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Stability of transverse changes with clear aligners and hyrax expanders from the mixed to the permanent dentition

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Introduction: This study evaluated the longitudinal stability of transverse changes in patients treated with the Invisalign First system (IFS; Align Technology Inc, Tempe, Ariz) and hyrax expanders during the mixed dentition, followed through the permanent dentition. The objective was to determine whether expansion achieved during the mixed dentition was maintained through the transition to the permanent dentition. **Methods:** This retrospective longitudinal study included 119 patients: 44 patients treated with IFS, 36 patients treated with hyrax, and 39 untreated controls. Arch width changes at the canines, premolars, and first molars were measured on digital study models at 3 time points: pre-phase 1 treatment (T1), post-phase 1 treatment (T2), and pre-phase 2 evaluation (T3). Vertical skeletal changes were evaluated in a cephalogram subgroup. Statistical analyses included analysis of variance and linear mixed-effects models. **Results:** Both IFS and hyrax groups showed greater maxillary arch width increases from T1 to T3 (IFS: 1.8-2.8 mm; hyrax: 2.2-3.7 mm) than controls (0.4-1.2 mm; $P < 0.0001$). At T2, hyrax showed significantly greater interpremolar and intermolar expansion (4.1-4.8 mm) than IFS (1.9-2.8 mm), but more relapse from T2 to T3. The IFS group also showed increased mandibular arch width from T1 to T3 (1.9-2.9 mm) compared with controls ($P < 0.05$). No significant vertical skeletal changes from T1 to T3 were observed. **Conclusions:** Both IFS and hyrax produced maxillary arch expansion that was maintained throughout the transition from mixed to permanent dentition. The IFS also showed stable mandibular arch expansion, supporting its use for mild crowding or transverse deficiencies without long-term vertical effects. (Am J Orthod Dentofacial Orthop 2026;169:776-85)

Discrepancies in the transverse dimension and arch length deficiencies can be corrected during the mixed dentition through maxillary expansion.[1] Approximately 7% of American children present with posterior crossbite, a condition that rarely self-corrects, and the prevalence of crossbites increases to 9.5% in adults.[2] Because transverse facial growth is typically completed earlier than sagittal and vertical growth, early expansion is indicated to correct maxillary constriction, promote arch development, and preserve space, which are frequently considered key objectives of mixed dentition (phase 1) treatment.[2,3]

A variety of expansion devices are available for use in mixed dentition, including fixed hyrax expanders, Haas expanders, Quad helixes, and removable expanders.[4] The skeletal and dental effects of these appliances have been well documented.[4-6] In addition to transverse changes, maxillary expanders can also affect other dimensions. Previous studies have shown that rapid palatal expansion treatment tends to increase the vertical dimension because of the backward rotation of the mandible, a consequence of maxillary downward displacement during midpalatal suture opening[5] and dental tipping or extrusion of lingual cusps of maxillary posterior teeth.[6]

Clear aligner therapy was extended to younger patients with the introduction of the Invisalign First system (IFS; Align Technology Inc, Tempe, Ariz) in 2018. IFS is suggested to be effective, enabling clinicians to use clear aligners during the mixed dentition to promote arch development and address crowding, protrusion, or

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rotations in growing patients.[7,8] Similar to other clear aligner therapies, IFS offers several advantages, such as fewer dietary restrictions and easier maintenance of oral hygiene compared with fixed appliances.[9] For patients with mild crowding or limited transverse maxillary deficiency, several studies have shown that IFS can serve as a reasonable alternative to conventional maxillary expanders.[10–12] However, clear aligners primarily achieve dentoalveolar expansion rather than skeletal expansion, which may have different long-term stability characteristics compared with the expansion achieved by hyrax expanders.

Recent studies have examined the short-term transverse effects of the IFS.[10–15] These reports indicated that IFS can produce clinically useful expansion in appropriately selected patients. However, to the best of our knowledge, no study has evaluated whether these transverse changes achieved by IFS during mixed dentition, measured as arch width increases between primary canines and primary molars, are maintained after the exfoliation of the primary teeth and the eruption of the permanent successors (canines and premolars), at the beginning of phase 2 treatment, particularly in comparison with outcomes from hyrax expanders or untreated controls.

The primary objective of this study was to assess the arch width changes from the start of phase 1 treatment in the mixed dentition to the start of phase 2 in the permanent dentition among patients treated with IFS, compared with those treated with hyrax expanders and untreated controls. A secondary objective was to assess whether the treatment-related transverse changes achieved in phase 1 were maintained through the transition to permanent dentition, by quantifying any relapse that occurred during the retention period. An additional objective was to assess whether vertical skeletal changes differed among the IFS, hyrax, and control groups.

