Modified ZeroExpander for patients with MIH and HSPM

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Abstract

Background Hypomineralisation of the first permanent molars (MIH) and second deciduous molars (HSPM) is an increasingly prevalent structural problem in paediatric patients. At the same time, the transverse palatal deficit is frequently found in that age group and necessitates early intervention. The purpose of this work is to present three new designs of the ZeroExpander, specifically developed for patients with hypomineralised teeth, which would otherwise be challenging to engage during orthodontic treatment.
Case report The ZeroExpanders for hypomineralised teeth are customized devices, digitally designed and produced from technopolymer. They feature overlay bands that fit over the hypomineralised teeth, combined with bioactive cements that facilitates continuous remineralisation of the dental enamel. These devices apply light forces within a pre-programmed, automatic expansion framework. Three examples of ZeroExpanders are presented: one for patients with both MIH and HSPM, one for MIH alone, and one for HSPM alone. Additionally, a case is illustrated where a patient with MIH in the early permanent dentition was successfully treated.
Conclusion The modified ZeroExpanders help preserve the integrity of both directly and indirectly involved hypomineralised teeth, including those in the lower arch. The workflow is effective and efficient, and they have the same level of effectiveness as the standard ZeroExpanders in terms of achieving the programmed expansion.

KEYWORDS Molar incisor hypomineralisation, hypomineralised second primary molar, intraoral scanner, automatic palatal expansion, digital paediatric orthodontics, metal-free orthodontics, self-driving orthodontics, bioactive restorative materials.

Introduction

Molar Incisor Hypomineralisation (MIH) is a developmental and qualitative defect of the enamel, characterised by reduced mineralisation and, in some cases, hypoplasia [Lygidakis et al., 2010]. This defect occurs during the enamel calcification phase and, unlike other forms of enamel hypomineralisation, begins at the dentine-enamel junction and progresses towards the enamel surface. Mild lesions are confined to the innermost enamel, while more severe lesions affect the entire thickness of the enamel. The affected enamel has 20% less mineral content and has 3 to 15 times more proteins than healthy enamel [Almuallem and Busuttil-Naudi, 2018]. MIH primarily affects the first molars and permanent incisors. The defects ranged from white or yellow in mild cases to yellow-brown in more severe forms. Well-demarcated opacities can affect both the occlusal and buccal/lingual/palatal surfaces of the crown, with the tooth neck remaining unaffected. The defects vary in shape and size, thickness, and extent, and may be confined to a small area or involve almost the entire crown. In some cases the defect becomes no longer visible, when the affected tissue has a high degree of porosity, causing the enamel to disintegrate under the pressure of masticatory forces. This phenomenon, known as Posteruptive Enamel Breakdown (PEB), exposes the underlying dentin, which is more susceptible to decay. In other cases, atypical conservative treatments are detected, or early molar extractions may be documented in the patient's medical history [Lygidakis et al., 2010]. The severity of a case with MIH depends on the number of teeth affected (with all molars and incisors potentially involved) and the severity of each defect. Several classifications have been proposed, with the most recent and comprehensive being the Molar Incisor Hypomineralisation - Severity Scoring System (MIH-SSS) [Cabral et al., 2020]. However, the Mathu-Muju and Wright classification (Tabl. 1) is widely used in both research and clinical practice, and was therefore selected for this study [Mathu-Muju and Wright, 2006]. MIH has become a significant health concern, with its incidence and, consequently, prevalence increasing worldwide [Schwendicke et al., 2018]. As a result, severe forms of MIH are becoming more prevalent, accompanied by related complications:

- porosity favours dental hypersensitivity. The discomfort reported by the patients may be spontaneous or triggered by thermal or mechanical stimuli. Depending on its intensity, hypersensitivity can be considered a barrier for the implementation of effective oral hygiene leading to an accumulation of plaque and increased susceptibility to carious lesions. Additionally, hypersensitivity can complicate the administration of local anaesthesia, which may increase patients' anxiety and cause behavioural issues during clinical procedures, thus the treatment of affected molars becomes a challenge [Raposo et al., 2019; Linner et al., 2021];
- tissue affected by MIH is fragile and prone to breakdown. PEB especially occurs in molars with brownish opacities, both during eruption and subsequently under masticatory forces. This phenomenon tends to worsen over time, leading to the exposure of large areas of dentin near the pulp [Neves et al., 2019];

