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Facultad de Odontología

Carrera de Odontología

Innovation in interceptive orthodontics: Digital space maintainers with CAD/CAM and 3D printing. Bibliographic review

Trabajo de titulación previo a la obtención del título de Odontólogo.

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Resumen

Introducción: Actualmente la tecnología 3D y CAD/CAM ha sido ampliamente adoptada por la mayoría de los odontólogos y en la ortodoncia pediátrica no es la excepción. Esta tecnología permite a los ortodoncistas crear modelos dentales digitales, facilitando así el diseño y la fabricación de aparatos ortopédicos personalizados para las necesidades específicas de cada paciente. Objetivo: Recopilar información científica que describa detalladamente el manejo, ventajas y desventajas de la utilización de la tecnología CAD/CAM y 3D en la fabricación de mantenedores de espacio. Materiales y métodos: Se llevó a cabo una búsqueda en diversas bases de datos, incluyendo PubMed, Scopus, Springer link, Science Direct y Google Académico. Se seleccionaron 14 artículos que cumplían con los criterios de inclusión. Resultados: 10 estudios utilizaron materiales como polieteretercetona, polimetilmetaclilato y polímero (Trilor), fresados para elaborar mantenedores de espacio. Otros 3 estudios aplicaron polvo de titanio con técnicas de impresión 3D por adición con este mismo propósito y finalmente, 1 estudio empleó un bloque de zirconio (BruxZir) para mediante fresado fabricar una banda ansa. Conclusiones: Los mantenedores de espacio digitales (MED) muestran resultados equiparables a los mantenedores de espacio convencionales (MEC), con la ventaja adicional de ser más estables y resistentes. Aunque su costo puede representar una limitación, se recomienda realizar más estudios y seguimientos a largo plazo, para aprovechar los beneficios de la innovación tecnológica en la fabricación de mantenedores de espacio y acrecentar la calidad de atención a los pacientes.

Palabras clave del autor: mantenedor de espacio, space maintainer 3D, dental space maintainer, pérdida dental decidua, CAD/CAM

Abstract

Introduction: 3D and CAD/CAM technology has now been widely adopted by most dentists and pediatric orthodontics is no exception. This technology allows orthodontists to create digital dental models, thus facilitating the design and fabrication of orthopedic appliances customized to the specific needs of each patient. Objective: To gather scientific information that describes in detail the management, advantages and disadvantages of using CAD/CAM and 3D technology in the fabrication of space maintainers. Materials and methods: A search was carried out in several databases, including PubMed, Scopus, Springer link, Science Direct and Google Scholar. Fourteen articles that met the inclusion criteria were selected. Results: 10 studies used materials such as polyetheretheretherketone, polymethylmethacrylate and polymer (Trilor), milled to produce space maintainers. Another 3 studies applied titanium powder with addition 3D printing techniques for the same purpose and finally, 1 study used a zirconium block (BruxZir) to manufacture a band by milling. Conclusions: Digital space maintainers (DSM) show comparable results to conventional space maintainers (CSM), with the additional advantage of being more stable and resistant. Although their cost may represent a limitation, further studies and long-term follow-ups are recommended to take advantage of the benefits of technological innovation in the manufacture of space maintainers and improve the quality of patient care.

Author Keywords: space maintainer, space maintainer 3D, dental space maintainer, deciduous tooth loss, CAD/CAM

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1. Introduction

Premature tooth loss, characterized by tooth exfoliation before the expected time, constitutes one of the most frequent dental problems in the deciduous dentition [1]. This anomaly can occur as a consequence of the presence of dental caries, advanced periodontal disease, acute or chronic dental trauma, premature root resorption and extraction of neonatal teeth [2,3].

Dental caries is the main cause of premature deciduous tooth loss (PDTL) [4]. Upper incisors and temporary molars have a higher prevalence of caries than other deciduous teeth because they are related to factors such as: eruption time, location in the oral cavity and their specific anatomy, contributing to a greater accumulation of bacterial plaque [2,5,6].

If this anomaly is not treated in a timely manner, it can lead to consequences such as loss of arch length, mesialization or migration of the adjacent tooth, extrusion of the antagonist tooth, crowding of the dental arch and ectopic eruption. If the tooth loss is in the anterior sector, it causes problems during phonoarticulation, chewing, swallowing and tongue position [2,7]. All these effects over time can lead to malocclusion, anterior crossbite, increased overbite and overjet, midline deviation and improper molar relationship [7,8]. In addition to functional problems, PDTL can have a significant impact on the psychosocial aspects of the child, especially if these defects are visible during speech and smiling [1].