MATERIAL AND METHODS

This retrospective longitudinal cohort study was approved by the institutional review board at the University of the Pacific in San Francisco, California (#2022-183). A total of 119 patients were identified and categorized into 3 groups: IFS, hyrax, and untreated controls. The control group was obtained from the American Association of Orthodontists Foundation Craniofacial Growth Legacy Collection (Michigan and Oregon growth collections). Treatment groups were derived from 2 private practices (S.T. and M.B.), with both practitioners holding American Board of Orthodontics certifications.

To minimize selection bias, the practitioners were not involved in the sampling process. Consecutive eligible patients treated between September 2018 and June 2022 were screened. The inclusion criteria consisted of complete digital study casts at all 3 time points: T1 (pretreatment in mixed dentition), T2 (posttreatment in mixed dentition), and T3 (at least 1 year after T2, in permanent dentition) and $\geq$4.0 mm planned maxillary expansion. Exclusion criteria included the use of other appliances, such as mandibular advancement devices. Patients with bilateral posterior crossbites were also excluded, as both clinicians used hyrax expanders in these patients to achieve skeletal maxillary expansion. After applying the inclusion and exclusion criteria, 44 and 36 patients met the requirements for the IFS group and the hyrax group, respectively.

The control group consisted of 39 untreated subjects from the American Association of Orthodontists Foundation Growth Legacy Collection, with records available at comparable time intervals. The control group was matched to the treatment groups by age, sex, and Angle classification.

Sample size calculations were performed to ensure study power with a 2-tailed test α of 0.05 and 80% power. To detect a change of $\geq$1 mm in intermolar width, corresponding to an effect size of 0.7 based on a previous study,[13] the required sample size was estimated to be 18 patients per group.

IFS treatment used removable clear aligners in both maxillary and mandibular arches, with sequential staging expansion, 0.25 mm expansion per aligner, and 7-day aligner changes. The patients were instructed to wear aligners primarily after school and at night. During retention (T2-T3), passive aligners were used as retainers until they no longer fit the erupting dentition, after which no retainers were used. Patients were monitored approximately every 4 months during the retention period.

In the hyrax group, tooth-borne hyrax expanders were banded to the permanent maxillary first molars and activated one-quarter turn per day (0.25 mm) for approximately 4 weeks, then 3 turns per week as needed until the lingual cusps of the maxillary molar approximated the buccal cusps of the mandibular molar. Expanders were retained passively for an additional 3 months, after which maxillary 2 $\times$ 4 fixed appliances were placed. In the mandibular arch, 40% patients received a lower lingual holding arch, 20% had lower 2 $\times$ 4 or 2 $\times$ 6 fixed orthodontic appliances, and 40% received no treatment. Retention consisted of clear maxillary retainers with palatal and molar occlusal coverage, incorporating cutouts for erupting teeth. For patients with mandibular fixed appliances, the lower

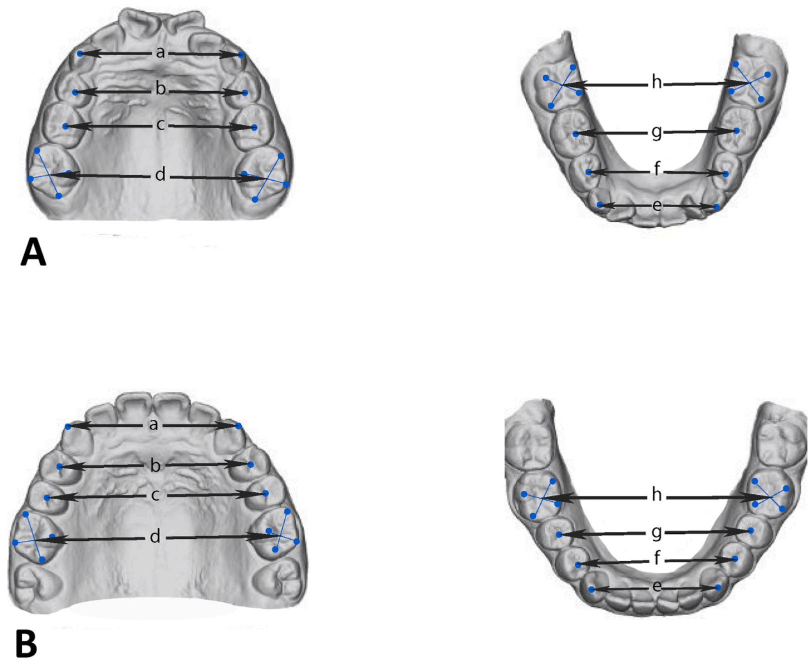

Fig 1. Arch width measurements on the study casts: **A,** Mixed dentition; **B,** Permanent dentition. a, Maxillary C-C or 3-3; b, Maxillary D-D or 4-4; c, Maxillary E-E or 5-5; d, Maxillary 6-6; e, Mandibular C-C or 3-3; f, Mandibular D-D or 4-4; g, Mandibular E-E or 5-5; and h, Mandibular 6-6.

lingual holding arch served as retention; otherwise, no mandibular retention was used.

