Original Article

A Long-term Study on the Expansion Effects of the Cervical-pull Facebow With and Without Rapid Maxillary Expansion

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Abstract: This study evaluates the long-term stability of maxillary expansion achieved by widening the inner bow of a facebow, with or without concurrent rapid maxillary expansion (RME) (Haas type), followed by treatment with fixed edgewise appliances. The parent sample included 154 nonextraction patients who started their orthodontic treatment during a defined time period. The exclusion criteria reduced the number of patients to 61 in the cervical-pull facebow group (CFB) and 41 in the RME-CFB group. All subjects were in the late-mixed to early-permanent dentition stage at the start of treatment. Dental casts were measured using a digital imaging system at four different times: start of treatment (T_1), end of active treatment (T_2), end of retention (T_3), and postretention follow up (T_4). The RME-CFB protocol produced a greater increase in maxillary arch width (6.1 mm) than did the CFB protocol (4 mm). The RME-CFB protocol provided greater net maxillary arch perimeter increase than did expansion with an inner bow of a cervical facebow. The RME-CFB group had three mm more arch perimeter 10 years after treatment completion than did the CFB group. The stability of expansion achieved with an inner bow of a facebow was equal to that achieved with a Haas-type RME appliance. Both expansion protocols retained 90% of the initial intermolar expansion 15 years after expansion. (*Angle Orthod* 2004;74:439–449.)

Key Words: Rapid maxillary expansion; Facebow; Edgewise therapy; Arch perimeter; Irregularity index; Cast analysis

INTRODUCTION

Rapid maxillary expansion (RME) has been used routinely by orthodontists for the last three decades to widen orthopedically the maxillae of growing patients. Arch expansion also has been produced simply by widening the inner bow of a facebow for over half a century. Surprisingly, however, despite the extensive use of both methods, there have been relatively few studies that have evaluated the long-term stability of either procedure when followed by a phase of fixed appliances.

Numerous investigators have suggested using maxillary expansion for correcting transverse discrepancies that result in posterior crossbites, either unilateral or bilateral.[1–5] In addition to correcting posterior transverse discrepancies, RME therapy has been advocated to help alleviate tooth-size/arch-length problems.[5] Adkins et al[6] determined that for every millimeter of interpremolar width increase, the resultant gain in arch length is approximately 0.7 mm. The gain in arch perimeter resulting from orthopedic maxillary expansion in combination with other methods of gaining arch perimeter such as interproximal reduction and molar distalization can be used to help eliminate crowding in some patients without the need to extract permanent teeth.

The long-term stability of RME reported in the literature varies considerably, as illustrated by the range of percent relapse after retention, 0–56%[7–14] (Table 1). Many factors must be taken into account if sutural separation (orthopedic expansion) is the primary objective. Arguably, the most im-

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TABLE 1. Posttreatment Changes After Orthopedic Maxillary Expansion

Reference	Sample Size	Age (y)	Years Out of Tx/Ret	Expansion (mm) Initial 6/6	Initial 3/3	Residual 6/6	Residual 3/3	Relapse (%) 6/6	Relapse (%) 3/3	Statistical Analysis
Stockfish[7]	150	6–32	5	8–14	—	6–10	—	24–29	—	No
Timms[8]	26	10–15	5	4.1–9.4	—	—	—	56	—	No
Linder-Aronson and Lindgren[9]	23	10–21	5	6	2.1	3.6	0.81	40	61	Yes
Haas[10]	10	—	5–12	9–12	4–5	9–12	4–5	0	0	No
Mew[11]	25	8–13	2.5	3.44	—	3.37	—	2	—	No
Herold[12]	19	13	5.6	3.9	3.2	2.1	1.9	44	41	NA[a]
Brust and McNamara[22]	146	8.7	>2.4	6.0	4.8	5.1	3.9	15	19	Yes
Moussa et al[13]	55	8–19	15	6.7	3.6	5.5	2.7	18	25	Yes
McNamara et al[14]	112	10–14	6.5	4.5	4.0	4.5	2.5	0	37	Yes

[a] NA indicates not available; Tx, treatment; and Ret, retention.