When PDTL has been unavoidable, it is crucial to implement a treatment plan that preserves or restores lost space in order to prevent the series of malocclusions that can arise as a consequence of this situation. Therapeutic strategies include the use of space maintainers (SM) [7] or space retrievers [8]. The decision to choose between a space maintainer or a space retriever will depend on the time elapsed since PDTL, whether or not there has been a decrease in arch length and/or the time remaining until the eruption of the permanent tooth [9].

Conventional space maintainers have been successfully employed to maintain adequate space in the dental arches when a deciduous tooth has been prematurely extracted, allowing the permanent tooth to erupt properly into place. However, digital progress, the use of CAD/CAM technology, along with the introduction of new 3D printed materials, are providing greater efficiency in obtaining the desired results [10,11]. Also, by incorporating digital systems, errors can be reduced throughout the different phases of treatment, in addition to reducing the time required, which leads to greater collaboration and patient satisfaction [12].

At present, there is scarce scientific information on the incorporation and application of these technological tools in preventive orthodontics for the fabrication of SMs. For this reason, the purpose of this study is to compile as much information as possible on the management and technology needed, benefits, complications, advantages, disadvantages and results obtained when using digital and 3D printing fabricated SMs after PDTL in children.

2. Conventional space maintainers

The purpose of SMs is to prevent loss of length in the dental arch. They are orthodontic devices that are used during the primary or mixed dentition first phase, when a deciduous tooth has been prematurely lost [13,14]. The characteristics that an SM should meet are: not interfere with the growth and development of the jaws and teeth, be stable, resistant, prevent extrusion of the antagonist, not interfere with function, and if possible, should restore masticatory function, swallowing, phonation and esthetics [15,16]. The disadvantages or complications that SMs can present are: soft tissue alteration such as friction hyperplasia, interlocking, dental caries, gingival disease and difficulty in dental hygiene [13].

The factors that should be taken into account for the placement of SMs are: dental age of the child, sequence and pattern of tooth eruption, time interval of the loss or extraction, amount of bone covering the successor tooth and type of arch [13].

It is indicated to use SMs when the arch length has not been shortened and the successor is developing normally; the molar or canine relationship has not been affected; to prevent the acquisition of harmful habits and when the patient experiences self-esteem problems after premature tooth loss especially in the anterior sector [17,18].

SMs can be classified as fixed or removable and the selection of the appliance will depend on the specific treatment needs of the patient.

3. Fixed Space Maintainers

Fixed SMs can be unilateral or bilateral:

Unilateral fixed space maintainers are nonfunctional devices, employed when there is premature loss of the first or second deciduous molar. They include the wide band space maintainer, which consists of a metal band with a stainless steel wire loop (0.036), which is easy to fabricate and inexpensive, although it does not prevent eruption of the antagonist tooth and may retain biofilm [14,17]. Similarly, the crown-loop space maintainer, with a chrome-plated steel crown and a steel wire loop, prevents mesial migration of the molars, but does not restore masticatory function and in case of fracture will require replacement of the entire appliance [16,17]. On the other hand, the distal slipper space maintainer, with a chrome-plated steel band or crown and a steel wire, serves as a guide for the eruption of the first permanent molar avoiding its mesialization, although its placement requires complex technique and can accumulate plaque [17,19]. There is also the direct bonded space maintainer, which uses a stainless steel wire (0.028) bent and adjusted according to the extraction space [20], is inexpensive and easy to fabricate, but susceptible to decementation or fracture [10,21]. Finally, the fiberglass-reinforced resin space maintainer is esthetic and minimally invasive, made of prefabricated fibers and light-curing resin, although it is inexpensive and has minimal effects on soft tissue, requires precise handling with adequate isolation and may de-cement if the cementation procedure is not carefully followed [22].

As for fixed bilateral space maintainers, being non-functional like the previous ones, we have the lingual arch, used in the lower arch [20], consisting of an adapted steel wire with loops (omegas) soldered to bands in the first permanent molars, being economical but prone to interference with the tongue, difficult cementation and biofilm accumulation [10,17]. The Nance button, used in the maxilla, provides anchorage and stability [17] by containing bands in the upper first molars and a palatal arch with an acrylic button [23], but can cause palatal ulcers [16]. The transpalatal arch, also in the maxilla, is recommended for stabilizing permanent molars after extraction of primary molars [17], being easy to fabricate, but retaining biofilm and not preventing eruption of the antagonist [23,24]. Finally, the fixed functional esthetic space maintainer, used in temporary upper second molars, offers an esthetic and functional restoration, although it may cause soft tissue irritation and dental plaque accumulation [17].

4. Removable space maintainers

They can be uni or bilateral, functional or non-functional. Among these we have the acrylic SM and the Hawley plate. They are used when there is uni or bilateral loss of anterior or posterior teeth. In addition, they can be modified for other types of needs such as expansion by incorporating screws in their fabrication, modifying crossbites, adding teeth to convert it into an esthetic SM, or adding springs to the Hawley plate to correct small rotations [13,25]. As advantages we have that including acrylic extensions or artificial teeth in the edentulous area contributes to maintaining the vertical dimension and favoring functionality, in addition to allowing minor orthodontic movements [13]. However, its effectiveness requires the collaboration of the patient. In addition, it can present problems of retention, plaque accumulation and possible soft tissue irritation [13,17].

