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RESEARCH

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Conventional vs. 3D printed band and loop space maintainers: a fracture strength analysis

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Abstract

Premature loss of primary teeth is a common occurrence in pediatric dentistry and often necessitates the use of space maintainers to prevent complications. Traditional space maintainers, such as band and loop space maintainers (BLSM), have been widely used, but are fabricated using conventional methods. With advancements in technology, three-dimensional (3D) printing has emerged as a promising alternative for fabricating dental appliances including space maintainers. This study aimed to evaluate and compare the fracture strengths of conventional band and loop space maintainers (C-BLSMs) fabricated using stainless steel with that of 3D printed BLSMs manufactured using additive manufacturing techniques. Fifteen C-BLSM and fifteen 3D printed BLSMs were fabricated and subjected to fracture-strength testing using a universal testing machine. The maximum occlusal bite force in the mixed dentition was determined based on established literature. Statistical analysis was performed to compare the mean fracture resistance between the two groups. The mean fracture resistance of the 3D printed BLSMs was significantly higher (308.53 N) than that of C-BLSMs (130.85 N). This difference was statistically significant ($p < 0.05$), highlighting the superior mechanical properties of 3D printed BLSMs. Three-dimensional printing technology offers significant advantages in terms of fracture strength compared with conventional fabrication methods for BLSMs.

Keywords Premature tooth loss, Space maintainers, Band and loop space maintainer, Three-dimensional printing, Fracture strength, Dentistry

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Introduction

Premature loss of primary teeth is a prevalent and significant issue in pediatric dentistry affecting numerous children worldwide. This condition can arise from a variety of causes including dental caries (tooth decay), trauma, or congenital absence of teeth. Each of these factors can contribute to the early loss of primary teeth, which serves as a critical concern due to the essential roles these teeth play in a child's oral development.

Dental caries, a common culprit, is one of the most prevalent chronic diseases among children. Poor oral hygiene, high sugar intake, and inadequate fluoride exposure can lead to the rapid development of cavities in primary teeth. If left untreated, these cavities can progress to severe decay, ultimately resulting in the premature loss of the affected teeth [1, 2]. Trauma is another frequent cause of early tooth loss, where accidents or injuries lead to the dislodgement or damage of primary teeth beyond repair [3]. Additionally, some children may experience congenital absence of certain teeth, a condition known as hypodontia, where the teeth fail to develop at all [4].

The premature loss of primary teeth can lead to significant dental complications including malocclusion and the collapse of the dental arch. Malocclusion refers to the misalignment of teeth and improper fitting of the upper and lower teeth when the mouth is closed. When primary teeth are lost prematurely, the adjacent teeth tend to drift into the empty space leading to crowding and improper alignment [5]. This misalignment can complicate the eruption of permanent teeth, potentially causing them to emerge in incorrect positions. Furthermore, the collapse of the dental arch can occur due to the lack of structural support from the primary teeth, leading to a narrower arch and more severe alignment issues [6].

These adverse effects can negatively impact the development of the permanent dentition and the overall oral health of the child. Misaligned teeth can lead to difficulties in chewing and speaking, increased risk of cavities and periodontal disease due to harder-to-clean crowded areas, and potential issues with self-esteem and social interactions [7, 8]. Thus, addressing premature tooth loss promptly and effectively is crucial to mitigating these long-term consequences.

To mitigate the consequences of premature tooth loss, space maintainers are commonly employed. Space maintainers are dental appliances designed to hold the space left by the lost primary teeth, ensuring that there is adequate room for the proper eruption of permanent teeth. Their primary function is to maintain the alignment and spacing within the dental arch, preventing the drifting of adjacent teeth into the space created by the missing tooth [9]. By preserving this space, space maintainers help ensure that the permanent teeth erupt in their correct positions, contributing to a well-aligned and functional dental arch [10].

Among the various types of space maintainers, Band and Loop Space Maintainers (BLSMs) are widely used due to their simplicity and effectiveness. Traditional BLSMs are fabricated using stainless-steel bands and wires. These components are custom-fitted to the patient's teeth, with the band encircling an anchor tooth and the loop spanning the gap created by the missing tooth [11]. The primary function of BLSMs is to hold the space until the permanent teeth erupt, ensuring the proper alignment and spacing of the new teeth. The simplicity of their design, combined with their proven efficacy, makes them a staple in pediatric dentistry for managing space after premature tooth loss [12].

