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ORIGINAL RESEARCH ARTICLE

Comparison of Dentoalveolar Expansion with Clear Aligners by Using Two Different Treatment Protocols in the Early Mixed Dentition: A Retrospective Study

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Abstract

Purpose: To evaluate the effect of different expansion protocols on tooth movements during maxillary arch expansion with Invisalign First System® (IFS) in the mixed dentition.
Materials and Methods: This study was conducted using digital models of 20 patients treated with sequential expansion (MFE, mean age: 7.88±0.60; 9 girls, 11 boys) and 20 patients treated with simultaneous expansion (SIE, mean age: 7.94±0.51; 12 girls, 8 boys) acquired before (T0) and after (T1) treatment. Maxillary parameters were measured on each model at T0 and T1. Mann Whitney U tests were used for comparisons between groups, and Wilcoxon tests were used for the analysis of intra-group.
Results: In both groups, the greatest increase of maxillary arch width (AW) was determined at both the cusp tips and gingival levels of the upper first deciduous molars followed by the second deciduous molars and by the deciduous canines ($p < 0.01$). The lowest increase of AW was found in the at the permanent first molars ($p < 0.01$).
Conclusions: TBoth protocols with IFS can be considered effective in patients in early mixed dentition. The greatest increase was detected at the level of the upper first deciduous molars, whereas the least increase was observed at the level of the first permanent molars.

Key words: Clear Aligners; Invisalign® First system; Mixed dentition

Introduction

The primary purpose of treatment in the mixed dentition period is to create suitable spaces for the correct alignment of teeth on the arch and to correct any mismatches in the occlusal relationship. When dental crowding is mild, crowding can be compensated for by growth and development, but if it is severe, the dentoalveolar expansion procedure is considered an effective option.[1] The expansion of the maxillary arch has been carried out for many years with a variety of appliances.[2–4] The clear aligner (CA) option can be advantageous, especially when children are reluctant to approach conventional methods for social reasons.[5] For this purpose, in 2018, Align Technology, Inc. launched an IFS specifically designed for patients in the early mixed dentition period. This system makes possible the simultaneous correction of different dental problems and offers a more aesthetic and comfortable treatment option.[6,7]

Two protocols are commonly used in treatments involving expansion and using IFS: • Sequential expansion (Molars move first, MFE): First, the permanent first molar teeth are moved to the buccal position by using the other teeth in the arch as an anchor unit, then the buccal movement of the deciduous molars and canines is performed.

• Simultaneous expansion (SIE): The permanent first molars, the deciduous molars and canines are all moved buccally at the same time.

In the orthodontic treatment of patients with IFS, specially designed optimized retention attachments and eruption compensation features are used. This system aims to improve arch form while providing space for erupting teeth. In addition, it has made the management of short clinical crowns and tooth movements easier.[6,8]

The orthodontic literature contains several studies investigating maxillary expansion with IFS.[6,8–13] However, differences in the treatment efficacy of MFE and SIE during the mixed dentition

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period have not been compared. The aim of this retrospective study was to compare the treatment efficacy of these two protocols in patients in the mixed dentition period who had undergone either MFE or SIE with IFS. The null hypothesis of this study was that the two different expansion protocols of the Invisalign First System®, MFE and SIE were equally effective in increasing maxillary transverse arch widths in mixed dentition patients.

Material and Methods

The study was approved by the Karadeniz Technical University, Faculty of Dentistry Ethics Committee (Protocol number: 2023/1). Signed informed consent was obtained from the parents of all patients participating in the study.

Subject Selection and ethical considerations

A study by Lione et al.12 guided the calculation of the sample size: with alpha error = 0.05, beta error = 0.20, and effect size 0.8, it was concluded that having 18 patients in each group (36 patients in total) would be sufficient. However, to increase the power of the study, a total of 40 patients (mean age: 7.94 ± 0.51; 21 girls, 19 boys) were included. 20 patients (mean age: 7.88 ± 0.60; 9 girls, 11 boys) were treated with MFE with IFS, and 20 patients (mean age: 7.88 ± 0.60 years; 12 girls, 8 boys) were treated with SIE with IFS (Align Technology Inc., Tempe, AZ, USA).