5. Digital space of maintainers

Dentistry has embraced digital workflow since the 1980s, taking advantage of technologies such as CAD/CAM (computer-aided design/computer-aided manufacturing). This approach has also extended to the field of pediatric orthodontics, where digital tools are used for the development of SMs. This choice is justified by the limitations and disadvantages associated with conventional fabrication methods [12,26]. There are three general steps for digital CAD/CAM work-up: intraoral scans for data collection, data processing by software program, and fabrication [26]. The introduction of intraoral scanning, as compared to traditional impressions, has been widely accepted by children, this innovation not only facilitates impression taking, but also promotes greater collaboration by patients throughout the treatment by significantly reducing fear and stress, establishing a more positive environment that encourages continued cooperation by children during their dental care [27].

The following procedure for the elaboration of digital SMs has been used in one of the first studies carried out by Ierardo and consists of the following steps:

1. An accurate conventional dental impression is made, followed by casting and digitizing the models using an extraoral scanner. This scanner uses light beams and micro cameras to capture several scans throughout the model, generating a point cloud. The software then connects these points to reconstruct a virtual model by creating small polygons [12].
2. Using the CAD software, the design of customized devices is started since it presents tools such as zoom, rotation and panning, therefore, they allowed to examine the virtual model obtained from different angles and magnifications for a detailed analysis. It was possible to adjust the material thickness, retention, undercuts, space for cementation and support points [12].
3. Once the design is completed, the file is sent to the CAM system to start the construction by milling, this process is known as subtractive manufacturing. The milling machine carves the block from the selected material to the shape previously designed in the CAD software in approximately one hour [12].

The technology or 3D printing also known as additive manufacturing consists of making 3D objects layer by layer from a 3D model or a computerized digital file. The most commonly used format or file for digital printing is standard tessellation language/stereolithography (STL). Digital 3D intraoral scanners have been used to obtain accurate replicas of the topography of the hard and soft tissues of the oral cavity. These digital representations can be used in the construction of space maintainers, using CAD-CAM technology and 3D printing [28]. Some of the materials used for the fabrication of SMs are polyetheretheretherketone (PEEK) polymer, polymethylmethacrylate (PMMA) Zirconia (BruxZir), Trilor polymer and titanium-based metal.

6. Materials used for the manufacture of digital space maintainers

6.1 PEEK: It is a semi-crystalline, thermoplastic, polyaromatic polymer, certifiable from the nutritional point of view, meeting both European and American (FDA) legislation [12,29]. It has been used in the biomedical, petroleum, chemical and aerospace fields [12]. Since 1998 it has been used as an implant material in various medical fields and in dentistry as an alternative to metals. This is due to its mechanical properties as it exhibits an elastic modulus of 3.6 GPa similar to bone [11]. However, biocompatibility is its most relevant property, since it has been used for a long time in contact with body tissues without causing rejection reactions, being non-toxic, non-immunogenic, non-mutagenic and non-carcinogenic [11,12]. In addition, it is a material that provides chemical resistance to wear, stability to high temperatures and radiation, so it has also been used for the elaboration of endocrowns, temporary abutments for implant-supported prostheses, removable partial dentures and fixed prostheses [11,29]. Its incorporation in the field of orthodontics experienced a significant advance in 2015, driven by a study that proposed it as an alternative for esthetic and metal-free orthodontic wires, as well as for orthodontic retainers. [12,29]. Among its advantages, PEEK offers superior esthetics compared to metallic materials, being appropriate for use in patients allergic or sensitive to metallic taste, offering a more tolerable and comfortable option. The high cost is one of its main disadvantages, as well as another limitation is that, although it presents an esthetic color, it is not suitable for use in the anterior area of the teeth because it does not completely match the natural color of the teeth. However, this limitation could be overcome by the addition of colorants to improve its appearance [12].

