

Optimization of Orthodontic Treatment for Maxillary Constriction in Children Using Direct 3D Printing of Appliances

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Abstract

Objective. To evaluate the effectiveness and advantages of orthodontic appliances fabricated by direct 3D printing for the treatment of maxillary constriction in children compared to the traditional method. **Materials and Methods.** The study included 30 children aged 8–10 years with transverse maxillary constriction and unilateral or bilateral posterior crossbite. Patients were randomly divided into two equal groups (n=15 each). In the control group, a conventional fixed palatal expander (Haas/Hyrax type) was used, fabricated in the laboratory with standard orthodontic bands. In the study group, an analogous appliance was designed digitally and manufactured using direct 3D printing from cobalt-chromium alloy. The parameters assessed included appliance fabrication time, number of visits required for placement, need for separator rings, patient comfort (pain VAS and questionnaire), and clinical outcomes of maxillary expansion based on dental models and CBCT data before and after treatment. **Results.** Both methods successfully eliminated maxillary constriction in all patients. However, the 3D-printed group achieved significantly greater expansion (intermolar width increase of +7.3 mm vs +5.5 mm, $p=0.02$) and a more pronounced increase in nasal cavity width (though the difference was not statistically significant, $p=0.10$). The digital workflow eliminated the need for separator rings and appliance adjustment during placement, reducing fabrication time (7 vs 14 days) and the number of visits. Subjective discomfort was significantly lower in the 3D group (pain intensity 3.0 ± 1.2 vs 4.5 ± 1.0 points, $p<0.05$), which correlated with the absence of the separator stage and superior appliance fit. **Conclusions.** Direct 3D printing of palatal expanders optimizes the treatment of maxillary constriction in children by shortening treatment timelines, simplifying clinical stages, and improving patient comfort without compromising clinical outcomes. The findings support the promising role of digital technologies (CAD/CAM and 3D printing) in pediatric orthodontics for narrow maxillary arches.

Keywords: Maxillary Constriction, Palatal Expander, 3D Printing, Orthodontics, Children, Haas, Hyrax, Posterior Crossbite

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Introduction

The formation of normal maxillary width during childhood is crucial for the proper development of the dentofacial system. It is well known that the main growth peak of the maxilla is completed by approximately 9–10 years of age. Therefore, frequent nasal congestion, adenoid hypertrophy, allergic reactions, and mouth breathing during this period often result in insufficient transverse growth (constriction) of the maxilla. Timely maxillary expansion is one of the primary tasks of pediatric orthodontics and is among the most common interventions in children aged 6–9 years.

Rapid maxillary expansion (RME) using a fixed expander (Haas, Hyrax, or similar) anchored on deciduous molars and canines is the method of choice for correcting maxillary constriction [1]. The active expansion phase usually lasts 1–2 months and effectively eliminates posterior crossbite. The appliance remains in place for approximately one year for stabilization and to prevent relapse. It is preferable to perform such treatment before the age of 10 years, while the midpalatal suture is still patent. After 12–15 years, the effectiveness of conservative expansion decreases significantly, and severe cases may require skeletal anchorage or surgical assistance (surgically assisted rapid palatal expansion) [2].

The conventional fabrication of a palatal expander involves taking impressions and laboratory construction of the base with a screw and metal bands on the supporting teeth. Prior to appliance placement, elastic separator rings are traditionally placed to create space for the bands, which prolongs the preparatory phase and causes discomfort for the child. Moreover, prefabricated bands often do not perfectly fit deciduous molars, requiring additional adjustment.

In recent years, digital technologies have significantly improved this process [3]. 3D printing now allows enhancement of the classic appliance design, simplifying both fabrication and clinical use. The digital protocol includes scanning of a dental model or direct intraoral scanning, virtual design in CAD software, and additive manufacturing of the appliance. In this study, we used 3D printing of a photopolymer model followed by casting of a metal framework from Co-Cr alloy. This produced a monolithic metal framework that precisely replicates the patient's palatal anatomy [4]. The resulting appliance offers excellent fit, requires no chairside adjustment, and eliminates the need for separator rings. Additive manufacturing ensures structural homogeneity without soldering joints or porosities. Additionally, the CAD/CAM approach enables patient-specific design (e.g., customization of support teeth number and position), and the overall fabrication time is substantially reduced.