Mild MIH	Moderate MIH	Severe MIH
• There are isolated opacities. • Demarcated opacities are in nonstress-bearing areas of the molar. • No enamel loss from fracturing is present in opaque areas. • There are no caries associated with the affected enamel. • There is no history of dental hypersensitivity. • Incisor involvement is usually mild if present.	• Demarcated opacities are present on occlusal/incisal third of teeth without posteruptive enamel breakdown. • Posteruptive enamel breakdown/caries are limited to 1 or 2 surfaces without cuspal involvement. • Intact atypical restorations can be present. • Dental sensitivity is generally reported as normal. • Aesthetic concerns are frequently expressed by the patient or parents.	• Posteruptive enamel breakdown is present and frequently occurs as the tooth is emerging. • Crown destruction can readily advance to involve the dental pulp. • Frequently, widespread caries experience is associated with the affected enamel. • Defective atypical restoration is present. • There is a history of dental sensitivity. • Aesthetic concerns are expressed by the patient or parents.

TABLE 1 MIH classification proposed by Mathu-Muju and Wright. The authors developed a useful nomenclature for assessing the severity of MIH, which describes three clinically progressive types of lesions from mild MIH up to severe MIH.

- caries experience is high, especially in areas where patients are unable to brush due to hypersensitivity and where dentine is exposed. Furthermore, it could be difficult for the clinician to distinguish between tissue affected by non-carious MIH and tissue with carious MIH [Bullio Fragelli et al., 2015];
- adequate restorations cannot be maintained over time because the PEB phenomenon tends to recur [Neves et al., 2019]. Consequently, objective difficulties arise when these teeth need to be involved in orthodontic treatments.

Luckily, topical products such as mousses, varnishes, toothpastes, etc. which are based on fluoride, casein or other remineralising agents can help as secondary and/or tertiary prevention [Kumar et al., 2022; Olgen et al., 2022; Enax et al., 2023]. In the last years, features similar to MIH have also been observed in primary teeth. The hypomineralisation can affect deciduous canines (Hypomineralised Primary Canines – HPC) and/or second deciduous molars (Hypomineralised Second Primary Molars – HSPM). These teeth show the same clinical manifestations and complications of those with MIH. Besides, the presence of HPC and HSPM is predictive of MIH [Garot et al., 2018].

Young patients with hypomineralised teeth may be also affected by orthodontic problems. An absolute or relative transverse palatal skeletal deficit is a daily challenge for orthodontists [Lombardo et al., 2020]. Over time, many fixed palatal expanders have been proposed, both those that expand the palate rapidly (e.g. Hyrax, mini-Hyrax, Haas, McNamara, Fan-type and expanders with differential opening) [AAVV, 1994; Silveira et al., 2021; Haas, 1970; Wendling et al., 2005; Massaro et al., 2021] and those that expand the palate slowly (e.g. Espansore Lento Ammortizzato – ELA, Leaf Expander, Self Leaf Expander) [Lanteri et al., 2016; Beretta et al., 2019]. Their metal structure could be eventually integrated by resin pads or occlusal planes [Haas, 1970; Wendling et al., 2005]. These traditional models can be manufactured with 3D technology if a laboratory scanner or an oral scanner is available (hybrid or full digital workflow) [Battista et al., 2020; Federici Canova, 2021]. The latest expansion appliance is the ZeroExpander proposed by Beretta et al. [2021]. It is a completely novel device, created using a fully digital workflow, and is both custom-made and metal-free. It is digitally designed based on a virtually expanded upper arch, with the anchor teeth selected according to the treatment requirements, and subsequently produced in technopolymer, polyether ether ketone (PEEK) or polyamide 12 (PA12). The design is minimalistic, following the "less is more philosophy": the bands or, more commonly, hemibands are placed on the second deciduous molars or, sometimes, on the first permanent molars, and are connected by an expansion bar with an Ω loop, which contracts during cementation and self-expands over time, applying a force of approximately 450 grams [Beretta et al., 2021; Beretta et al., 2022; Paglia et al., 2022]. Alternatives for skeletal expansion in childhood could be removable appliances, but they require a significant patient cooperation for a longer time, and expanders on miniscrews, which are not always accepted by the parents of paediatric patients.