portant factors are the age and level of skeletal maturity of the patient.[15] The rigidity of the appliance also must be considered. Studies conducted by Hicks[16] and Krebs[17] reported that the skeletal contributions to the increase in arch width were 16–30% and 50%, respectively. These two studies indicate that a large amount of orthodontic expansion (tooth tipping) occurs. On the other hand, Moussa et al[13] and McNamara et al[14] evaluated more rigid expansion appliances and suggested that orthodontic expansion (tooth tipping) accounts for very little of the total expansion. Unfortunately, the validity of the conclusions reached by the majority of studies reporting both good and poor stability is questionable because most had large age ranges, small samples, and/or lacked any statistical analysis.[18] The investigations of both Gryson[19] and Sandström et al[20] failed to show any correlation between the change in mandibular arch width and the change in maxillary arch width. The few studies that suggest RME can influence the mandibular dentition indicate that the response is highly variable. The changes produced (if they exist at all), therefore, do not appear to be predictable or stable to any clinically significant degree, especially in the mandibular intercanine and arch perimeter dimensions.

To date, there has been only one investigation[21] that examined the transverse changes associated with intentional expansion of the inner bow of a cervical headgear. It should be noted, however, that no long-term data were presented in this study.

To summarize, the last two decades have seen a steady decline in the extraction rate during orthodontic treatment, especially in patients with mild to moderate amounts of crowding. Maxillary expansion, either with RME and/or a widened inner bow of a facebow, is being used with increasing frequency to gain additional arch length in these types of patients. The aim of this investigation was to compare and test statistically the effects and stability of two methods of treatment used to expand the maxillary arch, a cervical-pull facebow (CFB) with expansion of the inner bow and a Haas-type expander followed by the CFB. The long-term effects on dental cast samples that were approximately 10 years postorthodontic treatment and approximately 15 years postexpansion therapy were evaluated.

MATERIALS AND METHODS

The patients who participated in this study were recruited from the practice of a single orthodontic practitioner (Dr Veith). The original parent sample included 154 nonextraction patients who started their orthodontic treatment between the years 1973 and 1981. All subjects were in the late-mixed to early-permanent dentition stage, and they presented with a variable degree of contraction of the dental arches at the time of initial observation. The maxillary arches of these patients were expanded with one of two appliances: a Haas-type RME appliance in conjunction with a cervical facebow (RME-CFB) or a cervical facebow with expansion of the inner bow (CFB). In the RME-CFB group, the facebow was used right after RME treatment. The RME-CFB group did not present with more severe constriction of the dental arches than the CFB-only group. Both groups received similar fixed appliance therapy at the end of expansion.

Each complete patient record consisted of serial dental casts measured at four different times: start of treatment (T_1), end of treatment (T_2), end of retention (T_3), and postretention follow up (T_4). The average end-of-treatment to postretention follow-up-interval was 10.6 years. Each patient wore a banded mandibular first-premolar-to-first-premolar retainer until well past puberty, typically at least until 21 years of age.

Of the parent sample of 154 patients, 52 patients were eliminated because of one or more of the following exclusion criteria: damaged or unusable casts (n = 2); incomplete serial casts, typically a T_1 or T_2 cast (n = 40); extensive prosthodontic reconstruction (n = 3); postretention follow-up of less than two years (n = 7).

The exclusion criteria reduced the number of patients to 41 in group RME-CFB and 61 in group CFB. A total of 408 maxillary and mandibular dental casts of these 102 patients were measured at the four different stages de-

TABLE 2. Age Distribution (y)

Interval	CFB				RME-CFB			
	n	Mean	Range	SD	n	Mean	Range	SD
T_1	61	11.4	7.2–14.5	1.4	41	11.7	7.8–16.1	1.7
T_2	61	16.3	12.7–20.5	2.0	41	16.7	13.4–22.8	2.3
T_3	61	22.0	18.9–25.3	1.3	41	21.8	20.1–25.0	1.1
T_4	61	27.3	23.0–34.3	2.5	41	26.7	22.4–33.3	2.6

scribed previously using a digital imaging system. The sample age characteristics are summarized in Table 2. The CFB group consisted of 28 males and 33 females, whereas the RME-CFB group included 14 males and 27 females.