Nevertheless, clinical data on the advantages of direct 3D-printed palatal expanders in pediatric orthodontics remain limited. This study compares the outcomes of orthodontic treatment of maxillary constriction in children using 3D-printed appliances versus the conventional method, analyzing fabrication time, accuracy, patient tolerance, and dentoskeletal changes [5].

Materials And Methods

Study Design. A single-center prospective randomized controlled study was conducted. Inclusion criteria: children aged 8–10 years with diagnosed maxillary constriction (negative difference between upper and lower intermolar widths) and posterior crossbite. Exclusion criteria: previous orthodontic treatment, congenital craniofacial anomalies, severe crowding requiring extractions, or absence of key supporting teeth.

Thirty patients were randomly allocated into two groups of 15 each. In Group 1 (control), a conventional Haas-type (or Hyrax) palatal expander was used, fabricated in the laboratory with an acrylic base, central expansion screw, and metal bands on the deciduous second molars and canines. In Group 2 (experimental),

an identical design was employed but manufactured using a digital workflow. For each patient in Group 2, the working model was scanned, the appliance was virtually designed in CAD software considering individual palatal anatomy, and the framework was produced by 3D printing of a photopolymer pattern followed by cobalt-chromium casting. A plastic (acrylic) base was then added to the metal framework.

Treatment Protocol. Screw activation was identical in both groups: $\frac{1}{4}$ turn (0.25 mm) twice daily, performed by parents at home. The active expansion phase continued until slight overcorrection (supraocclusion of the upper molar cusps) was achieved, lasting 3–5 weeks (average 4 weeks). After active expansion, the screw was blocked with composite, and the appliance was retained for at least 6 months. Patients were monitored every 4–6 weeks. The appliance was removed after 6–8 months, followed by a removable retention plate worn at night.

Outcome Assessment. Measurements were taken at baseline (T1) and after appliance removal (T2):

- Intermolar width (between mesiobuccal cusps of the first permanent or second deciduous molars);
- Transpalatal width (CBCT);
- Nasal cavity width (minimum distance between lateral walls on CBCT);
- Maxillomandibular width difference;
- Molar inclination angle.

Patient experience was evaluated using a visual analog scale (VAS) for pain one week after activation began and an overall comfort questionnaire at T2.

Statistical Analysis. Data are presented as mean $\pm$ standard deviation. Student's t-test and Fisher's exact test were used. Significance level was set at $p < 0.05$.

Results

Patient Characteristics. Both groups were comparable in age (9.3 ± 1.0 vs 9.2 ± 1.1 years, $p = 0.81$) and sex distribution. All patients had maxillary constriction (2–5 mm deficit) and posterior crossbite. Baseline measurements did not differ significantly between groups ($p > 0.5$) (Table 1).

Treatment Process Comparison. Significant advantages were observed in the 3D-printed group (Table 2). Fabrication time was reduced from 14 ± 2 to 7 ± 1 days. The need for separator rings and band adjustment was completely eliminated. No adjustments were required during placement in Group 2, whereas 33% of cases in Group 1 needed band modification. Appliance debonding occurred in 3 patients (20%) in Group 1 during retention, but none in Group 2 [6].