The aim of the study was to propose fixed expansion devices specifically aimed at patients with MIH, HSPM or both. Expanders on miniscrews were excluded because of the young age of the patients. Other types of devices should necessarily be fixed to hypomineralised teeth, but at the same time they must exert as little stress as possible on the involved teeth, aiming to preserve or even support their structural integrity. The protection of other hypomineralised teeth (including the antagonistic ones) was also considered, even if they were not directly involved in the device. At the same time, the possibility of applying remineralisation protocols was ensured.

Modified ZeroExpander prototypes

Three prototypes were configured as a specific evolution of the ZeroExpander. ZeroExpander means a new point zero, customisable according to the needs of each patient [Beretta et al., 2021]. The principles taken from the ZeroExpander are:

- the fully digital workflow, as the digital revolution is nowadays a reality [Beretta et al., 2022];
- the application of slow forces in a self-expansion context by means of an Ω loop, whose activation does not require parents' collaboration;
- the production in latest-generation materials such as technopolymers. PA12 is better than PEEK because small post-production changes can be applied. Furthermore, PA12 binds with different types of adhesives, and it is more suitable for active devices, whereas PEEK is indicated for passive ones [Paglia et al., 2022];
- the possibility of customising the design of the expander itself.

Compared to the first ZeroExpander model, a new design of overlay bands was proposed, which almost completely cover the crown of the hypomineralised teeth, except for the neck area, which is not tipically affected by the structural defect. Considering the high risk of PEB, these bands are designed to preserve tooth structure, provide protection against friction with the antagonist teeth during expansive dental movements, and simultaneously deliver remineralising

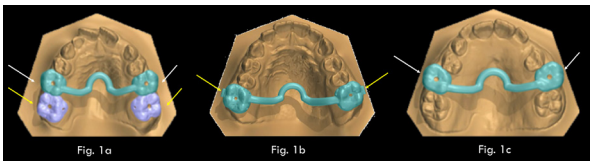

FIG. 1 Examples of modified ZeroExpanders. The modified ZeroExpander – prototype 1 for patients with both HSPM and MIH (a) has overlay bands on 55 and 65 (white arrows) and additional PA12 overlays on 16 and 26 (yellow arrows). The modified ZeroExpander – prototype 2 for patients with MIH (b) has overlay bands on 16 and 26 (yellow arrows). The modified ZeroExpander – prototype 3 for patients with HSPM (c) presents overlay bands on 55 and 65 (white arrows).

substances. Their surface features small additional holes through which excess bioactive cement [Beretta et al., 2023] can flow during the cementation phase. By means of these holes the bioactive cement also remains exposed and recharges with remineralising substances, when they are applied at home and in professional settings [Kumar et al., 2022; Olgen et al., 2022; Enax et al., 2023]. The appliance design can be further customised depending on specific clinical needs, for example with tubes on the bands, where engage orthodontic arches or an extraoral traction, or with facial mask hooks, etc. If the antagonistic elements present severe MIH, they can also be protected with PA12 overlays, if the patient is not hyperdivergent. The three typologies of modified ZeroExpander were designed on three possible clinical settings of hypomineralisation.

- Prototype 1: The first clinical setting includes patients with moderate or severe MIH (Tabl. 1) on the upper first permanent molars, which have either already experienced PEB or are currently affected by PEB, and, simultaneously, with HSPM in the upper arch. In this case the modified ZeroExpander provides overlay bands on the second deciduous molars (Fig. 1 a, white arrows). In addition, separated PA12 overlays are printed and cemented on the first permanent molars, to protect them during the expansion phase (Fig. 1 a, yellow arrows). If the patient is not hyperdivergent, these covers can be left in place even after the ZeroExpander has been removed so that they continue to contain and keep compact the precarious dental coronal structure.
- Prototype 2: The second clinical setting includes patients with moderate or severe MIH (Tabl. 1) on the upper first permanent molars, which have either already experienced PEB or are currently affected by PEB. The second deciduous molars cannot be used as anchorage because they are close to exfoliate or are absent due to an early loss due of caries, resorptions, breakdowns, etc. In this case, the modified ZeroExpander provides overlay bands directly on teeth 16 and 26 (Fig. 1 b, yellow arrows). Following the expansion phase, if the patient is not hyperdivergent, it is possible to cut the Ω loop with small sterile scissors and keep the bands to protect the molars.
- Prototype 3: The third clinical setting includes patients whose first permanent molars have mild MIH (Tabl. 1) or are not affected by hypomineralisation, but whose second deciduous molars are hypomineralised. In this case the modified ZeroExpander includes only overlay bands on teeth 55 and 65 (Fig. 1 c, white arrows). No specific treatment is required for the first permanent molars, except, eventually, the application of topical remineralising products, including toothpastes, gels, mousses and varnishes [Kumar et al., 2022; Olgen et al., 2022; Enax et al., 2023]. The following case report shows the working steps common to the three types of modified ZeroExpander described above.