6.2 PMMA: It is a thermoplastic polymer, moldable in the presence of heat [30]. It is produced from methyl methacrylate as a monomer through a radical polymerization reaction. This polymerization can be initiated thermally or using a peroxy initiator, such as benzoyl peroxide (BPO) [31]. This material has been used in the medical area, as sutures, skin tissues, in ophthalmology as artificial lenses, therefore; thanks to its remarkable characteristics, its use has been extended to the dental field as dental adhesives, implants and dental prostheses. [31,32]. Among its characteristics we have that it is an aesthetic material since fibers or pigments can be added, it is light, resistant but plasticizers can also be added to improve its ductility, it has a shrinkage (from 0.2% to 0.5%) with the capacity to absorb or yield water, it is not soluble in water or saliva and it is highly biocompatible [30,32]. However, one of the drawbacks with PMMA is the microbial adhesion that can cause infections or stomatitis, but it has been verified that adding metal nanoparticles such as Ag and Cu can counteract this defect [32]. Another method to improve the disadvantages of PMMA was the introduction of PMMA to a CAD/CAM process, obtaining a special plastic with good surface properties, high mechanical performance, good marginal adaptation and excellent biocompatibility. It is used in fixed prosthetics for repairing crown bridges and in the fabrication of denture bases. It can be moldable and easily cut by the CAD/CAM process, so it has been considered for use in the fabrication of 3D printed SM, especially for removable SM [33].

6.3 Zirconia (BruxZir): A monolithic zirconia material, it presents biocompatibility with high esthetic potential, good dimensional stability and excellent mechanical properties compared to other dental ceramics [34]. Flexural strength is one of its most outstanding characteristics as it can resist up to 1465 MPa and presents three to five times the fracture toughness of typical zirconia, it also causes minimal wear to its antagonist tooth, as well as excellent thermal shock resistance with low thermal expansion, which means that the restorations will remain stable in the mouth after ingestion of hot and cold liquids [35, 36]. They have been used in the fabrication of crowns, bridges, implants and inlays [34]. It can be dipped in stains to obtain the desired shade; however, zirconia (BruxZir) is currently available in all Vita Classic and Gingival shades, which meets the esthetic demands of the patient. Therefore, it has been considered an ideal material for the fabrication of CAD/CAM fabricated SMs [35,37].

6.4 Trilor polymer: It is an ethoxylene thermosetting resin reinforced with FRC glass fiber, it is phenolic, aramidic, polyamide, silicone, epoxy, Bis phenol free [38]. It has good tensile strength, elastic modulus of 26 Gpa, compressive strength (perpendicular) and has shown higher impact strength [38]. Durability, low weight, biocompatibility and reparability are some of the benefits [10]. These materials are currently being used in implant-implant connection bars, single crown, multiple crown, full-arch frameworks, partial or full removable denture reinforcement, implants, and orthodontic retainers [38]. This may be a material of choice when a patient is allergic to metal, has special needs, or has medical conditions that require periodic MRI scans. [39].

6.5 Titanium based metal (Ti): It is a lightweight material, being 43% lighter than steel. In addition, it is highly ductile, strong, surpassing steel in stiffness and strength, it also has the ability to be melted, cast and welded [40]. In the industrial field, the most widely used alloy is 3Al-2.5V, composed mainly of titanium (94.5%), with 3% aluminum and 2.5% vanadium. In the medical and dental field, two alloys stand out mainly: Ti-6Al-4V and Ti-Al-Nb, presenting good biocompatibility, corrosion and fracture resistance [40]. The most widely used alloy in orthodontics is nickel titanium for the production of wires and brackets. In the last decade, Ti has been used with 3D printing/additive manufacturing (3DP/AM) technologies for the fabrication of implants improving their mechanical strength and thus increasing the survival rate [41]. On the other hand, its application in 3D SM production has been considered due to its efficiency and practicality in terms of time and fabrication, in contrast to traditional methods. This makes them particularly suitable for poorly collaborating patients [42].

7. Materials and methods

This study is a descriptive systematic review that has addressed studies dealing with the elaboration of space maintainers using CAD/CAM technology, as well as those printed in 3D and their use after PDTL. Data were collected by means of an electronic search through scientific databases such as: PubMed, Scopus, Springer link, Science Direct and the Google Scholar meta-search engine. Keywords such as: "Space Maintainer", "Space Maintainer 3D", "Dental space maintainer", "Deciduous tooth loss", "tooth loss" "CAD/CAM" were used. The article selection process was carried out using the PRISMA flow chart [Figure 1].

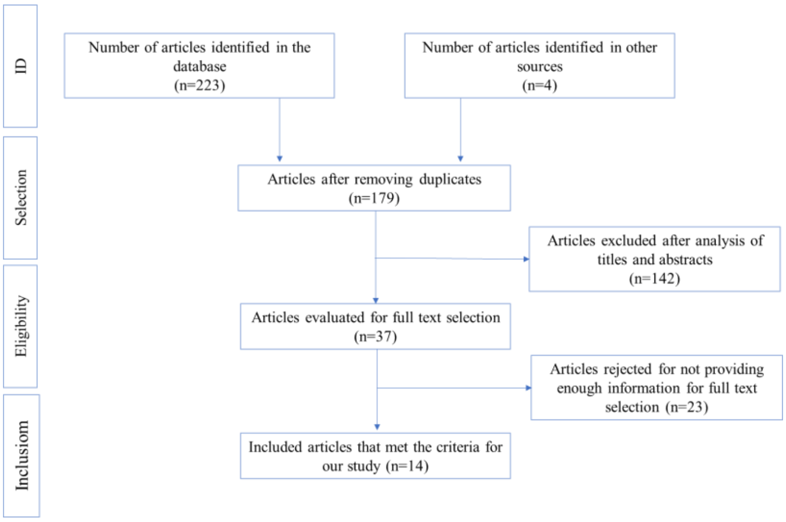

Figure 1. PRISM flow chart, summary of the search strategy.