T0 and T1 digital dental models were evaluated when selecting patients for the MFE and SIE groups. The following inclusion criteria were applied: in the mixed dentition period; presence of deciduous canine, molars and permanent first molars; and good cooperation. Exclusion criteria included severe malocclusion, dental agenesis, supernumerary tooth, periodontal disease, and the presence of craniofacial abnormality. None of the patients had posterior crossbites. In addition, cases in which simultaneous distalization of the first molar teeth during expansion was observed were not included in the study.

Treatment Protocol

The study groups were treated with IFS without any auxiliary mechanics other than the attachments, and none of the patients included were scheduled for interproximal reduction (IPR) of the teeth during treatment. All patients had horizontal attachments on the upper deciduous canines, molars, and first permanent molars, both to provide torque control and to support retention. In each case, ClinCheck was planned to achieve an arch expansion of 0.15 mm per aligner in the upper arch using IFS.[14] Simultaneously, an additional 5° buccal root torque was added to the first molars of all patients during expansion. Although only the first round of aligners was included in the study, no refinement steps were included. The mean duration of treatment in MFE was 7.35 ± 3.11 months, and in SIE was 6.25 ± 1.80 months. All patients in both groups changed their aligners every seven days.

Measurement Protocol

Digital models of all patients in the treatment groups were obtained at T0 and T1. All maxillary digital models were obtained with the iTero® (Align Technology Inc., Tempe, AZ, USA) intraoral scanner. They were exported in -stl format, and the files were loaded into the 3Shape OrthoAnalyzer 2021.1 1.10.0.7 (Copenhagen, Denmark) to evaluate changes in the models. Ten linear measurements, and two angular measurements were made on the digital models, as recorded in the 3Shape Ortho Analyzer (Figure 1 and Figure 2). On the digital intraoral scan image taken at T0 and T1, for the patients in both groups, all these measurements were performed, and the measurements for the two time points were compared.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS), version Windows 17.0 (IBM Corp., Chicago, IL, USA), was used for the statistical analysis. The Shapiro-Wilk test was used to ensure the conformity of the data to the normal distribution. Descriptive statistics were given as median, minimum, and maximum values. The intra-observer consistency coefficient was calculated. Since the data were not normally distributed, the Mann-Whitney U test was used for comparisons between groups, and the Wilcoxon test was used for the analysis of intra-group variation over time. A $p < .05$ level was considered statistically significant. The reliability of the measurements was evaluated by calculating the interclass correlation coefficient (ICC).

Results

To determine intra-observer reliability, digital model measurements were repeated by the same orthodontist three weeks after the first measurements. Intra-examiner error was evaluated as $p < .05$ and was found to be statistically insignificant. The ICC analysis showed that the observer's measurements at different times were highly concordant, with a ratio of 0.98.

A comparison of the chronological ages and model parameters of the groups during the T0 period is given in Table 1. There was no difference between the groups in terms of patient age at the T0 period. Model measurements at T0 showed that the upper right molar rotation angle (RA) in MFE were higher than in SIE ($p < 0.05$) ((Table 1)).

The changes in the maxillary arch in MFE from the T0 to T1 periods are given in Table 2. Significant increases were found in all AW and arch perimeter (AP) measurements. Significant increases were found in all transversal AWs at the cusp tip (CL) and gingival (GL) levels of the teeth ($p < 0.01$). The greatest increase in maxillary AW was at the level of the upper first molars (CL, 4.15 ± 1.63; GL, 2.89 ± 1.53 mm), followed by the second deciduous molars (CL, 4.12 ± 2.11; 2.73 ± 1.59 mm), and then, as detected in the deciduous canines (3.79 ± 2.16; GL, 2.64 ± 1.76 mm). The increase in AW in the first molars (CL, 2.92 ± 1.91; GL, 1.39 ± 1.10) was observed to be the least. Significant increases were detected in AP (4.14 ± 3.13 mm; $p < .001$), and there was a slight decrease in AL (0.47 ± 0.97 mm; $p < 0.05$). The intermolar angle (IMA) and the RA measurements were found to be significantly reduced ($p < 0.01$) (Table 2).