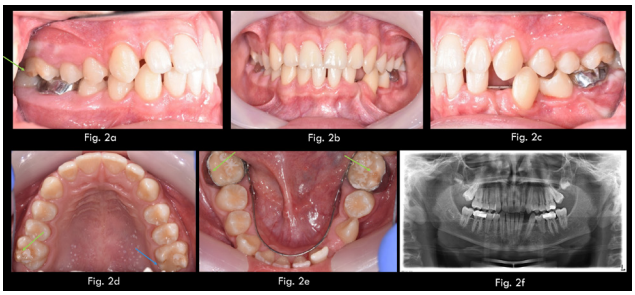

FIG. 2 Orthodontic records at T0. Intraoral photographs: right lateral (a), frontal (b) and left lateral (c) views; occlusal views of the upper (d) and lower (e) arches. Light green arrows indicate PEB of different entities of 16, 36 and 46; a light blue arrow points to a restoration on 26 to be replaced. Orthopanoramic view of the dental arches (f).

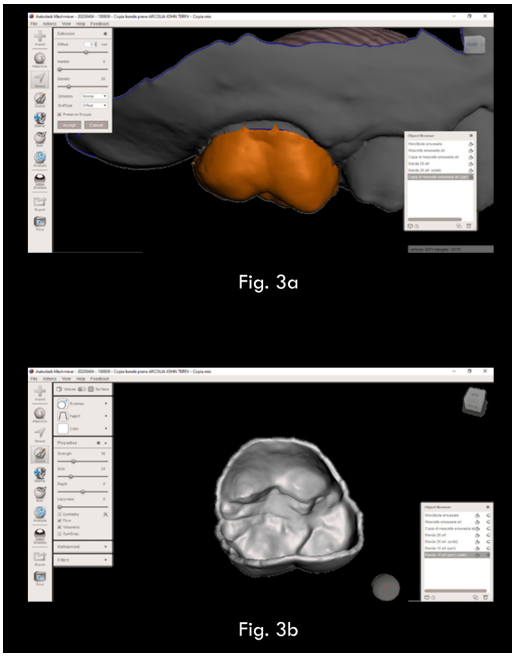

FIG. 3 Band for 16 proposed via an open-source software.

Case report

Patient selection and preparation

Orthodontic records should be collected as a preliminary phase. Conservative and endodontic treatments, if indicated, should be performed before orthodontic therapy. Then, new digital scans are needed for the device project.

A.J.T., a 12 years-old patient with MIH, was in treatment at the dental clinic of the Spedali Civili in Brescia since a cyst in the left lower jaw and element 34 were removed 4 years before. The records collected before starting the orthodontic fixed appliance treatment were the following: intraoral photographs (Figs. 2 a-e), intraoral scans, orthopantomography (Fig. 2 f) and latero-lateral teleradiography of the skull.

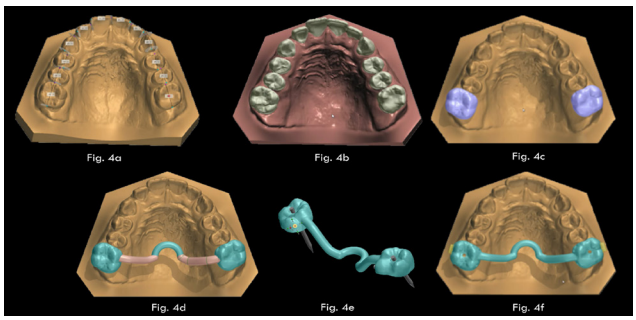

FIG. 4 Preparation and segmentation of the digital cast (a). Design of the modified ZeroExpander (b-f): digital expansion (b), design of the overlay bands (c), insertion of the Ω loop and palatal arms (d), creation of the holes in the overlay bands (e) and addition of any auxiliaries (f).