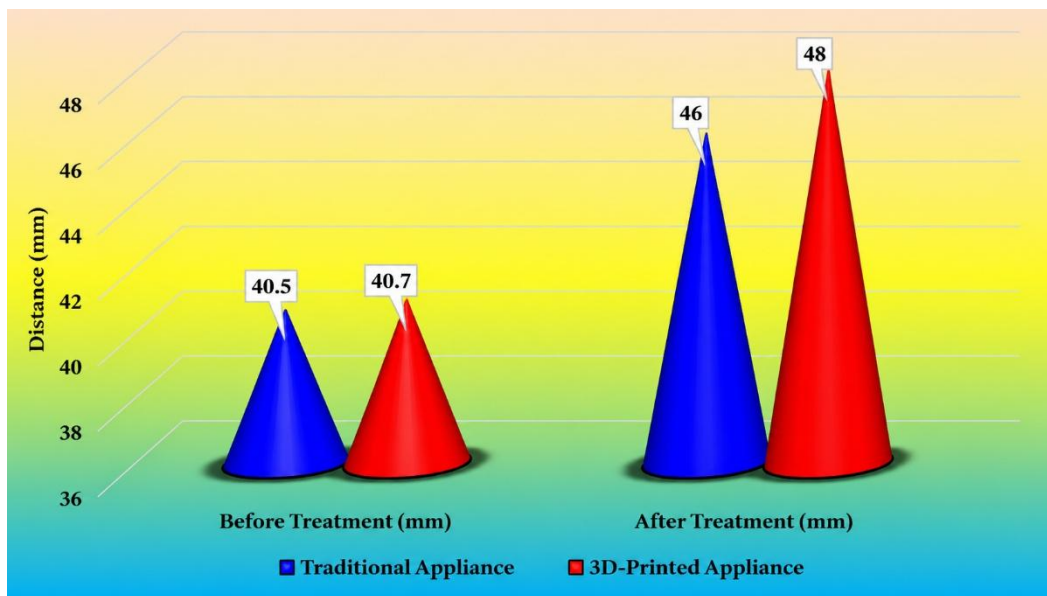


Figure 1. Mean maxillary width (intermolar distance) before and after treatment in the traditional and 3D-printed appliance groups

Clinical Expansion Outcomes. Both methods achieved successful expansion. However, the 3D-printed group demonstrated significantly greater intermolar width increase (+7.3 mm vs +5.5 mm, $p=0.02$) (Figure 1, Table 3). Greater maxillary overcorrection was also achieved in Group 2 (+1.0 mm vs 0.0 mm, $p=0.04$). The increase in nasal cavity width was greater in the 3D group (+3.2 mm vs +2.5 mm), though the difference was not statistically significant ($p=0.10$). No significant difference in molar tipping was observed between groups ($p>0.1$).

Patient Comfort. Pain intensity during the first week was significantly lower in the 3D group (3.0 ± 1.2 vs 4.5 ± 1.0 , $p<0.05$). Overall treatment comfort score at T2 was higher in Group 2 (9.0 ± 0.7 vs 8.0 ± 1.0 , $p=0.02$). All parents in both groups stated they would consent to the same treatment again if needed [7].

Table 1. Baseline Characteristics of the Patients (Mean $\pm$ SD)

Parameter	Group 1 (Standard appliance)	Group 2 (3D-printed appliance)	p-value
Number of patients, n	15	15	—
Age, years	9.3 ± 1.0	9.2 ± 1.1	0.81
Sex, boys/girls	8/7	7/8	0.75
Intermolar distance (mm)	40.5 ± 2.0	40.7 ± 1.8	0.80
Nasal cavity width (mm)	25.0 ± 2.5	25.3 ± 2.2	0.82
Maxillomandibular discrepancy (mm)	-3.9 ± 1.0	-4.2 ± 0.9	0.59

This Table 1 demonstrates the initial comparability of the clinical groups before the start of treatment. The specified parameters—age, sex, upper jaw width, nasal cavity width, and upper-lower jaw difference—did not show statistically significant differences between the groups ($p>0.5$). This confirms the correctness of randomization and the uniform distribution of patients according to their primary anatomical and clinical characteristics. The average age of the examined children was approximately 9 years, which corresponds to

the optimal age for palatine dilation. Intermolar distances and nasal cavity parameters before treatment were practically identical in both groups (≈ 40.6 mm and ≈ 25 mm, respectively), indicating the same degree of upper jaw narrowing in the study participants [8].

Table 2. Comparison of the Fabrication and Installation Process of the Appliance Between Groups

Parameter	Group 1: Traditional Method	Group 2: Direct 3D Printing
Separation rings before treatment	Yes, mandatory (5–7 days before appliance fixation)	No (not required)
Number of visits before appliance fixation	2 visits (impression taking, ring fitting)	1 visit (digital scanning)
Average appliance fabrication time	14 days	7 days
Need for adjustment during installation	Sometimes required ($\approx 33\%$ of cases)	Not required
Framework material of the appliance	Stainless steel (brazing, casting)	Cobalt-chromium (SLM / model casting)
Accuracy of tooth adaptation	Standard bands, possible gaps	Individual cast supports, precise fit
Aesthetic options for base	Limited (monochrome acrylic)	Custom color and design options available

This Table 2 reflects the differences between the traditional laboratory approach and the digital direct 3D printing method during the preparation and installation stages of the orthodontic apparatus. It can be seen that with the traditional method, mandatory dividing rings, two preliminary visits, and approximately 14 days were required to manufacture the structure. Whereas with the digital approach, all the manipulations were reduced to one visit with intraoral scanning and weeks of waiting for the finished device. Furthermore, individually printed structures were characterized by a more precise fit and no need for adjustment during fixation, which significantly increased comfort and reduced the risk of technical errors. Thus, the table clearly demonstrates the advantage of the digital protocol in speed, accuracy, and the aesthetics of the finished product [9].