Source: Authors (2023)

A total of 227 articles were found, and after an analysis of the title, abstract and study population there were 14 articles that met the inclusion criteria. The inclusion criteria took into account studies carried out in children with deciduous or mixed dentition in the first phase, case reports on pediatric patients who received treatment with 3D printed SM after premature tooth loss and for clinical purposes, comparative studies between conventional SM and digital SM. Exclusion criteria include: studies that use 3D printed materials in corrective orthodontic treatment in the permanent dentition.

8. Results

Of the selected articles, 10 studies used materials such as PEEK, PMMA and polymer (Trilor) in blocks and discs, which were milled for the production of anterior and/or posterior space maintainers, in the following 3 studies titanium powder was used by 3D printing techniques, by addition using a microlaser, for the production of these maintainers and finally 1 study that uses a zirconium block (BruxZir) to mill a posterior band type SM. Some of the relevant characteristics of these studies are presented in the following table.

Table of the relevant characteristics of the articles selected for the study:

Author(s) and year	Aim	ME work technique	Advantages and disadvantages
Ierardo G et al., 2017 [12]	To investigate the effectiveness and test the function of SMs made of PEEK for three children using digital workflow, CAD design system and CAM milling.	• Taking a conventional impression and making a plaster model. • Digitization using the extraoral scanner. • Preparation of space maintainers with CAD: wide band, lingual arch and removable plate. • Manufacturing using CAM: a PEEK block was used and milled until the devices were obtained.	✓ Comfort and acceptance by patients. ✓ Reduced processing time. ✓ Little plaque buildup and easy cleaning. ✓ Good biocompatibility; No allergies or tissue irritation were recorded. ✓ It remains stable and without fractures. ✗ Short-term follow-up (9 months). ✗ High price.
Matteo Beretta and Nunzio Cirulli, 2017 [39].	Preparation of a metal-free SM for a patient with special needs and to promote the eruption of the tooth 1.3	• Upper and lower models are obtained in STL file through intraoral scanning. • The personalized device (modified Nance) is designed using CAD on the imported superior model. • In the CAM manufacturing phase, a block of machined fiber composite called Trilor TM was used and milling was carried out to obtain the device.	✓ It does not contain metal and is aesthetic. ✓ Light and comfortable for the patient. ✓ Easy to clean. ✓ Short preparation time. ✗ High price

Soni HK., 2017 [35]	Fabrication of a metal-free band and loop space maintainer using the CAD/CAM system, after premature tooth extraction due to caries.	• Conventional impression taking with elastomeric material and the model was manufactured in plaster. • It was taken to the laboratory for the procedure using an extraoral scanner and CAD/CAM system. • For milling, the zirconia material (BruxZir) was used in bulk until the band and loop apparatus was obtained. • Finally, it was immersed in dye and sintered in the oven until the final device was obtained.	✓ Resistant due to its monolithic design. ✓ Accepted by the patient for comfort and aesthetics. ✓ It does not have metal; this way allergies or discomfort are avoided. ✓ Biocompatible, no gingival lesions were observed. ✗ High price ✗ Requires laboratory assistance.
Guo H. et al., 2020 [11]	To investigate the application of CAD/CAM for the design and manufacturing of in vitro PEEK removable space maintainers (RSMs) used in pediatric dentistry and evaluate the suitability of the technique for clinical applications.	• A standard plaster model was taken as a reference (first phase mixed model), the extraoral scan was performed. First, the digital model was designed with modifications, extracting the first and second deciduous molars. • The design of the RSMs continued using CAD with specialized software: 20 functional aesthetic RSMs. • The RSMs were manufactured using CAM and a block of PEEK material was milled. • Finally, the manufactured RSMs were evaluated in terms of fit, comfort, and effectiveness in clinical applications. The space between the tissue surface and the space maintainer was measured by 3D analysis of variance.	✓ Reduction in processing time, ✓ Better fit and resistance related to conventional MEs. ✓ Good suitability. ✗ High cost ✗ Limited color options.