Dental cast measurements

Occlusal images of the dental casts were generated using video-imaging hardware and software (Bioscan OPTIMAS Imaging Systems, Seattle, Wash) that had been modified specifically for the analysis of dental casts.[22] Measurements of arch width, arch depth, arch perimeter, incisor irregularity, and molar angulation were generated with the aid of the OPTIMAS software on both arches.

Arch width. Two methods were used to determine arch width. The first method measured the distance between the computer-calculated centroid of one tooth and the centroid on its antimere. This method of measurement was denoted as arch width (centroid).[23] The second method measured the distance between a point on the lingual surface of each tooth to a homologous point on its antimere. The measure derived using this method was denoted as arch width (lingual). Arch widths were measured for the canines, first premolars, second premolars, and first molars.

Arch depth. Arch depth was measured from a common midline point in the dental arch (the contact point between the central incisors) perpendicularly to a transverse line connecting the mesial surfaces of the canines, first premolars, second premolars, and first molars.[23]

Arch perimeter. Arch perimeter was measured as the sum of the lengths of line segments anterior to the first permanent molars between the contact points of adjacent teeth.[23]

Incisor irregularity index. Incisor irregularity index was measured as the five summed linear displacements of the mesial and distal anatomical contact points of the six lower anterior teeth, as described previously by Little.[24]

Molar angulation. Molar angulation refers to the angle of intersecting lines drawn through the mesiobuccal and the mesiolingual cusp tips of the maxillary and mandibular first molars.

Statistical evaluation

Means and standard deviations were calculated for the dental cast variables at T_1, T_2, T_3, and T_4, as well as changes between T_1-T_2, T_2-T_4, and T_3-T_4. An analysis of variance (ANOVA) was used to test for significant differences ($P <$ .05 and $P <$ .01) between the means of the two groups at the start of treatment (T_1) and to identify significant differences for the changes between T_1-T_2 (expansion effect) and T_2-T_4 (postexpansion effect) for the two treatment groups. A statistical program (Systat for Windows™, version 5.03) aided in the statistical computations.

Error of the method

The order of digitization of the casts of each subject was selected at random, and then all arch dimensions on the T_1, T_2, T_3, and T_4 casts were digitized on the same occasion in an attempt to reduce the systematic error in the measurements.[25] In an attempt to determine how accurately the various arch dimensions could be measured on two separate occasions, 18 subjects' casts were selected randomly and redigitized to calculate intraclass correlation coefficients (ICC): ICC = variance component/(variance component + mean square within), where variance component = (mean square between − mean square within)/q, and q equals the number of measures per subject (ie, two). The mean square between used the ''patient × cast'' mean square. The ICC was calculated using an (M)ANOVA model. The ICC as well as the mean measurement difference and standard deviation for all variables are summarized in Table 3.

RESULTS

Analysis of starting form

The results of the ANOVA of pretreatment values (Table 4) revealed that there were no significant differences ($P <$ .05) between the two groups before treatment, with the exception of a larger mandibular first interpremolar arch width dimension in the CFB group, measured lingually. All between-group differences were within a one mm range.

Analysis of treatment and posttreatment effects

Table 5 summarizes the descriptive statistics for the two groups at T_2 through T_4. Table 6 illustrates the changes from pretreatment to end-of-treatment (T_1-T_2), end-of-treatment to start-of-retention (T_2-T_3), end-of-retention to postretention (T_3-T_4), and postretention to end-of-treatment (T_2-T_4) for both groups, along with the results of the comparison of the changes over time in the T_1-T_2 and T_2-T_4 intervals between the two groups using ANOVA.

Treatment (T_1-T_2)

Generally, most measurements increased in group RME-CFB during treatment. For example, maxillary intermolar width increased an average of 6.1 mm. Similarly, mandibular intermolar and maxillary and mandibular intercanine widths also increased during treatment. Treatment also increased both maxillary and mandibular arch perimeters. Specifically, maxillary arch perimeter increased 4.8 mm. As

TABLE 3. Intraclass Coefficient Correlations[a]