Elements 16 and 36 showed PEB phenomena on the vestibular surfaces and element 46 was minimally disintegrated next to the vestibular sulcus (Fig. 2 a, Fig. 2 d, Fig. 2 e, light green arrows), besides the composite restoration of 26 was no longer congruent (Fig. 2 d, light blue arrow). Therefore, new conservative restorations were made on 16, 26 and 36 before taking new intraoral scans for the appliance.

Preliminary project of the bands for the dental technician

The preliminary project design of the bands by the orthodontist is an optional but recommended step because it improves communication with the dental lab.

For this clinical case Autodesk MeshMixer®, which is an open-source software [Federici Canova et al., 2021], was used and three-dimensional STL models of the overlay bands for teeth 16 (Fig. 3) and 26 were sent to the dental technician.

Digital project of the modified ZeroExpander

The overall digital project of the modified ZeroExpander takes place in a dental laboratory.

For this clinical case, 3Shape Dental Designer Software (3Shape, Denmark) was used for digital casts preparation, segmentation phase (Fig. 4 a) and digital design of the modified ZeroExpander (Figs. 4 b-f). Several sub-phases were needed such as the expansion of the upper arch on the digital cast, taking the lower arch as reference (Fig. 4 b); the definitive design of the bands perpendicularly to the occlusal plane, with shell thickness of 0.9 mm and offset of 0.05 mm for bonding space (Fig. 4 c); the position of the Ω loop along the maxillary midline – sized based on both expansion needed and palatal dimensions – and the design of the connection arms (Fig. 4 d); the creation of the holes in the bands trough DrillHole function of 1.6 mm (Fig. 4 e) and the insertion of vestibular tubes as additional elements (Fig. 4 f). The parts were joined together, so that a single STL file was sent to production (Fig. 4 f).

Production of the modified ZeroExpander

Production takes place in a specialised centre/laboratory. Usually, two devices are supplied to the patient; the cemented device and a spare one.

Figs. 5 a-b shows the modified ZeroExpander for A.J.T.

Cementation of the device

The modified ZeroExpander is cemented by the orthodontist.

The steps for device cementation were as follows: after intraoral try-in, the sterilised ZeroExpander was minimally remodelled (Fig. 6 a); the adhesive system Transbond™ XT Light Cure Adhesive Primer (3M Unitek, USA) was used on the device (Figs. 6 b-c); at the same time teeth 16 and 26 were cleaned and etched (Figs. 6 d-e); the adhesive system Transbond™ XT Light Cure Adhesive Primer (3M Unitek, USA) was also applied to the tooth surfaces (Figs. 6 f-g); the bioactive cement Activa Bioactive Cement (Pulpdent, USA) was dispensed directly into each overlay (Fig. 6 h), the excess was removed and the material was light-cured (Figs. 6 i-j). The occlusal surfaces of the two bands should be protected to prevent premature deterioration: the same adhesive used for cementation was employed (Fig. 6 k) and light-cured (Fig. 6 l), then a chromatic composite was applied (Fig. 6 m) and light-cured (Figs. 6 n-o). Alternatively, a bulk composite material can be used.

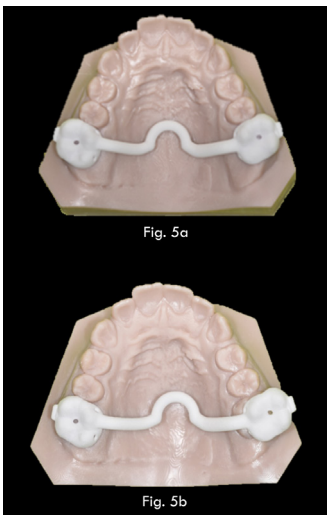

FIG. 5 Modified ZeroExpander on an expanded model (a) and on an unexpanded model (b). Figure b shows the extent of the desired expansion.

Clinical controls and application of fluoride products

The patient is asked to follow a program at home with remineralising toothpastes and mousses or gels. In addition, professional applications of topical remineralising products are performed at each clinical follow-up.