With advancements in technology, the field of dentistry has seen the introduction of additive manufacturing techniques, particularly 3D printing. This innovative approach offers numerous advantages over conventional methods. 3D printing, or additive manufacturing, is a process of producing three-dimensional objects from a digital file by layering material incrementally. This technique allows precise customization of dental appliances, enabling the creation of complex geometries with high accuracy [13]. One of the significant benefits of 3D printing is rapid prototyping, which facilitates the quick production and testing of new designs. Additionally, 3D printing allows for the creation of tailor-made solutions specific to the individual needs of each patient, enhancing the fit and functionality of the dental appliances [14].

Despite the promise shown by 3D printed BLSMs, there is limited research on their mechanical properties, especially concerning their fracture strength compared to traditionally fabricated BLSMs. The mechanical performance of space maintainers is crucial as it determines their durability and clinical utility in pediatric patients. Space maintainers need to withstand the forces exerted during mastication and other oral functions without breaking or deforming [15]. Therefore, assessing the fracture strength of 3D printed BLSMs is essential to ensure they can endure the stresses of daily use and provide reliable space maintenance until the eruption of permanent teeth [16].

Understanding the mechanical properties of 3D printed BLSMs, such as their fracture strength, will provide valuable insights into their clinical performance and potential applications in pediatric dentistry [17]. This knowledge will aid in determining the feasibility of using 3D printed space maintainers as a reliable alternative to conventional stainless-steel BLSMs. If 3D printed BLSMs are found to possess comparable or superior mechanical properties, they could offer a significant advancement in pediatric dental care, providing custom-fit, durable, and efficient solutions for managing premature tooth loss in children [18].

The motivation for this study stems from the necessity to close the knowledge gap concerning the mechanical properties of 3D-printed BLSMs. By evaluating and comparing the fracture strengths of conventional stainless-steel BLSMs and 3D printed BLSMs, the study aims to provide valuable insights into their clinical performance and potential applications in pediatric dentistry [19]. Understanding these properties will aid in determining the feasibility of using 3D printed space maintainers as a reliable alternative to conventional ones [18].

The primary objective of this study is to evaluate and compare the fracture strength of C-BLSMs fabricated using stainless steel with that of 3D printed BLSMs manufactured through additive manufacturing techniques. By assessing the mechanical properties of these two types of space maintainers, the study seeks to provide valuable insights into their clinical performance and potential applications in pediatric dentistry [19, 20].

Additionally, the study aims to explore the potential implications of its findings for the selection of materials and fabrication techniques for space maintainers. By understanding the mechanical performance of 3D printed BLSMs, dental practitioners can make informed decisions regarding their use, ultimately contributing to improved patient outcomes and quality of care in pediatric dental practice [21]. The findings of this study could lead to advancements in the design and fabrication of space maintainers, enhancing their effectiveness and reliability in maintaining dental arch integrity in children [20].

This study is significant as it addresses an important gap in the literature regarding the mechanical properties of 3D printed BLSMs. The findings of this study may have implications for the selection of materials and fabrication techniques for space maintainers in pediatric dentistry, ultimately contributing to improved patient outcomes and quality of care [21].

Materials and methods

This study employed a mixed dentition mandibular cast featuring a permanent first molar, deciduous second molar, and deciduous first molar. To simulate clinical conditions, the deciduous second molar was scraped from the cast, resulting in modified mixed-dentition model.

Fabrication of the conventional band- and loop-type space maintainers

Conventional band- and loop-type space maintainers were fabricated on these casts using stainless steel, which is a prevalent material in pediatric dentistry. Fabrication involved banding the permanent first molar and shaping the wire component to fit the available space, followed by soldering the band and wire together (Fig. 1). Fifteen conventional space maintainers are fabricated.