Measure (mm)	Difference (n = 18)		
	Mean	SD	ICC
Max. arch width (centroid)			
Intercanine	0.18	0.14	0.95
Interpremolar (first)	0.16	0.14	0.98
Interpremolar (second)	0.15	0.14	0.99
Intermolar (first)	0.19	0.14	0.98
Max. arch width (lingual)			
Intercanine	0.37	0.46	0.88
Interpremolar (first)	0.40	0.99	0.55
Interpremolar (second)	0.48	0.87	0.80
Intermolar (first)	0.36	0.30	0.92
Man. arch width (centroid)			
Intercanine	0.14	0.10	0.96
Interpremolar (first)	0.16	0.11	0.96
Interpremolar (second)	0.15	0.13	0.98
Intermolar (first)	0.18	0.13	0.97
Man. arch width (lingual)			
Intercanine	0.38	0.68	0.65
Interpremolar (first)	0.42	0.85	0.64
Interpremolar (second)	0.39	0.87	0.68
Intermolar (first)	0.27	0.22	0.91
Max. arch depth			
Canine	0.20	0.34	0.90
First premolar	0.19	0.17	0.96
Second premolar	0.21	0.17	0.97
First molar	0.21	0.17	0.97
Man. arch depth			
Canine	0.21	0.26	0.82
First premolar	0.16	0.13	0.96
Second premolar	0.15	0.11	0.97
First molar	0.15	0.12	0.96
Arch perimeter			
Maxillary	0.37	0.27	0.98
Mandibular	0.31	0.22	0.96
Incisor irregularity			
Maxillary	0.47	0.51	0.74
Mandibular	0.37	0.37	0.85
Molar angulation (°)			
Maxillary	1.47	1.37	0.80
Mandibular	1.09	2.67	0.72

[a] ICC indicates intraclass correlation coefficients; Max., maxillary; and Man., mandibular.

expected, both maxillary and mandibular incisor irregularities decreased. There was a very slight tipping effect or increase in maxillary molar angulation and a slightly greater uprighting or decrease in mandibular molar angulation. The same general trends noted in group RME-CFB also occurred in group CFB. The between-group differences were statistically significant for maxillary interpremolar and intermolar widths and maxillary arch perimeter. These measures showed a greater increase in the RME-CFB group than in the CFB-only group. The changes in the other variables were not statistically different during the expansion interval.

Retention period (T_2-T_3)

Both maxillary and mandibular incisor irregularities remained essentially unchanged in both groups during the retention period. It is interesting to note that even with a fixed retainer, mandibular intercanine width decreased slightly. Generally, all other measurements also decreased slightly, but not to a significant degree. Both maxillary and mandibular molar angulations increased by a small amount.

Postretention period (T_3-T_4)

Both maxillary and mandibular incisor irregularities increased very slightly after the fixed mandibular retainer was removed in both RME-CFB and CFB groups. All other measurements showed a general trend toward a decrease, except maxillary intermolar width and maxillary and mandibular molar angulations, which did not change. The magnitude of change did not exceed one mm for any of the variables examined.

Overall posttreatment period (T_2-T_4)

Most measurements decreased in group RME-CFB during the end-of-treatment to postretention period. Both maxillary and mandibular arch perimeters showed the largest magnitude of decrease, 1.7 and 1.6 mm, respectively. Maxillary and mandibular incisor irregularities and mandibular molar angulation increased slightly, but not significantly. The same general trends noted in group RME-CFB also occurred in group CFB. During the end-of-treatment to postretention interval, the only significant difference between groups CFB and RME-CFB was represented by the decrease in mandibular intermolar width, which was larger in the RME-CFB group; however, the magnitude of the difference was not clinically significant (0.4 mm).

DISCUSSION

Maxillary arch width

In group RME-CFB, the mean maxillary intermolar treatment increase of 6.1 mm is consistent with the treatment changes recorded in numerous investigations[7–10,13,22] and slightly greater than the increase reported by McNamara et al (4.5 mm).[14] Several investigations also have reported mean maxillary intercanine treatment increases similar to the 3.9 mm reported in this study for group RME-CFB.[9,12–14] The net posttreatment gain of 5.5 mm in maxillary intermolar width (Table 5) is similar to the net gains reported by Moussa et al,[13] McNamara,[26] and McNamara et al.[14] In this study, the decrease in maxillary intermolar width 15 years after expansion was small, approximately 0.5 mm.