Digital study models were measured with Ortho Analyzer software (3Shape, Copenhagen, Denmark). Three calibrated examiners identified dental landmarks: the cusp tips of canines, the central fossae of primary molars and permanent premolars, and the centroid of the permanent molars. The centroid measurement was determined by connecting the 4 main cusps of each first molar and identifying the geometric intersection point.[16] Four transverse measurements were recorded at each time point (T1, T2, and T3) per arch for all 3 groups (Fig 1, *A* and *B*). Interexaminer reliability was excellent (intraclass correlation coefficient = 0.97-0.98), and the average of the 3 examiners' measurements was used for analysis. Lateral cephalometric radiographs were available for 94 patients (IFS group: 31, hyrax group: 30, and control group: 33). Cephalometric tracing was performed using Dolphin Imaging & Management Solutions (version 12; Chatsworth, Calif) by a single examiner (A.T.) and verified by a faculty member. A standard set of cephalometric measurements was recorded at T1 to confirm baseline comparability among the 3 groups. Two vertical skeletal measurements, SN-MP and FMA, were analyzed longitudinally to evaluate potential vertical changes associated with expansion.

Statistical analysis

Descriptive statistics were computed to report the mean, standard deviation, and percentage. Group differences were assessed with analysis of variance, and *P* values were adjusted for multiple comparisons using false discovery rate. Changes in the arch width were further evaluated with a linear mixed-effects model, including fixed effects for treatment, timepoints, and their interaction, to compare changes from T1 to T3 between treatment and control groups. The significance level for all statistical analyses was set at $P = 0.05$. Statistical analyses were performed using statistical packages in R (R Foundation for Statistical Computing, Vienna, Austria) and Python (version 3.12.2, Python Software Foundation, Wilmington, Del), which implement standard procedures equivalent to those used in conventional statistical software.

RESULTS

The study comprised 3 groups: control (n = 39; 17 males and 22 females), hyrax (n = 36; 12 males and 24 females), and IFS (n = 44; 21 males and 23 females). No statistically significant differences were observed in the age and Angle classification distribution among the 3 groups (Table 1). The mean age at T1 was approximately 9.1 years across groups. The mean time interval

Table I. Subject characteristics by group

	Control (n = 39)	*Hyrax (n = 36)*	*IFS (n = 44)*	*P value*
Age (y)				
T1	9.12 ± 1.23	9.16 ± 1.14	9.21 ± 1.26	0.94
T2	10.49 ± 1.10	10.35 ± 1.20	10.43 ± 1.07	0.87
T3	12.87 ± 1.18	13.07 ± 1.05	12.52 ± 1.31	0.23
Time interval (y)				
T1-T2	1.37 ± 0.95	1.19 ± 0.53	1.22 ± 0.48	0.66
T2-T3	2.38 ± 1.27	2.72 ± 1.05	2.09 ± 0.88	0.12
T1-T3	3.75 ± 1.18	3.91 ± 1.03	3.31 ± 0.96	0.12
Sex				
M:F	17:22	12:24	21:23	0.42
Angle classification				
Class I	19	19	20	
Class II	17	13	19	0.93
Class III	3	3	5	
Crowding (>3 mm)				
Mx at T1	0 (0)	7 (19.4)	9 (20.5)	0.003
Md at T1	1 (2.6)	11 (30.6)	22 (50.0)	<0.0001
Mx at T3	4 (10.3)	6 (16.7)	2 (4.5)	0.22
Md at T3	7 (17.9)	5 (13.9)	3 (6.8)	0.29
Unilateral crossbite at T1	1 (2.6)	13 (36.1)	9 (20.5)	0.006

Note. Continuous variables are presented as mean ± standard deviation; categorical variables are presented as counts (percentages) (n [%]).
P value and 1-way ANOVA are continuous, and chi-square tests are categorical.
M, male; *F,* female; *Mx,* maxillary; *Md,* mandibular; *ANOVA,* analysis of variance.

Table II. Cephalometric measurements at T1

	Control (n = 33)		*Hyrax (n = 30)*		*IFS (n = 31)*		
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*P value*
SNA (°)	81.60	3.52	81.35	4.28	81.76	4.15	0.92
SNB (°)	76.85	3.74	77.24	4.08	77.01	3.31	0.92
ANB (°)	4.74	2.51	4.12	2.44	4.74	2.00	0.66
SN-MP (°)	34.33	4.46	33.62	4.77	34.69	5.06	0.84
FMA (°)	26.02	4.00	24.83	4.44	26.44	4.56	0.54
U1-SN (°)	102.89	7.85	102.84	9.96	101.17	10.96	0.84
IMPA (°)	90.88	5.93	94.18	5.70	91.02	5.56	0.13
IIA (°)	131.91	9.54	129.37	11.23	133.11	10.57	0.55
Overjet (mm)	4.61	1.97	3.52	1.92	4.34	2.69	0.29
Overbite (mm)	1.38	3.40	2.05	2.13	2.86	2.45	0.25