Maxillary arch changes in SIE from the T0 to T1 periods are given in Table 3. Significant increases were detected in all AW values and in the AP ($p < 0.01$). The greatest increase in AW was at the level of the upper first deciduous molars (CL, 3.54 ± 2.24; GL, 2.67 ± 1.59 mm), followed by the second deciduous molars (CL, 3.51 ± 1.89; 2.56 ± 1.35 mm), and then the deciduous canines (CL,3.49 ± 2.12; GL, 2.50 ± 1.64 mm). The increase in AW in the first molars (CL, 2.25 ± 1.14; GL, 1.40 ± 0.83) was observed to be the least. There was a decrease in arch length (AL), but this was insignificant ($p > 0.05$). Significant decreases were found in the IMA and the RA values ($p < 0.01$) (Table 3).

The intergroup comparison of model measurement changes occurring in the T1–T0 period is given in Table 4. The reduction values in the RAs of the right molar teeth in MFE were slightly higher ($P < 0.05$). Apart from this, no significant differences were observed in the changes in measurements between the groups ($p > 0.05$) (Table 4).

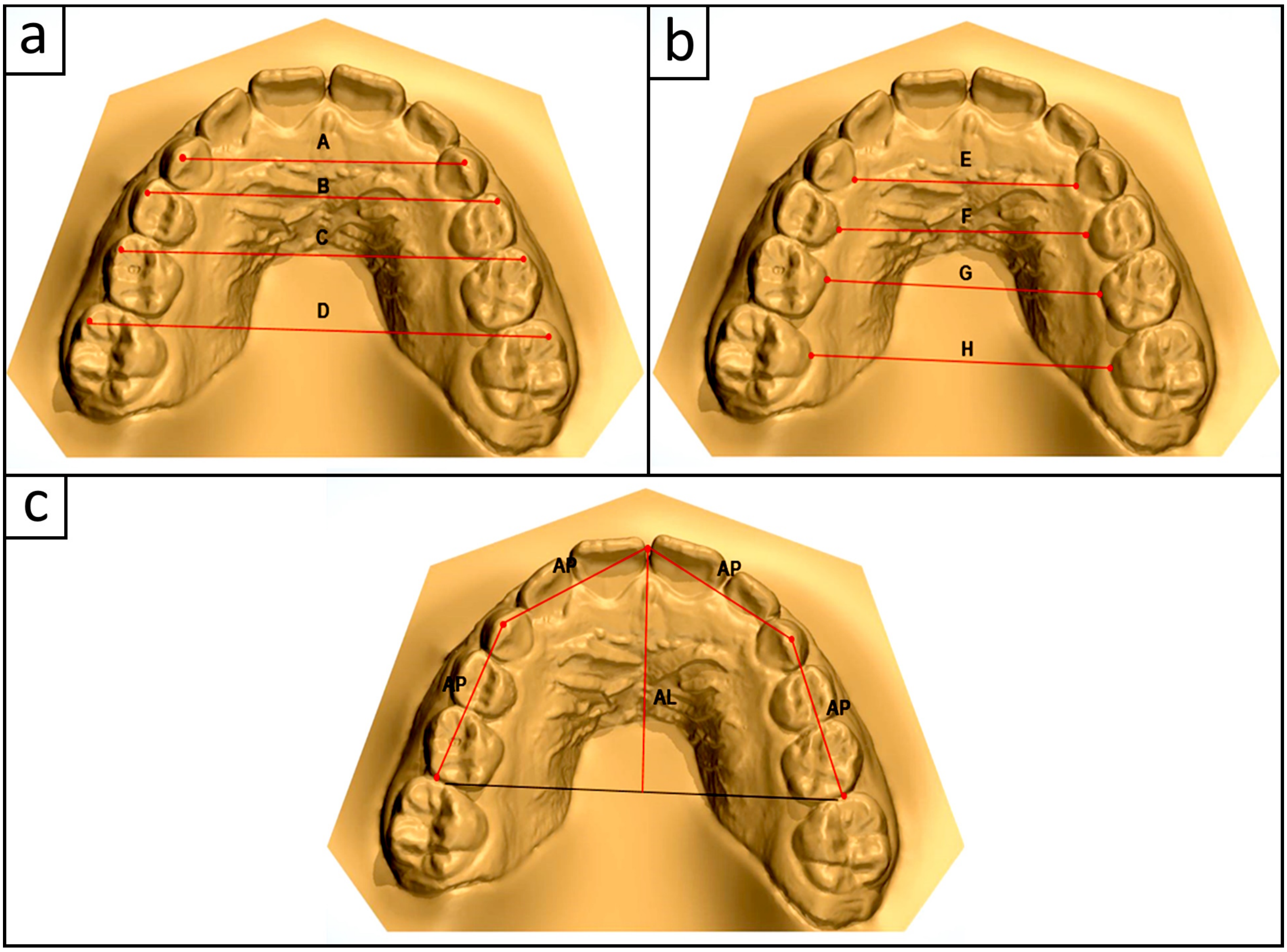

Figure 1. Upper arch width: (a) between the deciduous canine cusp tips (A), buccal cusp tips of first deciduous molars (B), the second deciduous molars (C), and mesiobuccal cusp tips of the first permanent molars (D); (b) between the deepest palatal gingival points of the deciduous canines (E), the first deciduous molars (F), the second deciduous molars (G), the first permanent molars (H); (c) Arch perimeter (AP) and arch length (AL)

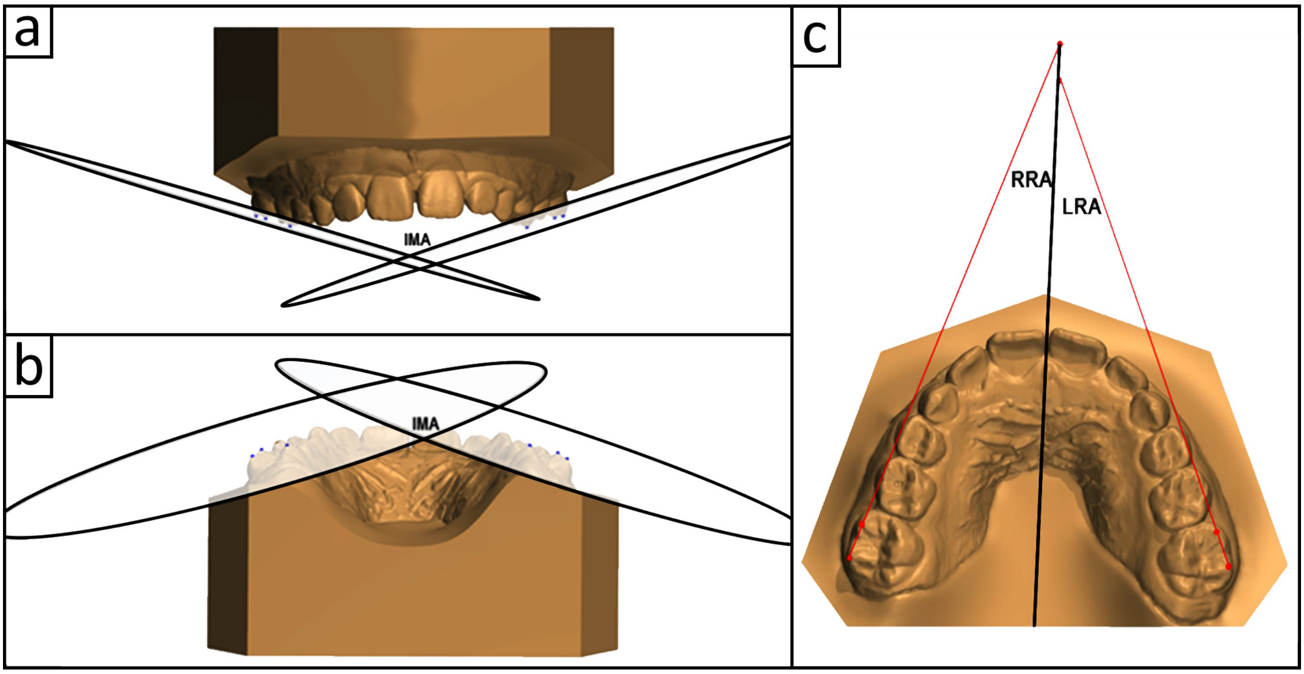

Figure 2. (a, b) Front and back view of the intermolar angle (IMA); (c) Right (RRA) and left permanent molar rotation angle (LRA)

Discussion

Conventional dentoalveolar expansion treatment, which may be preferred in the mixed dentition period, is mainly performed in arch expansion by means of removable appliances with expansion screws, fixed appliances made of wire such as quad helix, or re-