Table 3. Changes in Jaw Dimensions and Nasal Cavity Size After Treatment (M $\pm$ SD)

Parameter	Group 1 (Standard) T1 $\rightarrow$ T2	Group 2 (3D Printing) T1 $\rightarrow$ T2	p (between groups)
Intermolar distance (mm)	40.5 $\pm$ 2.0 $\rightarrow$ 46.0 $\pm$ 2.1 (Δ +5.5)	40.7 $\pm$ 1.8 $\rightarrow$ 48.0 $\pm$ 1.9 (Δ +7.3)	0.02
Nasal cavity width (mm)	25.0 $\pm$ 2.5 $\rightarrow$ 27.5 $\pm$ 2.6 (Δ +2.5)	25.3 $\pm$ 2.2 $\rightarrow$ 28.5 $\pm$ 2.4 (Δ +3.2)	0.10
Maxillomandibular discrepancy (mm)	-3.9 $\pm$ 1.0 $\rightarrow$ +0.0 $\pm$ 0.5 (Δ +3.9)	-4.2 $\pm$ 0.9 $\rightarrow$ +1.0 $\pm$ 0.4 (Δ +5.2)	0.04
Inclination of the 1st molar crown ($^{\circ}$)	85.0 $\pm$ 3.5 $\rightarrow$ 89.5 $\pm$ 4.0 (Δ +4.5)	85.2 $\pm$ 3.8 $\rightarrow$ 88.5 $\pm$ 3.6 (Δ +3.3)	0.15

Table 3 presents the measurement results of key anatomical parameters before and after treatment in both groups. The data show a significant increase in intermolar distance and transpalate width in all patients; however, more pronounced changes were recorded in the group with 3D printing devices. The increase in intermolar distance was 7.3 mm versus 5.5 mm ($p=0.02$), while the maxillofacial difference improved by 5.2 mm versus 3.9 mm ($p=0.04$), indicating a predominantly skeletal nature of expansion during the digital

approach. There was also a trend toward a greater increase in nasal cavity width (3.2 mm versus 2.5 mm), although without statistical significance. Changes in the inclination angle of the molars were insignificant ($p=0.15$). The table confirms the effectiveness and accuracy of 3D printed structures in correcting transverse bite anomalies in children [10].

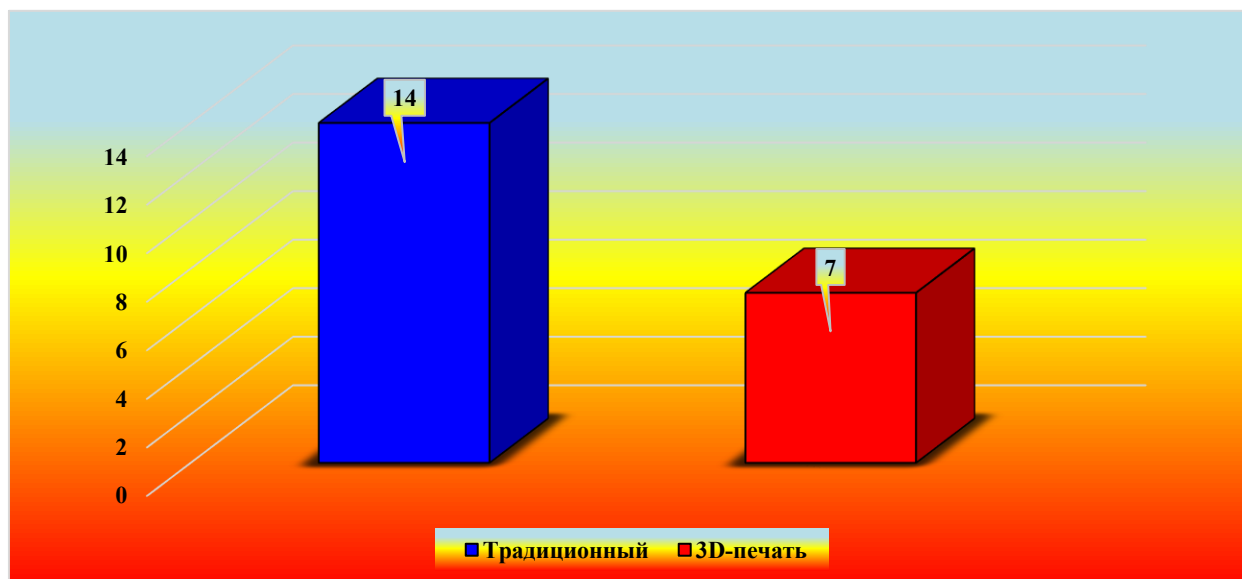


Figure 2. Comparison of appliance fabrication times: the interval from impression taking/scanning to appliance placement is significantly shorter with the digital protocol