Pawar BA., 2019 [42]	Investigate and present a new approach to manufacturing space maintainers using three-dimensional (3D) printing for a 7-year-old child.	• Conventional impression taking with added silicone and a plaster study model was obtained. • It was sent to the laboratory for extraoral scanning. • A band and loop SM was designed using CAD. • The device was printed with titanium-based powder metal material using microlaser sintering technology.	✓ Short processing time ✓ Obtaining a single device without welding, minimizing fractures ✓ Reduction of errors when manufacturing. ✓ You do not need to polish the device. × Higher cost than a conventional design. × Short-term follow-up (3 months)
Guo H. et al., 2020 [33]	Analyze the effectiveness and feasibility of the CAD/CAM design for the preparation of PMMA-based RSM in vitro for clinical application in pediatric dentistry and evaluate its suitability.	• A standard plaster model was used as a reference (first phase mixed model) and scanned extraorally, a digital model was created with modifications, where the first and second deciduous molars were removed. • In the digitally modified model, the design of the RSMs began using CAD with specialized software: 20 functional aesthetic RSMs. • The RSMs were manufactured using CAM, a block of PMMA material was milled. • Finally, the manufactured MERs were evaluated in terms of fit, comfort, and effectiveness in clinical applications. The space between the tissue surface and the space maintainer was measured by 3D analysis of variance.	✓ Decrease in the manufacturing process. ✓ Error reduction ✓ More stable, avoiding deformations and fractures. ✓ Better fit and resistance related to conventional SMs. × Higher cost than a conventional design.

Essawy K. et al., 2021 [43]	To evaluate the clinical performance of the PEEK polymeric material used for the elaboration of posterior fixed functional SMs using CAD/CAM technology for 30 children between 4 and 7 years old.	• The conventional impression was taken and a plaster study model was obtained. • The model was scanned extraorally. • The space maintainers were subsequently designed and manufactured using block PEEK which was milled.	✓ Greater resistance to fatigue and wear. ✓ It does not present color changes. ✓ Highly resistant device. × High price. × Short-term study (1 year).
Khanna S. et al., 2021 [44]	Analyze the use of 3D printing technology for the production of a band and loop SM when compared to a conventionally manufactured ME.	• A conventional study impression and model was obtained. • It was taken to the laboratory for extraoral scanning. • The band and loop model was designed using CAD software. • Through the additive manufacturing process with microlaser sintering technology, the 3D printed device was obtained.	✓ Greater cooperation on the part of the patient. ✓ Fewer number of citations. ✓ Highly biocompatible compared to conventional SM, less plaque accumulation and gingival inflammation. ✓ Better stability, without presence of fractures. ✓ Fine adaptation without occlusal interference. × Unprofitable. × Short-term follow-up (6 months).
Beretta M et al, 2022 [46]	To illustrate a new fully digital approach for temporary	• An impression was taken using an intraoral scanner. • The models were designed using CAD software: thin bands on the	✓ The bands are aesthetic without the presence of metals.

	rehabilitation in the case of premature loss of primary incisors, using a metal-free fixed orthodontic prosthesis made of polyether ether ketone (PEEK).	canines, pads on the lateral incisors, and the design of central abutments. • Manufacturing proceeded after milling the PEEK block.	✓ Comfortable for the patient. ✓ It is not necessary to prepare the anchor teeth. × Expensive × Its color is not similar to the tooth for placement in the anterior sector, therefore, it is not feasible to mill the structure and the teeth in a single piece.
Rodrigues LP et al., 2022 [45]	Describe a technique to digitally design and fabricate a CAD-CAM fixed space maintainer for growing patients awaiting prosthetic rehabilitation, illustrated in an 8-year-old child.	• Initially, an intraoral scan of both arches was performed before extracting the tooth. • He imported the file into CAD software, where he expertly proceeded to digitally extract the tooth. • Subsequently, the appliance was designed: SM as a posterior unilateral fixed prosthesis containing a pontic to replace the lost tooth and two clasps as retainers. • Its manufacturing process was carried out using CAM software, milling a block of PMMA. • Finally, the tooth was extracted atraumatically and the SM was placed.	✓ Greater collaboration on the part of the patient. ✓ Greater durability and mechanical resistance. ✓ Several copies can be made immediately in case of fractures. × Need for healthy, erupting teeth adjacent to the edentulous space.
Aboul Azm N et al., 2022 []	To study the clinical effectiveness and patient comfort of the	• Through intraoral scanning of both arches, digital models were obtained and sent to the laboratory. • The design was carried out in the band and loop type SM CAD	✓ Greater aesthetic acceptance and comfort for the patient. ✓ Reduction of time during the procedure.