Note. P value and ANOVA tests are adjusted for multiple comparisons.
SD, standard deviation; *ANOVA,* analysis of variance.

from T1 to T3 was 3.8 years for control, 3.9 years for hyrax, and 3.3 years for IFS groups, with a minimum of 1 year of supervision between T2 and T3 for all groups. At the baseline (T1), no statistically significant differences were observed in the skeletal or dental cephalometric measurements (Table II). The IFS group showed a slightly greater maxillary intermolar width (46.8 ± 2.3 mm) than the control group (44.4 ± 2.5 mm) (Table III). Both treatment groups achieved significant expansion during phase 1 treatment compared with the control group (*P* <0.0001 for all measurements; Table IV). The hyrax group demonstrated greater maxillary expansion, with increases of 3.6 ± 1.9 mm in intercanine width and 4.4 ± 2.1 mm in intermolar width. The IFS group showed a smaller but still statistically significant increase of 2.9 ± 2.0 mm (intercanine) and 1.9 ± 1.3 mm (intermolar). In contrast, the control group showed minimal changes, ranging from 0.2 ± 0.7 mm to 0.7 ± 0.8 mm. In the mandibular arch, the IFS group showed significant increases in widths of

Table III. Arch width measurements at T1

	Control (n = 39)		Hyrax (n = 36)		IFS (n = 44)			
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*P value*	*Group comparison**
Maxilla								
3-3	31.49	2.12	31.24	2.04	32.08	2.12	0.40	
4-4	33.77	2.23	34.0	2.23	34.83	2.29	0.30	
5-5	38.93	2.77	39.09	2.74	40.56	2.18	0.06	
6-6	44.43	2.54	45.55	2.87	46.83	2.30	0.01	Control and IFS
Mandible								
3-3	26.04	1.66	25.20	2.10	25.39	2.06	0.32	
4-4	29.11	1.75	29.16	1.79	29.11	2.38	0.97	
5-5	34.99	2.07	35.17	2.32	35.49	2.36	0.79	
6-6	40.23	2.21	40.71	2.27	41.22	2.09	0.30	

Note. *P* value and ANOVA tests are adjusted for multiple comparisons.
For consistency across the tables, C-C is denoted as 3-3, D-D as 4-4, and E-E as 5-5, even in the mixed dentition.
SD, standard deviation; *ANOVA*, analysis of variance.
*Tukey honest significant difference test (post hoc) was used.

Table IV. Arch width changes from T1 to T2

	Control (n = 39)		Hyrax (n = 36)		IFS (n = 44)			
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*P value*	*Group comparison**
Maxilla								
3-3	0.16[a]	1.59	3.55[b]	1.87	2.87[b]	1.96	<0.0001	Control and hyrax; control and IFS
4-4	0.15[a]	0.70	4.10[b]	1.88	2.75[c]	1.93	<0.0001	Control; hyrax; IFS
5-5	0.23[a]	0.67	4.75[b]	2.31	2.67[c]	1.69	<0.0001	Control; hyrax; IFS
6-6	0.66[a]	0.80	4.36[b]	2.06	1.88[c]	1.32	<0.0001	Control; hyrax; IFS
Mandible								
3-3	−0.19[a]	1.02	0.91[b]	1.48	2.01[c]	1.78	<0.0001	Control; hyrax; IFS
4-4	0.40[a]	1.16	1.46[a]	1.95	3.65[b]	2.58	<0.0001	Control and IFS; hyrax and IFS
5-5	0.07[a]	0.67	1.59[b]	1.77	3.24[c]	2.16	<0.0001	Control; hyrax; IFS
6-6	0.12[a]	0.67	2.18[b]	1.27	2.44[b]	1.44	<0.0001	Control and hyrax; control and IFS

Note. *P* value and ANOVA tests are adjusted for multiple comparisons. Mean values with the same superscript letter did not differ from each other.
SD, standard deviation; *ANOVA*, analysis of variance.
*Tukey honest significant difference test (post hoc) was used.

2.0 ± 1.8 mm (intercanine), 3.7 ± 2.6 mm (inter-first primary molar), 3.2 ± 2.2 mm (inter-second primary molar), and 2.4 ± 1.4 mm (intermolar).