The net long-term gain in maxillary intercanine width of

TABLE 4. Pretreatment (T_1): Descriptive and Inferential Statistics[a]

Measure (mm)	CFB n	CFB Mean	CFB SD	CFB-RME n	CFB-RME Mean	CFB-RME SD	ANOVA Significance
Max. arch width (centroid)							
Intercanine	50	27.7	2.6	30	27.8	2.8	NS
Interpremolar (first)	60	32.0	2.8	41	31.7	2.9	NS
Interpremolar (second)	56	36.3	2.9	39	35.9	2.7	NS
Intermolar (first)	61	40.9	3.0	41	40.8	3.1	NS
Max. arch width (lingual)							
Intercanine	50	22.8	2.7	30	22.6	2.7	NS
Interpremolar (first)	60	23.4	2.3	41	22.3	2.5	*
Interpremolar (second)	56	27.2	2.7	39	26.5	2.7	NS
Intermolar (first)	61	30.3	2.9	41	30.1	2.8	NS
Man. arch width (centroid)							
Intercanine	51	22.0	1.7	38	22.6	1.5	NS
Interpremolar (first)	56	28.0	2.1	39	28.8	2.0	NS
Interpremolar (second)	59	32.7	2.3	39	33.5	2.3	NS
Intermolar (first)	61	38.1	2.6	41	39.1	2.8	NS
Man. arch width (lingual)							
Intercanine	51	18.0	1.8	38	18.1	1.6	NS
Interpremolar (first)	56	21.8	1.8	39	22.7	2.5	NS
Interpremolar (second)	59	25.3	2.1	39	26.2	2.2	NS
Intermolar (first)	61	29.1	2.2	41	30.2	3.0	NS
Max. arch depth							
Canine	50	7.4	1.6	30	7.1	1.8	NS
First premolar	60	13.1	1.7	41	12.4	2.2	NS
Second premolar	56	19.0	2.0	39	18.7	2.2	NS
First molar	61	26.0	2.4	41	25.6	2.6	NS
Man. arch depth							
Canine	51	3.3	1.2	38	2.9	1.1	NS
First premolar	56	8.0	1.5	39	7.8	1.4	NS
Second premolar	59	13.9	1.5	39	14.1	1.5	NS
First molar	61	21.6	2.0	41	21.3	1.8	NS
Arch perimeter							
Maxillary	61	70.3	4.8	41	69.1	5.3	NS
Mandibular	61	61.0	4.2	41	61.7	3.8	NS
Incisor irregularity							
Maxillary	50	7.8	2.8	30	7.5	3.3	NS
Mandibular	51	4.8	2.1	38	4.9	2.0	NS
Molar angulation (°)							
Maxillary	61	173.8	5.0	41	174.5	5.1	NS
Mandibular	61	190.2	5.9	41	190.8	6.0	NS

[a] CFB indicates cervical-pull facebow group; RME, rapid maxillary expansion; Max., maxillary; Man., mandibular; and NS, not significant.
* $P < 0.05$.

three mm for group RME-CFB also is similar to the net gains reported by Moussa et al[13] and McNamara et al[14] but larger than the net gains reported by Linder-Aronson and Lindgren,[9] Herold,[12] and McNamara.[26] It is interesting to note that the maxillary intercanine width decreases significantly, approximately one mm, from age 14 to 48 years in untreated subjects.[27,28] Thus, the net gain of three mm recorded in intercanine width for group RME-CFB represents a stable increase that is clinically significant.

In the literature, there is only one investigation that evaluated the short-term effects of using a facebow to expand the maxillary arch. Kirjavainen et al[21] reported a maxillary intermolar treatment increase of 6.6 and 5.1 mm in males and females, respectively, and a maxillary intercanine increase of 4.9 and five mm, in males and females, respectively. These investigators did not quantify the relative amounts of tooth tipping that may have occurred. In this study, there was a four-mm treatment increase in maxillary intermolar width and a 3.2-mm treatment increase in maxillary intercanine width for group CFB. Surprisingly, there was only 1.8° of maxillary first molar angulation increase associated with this increase in arch width produced by the

TABLE 5. End of Treatment (T_2), End of Retention (T_3), and Posttreatment (T_4): Descriptive Statistics[a]