	CAD/CAM PEEK space maintainer and compare it with the conventional band and loop space maintainer.	software, a hook was created on the first permanent molar and a minor connector. • For manufacturing, a PEEK disc was inserted for milling, finally the oral surfaces were micropolished and subjected to microsandblasting.	✓ Less plaque accumulation and gingival inflammation compared to conventional SMs. ✗ High cost equipment and manufacturing. ✗ Short-term follow-up (6 months).
Abdelshahed P et al., 2023 [48]	To evaluate two different SM CAD/CAM designs made of PEEk versus conventional belt and loop considering their effectiveness and failure rate.	• A digital impression was taken and working plaster models were obtained. • The models were scanned and the design was proceeded through the CAD software, two types of design were created, band and loop on the ridge line and another outside the ridge. • Finally, the device was manufactured using CAM, to extract the space maintainer from the PEEK disk through a subtractive process.	✓ Good fit to the tooth. ✓ Greater resistance and stability. ✗ The resistance to fracture will depend on the design, in this case the loop was shorter so it suffered fractures. ✗ Short-term follow-up (9 months).
Wang Q et al.,2023 [47]	To introduce a fully digital workflow to manufacture semi-rigid SM bridges using CAD/CAM technology and evaluate its clinical effectiveness, in 15 children between 4 and 8 years old.	• Conventional impressions were made, obtaining plaster work models which were scanned. • The files were imported into the software for the design of the SMs, a semi-rigid bridge was made that consisted of: two retainers; rigid crown or band and another type of non-rigid hook, pontic and connector. • Finally, the designs were sent to the CAM system to proceed with milling using PEEK discs.	✓ Greater satisfaction on the part of children and parents. ✓ Accepted mostly for its aesthetics and without the use of metals. ✓ Reduction in processing time. ✓ High resistance to wear and fracture. ✓ Good biocompatibility. ✗ Hygiene around the pontic is a bit complicated.

			× Short-term follow-up (6 months).
Tokuc M. and Yilmaz Hakan, 2022 [49]	In Vitro Study: Evaluate the fit of metallic band and loop space materials manufactured using conventional and 3D printing technology for clinical applications.	• Selection of intraoral impressions of children between 8 and 10 years old, who have lost a molar either unilaterally or bilaterally, the tooth has completely erupted and it is intact. • The images were sent in STL file for the manufacture of the device: band and loop. • Finally, we proceeded with the metallurgy printing of titanium powders using a 3D metal printer.	✓ Shorter processing time ✓ Weldless devices avoiding fractures. ✓ They have greater rigidity × High cost

9. Discussion

For years, conventional space maintainers have been an efficient option for maintaining adequate space in the dental arch after premature loss of a primary tooth. However, they present drawbacks such as gingival irritability, which can generate pain and discomfort in children. In addition, some components of the materials used in their manufacture can trigger allergic reactions [10].

On the other hand, DSMs offer a promising alternative, with the ability to provide a precise fit, greater comfort and more efficient fabrication since CAD/CAM technology and 3D printing are applied for their fabrication [10].

One of the first studies that evidenced the application of CAD/CAM technology and 3D printing for the elaboration of these devices was performed by Ierardo et al. (2017) [12], in this pilot study, they used PEEK material to make a wide band, a lingual arch and a removable plate in three children between 8 and 10 years old, after PDTL. The results were promising: patients experienced comfort and freedom from pain, the device was easy to clean and did not accumulate plaque. In addition, PEEK proved to be highly biocompatible, mechanically resistant, durable, lightweight and dimensionally stable. The results obtained in this study are in agreement with the findings of a randomized clinical trial conducted by Essawy et al. (2021) [43], in that study, unilateral band and loop type fixed space maintainers were applied to 30 children, and no significant differences were found in the evaluated parameters, such as color, anatomical contour and fractures at a follow-up of 3, 6 and 12 months.

The main 3D printing methods include SLA, sintering/selective laser melting (SLS), fused material deposition (FDM), powder metal printing (PMP), laminated object manufacturing (LOM), and inkjet and Polyjet 3D printing. In additive methods, such as FDM and SLS, material is added layer by layer to build the part, whereas, in subtractive methods, such as LOM and SLA, materials are removed by milling to create the desired shape. [28].

Pawar B. (2019) [42] was one of the first to explore 3D printing to fabricate band and loop type space maintainers by the additive method using titanium powder based metal and micro laser sintering. Their findings showed a reduction in time and errors during fabrication, along with no detachment or fracture of the device. These results align with another study by Khanna S. et al. (2021) [44] who compared DSM with conventional band and loop types, placing them in different quadrants of the same patient. They found that the DSM demonstrated excellent results, with no fractures or plaque accumulation, unlike the conventional which showed microfracture and depressions from occlusal forces. Despite the possible lack of cost-effectiveness of these devices, both studies suggest that their clinical benefits, together with their adaptability for uncooperative patients, may justify their cost.