From T1 to T3, both treatment groups maintained significantly greater maxillary arch width increases compared with the control group (Table V). In the maxillary arch, the IFS group showed an increase of 2.8 ± 2.1 mm (intercanine), 2.3 ± 1.8 mm (inter-first premolar), 2.4 ± 1.8 mm (inter-second premolar), and 1.8 ± 1.6 mm (intermolar). The hyrax group showed increases of 3.7 ± 1.8 mm (intercanine), 2.2 ± 1.6 mm (inter-first premolar), 2.4 ± 2.3 mm (inter-second premolar), and 2.4 ± 1.4 mm (intermolar). In contrast, the control group showed only minimal changes, ranging from 0.4 ± 1.0 mm to 1.2 ± 2.1 mm, which were significantly smaller than those of both treatment groups ($P < 0.05$) (Fig 2).

To account for normal growth, a linear mixed-effects model analysis was performed, and it confirmed these findings (Table VI). Compared with the control group, the IFS group demonstrated additional maxillary arch width increase of 1.7 mm (intercanine), 1.8 mm (inter-first premolar), 2.0 mm (inter-second premolar), and 0.7 mm (intermolar). The hyrax group showed comparable gains of 2.6 mm (intercanine), 1.8 mm (inter-first premolar), 2.0 mm (inter-second premolar), and 1.3 mm (intermolar) relative to the control group. In the mandibular arch, the IFS group maintained significantly greater increases than both the control and hyrax groups, with changes ranging from 1.9 ± 1.7 mm (intermolar) to 2.2 ± 2.0 mm (intercanine) (Table V).

Analysis of changes from T2 to T3 revealed distinct relapse patterns between the 2 treatment groups (Table VII). In the maxillary arch, the intercanine width

Table V. Arch width changes from T1 to T3

	Control (n = 39)		*Hyrax (n = 36)*		*IFS (n = 44)*			
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*P value*	*Group comparison**
Maxilla								
3-3	1.19[a]	2.08	3.71[b]	1.78	2.76[b]	2.10	<0.0001	Control and hyrax; control and IFS
4-4	0.40[a]	1.03	2.22[b]	1.56	2.29[b]	1.83	<0.0001	Control and hyrax; control and IFS
5-5	0.35[a]	0.99	2.36[b]	2.32	2.35[b]	1.76	<0.0001	Control and hyrax; control and IFS
6-6	1.06[a]	1.14	2.36[b]	1.38	1.81[b]	1.64	<0.0001	Control and hyrax; control and IFS
Mandible								
3-3	−0.13[a]	1.51	1.29[b]	1.80	2.20[b]	1.95	<0.0001	Control and hyrax; control and IFS
4-4	0.75[a]	1.21	0.90[a]	1.75	2.89[b]	2.13	<0.0001	Control and IFS; hyrax and IFS
5-5	0.10[a]	1.08	0.02[a]	1.95	2.19[b]	1.96	<0.0001	Control and IFS; hyrax and IFS
6-6	0.60[a]	1.23	0.82[a]	1.50	1.87[b]	1.69	<0.0001	Control and IFS; hyrax and IFS

Note. *P* value and ANOVA tests are adjusted for multiple comparisons. Mean values with the same superscript letter did not differ from each other.
SD, standard deviation; *ANOVA*, analysis of variance.
*Tukey honest significant difference test (post hoc) was used.

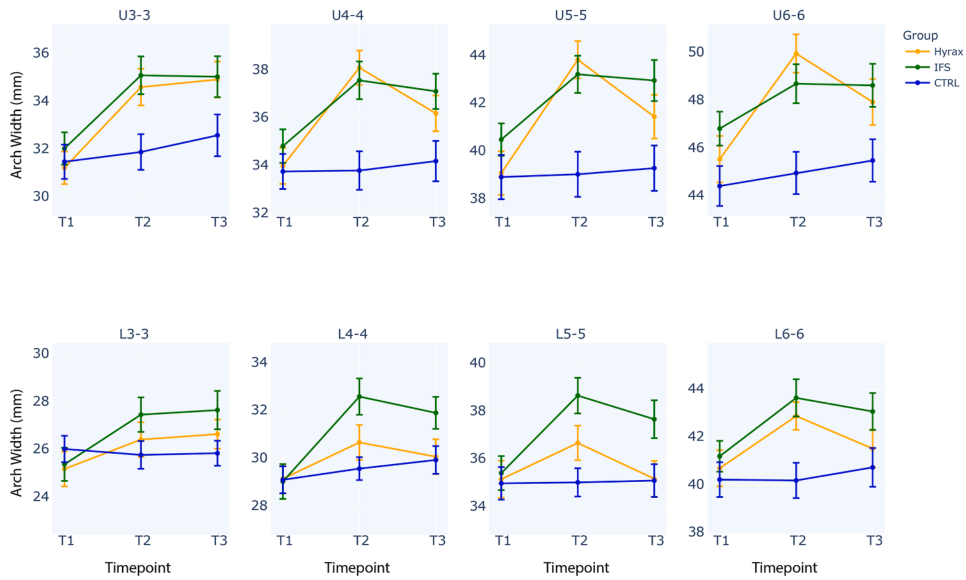

Fig 2. Arch width changes over time (mean ± 95% confidence interval; mm).

decreased by 0.2 ± 1.7 mm in the IFS group. For all other transverse measurements, the hyrax group showed significantly greater relapse, with decreases of −1.9 ± 1.5 mm (inter-first premolar), −2.4 ± 1.4 mm (inter-second premolar), and −2.0 ± 1.7 mm (intermolar). In contrast, the IFS group showed minimal reduction of −0.5 ± 1.6 mm (inter-first premolar), −0.3 ± 1.6 mm (inter-second premolar), and −0.1 ± 1.2 mm (intermolar) for the same measurements.