Fabrication of the 3D printed band- and loop-type space maintainers

To produce 3D printed space maintainers, the casts were scanned using a desktop 3D scanner (Exocad DentalCAD 2.2 Valetta; Exocad GmbH), and a standard tessellation

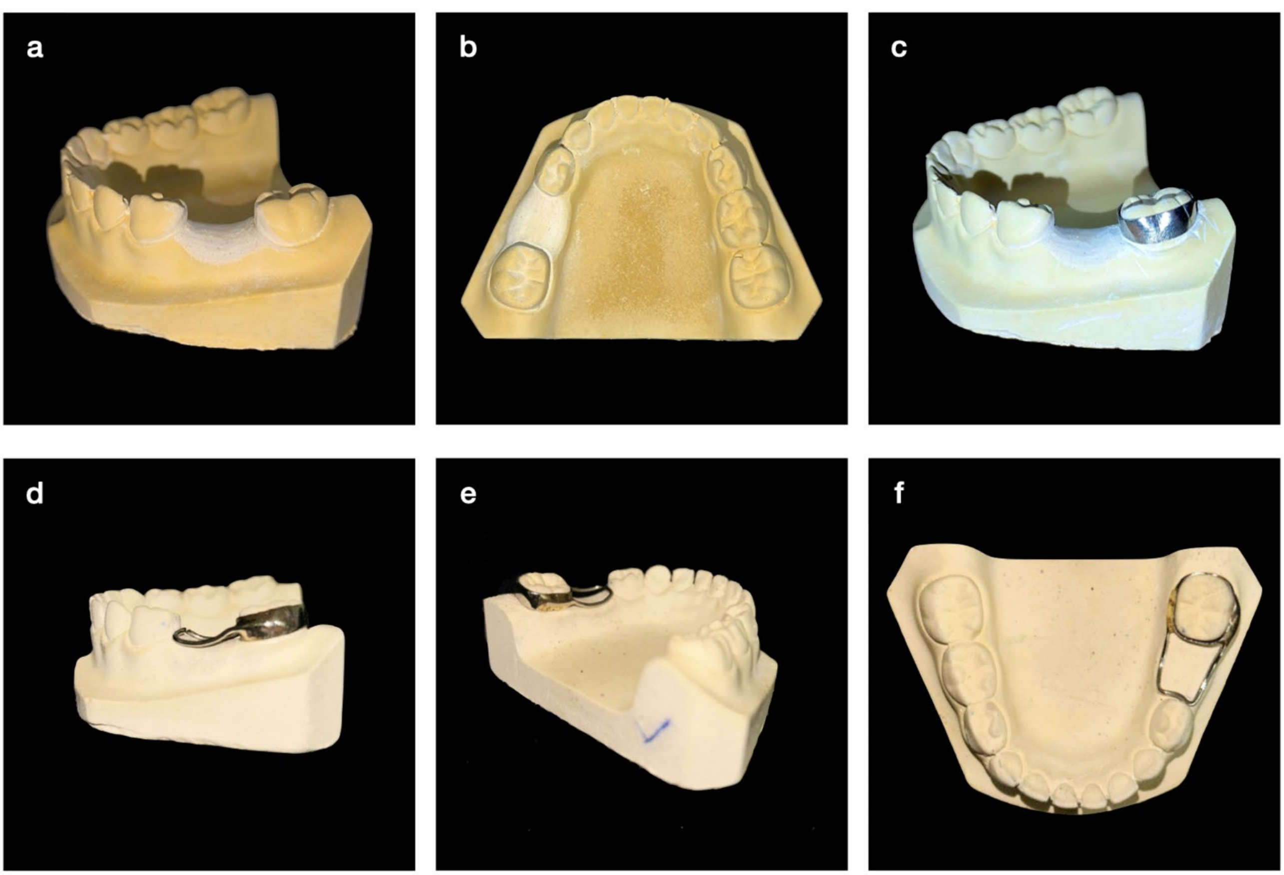

Fig. 1 Fabrication of conventional band and loop space maintainer (**a**) and (**b**) the mixed dentition cast after scrapping the deciduous second molar, (**c**) adaptation of the molar band, and (**d**), (**e**), and (**f**) adaptation of the loop and soldered loop to the molar band