	T_2				T_3				T_4			
	CFB		CFB-RME		CFB		CFB-RME		CFB		CFB-RME	
Measure (mm)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Max. arch width (centroid)												
Intercanine	30.4	1.9	31.1	2.0	29.9	2.1	30.5	2.1	29.7	2.1	30.2	2.1
Interpremolar (first)	36.2	2.1	37.5	1.9	35.9	2.4	37.0	2.2	35.6	2.4	36.6	2.3
Interpremolar (second)	40.5	2.5	42.4	2.3	40.3	2.8	41.8	2.5	40.1	2.8	41.6	2.7
Intermolar (first)	44.9	2.9	46.9	2.7	44.6	3.0	46.4	2.8	44.5	3.1	46.3	2.9
Max. arch width (lingual)												
Intercanine	24.3	1.9	25.0	2.0	23.5	2.1	23.9	1.8	23.0	1.8	23.6	2.0
Interpremolar (first)	26.9	2.0	27.7	1.9	26.7	2.0	27.3	2.0	26.6	2.1	27.1	2.0
Interpremolar (second)	31.3	2.6	32.5	2.3	31.0	2.4	32.1	2.3	31.0	2.4	32.0	2.4
Intermolar (first)	34.3	2.8	35.8	2.7	33.9	2.8	35.3	2.5	33.8	2.8	35.5	2.8
Man. arch width (centroid)												
Intercanine	23.3	1.6	24.0	1.3	23.0	1.7	23.7	1.5	22.6	1.8	23.4	1.7
Interpremolar (first)	30.7	2.0	31.8	1.7	30.7	2.0	31.8	1.8	30.2	2.1	31.3	1.9
Interpremolar (second)	35.5	2.4	36.9	2.0	35.2	2.5	36.3	2.2	34.8	2.6	35.9	2.3
Intermolar (first)	40.3	2.8	42.3	2.4	40.3	2.9	41.9	2.7	40.2	3.0	41.8	2.7
Man. arch width (lingual)												
Intercanine	17.9	1.3	18.1	1.4	17.8	1.5	18.2	1.5	17.3	1.5	17.7	1.8
Interpremolar (first)	24.2	1.8	25.2	1.8	24.4	1.8	25.2	1.9	24.3	2.0	25.2	2.1
Interpremolar (second)	28.2	2.2	29.2	2.0	27.9	2.3	28.7	2.2	27.6	2.3	28.5	2.6
Intermolar (first)	31.2	2.5	33.0	2.4	31.3	2.6	32.7	2.7	31.1	2.7	32.5	2.7
Max. arch depth												
Canine	5.7	0.9	5.7	1.0	5.7	0.9	5.8	1.0	5.6	1.0	5.8	1.0
First premolar	12.1	1.3	12.0	1.4	11.8	1.4	11.9	1.4	11.7	1.4	11.8	1.5
Second premolar	18.4	1.7	18.4	1.6	17.9	1.7	18.1	1.7	17.7	1.6	18.0	1.8
First molar	24.3	2.0	24.7	1.9	23.7	2.0	24.2	2.0	23.5	2.0	24.1	2.3
Man. arch depth												
Canine	2.9	0.7	2.9	0.8	2.9	0.6	3.0	0.7	2.8	0.1	2.7	0.7
First premolar	7.8	1.1	7.9	0.9	7.7	1.1	7.8	0.9	7.6	1.1	7.6	0.9
Second premolar	14.1	1.5	14.4	1.2	13.9	1.4	14.2	1.3	13.6	1.5	13.8	1.2
First molar	20.4	1.9	20.8	1.7	20.0	1.8	20.5	1.8	19.7	1.8	20.1	1.8
Arch perimeter												
Maxillary	72.1	4.5	73.9	4.1	70.8	4.4	72.5	4.4	70.3	4.5	72.2	4.4
Mandibular	61.6	4.1	63.2	3.4	60.7	4.1	62.5	3.6	60.0	4.0	61.6	3.6
Incisor irregularity												
Maxillary	2.2	1.0	2.2	1.0	2.2	1.1	2.3	1.0	2.4	1.2	2.7	1.2
Mandibular	2.1	0.7	2.3	1.0	2.1	0.8	2.4	1.3	2.6	1.0	2.9	1.3
Molar angulation (°)												
Maxillary	175.6	5.6	176.7	4.9	175.9	5.5	177.4	5.1	175.6	4.8	177.3	4.5
Mandibular	184.7	5.1	183.3	4.1	184.7	4.7	184.2	4.8	185.1	4.9	184.2	4.3

