient reported a slightly looser fit. This reduction in retentive force is thought to result from greater relief of undercut areas during the digital design process compared with the conventional method. The conventional brush-dip technique allows for manual adaptation to individual oral morphologies, enabling minimal relief and the strategic use of undercuts—particularly on the lingual side. By contrast, in digital designs, undercuts are determined based on the attachment and detachment direction, and relief is typically provided, including in the lingual undercut areas. Lingual undercuts play an important role in ensuring the retention and stability of RSMs, particularly in primary dentition where clinical crowns are short. Future design protocols should incorporate optimized retentive components, refined undercut settings in CAD-CAM-based RSM design, and occlusal pressure simulation. In addition, it is necessary to consider the incorporation of retentive components, such as clasps, to improve retention and stability.

Unlike patient 1, patient 2 presented with a maxillary case. Accordingly, the direction of insertion and removal was adjusted to minimize the undercut relief on the palatal side, with consideration given to palatal retention—an approach believed to have enhanced the overall retention of the appliance. To improve esthetics, artificial teeth were fabricated from white (A1-colored) resin, whereas the denture base was constructed from transparent resin. Using different colors for the artificial teeth and denture base enhanced aesthetic outcomes and resulted in esthetic satisfaction from the patient and guardian.

This result demonstrates the design flexibility afforded by CAD-CAM technology, which enables the milling of individual components from different materials followed by subsequent bonding. However, challenges such as lifting at the bonded interface, insufficient adhesive strength, and discoloration at the junction between the artificial teeth and denture base have been noted. Future studies should evaluate the physical properties of these bonded areas and examine their long-term stability. In addition, the use of a transparent PMMA disk for the denture base allows for direct visualization of mucosal pressure and potential blanching during wear, facilitating a more objective assessment of RSM fit—an advantage not offered by conventional fabrication methods.

Although the PMMA disks used exhibit excellent mechanical strength, workability, and esthetic properties, long-term evaluation of wear, discoloration, and fracture risk remains necessary. Particular attention should be given to durability and reparability, especially in growing children with increasing occlusal forces. Biocompatibility and the potential for allergic reactions must also be verified through further clinical case studies.

In these patients, an intraoral scanner was not used; however, a working model produced through conventional methods was scanned using a laboratory scanner and digitized. In recent years, direct impression-taking using an intraoral scanner has been suggested to reduce patient burden [9–11]. Panwar *et al*. [9] reported that intraoral scanners can simplify both clinical and laboratory workflows while improving accuracy. This improvement is attributed to the elimination of common errors associated with conventional methods, such as material shrinkage, distortion of impression materials, and expansion of plaster casts. In addition, studies by Patel and Mahima *et al*. [9, 11] have demonstrated that the accuracy of intraoral scanners is comparable to, or greater than, that of traditional alginate impressions. Furthermore, the use of intraoral scanners is expected to minimize discomfort, gag reflex, and the risk of foreign body aspiration in pediatric patients, thereby enhancing procedural safety [12, 13]. Therefore, the incorporation of digital technology during the impression-taking phase of RSM fabrication represents a critical advancement to be addressed in future clinical practice.

Compared with the brush-dip technique, the subtractive manufacturing of RSMs offers significantly higher accuracy in reproducing predesigned forms. The ability to insert the prosthesis intraorally without requiring adjustments is considered a significant clinical advantage. This feature is particularly beneficial for pediatric patients with limited cooperation, as it may reduce chair time and the risk of remanufacturing [14].

Moreover, subtractive manufacturing provides additional advantages over conventional methods. Once a digital design has been created, remanufacturing or modifications can be performed efficiently using the same design data. With the establishment of streamlined workflows for scanning, designing, and milling, the standardization of RSM fabrication becomes feasible. This standardization enables the outsourcing or remote production of prosthetic devices, thereby increasing the efficiency of prosthetic treatment in pediatric dentistry.

In conventional RSM fabrication, multiple procedures are required following impression-making, including plaster injection, model trimming, and articulator mounting. With the implementation of a fully digital workflow, digital design can be initiated immediately after the impressions are obtained. Furthermore, the need to wait for resin build-up or polymerization of autopolymerizing resin is eliminated. As CAD-CAM technology produces an RSM that closely approximates the final form, the time required for morphological adjustments and polishing is significantly reduced. Although the initial introduction of a CAD-CAM system entails a financial investment, it is considered cost-effective over time due to reduced fabrication time and enhanced precision. Additionally, the automation of design and milling processes reduces the manual workload. However, standardized protocols for RSM design have yet to be established. The establishment of universally applicable design guidelines that enable consistent and appropriate fabrication remains an important goal for future research.

Positive responses were received from both pediatric patients and their guardians regarding the transparent floor and color-coordinated RSMs. Particularly, the transparent denture plate, which blended harmoniously with the oral mucosa, was subjectively perceived as less uncomfortable during wearing. In pediatric dentistry, such aesthetic considerations are important for improving the acceptability and compliance of prosthetic device use.

In growing children, changes in dentition and jaw development are inevitable, often necessitating prosthesis remaking and repair [15–17]. In the present milled RSMs, the transparency of the denture plate facilitated clinical observation and allowed for effective monitoring of oral growth. The ability to remanufacture identical designs, when necessary, supports their utility as part of a prosthetic strategy oriented toward long-term management. However, challenges arise during repair procedures, particularly with the Adam's clasps and the bonding of the denture plate to these clasps using self-curing resin.

In summary, the fabrication of RSMs using subtractive manufacturing offers numerous advantages in terms of clinical fit, work efficiency, visibility, and aesthetics. However, technical improvements are required to further enhance fit accuracy. In addition, the standardization of CAD-CAM-based design and fabrication is expected to facilitate the delivery of more precise, high-quality prosthetic devices tailored to the individual needs of pediatric patients.

Currently, a certain level of proficiency is required to operate and design using CAD-CAM systems, and the standardization of technical training for both clinical and laboratory personnel remain a critical issue. Furthermore, the accumulation of clinical evidence—particularly regarding occlusal pressure distribution, dynamic adaptation, and long-term follow-up outcomes—is essential to support widespread adoption. Future developments in artificial intelligence-assisted automatic design and advancements in material technology are expected to enable the development of more personalized, highly aesthetic, and functional prosthetic devices.

This report presents the intraoral applicability, fit, and comfort of RSMs fabricated using a CAD-CAM system in actual clinical cases over a short-term period. Therefore, the absence of data regarding the long-term utility of RSMs, time-dependent changes, material degradation, and adaptation to changes in the intraoral environment is an inherent limitation of this report.

4. Conclusions

The use of subtractive manufacturing for RSM fabrication offers several advantages, including clinical fit, efficiency, visualization, and esthetics. However, further technological improvements are needed to improve clinical accuracy in order to achieve a fit and retention comparable to conventional methods.

AVAILABILITY OF DATA AND MATERIALS

The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

KK, KW and YT—designed the research study. KK and YN—performed the research. YT, YN and YY—provided technical support and advice technical guidance. KK and KW—project implementation. KK, KW and TI—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethical approval was obtained from the institutional research ethics committee of the Institute of Science Tokyo (D2022-037). Consent for publication was obtained from the patient's legal guardian, with assent from the patient. The case reports adhere to the ethical standards of the aforementioned institution, as well as the principles of Declaration of Helsinki.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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