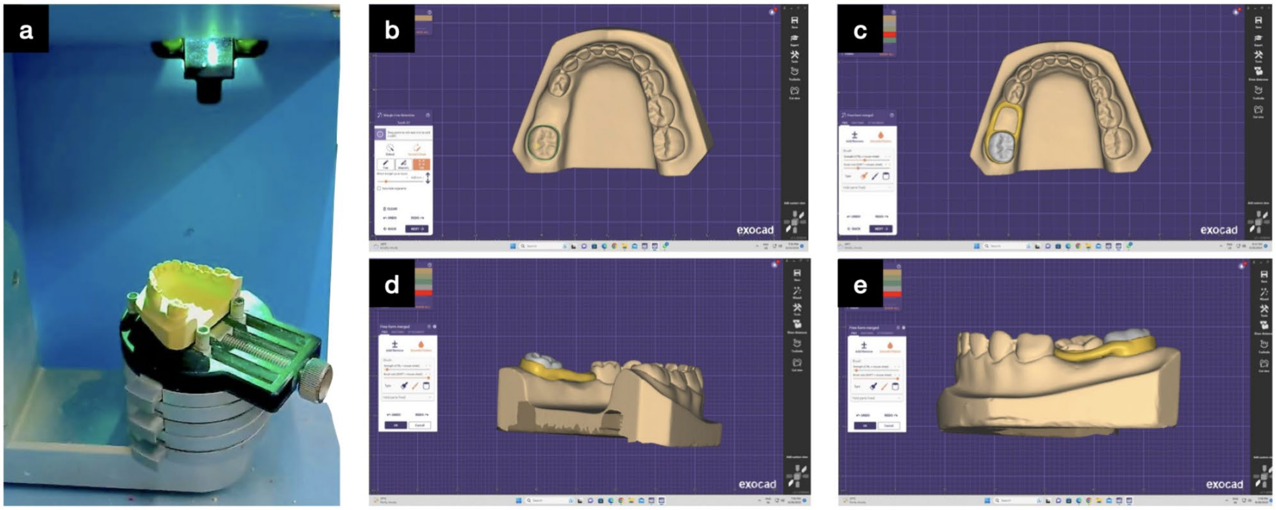

Fig. 2 Fabrication of 3D printed space maintainer; (**a**) digital scanning of the mixed dentition cast, (**b**) scanned cast, (**c**), (**d**), and (**e**) design of the 3D printed space maintainer

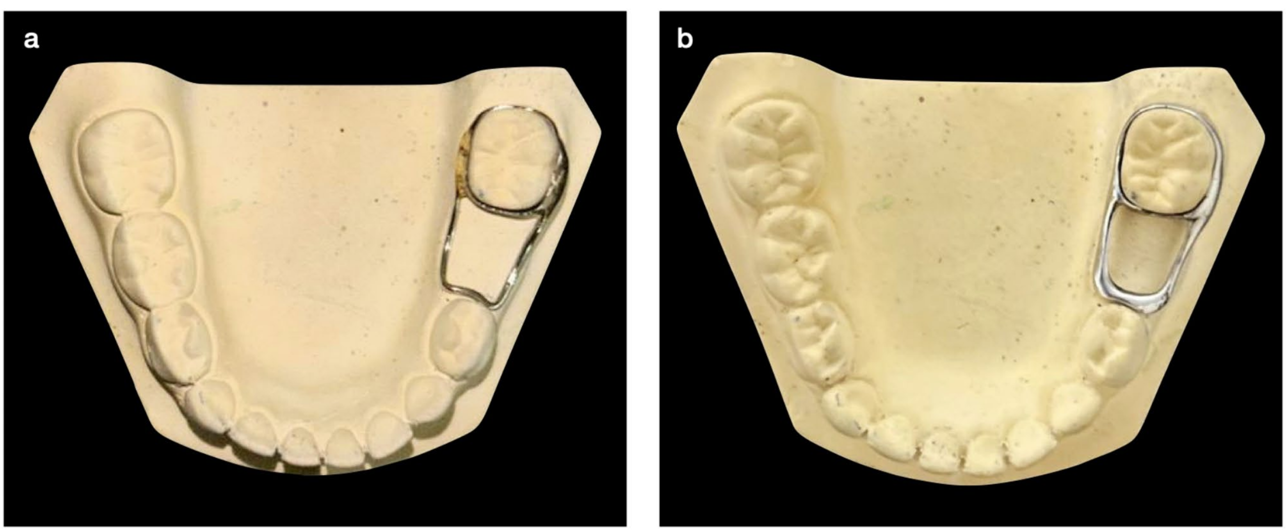

Fig. 3 Band and loop space maintainers; (**a**) C-BLSM and (**b**) 3D-BLSM

file (STL) was generated by designing the space maintainer in the software. Care was taken to maintain a small tessellation size to avoid a grainy texture, and the 3D printed space maintainer design closely resembled its conventional counterpart. Multilayer steel (MLS) was employed as the printing material, and 15 space maintainers were manufactured using additive manufacturing techniques (Fig. 2). Group 1 ($n=15$)– C-BLSMs (Fig. 3a) and Group 2 ($n=15$)– 3D-BLSMs (Fig. 3b), fabricated using Exocad software in an STL file, with multilayer steel as the material.