Per the T1-T2 results, the magnitude of achieved arch expansion was significantly greater in the hyrax group than in the IFS group. When expressed as percentages of the initial expansion achieved, the IFS group showed relapse rates of 3%-20% for the interpremolar and intermolar measurements. The hyrax group showed higher relapse rates of 44%-62% for the same measurements. In the mandibular arch, both groups showed some degree of relapse during the retention period. Because of the variability in mandibular treatment within the hyrax group, the analysis focused on the IFS group. The IFS group experienced changes of −0.7 ± 1.7 mm (inter-first premolar), −1.1 ± 1.8 mm

Table VI. Arch width changes from T1 to T3 compared with control (in millimeters)

	Treatment	Estimate	P value
Maxilla			
3-3	Hyrax	2.55	<0.0001
	IFS	1.70	0.001
4-4	Hyrax	1.80	<0.0001
	IFS	1.83	<0.0001
5-5	Hyrax	2.01	<0.0001
	IFS	2.03	<0.0001
6-6	Hyrax	1.31	0.0001
	IFS	0.72	0.016
Mandible			
3-3	Hyrax	1.50	0.001
	IFS	2.37	<0.0001
4-4	Hyrax	0.13	0.803
	IFS	2.11	<0.0001
5-5	Hyrax	−0.09	0.828
	IFS	2.11	<0.0001
6-6	Hyrax	0.24	0.485
	IFS	1.24	0.0003

Note. Each estimate represents the treatment vs control difference in arch width change (in millimeters) from T1 to T3.
P value; linear mixed-effect model.

(inter-second premolar), and −0.6 ± 1.2 mm (intermolar), corresponding to relapse rates 22%-32% for the interpremolar and intermolar widths.

A subgroup of 94 patients had complete lateral cephalometric radiographs at all 3 timepoints (control group: 33, hyrax group: 30, and IFS group: 31). At T1, skeletal measurements did not differ significantly among groups. During phase 1 treatment (T1-T2), small differences in FMA were observed: −1.3° ± 1.9° in the control group, no change (0.01° ± 1.9°) in the hyrax group, and −0.4° ± 2.2° in the IFS group (Table VIII). However, long-term vertical skeletal changes (T1-T3) did not significantly differ among the 3 groups. These findings suggest that any short-term vertical changes induced by expansion were transient and ultimately masked by normal vertical growth over the 3-year observation period.

DISCUSSION

This study evaluated the stability of expansion achieved with IFS and hyrax expanders during the mixed dentition, followed longitudinally through the transition into the permanent dentition. To our knowledge, this is the first investigation to compare IFS with both hyrax expanders and untreated controls from the mixed dentition into the permanent dentition, after the eruption of the successors to the primary teeth expanded during phase 1. Unlike the hyrax group, in whom midpalatal suture opening contributed to skeletal expansion, the IFS group achieved expansion primarily through dentoalveolar changes. A central question was whether, after exfoliation of the expanded primary teeth, the permanent canines and premolars would erupt into a wider arch dimension compared with controls.

The efficacy and effectiveness of the IFS compared with conventional approaches have been increasingly studied over the last few years,[10–13] yet the long-term effects have not been thoroughly examined. This longitudinal study assessed the transverse arch width and vertical changes produced by IFS, comparing outcomes with those of the hyrax expander and control groups.

This study demonstrated that both IFS and hyrax expanders achieved arch width increases that were maintained into permanent dentition at the start of phase 2 treatment. The primary finding is that IFS produced approximately 1 mm greater increase in maxillary intermolar width and approximately 2 mm greater increase in interpremolar width at phase 2 start compared with controls. Intermolar width increase in the IFS group was smaller than both the increase observed in the hyrax group and the intercanine and interpremolar expansions within the IFS group itself. Although the intermolar width change from T1 to T3 was 1.8 mm, this represented only a 0.7 mm increase relative to the control group ($P < 0.05$), and the clinical significance of this difference remains uncertain and warrants further study. Nevertheless, permanent premolars erupted into a broader arch dimension despite being unerupted during treatment, suggesting that transverse changes achieved in mixed dentition can be preserved after eruption of the permanent successors. These results support IFS as a viable treatment option for mild transverse deficiencies that can be resolved with dentoalveolar expansion. In our sample, 13 patients (36%) in the hyrax group and 9 patients (21%) in the IFS group presented with unilateral posterior crossbite, whereas only 1 patient in the control group had unilateral posterior crossbite. It should be noted that both clinicians used the hyrax expander to correct more severe transverse discrepancies associated with bilateral crossbites.