In this case, the patient was instructed to use both Curasept Biosmalto toothpaste (Curasept S.p.A., Saronno, Italy) almost twice per day for at least 2 minutes and Curasept Biosmalto mousse (Curasept S.p.A., Saronno, Italy) almost once per day at home, whereas Embrace™ Varnish (Pulpdent, USA) was professionally applied monthly (Fig. 6 p). At the third follow-up, brackets were bonded on the buccal side with a direct technique. The deflection of the arch between teeth 25 and 26 shown in Fig. 7 a was indicative of the expansion obtained.

Device removal

During device removal, it is advisable to avoid the direct use of a band remover instrument in order to prevent excessive stress on the precarious dental structure. Bands of modified ZeroExpander of type 1 or 2 can be eventually left in place, as previously mentioned.

In this clinical case, the bands were cut with a bur (Fig. 7 c) and progressive de-cementation was performed with the aid of an ultrasonic instrument (Fig. 7 d).

Regarding this clinical case, the expansion was successful (Fig. 7 b, Fig. 7 e). The printed tubes proved to be an effective and efficient choice, as a 014 Niti archwire was inserted and, within just one month, they guided the lateral-posterior teeth of the right side and, above all, on the left side, to a more buccal position. Once the device was removed, the teeth

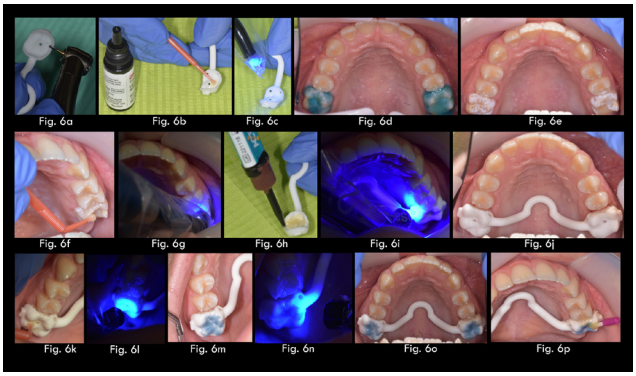

FIG. 6 Steps for device cementation: small adjustments after intraoral try-in (a), adhesive system on the appliance (b-c), etching of 16 and 26 (d-e), adhesive system on the tooth surfaces (f-g), bioactive cement (h) and light curing (i-j), adhesive system (k-l) and occlusal composite on the overlay bands (m-o). Applications of fluoride varnishes immediately began (p).

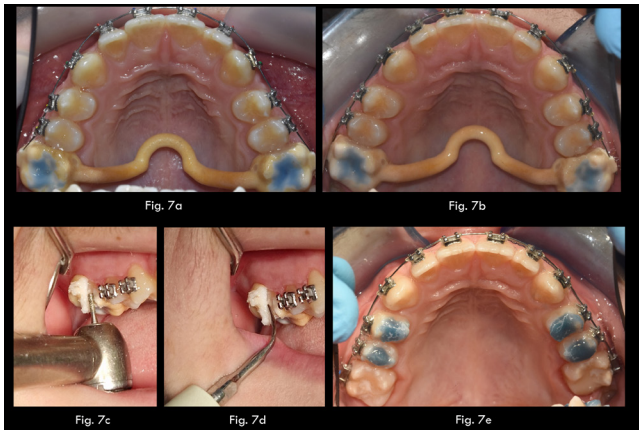

FIG. 7 Intraoral occlusal views of the upper arch at the beginning of the fixed orthodontic therapy (a), immediately before (b) and after (e) modified ZeroExpander debonding. Removal was performed with a cylindrical bur to section the overlay bands (c) and with the use of an ultrasonic instrument (d).

directly involved and their antagonists did not exhibit further PEB phenomena. No clinical or management problems were encountered with the modified ZeroExpander: no de-cementations, no discomfort, no adverse effects on the temporomandibular joint, and no difficulties in home oral hygiene in combination with the daily protocols prescribed for remineralisation.