Fracture strength testing

The maximum occlusal bite force in mixed dentition was determined based on the established literature, indicating a range of 190–200 N. The fracture strength testing was conducted using a flat blade tip on a universal testing machine. A load was applied at the soldering joint, which was the point of differentiation between the two types of space maintainers. Soldering, employing a metal with a low fusion temperature, was utilized for conventional space maintainers, while multiple layers of material were added to the 3D printed space maintainers. Space maintainers were positioned to direct the force to half of the soldering joint (Fig. 4). Conventional space maintainers exhibited fractures at a mean force of 130.8533 N, whereas 3D printed space maintainers fractured at 308.52667 N.

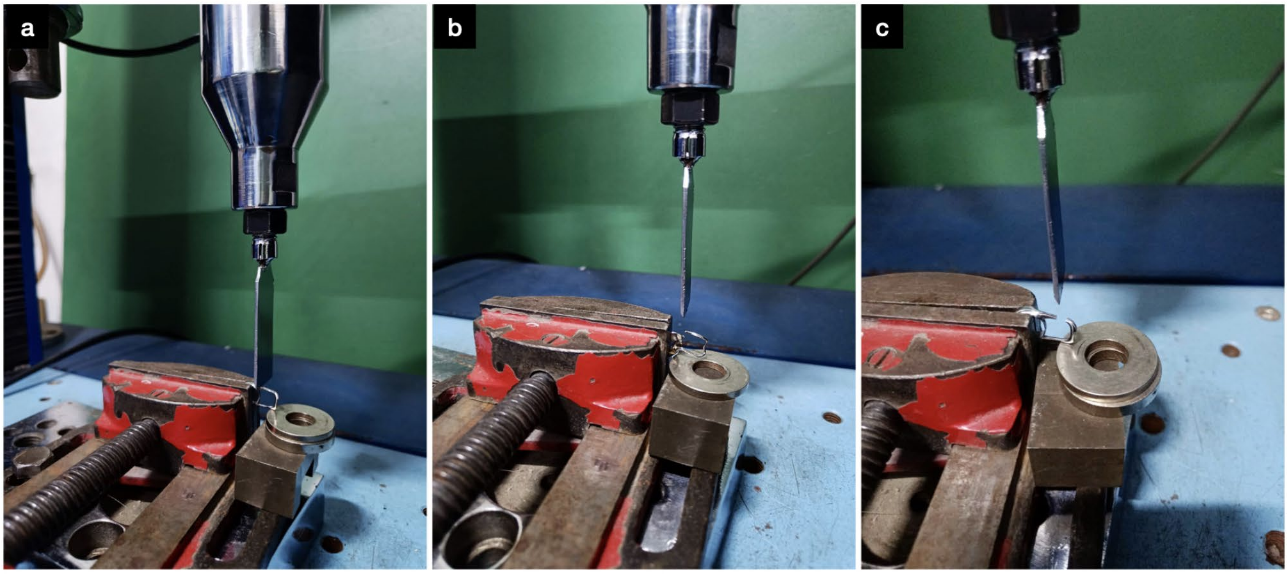

Fig. 4 Fracture testing using universal testing machine (UTM); (**a**) placement of the tip of the UTM on the space maintainer, (**b**) fracture of C-BLSM after application of the load, and (**c**) fracture of 3D-BLSM after application of the load

Table 1 Comparison of the mean fracture resistance

Group	*N*	Mean	Std. Dev.	t value	*p* value
C-BLSM	15	130.8533	20.98632	12.657	0.000*
3D-BLSM	15	308.5267	50.15256		