IFS also appeared beneficial for arch development and the resolution of crowding.[7,8] at T1, >3 mm anterior crowding was observed in 9 patients (21%) in the maxilla and 22 patients (50%) in the mandible. By T3, these numbers decreased to 2 patients (5%) and 3 patients (7%), respectively. In contrast, the control group showed an increase in crowding, from 0 patients at T1 to 4 patients (10%) in the maxilla and 1 patient (3%) to 7 patients (18%) in the mandible at T3. Although not a primary focus of this study, these findings suggest a potential benefit of IFS for crowding resolution and arch development, warranting further study.

Table VII. Arch width changes from T2 to T3

	Control (n = 39)		Hyrax (n = 36)		IFS (n = 44)			
	Mean	SD	Mean	SD	Mean	SD	P value	Group comparison*
Maxilla								
3-3	0.95[a]	1.74	0.18[a]	1.99	−0.23[b]	1.70	0.034	Control and IFS; hyrax and IFS
4-4	0.19[a]	0.80	−1.91[b]	1.49	−0.53[a]	1.64	<0.0001	Control and hyrax; IFS and hyrax
5-5	0.13[a]	0.92	−2.38[b]	1.37	−0.25[a]	1.57	<0.0001	Control and hyrax; IFS and hyrax
6-6	0.40[a]	0.89	−2.03[b]	1.71	−0.11[a]	1.22	<0.0001	Control and hyrax; IFS and hyrax
Mandible								
3-3	0.05[a]	1.30	0.16[a]	1.19	0.13[a]	1.67	0.948	
4-4	0.33[a]	0.86	−0.68[b]	1.53	−0.72[b]	1.72	0.003	Control and hyrax; control and IFS
5-5	0.02[a]	0.85	−1.54[b]	1.34	−1.05[b]	1.76	<0.0001	Control and hyrax; control and IFS
6-6	0.45[a]	1.02	−1.36[b]	1.35	−0.64[c]	1.20	<0.0001	Control; hyrax; IFS

Note. *P* value and ANOVA tests are adjusted for multiple comparisons. Mean values with the same superscript letter did not differ from each other.
SD, standard deviation; *ANOVA*, analysis of variance.
*Tukey honest significant difference test (post hoc) was used.

Table VIII. Vertical cephalometric changes

	Control (n = 33)		Hyrax (n = 30)		IFS (n = 31)		
	Mean	SD	Mean	SD	Mean	SD	P value
T1 to T2							
SN-MP	−0.52	1.72	0.33	1.63	0.05	2.16	0.18
FMA	−1.26	1.88[a]	0.01	1.85[b]	−0.41	2.22[a]	0.04
T1 to T3							
SN-MP	−1.34	2.61	−0.65	2.70	−1.29	3.18	0.57
FMA	−2.67	2.41	−1.70	2.34	−2.45	3.05	0.31

Note. All values are in degrees (°). *P* value and ANOVA tests are adjusted for multiple comparisons. Tukey honest significant difference test (post hoc) was used. Mean values with the same superscript letter did not differ from each other.
SD, standard deviation; *ANOVA*, analysis of variance.

The relatively modest amount of increase observed in the IFS group compared with the control group indicates that similar results might be achieved through a comprehensive treatment in the permanent dentition. Although early expansion has been advocated for its potential to facilitate skeletal, dentoalveolar, and muscular adaptation before the eruption of permanent teeth,[17] its long-term stability remains uncertain. Evidence suggests that dental arch expansion in the permanent dentition frequently relapses, with mandibular constriction a common post retention finding.[1,18] Thus, although expansion in mixed dentition may provide benefits through the early permanent dentition, its long-term effectiveness is unclear, highlighting the need for further longitudinal evaluation. Ultimately, decisions regarding early expansion should rely on clinical judgement and patient-specific considerations, with careful weighing of benefits, cost, and compliance.

The control group showed arch width increases comparable with, or slightly less than, those reported in previous studies.[18–22] However, the magnitude of arch width changes varies widely across individuals and across studies because of multiple factors. Therefore, including a matched control group and applying a consistent measurement method across all groups is essential for reliable comparison.