Discussion and conclusion

The work aimed to propose three new typologies of ZeroExpander [Beretta et al., 2021] to obtain the transversal optimisation of the upper arch, which is a widespread need in paediatric orthodontics [Malandris and Mahoney, 2004; Lombardo et al., 2020], in patients affected by MIH [Lygidakis et al., 2010] and/or HSPM [McCarra et al., 2022]. The workflow before device cementation is fully digital, using new technologies and their associated possibilities [Battista et al., 2020; Federici Canova, 2021]. The advantages of the modified ZeroExpanders lie in the field of paediatrics, orthodontics and logistics. The primary goal is the maximum preservation of hypomineralised teeth. Firstly, the customised digitally designed overlay bands contain the fragile coronal structure, except for the unaffected neck area, preserving its integrity. Secondly, the protocol requires that the bands, which have small holes, are fixed using a bioactive cement, which remineralises the tooth structure by releasing ions and molecules, and reduces the risk of caries by interfering with bacterial metabolism. In addition, the application of dedicated topical products ensires a constant replenishment of remineralising substances. The third aspect that contributes to teeth preservation is the low expansion force of approximately 450 grams, similar to that applied by the screws of slow expanders, such as the Leaf Expander and the Self Leaf Expander [Lanteri et al., 2016; Beretta et al., 2019]. Fourthly, if the chromatic composite covers become worn, the brittle PA12 material will be reduced by the antagonist teeth, even if affected by MIH, and not vice versa. Finally, the simple device design facilitates effective good oral hygiene at home, indirectly preserving hypomineralised teeth and leaving patients with more time to focus on the remineralisation protocols. At the same time, the expansion is effective and efficient. Both a dental and skeletal transverse expansion of the upper arch is obtained, as demonstrated for the basic model of the ZeroExpander [Beretta et al., 2021] and, more generally, in the literature on slow expansion devices [Lanteri et al., 2016; Beretta et al., 2019]. The extent of expansion is programmed at the putset and, if it is more than 6 mm, two devices will be used consecutively. No collaboration from the patient's family is required. The workflow is both effective and efficient. Intraoral scans allow to directly capture models for both case study and device design, without discomfort for the patient, without the need for impression materials or trays and without physical casts to store. However, if desired, 3D printed casts can be requested. The digital design enables great cooperation between orthodontist and dental technician, even remotely. The clinician can preliminarily design the bands using an open-source software [Federici Canova et al., 2021] and send the STL files. Furthermore, the clinician can connect via videocall with the dental technician and follow all the project phases using the screen sharing option. Since the fabricated device is customised, it hardly requires major corrections before cementation. If the intraoral try-in reveals minimal overlaps between the bands and the mesial/distal teeth, they can be easily removed with a bur. Further holes on the bands can be added with the same bur. Besides, a second device copy is available in case the first one breaks or deteriorates; alternatively, it is possible to send again the same project for the printing process.

On the other hand, some critical aspects emerged. From the technical management point of view, device removal presents some difficulties as it requires cutting the bands with a bur to preserve the dental structure; however, the procedure takes only a few minutes. More generally, more performing technopolymers should be investigated. Polyamide 12 is biocompatible, can be 3D printed from an STL file, is sterilisable, can be combined with common dental adhesive systems, and is suitable for use in active devices in the oral cavity due to its elasticity and shape memory. Devices that are produced with this material can be kept in place during MRI scans; besides they are radiolucent, and they do not create overlaps or scattering phenomena in common dental radiological investigations [Beretta et al., 2021; Beretta et al., 2022]. However, despite the addition of stabilisers, the properties of PA12 tend to deteriorate, leading to increasing fragility and risk of overlays wearing out in the friction zones with the antagonist teeth, as well as yellowing. Furthermore, it is not currently possible to design an expansion loop greater

than 6 mm using this material [Beretta et al., 2021]. Finally, it must be considered that the ZeroExpander is a recently introduced device, with limited scientific literature available on the subject, so further limitations could emerge.

In conclusion, the ZeroExpander in PA12, modified with perforated overlay bands, cemented with a bioactive cement, has proven to be an effective device in this clinical case to protect teeth with MIH and/or HSPM, ensuring the expansion of the upper arch. Simultaneous remineralisation protocols are recommended. The device is particularly indicated for patients with special needs.

Authors' statement

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Authors' contributions

G. B. gave substantial contribution to conception and design of the three new prototypes of modified ZeroExpander, supported by M.B., F.F.C. and D.D. G.B. and S.B. carried out the clinical case. G.B. and I.T. wrote the manuscript; M.B. and F.F.C. performed manuscript critical revision. All authors read and approved the final version of the manuscript.

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