* Statistically significant difference

Results

Table 1 presents a comparison of the mean fracture resistance between two groups: 3D printed band and loop space maintainers (3D-BLSM) and C-BLSM. In this study, both types of space maintainers were subjected to fracture strength testing to assess their durability and resistance to the forces encountered in the oral cavity. The mean fracture resistance of the 3D printed band and loop space maintainers was found to be significantly higher than that of the conventional band and loop space maintainers. Specifically, the mean fracture resistance for the 3D-BLSM group was recorded at 308.53 N with a standard deviation of 50.15 N. In contrast, the mean fracture resistance for the C-BLSM group was notably lower at 130.85 N with a standard deviation of 20.99 N. This difference in fracture resistance was statistically significant, as evidenced by the calculated t-value of 12.657 and a corresponding p-value below 0.05. The p value indicates the probability of obtaining the observed difference in fracture resistance between the two groups by random chance alone. With a p-value significantly lower than 0.05, it is unlikely that the observed difference occurred because of chance, thus highlighting the robustness of the findings.

Discussion

Oral health in pediatric patients is a critical aspect of overall well-being, given the profound impact it has on their quality of life and long-term health outcomes [22]. Among the primary concerns in pediatric dentistry are dental caries and premature loss of primary teeth. Dental caries, or tooth decay, stands as one of the most prevalent chronic diseases affecting children globally. This condition arises from the accumulation of bacteria on the tooth surface, leading to the demineralization of tooth enamel and subsequent cavity formation. If left untreated, dental caries can progress, causing pain, infection, and ultimately, the premature loss of primary teeth [23].

The premature loss of primary teeth can have significant repercussions on a child's oral health and development [24]. Primary teeth serve essential functions in chewing, speech development, and the maintenance of space for permanent teeth. Premature loss disrupts this natural process, potentially leading to difficulties in eating, speaking, and proper alignment of permanent teeth [25]. Moreover, the loss of primary teeth can impact the child's self-esteem and social interactions, affecting their overall quality of life [26].

Furthermore, the consequences of premature tooth loss extend beyond oral health, affecting the child's overall health and well-being. Malocclusion, or misalignment of teeth, can result from the premature loss of primary teeth, leading to problems such as difficulty in biting and chewing, speech impediments, and temporomandibular joint disorders [27]. Additionally, the collapse of the dental arch due to untreated tooth loss can alter facial aesthetics and contribute to issues such as low self-esteem and poor oral hygiene practices [28].

Space maintainers play a crucial role in pediatric dentistry by addressing the aftermath of prematurely lost primary teeth. These dental appliances are specifically engineered to fill the void left by the missing tooth, ensuring that the surrounding teeth do not shift out of their natural positions [29]. This preservation of space is essential for facilitating the proper eruption of permanent teeth, as any deviation from the natural alignment can lead to malocclusion and other dental complications [30].

The primary objective of space maintainers is to prevent malocclusion, which refers to the misalignment of teeth. When a primary tooth is lost prematurely, adjacent teeth may begin to drift or tilt into the empty space, disrupting the alignment of the dental arch. This can create irregularities in tooth spacing and occlusion, compromising the overall harmony and functionality of the dentition. Additionally, the absence of primary teeth can contribute to the collapse of the dental arch over time, further exacerbating malocclusion and oral health issues [31].

By maintaining proper spacing within the dental arch, space maintainers act as guardians of the erupting permanent teeth. These appliances serve as placeholders, preserving the integrity of the dental arch until the permanent teeth emerge. By preventing the migration of adjacent teeth into the vacant space, space maintainers ensure that the permanent teeth have sufficient room to erupt in their correct positions. This promotes a well-aligned and functional dental arch, supporting proper occlusion and facilitating optimal chewing, speech, and oral hygiene practices [32, 33].

In essence, space maintainers act as proactive measures to safeguard the natural alignment and development of the dentition. By fulfilling their role in preserving space and preventing malocclusion and dental arch collapse, these appliances contribute to the long-term oral health and well-being of pediatric patients. Through the timely implementation of space maintainers, dental professionals can help guide the eruption of permanent teeth, promoting a harmonious and functional dentition that enhances the overall quality of life for the child [34].

Conventional band and loop space maintainers (C-BLSMs) have long been the mainstay of treatment in pediatric dentistry. These maintainers are fabricated using stainless-steel bands and wires, which are custom fitted to the patient's teeth. The process involves several steps: selecting a suitable stainless-steel band and adapting it to fit snugly around an adjacent tooth, constructing a loop from stainless steel wire to span the gap left by the missing tooth, and soldering the loop to the band and finishing the appliance to ensure smooth surfaces and proper fit. While C-BLSMs are effective, they come with certain limitations. The fabrication process is labor-intensive and requires significant skill and precision from the dental technician. Additionally, the fit and finish of the appliance can vary, potentially leading to discomfort for the patient. Moreover, the time-consuming nature of the process can be a drawback in busy clinical settings [35].