Treatment changes (T1-T2) observed in this study align closely with the earlier reports. The maxillary intermolar width changes for the IFS group (1.9 mm) and the hyrax group (4.4 mm) were similar to those reported by Torbaty et al (IFS group: 2.5 mm; hyrax group: 4.4 mm).[13] Notably, the hyrax group reached the >4 mm expansion that was planned, whereas IFS achieved a more modest dentoalveolar expansion. Although our study did not examine the ratio of planned expansion, previous studies have shown the efficacy of approximately 50%-70% for IFS.[13,23] In our study, the hyrax group demonstrated greater posterior expansion (intermolar width) than anterior expansion (intercanine width), which agrees with the established literature.[21,24] Our findings that the IFS group demonstrated greater anterior expansion than posterior expansion also agree with the findings of previous studies.[12,25] Notably, this pattern of expansion was maintained in the permanent dentition at the start of phase 2. Housley et al evaluated long-term stability of mandibular expansion and found that approximately 30% of expansion was lost after retention, regardless of retainer type,[26] consistent with the present findings of 22%-32% relapse in the IFS group using removable retainers.

Analysis of relapse (T3-T2) relative to the initial expansion (T1-T2) demonstrated that, despite achieving less initial expansion, the IFS group maintained a higher percentage of the expansion through the retention period. A recent pilot study by Wang et al using 3-dimensional analysis demonstrated that clear aligners in mixed dentition produce more controlled but moderate dental movement compared with the hyrax expanders, which may partly explain the less relapse observed.[12] In contrast, greater relapse was observed in the hyrax group compared with previous studies, such as Geran et al, which reported minimal relapse of 0.2 mm in intermolar width.[27] Although patient compliance and retention protocol may contribute, it is important to note that expansion produced by hyrax is highly variable and depends on the goals of the clinician.[20] In hyrax expansion, some degree of intentional overexpansion is considered acceptable. In such patients, part of the reduction observed indicates functional adaptation rather than true relapse.[21] In fact, not all patients in the hyrax group required the full 4.5 mm of expansion, and some reduction was anticipated and even desirable.

Managing vertical changes, especially in patients with hyperdivergence, is a common concern in orthodontic treatment. Previous studies have reported that vertical changes associated with rapid palatal expansion tend to be minor and largely normalized through growth and compensation over the long-term follow-up period of approximately 3 years.[28-30] Our findings corroborate this observation, as the vertical skeletal measurements from T1 to T3 showed no significant differences among groups. Although the change in FMA after treatment (T1-T2) did show a statistically significant difference between IFS and hyrax, the magnitude ($<0.5°$) was small and not clinically significant. Overall, these findings confirm that expansion with either appliance does not produce lasting adverse vertical effects.

This study has inherent limitations because of its retrospective design, including potential selection bias and limited control of confounding variables. The IFS group showed slightly greater arch widths at T1 compared with historical controls, which may reflect ethnic differences in the populations studied. Although retention protocols were standardized, patient compliance could not be fully verified. Only patients with unilateral crossbites were included to improve comparability, limiting generalizability to more severe transverse deficiencies. The study aimed not to compare IFS, a primarily dentoalveolar expansion appliance, directly with hyrax expanders, but rather to provide a clinical context through the inclusion of the widely used hyrax expander and a control group. It is also important to note that this study evaluated IFS, not the Invisalign palatal expander, which is intended for maxillary skeletal expansion. Although not the primary focus of this study, incorporating measures, such as dentoalveolar width, palatal surface area and volume, and tooth inclinations, could provide additional insight in future evaluations of maxillary expansion.[31-33] Future prospective multicenter studies with standardized retention protocols and longer follow-up beyond completion of phase 2 treatment are warranted.

CONCLUSIONS

Both IFS and hyrax expanders produced and maintained maxillary arch width increases from the mixed dentition to the permanent dentition, with IFS also maintaining mandibular expansion. Relapse of the interpremolar and intermolar widths during the retention period was lower in the IFS group (3%-20% in the maxilla) than in the hyrax group (44%-67%), although part of the apparent relapse in the hyrax group may reflect intentional overexpansion and functional adaptation. Compared with controls, IFS treatment during the mixed dentition yielded 0.7-2.0 mm greater maxillary arch width and 1.2-2.4 mm greater mandibular arch width at the start of phase 2 treatment in the permanent dentition. The IFS group also demonstrated less dental arch crowding at the start of phase 2 compared with untreated controls and the hyrax group. No clinically meaningful vertical skeletal differences were observed in the permanent dentition among groups, indicating that vertical changes associated with expansion were transient and largely masked by normal growth over the study period. Overall, IFS may be considered in certain patients with mild arch width deficiency, with transverse changes that were maintained through the transition to the permanent dentition.

AUTHOR CREDIT STATEMENT

Andrew Tsai contributed to investigation and original draft preparation; Heeyeon Suh contributed to conceptualization, data analyses, and manuscript review and editing; Sandra Khong Tai contributed to conceptualization, resource, and manuscript review and editing; Marta Baird contributed to conceptualization, resource, and manuscript review and editing; Heesoo Oh contributed to supervision of the project, conceptualization, and manuscript review and editing.

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