Compared to the additive manufacturing process, subtractive processes, such as CAD/CAM milling, are slower and result in more material waste. However, some studies have been found that employed subtractive methods for DSM fabrication and achieved satisfactory results. One such study was conducted by Guo H. et al. (2020) [11] who carried out an in vitro investigation with the purpose of evaluating the suitability of RSMs using two methods: PEEK and conventional methods (20 per group). Their aim was to perform a comparative analysis of the fitting accuracy of each RSM. For this purpose, the gaps between the tissue surfaces of the RSMs and the models were filled with silicone and the maximum and mean distances, as well as the standard deviation, were measured by applying a vertical force of 20 N. A 3D variance analysis was used to measure these gaps. The results showed that RSMs made with PEEK presented a superior fit to conventional ones, possibly due to their manufacturing process. A parallel study by Guo H et al. (2020) [33], employing the same in vitro methodology, but using PMMA as the material for DSM impression, also yielded comparable results. These findings support the efficacy of materials such as PEEK and PMMA in the fabrication of these devices, and suggest the possibility of further clinical studies in this area. but in this case PMMA was used as the material for the impression of the RSMs, obtaining comparable results. These findings support the suitability of materials such as PEEK and PMMA for the fabrication of space maintainers, and suggest the feasibility of future clinical studies in this field.

A prominent advantage of DSMs lies in their usefulness in specific situations, such as those involving patients who require frequent examinations such as MRI scans while undergoing orthodontic treatment. This is evidenced in a study by Beretta and Cirulli (2017) [39], which describes the development of a metal-free DSM for special individuals, using a machined fiber-reinforced composite material known as Trilor. This device acted as a modified Nance device, proved ideal for its ease of cleaning, good aesthetics, being lightweight and safe, qualities especially appreciated in this group of patients. In addition, another study using a metal-free material was conducted by Soni K. (2017) [35] who fabricated a BruxZir Zirconia band-and-loop type SM and applied it in an 8-year-old patient. After a 6-month follow-up, no signs of gingival irritation or inflammation, occlusal interference, or fracture were observed. This supports the use of this material not only to improve esthetics, but also to ensure strength.

On the other hand, Rodrigues et al. (2022) [45] demonstrated improvements in both esthetics and functionality of the SMs. Using CAD/CAM technology and 3D printing with PMMA, they fabricated a fixed prosthetic SM for an 8-year-old boy after extraction of a first primary molar due to extensive caries. The digital technique employed was very effective, using an expert mode to design the appliance, which allowed immediate placement after the dental procedure. The choice of material was based on its durability and mechanical strength, qualities that were successfully achieved in this appliance. PEEK material has also been used for the fabrication of prosthetic SM. Beretta M et al. (2022) [46] conducted another relevant study in prosthetic appliance fabrication, creating an orthodontic fixed prosthesis using PEEK using a fully digital approach. The structure of the appliance included clasps on the canines and abutments for the anterior teeth, as the color limitation of PEEK does not make it suitable for the anterior sector. To solve this problem, resin crowns were fabricated to be placed on anterior abutments. On the other hand, a controlled clinical trial by Wang Q et al. (2023) [47] fabricated a PEEK-based semi-rigid posterior fixed prosthesis consisting of two retainers, one rigid and one non-rigid, placed either as bands or crowns depending on the condition of the tooth. However, a drawback is the difficulty of cleaning in the pontic area. Despite this, both studies highlighted excellent strength, biocompatibility and superior esthetics compared to conventional appliances, as well as low plaque accumulation and a lower propensity to fracture.

Finally, as could be observed in our review, most of the devices fabricated using CAD/CAM technology and 3D printing have opted for PEEK as their main material. However, certain limitations have also been identified, as previously mentioned, such as the color discrepancy that affects its applicability in the anterior region of the mouth. Furthermore, drawbacks were observed in a study by Abdelshahed P. et al. (2023) [48], who conducted a controlled clinical trial with three groups: one conventional (group 1) and the other two fabricated with PEEK. In the latter, the difference was in the placement of the loop, one contouring the crestal surface (group 2) and the other located outside it (group 3). Two failures were recorded in group 1 and 2, both associated with fractures at 6 and 9 months follow-up, respectively. The study concluded that the fractures in the PEEK SMs could be due to their design, as those that suffered fractures were those with a shorter length compared to those in group 3. Despite this situation, this study considers PEEK SMs as a valuable alternative for use.

10. Conclusion

The results obtained by using CAD/CAM technology and 3D printing, together with advanced materials to fabricate DSMs, are highly promising. Patient comfort, reduced fabrication time and significant aesthetic improvements have been highlighted as advantages. In addition, fabrication of devices in one piece has been beneficial as this has provided greater strength, biocompatibility and stability. However, cost could represent a limitation to its widespread adoption, as well as the need to acquire specialized equipment and technology, in addition to having trained personnel for the fabrication of DSMs and although the lack of long-term studies and the scarcity of comprehensive research employing CAD/CAM in their fabrication is acknowledged, it is expected that more research will be conducted in the future to further explore the potential and benefits of this technology in the field of DSMs.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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