With advancements in technology, three-dimensional (3D) printing has emerged as a promising alternative for the fabrication of space maintainers. 3D printing, or additive manufacturing, is the process of constructing a three-dimensional object from a digital design by adding material in successive layers. This technology offers numerous advantages over traditional methods: precise control over the dimensions and geometry of the fabricated appliance, enabling high levels of customization to suit the individual patient's needs; rapid prototyping facilitating iterative design and testing, leading to improved designs and faster production times; the ability to create complex geometries that may be difficult or impossible to achieve with conventional fabrication techniques; and cost-effectiveness over time, as it reduces the labor and materials needed for traditional methods [36, 37].

Despite the promise shown by 3D printed BLSMs, there is limited research on their mechanical properties, especially concerning their fracture strength compared to traditionally fabricated BLSMs. The mechanical performance of space maintainers is crucial as it determines their durability and clinical utility in pediatric patients. Fracture strength is a critical parameter because space maintainers must withstand the forces exerted during mastication and other oral functions [38]. The rationale for this study arises from the need to bridge the knowledge gap regarding the mechanical properties of 3D printed BLSMs. By evaluating and comparing the fracture strengths of conventional stainless-steel BLSMs and 3D printed BLSMs, the study aims to provide valuable insights into their clinical performance and potential applications in pediatric dentistry. Understanding these properties will aid in determining the feasibility of using 3D printed space maintainers as a reliable alternative to conventional ones [39, 40].

This study aimed to compare the fracture strength of conventional and 3D printed band and loop space maintainers (BLSM) used in pediatric dentistry. The findings revealed a significant difference in fracture resistance between the two types of space maintainers, with 3D printed BLSM demonstrating higher resistance to fracture than its conventional counterparts [41].

The superior fracture resistance observed in 3D printed BLSM can be attributed to several factors. First, the manufacturing process of 3D printed BLSM allows for precise control over the material distribution and structure, resulting in optimized mechanical properties. The additive manufacturing technique used to create 3D printed BLSM enables the fabrication of complex geometries with uniform material density, which enhances the overall strength of the device [41, 42]. In contrast, conventional BLSM fabrication involves manual bending and soldering of metal components, which may introduce inconsistencies in the material distribution and weaken the structure [43].

Moreover, the choice of material may contribute to the differences in fracture resistance between the conventional and 3D printed BLSM. In this study, multilayer steel (MLS) was used as the printing material for 3D printed BLSM, whereas stainless steel was employed for the conventional BLSM. MLS offer superior mechanical properties, including high tensile strength and ductility, which are essential for withstanding occlusal forces in the oral cavity [44]. Therefore, the use of MLS in 3D printed BLSM may confer greater resilience to fracture compared to conventional stainless steel BLSM.

Another factor influencing fracture resistance is the manufacturing technique used to create the soldering joint in the conventional BLSM versus layer bonding in 3D printed BLSM. Conventional BLSM are assembled by soldering metal components together, which may result in localized weakness at the soldering joint owing to heat-induced metallurgical changes [45]. In contrast, 3D printed BLSM are fabricated layer-by-layer, with each layer fused to the previous one through a process such as selective laser melting or electron beam melting [46]. This homogeneous bonding throughout the structure of 3D printed BLSM may contribute to its enhanced fracture resistance compared to the conventional BLSM.

Furthermore, the design flexibility afforded by 3D printing technology allows for optimization of the stress distribution within the BLSM structure. By tailoring the geometry and infill pattern of the 3D printed device, it is possible to minimize stress concentrations and improve the load-bearing capacity [47]. Conversely, conventional BLSM have limited design flexibility, and their structural integrity may be compromised by sharp angles or abrupt changes in geometry [35].

One of the notable strengths of this study is its methodological approach. By employing a mixed dentition mandibular cast and simulating clinical conditions, this study closely mimicked real-world scenarios encountered in pediatric dentistry. The use of standardized fabrication techniques for both conventional and 3D printed BLSM ensured the consistency and reliability of the experimental setup [48].