Discussion

The results obtained demonstrate that applying the direct 3D printing method to manufacture a maxillary dilatation device in children provides a clinical effect comparable to the traditional method, with a number of significant advantages. Both approaches successfully addressed transverse insufficiency: all patients achieved the opening of the palatal suture and the elimination of the crossbite. This confirms the data from orthodontic practice that rapidly expanding the palate during growing age is a highly effective method for correcting transversal bite anomalies. In early childhood, the palatine suture is still flexible for expansion, and the results are stable after retention. In our groups, the average increase in intermolar distance was ~5.5–7.3 mm, which corresponds to literature data on the expansion range when using Haas/Hyrax devices in children (usually 4–8 mm) and sufficient for the correction of clinically significant narrowing [11].

It is important to note that in the 3D printing equipment group, expansion occurred to a slightly greater extent (by ~1.8 mm more than in the control). It can be assumed that this was facilitated by the higher stiffness and accuracy of the individual cast frame's fit. Modeling using the finite element method shows that a solid-metal (printed) expander creates more uniform and intense pressure on the seam compared to a traditional soldered device: for example, in the work of Bocklet et al. (2024), a fully printed Hyrax caused ~12% greater total displacement of the upper jaw halves compared to a classic one with the same screw opening value. The likely reason is the absence of bending and loosening in the design: the printing device is monolithic and does not have a weak link in the form of soldering or ring mobility. In our clinical study, we did not find significant differences in the degree of tooth inclination; however, the achieved hypercorrection (+1 mm versus 0) in group 2 indicates an advantage [12].

The expansion of the upper jaw in childhood has a favorable effect not only on occlusion but also on

respiratory functions. In our work, the transverse nasal opening increased (by an average of 2-3 mm) in both groups due to the expansion of the palate. Although the difference between the groups did not reach statistical significance, the experimental group exhibited a tendency toward a greater increase in nasal lumen. Both types of Haas and Hyrax devices, as shown in the literature, significantly improve nasal breathing parameters in children by expanding the nasal cavity. According to Cordasco et al., rapid palate expansion in children led to an ~8% increase in nasal cavity volume. In our study, the increase in the minimum nasal passage width by ~10–13% indirectly corresponds to these data. Interestingly, even transparent aligners used to expand tooth rows can have an effect on nasal breathing: for example, Pan et al. (2025) reported a ~15% increase in nasopharyngeal volume in children with jaw narrowing after treatment using a series of aligners. However, elayners required a longer course (~13 months versus the usual 6-7 months for RME), so in clinical practice, screw machines are still preferred for significant skeletal expansion in children. In future works, it is of interest to directly compare the efficiency of palate expansion with digital-made elayners and screw machines. One of the important advantages noted in our study was the better tolerance of treatment when using 3D printing devices. The absence of a separating ring stage and the high-precision seating of the expander allowed for a reduction in the level of discomfort in Group 2 patients. The difference in pain indicators during the first week was statistically significant (3.0 versus 4.5 points) in favor of the digital method. Parents of children in Group 1 frequently reported gum irritation and pain from separating rubbers before fixation - these undesirable phenomena were avoided in Group 2 thanks to the new manufacturing methodology [13]. Treatment comfort is a significant factor, especially in pediatric orthodontics, so striving to improve this aspect is justified. It should be noted that a clinical study is currently being conducted under the leadership of I. Andrade (University of Pittsburgh) with the participation of children aged 8-13 years, specifically dedicated to comparing 3D-printed and conventional palatine expanders in terms of treatment effectiveness and comfort. Increasing comfort and reducing side effects while maintaining therapeutic effect can increase the commitment of young patients to treatment and the satisfaction of parents. In our study, all families highly rated the results of therapy in both groups, but in Group 2, slightly more parents noted "very high" comfort from treatment. Analysis of adverse events did not reveal serious complications in either group. The adverse effects of RME described in the literature - pain, inflammation of the mucous membrane, asymmetry of dilation, tooth tilt, as well as rarely - complications such as pulp necrosis or damage to the nasal septum - were not observed in our limited study. A minor detachment of one of the metal rings occurred in 3 patients using the classic method, requiring minor correction (repositioning the device and re-fixing it with cement). A similar problem did not arise with individual 3D printing machines, which were a single cast structure that fitted precisely to the teeth. It can be assumed that the absence of soldering and standard standard parts reduces the risk of breakage and cementation during treatment - this is indirectly confirmed by the zero frequency of such incidents in Group 2 [14]. Furthermore, finite element analysis studies have previously indicated that the soldering joints in traditional palatal expanders represent the weakest points of the construction. In contrast, monolithic devices fabricated by 3D printing are free from this disadvantage and are likely to demonstrate greater reliability during long-term retention. Overall, the incidence of adverse effects was low and comparable between the two groups, which is consistent with findings from systematic reviews in the literature. According to pooled data, approximately 18% of patients using various types of palatal expanders experience minor complications. Importantly, the frequency of complications does not differ significantly between different modifications of Haas and Hyrax appliances [15].