Table 1. Comparison of the Mean Values of the Chronological Ages and Maxillary Linear and Angular Measurements at the Beginning of the Observation Period (T0) Between Groups

	MFE T0 (n = 20)		SIE T0 (n = 20)		Mann Whitney U test
	Mean	±SD	Mean	±SD	*P-Value*
Age (y)	7.88	0.60	7.94	0.51	0.807
Linear Measurements (mm)					
Intercanine dental width	30.15	2.50	30.29	2.51	0.602
First deciduous molar dental width	36.49	2.19	36.92	2.56	0.583
Second deciduous molar dental width	41.74	2.76	42.35	2.63	0.602
First permanent molar dental width	48.22	3.47	48.57	2.96	0.583
Canine gingival width	23.43	1.99	23.70	2.12	0.659
First deciduous molar gingival width	25.45	2.25	25.52	2.36	0.989
Second deciduous molar gingival width	27.73	2.52	28.24	2.47	0.445
First permanent molar gingival width	30.92	2.68	31.03	2.20	0.883
Arch perimeter	74.27	5.13	73.98	3.29	0.659
Arch length	28.03	2.55	27.44	2.15	0.758
Angular measurements (°)					
Intermolar angle	153.52	9.73	152.80	5.51	0.602
Right permanent molar rotation angle	21.12	8.12	15.34	5.02	0.015*
Left permanent molar rotation angle	15.40	6.86	15.51	5.93	0.883

SD indicates standard deviation; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

Table 2. Comparison of Maxillary Linear and Angular Measurements Between Preobservation (T0) and Postobservation (T1) Periods in MFE

n = 20	T0				T1				T1-T0 Wilcoxon test	
	Mean	±SD	Min	Max	Mean	±SD	Min	Max	Mean±SD	*P-Value*
Linear Measurements (mm)										
Intercanine dental width	30.15	2.50	26.88	35.42	34.14	2.54	29.79	41.12	3.79 ± 2.16	0.003**
First deciduous molar dental width	36.49	2.19	32.91	41.16	40.65	2.81	34.56	44.55	4.15 ± 1.63	0.002**
Second deciduous molar dental width	41.74	2.76	35.00	47.29	45.87	2.82	41.11	49.99	4.12 ± 2.11	0.002**
First permanent molar dental width	48.22	3.47	43.49	56.93	51.15	3.00	45.89	57.05	2.92 ± 1.91	0.003**
Canine gingival width	23.43	1.99	18.96	26.54	26.07	2.26	21.07	30.74	2.64 ± 1.76	0.004**
First deciduous molar gingival width	25.45	2.25	20.74	30.07	28.34	2.33	23.96	31.38	2.89 ± 1.53	0.002**
Second deciduous molar gingival width	27.73	2.52	21.91	32.04	30.46	2.40	26.51	34.48	2.73 ± 1.59	0.003**
First permanent molar gingival width	30.92	2.68	26.96	37.00	32.31	2.74	27.33	37.63	1.39 ± 1.10	0.004**
Arch perimeter	74.27	5.13	68.93	87.83	78.41	4.46	69.72	88.31	4.14 ± 3.13	0.002**
Arch length	28.03	2.55	23.49	34.22	27.56	2.21	23.96	33.55	-0.47 ± 0.97	0.048*
Angular measurements (°)										
Intermolar angle	153.52	9.73	134.88	174.24	147.89	10.04	129.02	169.27	-5.62 ± 4.84	0.003**
Right permanent molar rotation angle	21.12	8.12	6.79	35.55	10.13	5.62	1.63	23.93	-10.98 ± 8.06	0.003**
Left permanent molar rotation angle	15.40	6.86	1.54	28.68	8.15	5.66	1.30	18.48	-7.24 ± 5.40	0.005**

SD indicates standard deviation; min, minimum value; and max, maximum value.
* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