Moreover, the inclusion of both the conventional and 3D printed BLSM groups allowed for a direct comparison of fracture resistance under controlled conditions. By utilizing stainless steel for conventional BLSM and multilayer steel (MLS) for 3D printed BLSM, this study captured the impact of material choice on the fracture strength, providing valuable insights for clinical practice.

The findings of this study could have significant implications for pediatric dentistry. If 3D printed BLSMs demonstrate comparable or superior mechanical properties to conventional BLSMs, they could offer a viable alternative that provides enhanced precision, customization, and efficiency. This could lead to improved patient comfort, as better fitting appliances would be more comfortable for the patient, reducing the likelihood of irritation or discomfort. Additionally, more precise space maintainers that effectively preserve dental arch integrity and prevent malocclusion would result in improved long-term oral health outcomes for pediatric patients. The fabrication process would also be more efficient and less labor-intensive, saving time and resources in a clinical setting. Furthermore, there would be potential cost savings due to reduced labor and material costs associated with traditional fabrication methods. The use of 3D printed BLSM with superior fracture resistance may offer several advantages over conventional BLSM in terms of durability and longevity. Patients fitted with 3D printed BLSM may experience fewer instances of device failure or fracture, leading to reduced treatment costs and improved patient satisfaction [19, 35].

Moreover, the adoption of 3D printing technology in pediatric dentistry holds promise for treatment approaches tailored to individual patient needs. 3D printing allows the fabrication of patient-specific BLSM based on digital scans of the oral cavity, ensuring optimal fit and functionality. This personalized approach may lead to better treatment outcomes and enhanced patient comfort compared with conventional one-size-fits-all devices [49].

Despite the potential benefits of 3D printed BLSM, several considerations must be considered before widespread clinical implementation. First, further research is needed to evaluate the long-term performance and biocompatibility of 3D printed BLSM in vivo. Clinical studies examining the clinical efficacy and patient acceptance of 3D printed BLSM are warranted to validate the findings of this study.

Additionally, the cost-effectiveness of 3D printed BLSM compared to conventional BLSM should be carefully evaluated. Although 3D printing offers advantages in terms of customization and design flexibility, the initial investment in equipment and materials may be higher than that of traditional manufacturing methods. Cost-benefit analyses are necessary to determine the economic viability of integrating 3D printing technology into routine clinical practice.

Conclusions

Oral health in pediatric patients is critical, and the premature loss of primary teeth can lead to significant dental complications. Space maintainers, such as conventional band and loop space maintainers (C-BLSMs), play a crucial role in preserving dental arch integrity and preventing malocclusion. However, the advent of 3D printing technology offers a promising alternative that could enhance the precision, customization, and efficiency of space maintainer fabrication. Despite the potential benefits, limited research has been conducted to evaluate the mechanical properties of 3D printed BLSMs.

This study provides valuable insights into the fracture strengths of conventional and 3D printed band and loop space maintainers used in pediatric dentistry. These findings suggest that 3D printed BLSM exhibit superior fracture resistance compared to its conventional counterparts, potentially offering enhanced durability and longevity in clinical applications. However, further research is needed to confirm these findings and address the remaining questions regarding the performance, biocompatibility, and cost-effectiveness of 3D printed BLSM in pediatric dental practice.

Author contributions

Conceptualization, S.M., B.T., A.M.P and M.I.K methodology, B.T.; software, B.T.; validation, D.A.W., A.A.A., A.K and M.I.K.; formal analysis, S.M., S.R.V and A.M.P.; investigation, S.M.; data curation, S.M.; writing—original draft preparation, A.M.P. and S.M.; writing—review and editing, B.T., D.A.W., A.A.A., K.A and M.I.K.; visualization, S.R.V and A.M.P.; supervision, B.T.; project administration, B.T. All authors have read and agreed to the published version of the manuscript.

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Data availability

The data related to the study will be made available on request to the principal author or the corresponding author.

Declarations

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Ethical approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the Universitas Airlangga Faculty of Dental Medicine Health Research Ethical Clearance Commission (protocol code 679/HRECC.FODM/VI/2023 and date of approval June 19, 2023).

Informed consent

Not applicable.

Conflict of interest

The authors declare no conflicts of interest.

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