A separate discussion should be devoted to the economic and organizational aspects. The application of 3D technologies substantially reduces laboratory technician labor costs and shortens the manufacturing time of orthodontic appliances. Our results clearly demonstrate this advantage: the average time from scanning/impression to appliance delivery was 7 days in the digital group compared to 14 days in the conventional group (including model pouring, band soldering, and other laboratory stages). Starting treatment nearly one week earlier represents a significant benefit in time-sensitive situations, such as preparation for surgical intervention or when operating within a limited "growth window" in a child.

The reduction in the number of patient visits (eliminating the need for separator placement and band try-ins) also improves treatment compliance and decreases inconvenience for the patient's family. From an economic perspective, the cost of 3D printing was previously a barrier to widespread adoption; however, in recent years, the price of equipment and materials for additive manufacturing has decreased significantly, while productivity has increased. Currently, an increasing number of dental laboratories are adopting CAD/CAM and 3D printing technologies, making them more accessible. In the present study, we employed a hybrid approach: 3D printing of a burnout pattern followed by cobalt-chromium casting. An alternative is direct metal laser sintering (SLM) for framework fabrication. According to recent reviews, 3D printing of metallic orthodontic appliances is already widely used and demonstrates excellent quality and mechanical strength. Major manufacturers are also implementing these advancements. For example, in 2025, Align Technology introduced its own system for 3D-printed palatal expanders intended for both children and adult patients. It is highly likely that additive technologies will soon become a standard component of orthodontic treatment, enabling the production of highly accurate and predictable appliances in significantly shorter timeframes.

Limitations of the study. This study had a relatively small sample size and a short follow-up period, limited to the end of the retention phase (6–8 months after expansion). Future research will evaluate the long-term stability of the results over several years and conduct similar comparisons with a larger patient cohort. Another limitation is that the study compared only tooth-borne expanders in younger children. In adolescents and young adults with nearly completed growth, appliances with additional skeletal anchorage (such as MARPE — Mini-implant Assisted Rapid Palatal Expansion) are frequently used. In this patient category, the advantages of 3D printing may manifest somewhat differently. Nevertheless, the benefits identified in our study — improved accuracy, increased rigidity of the construction, enhanced patient comfort, and reduced fabrication time — are expected to remain highly relevant for skeletal-anchored appliances when produced using digital protocols.

Conclusion

Direct 3D printing of orthodontic expansion appliances is an effective technology that enables optimization of the treatment of maxillary constriction in children. The present study demonstrates that individually designed expanders fabricated using digital methods are not inferior to traditional appliances in their ability to correct transverse maxillary deficiency during the mixed dentition period. Moreover, they offer several significant advantages, including faster and more precise placement without the need for preliminary tooth preparation, reduced patient discomfort, shorter fabrication time, and fewer clinical visits.

The additional expansion achieved in the 3D-printed appliance group indicates a tendency toward a more pronounced skeletal effect, which may have a positive impact on the long-term stability of the results. Digital planning also opens new opportunities for individualization of treatment, thereby increasing its predictability.

Thus, the use of additive technologies in pediatric orthodontics makes treatment more comfortable, faster, and higher quality for both the clinician and the patient. The integration of 3D printing in combination with other modern methods (intraoral scanning and CAD/CAM) represents the next step in the advancement of orthodontic care for children with malocclusions.

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