Table 3. Comparison of Maxillary Linear and Angular Measurements Between Preobservation (T0) and Postobservation (T1) Periods in SIE

n = 20	T0				T1				T1-T0 Wilcoxon test	
	Mean	±SD	Min	Max	Mean	±SD	Min	Max	Mean±SD	*P-Value*
Linear Measurements (mm)										
Intercanine dental width	30.29	2.51	23.09	33.04	33.78	2.60	26.38	37.27	3.49 ± 2.12	0.004**
First deciduous molar dental width	36.92	2.56	31.73	42.81	40.46	2.90	33.92	44.20	3.54 ± 2.24	0.003**
Second deciduous molar dental width	42.35	2.63	37.98	48.03	45.86	3.19	39.49	50.58	3.51± 1.89	0.004**
First permanent molar dental width	48.57	2.96	43.03	55.44	50.82	3.13	43.60	56.84	2.25 ± 1.14	0.005**
Canine gingival width	23.70	2.12	19.02	26.38	26.20	2.15	21.07	29.36	2.50 ± 1.64	0.003**
First deciduous molar gingival width	25.52	2.36	20.92	29.58	28.19	2.55	22.43	31.46	2.67 ± 1.59	0.003**
Second deciduous molar gingival width	28.24	2.47	24.28	32.55	30.80	2.76	25.71	35.03	2.56 ± 1.35	0.004**
First permanent molar gingival width	31.03	2.20	26.81	34.45	32.44	2.42	27.46	36.49	1.40 ± 0.83	0.008**
Arch perimeter	73.98	3.29	67.65	80.24	77.26	3.44	71.05	84.93	3.28 ± 2.38	0.002**
Arch length	27.44	2.15	23.29	31.26	27.27	1.71	24.37	31.07	-0.16 ± 0.83	0.341
Angular measurements (°)										
Intermolar angle	152.80	5.51	143.66	165.14	149.12	6.62	134.94	162.15	-3.67 ± 3.59	0.004**
Right permanent molar rotation angle	15.34	5.02	7.39	27.95	9.72	4.62	2.39	16.93	-5.61 ± 3.72	0.003**
Left permanent molar rotation angle	15.51	5.93	1.24	22.85	9.67	5.82	0.98	21.21	-5.84 ± 4.75	0.003**

SD indicates standard deviation; min, minimum value; and max, maximum value.
* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

peated activations of the Leaf expansion appliance.[2–4] The option of dental arch expansion, which has been successfully performed with aligners, is a current approach, but arch expansion is usually achieved by a combination of tipping and parallel movement of the posterior teeth. Although treatments in the mixed dentition period with CA have been developed successfully in recent years,

Table 4. Comparison of the Postobservation (T1) – Preobservation (T0) Differences Between Groups

	MFE T1-T0 (n = 20)		SIE T1-T0 (n = 20)		T1-T0 Mann Whitney U test		
	Mean	±SD	Mean	±SD	Mean	±SD	*P-Value*
Linear measurements (mm)							
Intercanine dental width	3.79	2.16	3.49	2.12	3.61	2.12	0.414
First deciduous molar dental width	4.15	1.63	3.54	2.24	3.87	1.96	0.327
Second deciduous molar dental width	4.12	2.11	3.51	1.89	3.83	2.00	0.355
First permanent molar dental width	2.92	1.91	2.25	1.14	2.59	1.59	0.211
Canine gingival width	2.64	1.76	2.50	1.64	2.58	1.69	0.461
First deciduous molar gingival width	2.89	1.53	2.67	1.59	2.80	1.54	0.968
Second deciduous molar gingival width	2.73	1.59	2.56	1.35	2.67	1.46	0.738
First permanent molar gingival width	1.39	1.10	1.40	0.83	1.40	0.96	0.659
Arch perimeter	4.14	3.13	3.28	2.38	3.71	2.78	0.414
Arch length	-0.47	0.97	-0.16	0.83	-0.32	0.90	0.383
Angular measurements (°)							
Intermolar angle	-5.62	4.84	-3.67	3.59	-4.65	4.32	0.165
Right permanent molar rotation angle	-10.98	8.06	-5.61	3.72	-8.30	6.76	0.046*
Left permanent molar rotation angle	-7.24	5.40	-5.84	4.75	-6.54	5.07	0.242

SD indicates standard deviation; min, minimum value; and max, maximum value.
* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

scientific data on this system are considerably limited, and none of them include comparisons of expansion protocols. Therefore, the aim of this study was to compare the effects of sequential and simultaneous extension on the maxillary arch in order to evaluate the extension protocols applied with IFS in the mixed dentition.

In the MFE group, significant increases were found in all AWs measured at the cusp tip and at the gingival level in the maxillary arch. The AW increase occurred mostly at the level of the upper deciduous first molars. The amount of increase between the permanent first molars was less than that occurring between the deciduous canines and molars. These results are similar to those of a study by Lione et al.[11] At the same time, increases in the transversal dimension at the cusp tip level were found to be higher than at the gingival level, which was also similar to the findings of previous studies measuring the same teeth.[8,15–18] This can be explained by the fact that expansion with CA occurs by the buccal tipping of the teeth. In addition, it was observed that the width difference between the cusp tip and the gingival level was greatest in the first molars (1.53 mm). With the MFE protocol, we can state that the first stage of expansion involves the permanent first molars and causes those teeth to undergo more buccal tipping. Therefore, it is important to prioritize overcoming the side effects of tooth tipping by planning overcorrection, especially with extra buccal root torque. Moreover, with this protocol, there was a slight but significant reduction in arch length, similar to the findings of Levrini et al.[8] (Table 2).

As with the MFE, the efficiency of the transversal width increase decreased from the deciduous first molar to the permanent first molar after the SIE. These results are similar to those of other studies evaluating changes in expansion in the upper arch.[8,11,15,16] Likewise, the amount of increase between the permanent first molars were less than that revealed at the deciduous canine and molar level.[8,11] It was observed that the width difference between the cusp-gingival level of the teeth in SIE was less in the first molars (0.85 mm) than in the other teeth. This can be explained by the loss of strength in the buccolingual direction in the molar region as a result of the increased flexibility of the CA in the transversal direction, from anterior to posterior (Table 3).

The results of the current study show that the expansion planned with both protocols can provide satisfactory arch expansion in patients with mixed dentition. All increases in the transversal dimensions in the maxillary arch occurred similarly in both protocols. At the same time, the expansion between the cusp tips was higher than at the gingival level.[8,15,17,18] Zhou and Guo[19] report the superiority of the cusps in movement relative to the root in the ratio between root and cusp after expansion. Therefore, extra buccal root torque should be added according to the amount of expansion planned. According to the findings of this study, it would be useful to consider extra root torque in the MFE. The aim is to obtain as parallel a tooth movement as possible during expansion. Therefore, it is important to understand how to overcome the side effects of buccal crown tipping by applying extra buccal root torque. Consistent with the findings of Wong et al.[4], in the current study, although the arch length did not change in the SIE, the variation between the groups was similar. In general, it is explained that the reduction in AL after SIE is clinically greater. However, the results of the current study contradict this information. In this study, the fact that changes in AW after SIE were not significant when compared to the other group can be explained by the slightly greater reduction in AL. In both expansion protocols, the reduction of the IMA was associated with tipping in the first molars, and although the difference between groups was not significant, buccal tipping (-5.62°) was more common in the MFE group (Table 4).

In summary, distal rotation of the first molars was observed in both expansion protocols as a result of the force applied to the teeth with CA, and although it was more common in the MFE group, there was no significant difference between the groups. These findings can be explained by the maxillary expansion occurring in such a way that it supports the transition from oval to parabolic arch form.[11,20]

Limitations

Aligner–patient compatibility is very important if the effectiveness of CA is to be accurately assessed. For this reason, it will be useful to evaluate by adding a patient compliance indicator to each record for future studies. In addition, in the future, a comparison of expansion protocols can be examined with 3D imaging systems.

Conclusion

The null hypothesis was accepted. In both expansion protocols using IFS, the width increase was achieved by buccal tipping of the maxillary teeth. The maximum increase in maxillary transversal widths occurred in the deciduous first molars and the least in the permanent first molars. After expansion, distal rotation was also observed in the maxillary first molar teeth. Finally, no significant difference was found between the groups in all arch measurements except for the right first molar rotation angle.

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Author Contributions

N.K.: sample preparation, wrote the manuscript with input from all authors, design of the research, conceived the study and were in charge of overall direction and planning. Z.Y.: sample preparation, preformed the digital model measurements. G.C.: planned and carried out the simulations of all patients. E.C.T.: planned and carried out the simulations of all patients. H.G.: lead in writing the manuscript, final check of the manuscript, conceived the study and were in charge of overall direction and planning. All authors provided critical feedback and helped shape the research, analysis and manuscript

Conflict of Interest

Authors declare that they have no conflict of interest.

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