[a] CFB indicates cervical-pull facebow group; RME, rapid maxillary expansion; Max., maxillary; Man., mandibular; and NS, not significant.

cervical facebow. The minimal change in maxillary molar angulation associated with this clinically significant amount of intermolar expansion suggests that the expansion achieved using the facebow is similar in nature to that recorded in group RME-CFB.

In group CFB, the net long-term gain in maxillary intermolar and intercanine width was 3.6 and 2.5 mm, respectively. The losses in maxillary intermolar width (0.4 mm) and intercanine width (0.7 mm) postretention in this treatment group were similar to the losses recorded in group RME-CFB for the same dimensions.

Mandibular arch width

In group RME-CFB, the mean mandibular intermolar and intercanine treatment increases of 2.9 and 1.3 mm, respectively, are less than the 3.3 mm intermolar and 2.2 mm intercanine width treatment increases reported by Sandström et al.[20] The changes in arch dimensions are, however, larger than the two mm intermolar and 1.8 mm intercanine treatment increases reported by Moussa et al[13] and than the one mm intermolar and two mm intercanine treatment increases reported by McNamara et al.[14]

In group RME-CFB, the net long-term increase of 2.4 mm in mandibular intermolar width is greater than the range of 0.4 to 1.9 mm reported on patients treated only with fixed edgewise appliances.[29–31] This net increase of 2.4 mm is the same value reported by Moussa et al[13] and is greater than the value of 1.5 mm reported by McNamara[26] and McNamara et al[14] in patients treated with RME in addition to fixed edgewise appliances. There were large standard deviations associated with all the postretention means, however, suggesting much individual variation.

The results of this study are consistent with the trends reported in the literature regarding mandibular intercanine width. After a small (1.3 mm) treatment increase, the resultant net gain after retention was 0.7 mm. The results reported by Moussa et al[13] are identical to those found in this study. McNamara[26] and McNamara et al,[14] however, reported a net mandibular intercanine width increase of about 1.5 mm. One possible explanation for this difference is the age of the patients at final measurement. In this study, the mean age of patients was 26.7 years, whereas it was 21 years in the investigations by McNamara[26] and McNamara et al.[14] It is possible that the normal maturational process of a shrinking intercanine dimension has not occurred to the same extent in the previous studies.[14,26]

In group CFB, the mean mandibular intermolar treatment increase of 2.4 mm is similar to the 2.5 mm increase reported by Kirjavainen et al[21] for females but is somewhat less than the 3.4 mm increase they reported for males. Interestingly, the similarities and differences between males and females are reversed in the intercanine region. The mean mandibular intercanine treatment increase of 1.2 mm is similar to the 1.3 mm increase Kirjavainen et al[21] reported for males and is slightly less than the 1.8 mm increase reported for females. The net long-term gain in mandibular intermolar and intercanine width in the CFB group was 2.3 and 0.6 mm, respectively. As discussed previously, the treatment changes reported by Kirjavainen et al[21] were similar, but they did not present any long-term data.

Maxillary arch perimeter

Before interpreting the results of expansion therapy in terms of arch perimeter increase, it must be noted that investigations regarding the longitudinal changes in arch perimeter have shown that this dimension decreases with age.[23,27–40] Moyers et al[23] reported that maxillary arch perimeter decreases approximately two to three mm from ages 10 to 17 years. Carter and McNamara[27] reported a decrease of 1.4 mm from age 14 to 17 years. More recent investigations also have reported mean treatment increases in maxillary arch perimeter in patients who had RME therapy.[6,13,14,22,26,27] In this study, the mean treatment increase of 4.8 mm in group RME-CFB is similar to the 4.7-mm increase reported by Adkins et al[6] and the 4.1-mm increase reported by Moussa et al.[13] McNamara[26] and McNamara et al,[14] however, have reported larger mean treatment increases (ranging from 7.9 to 5.6 mm). Taking into account the 1.4 mm decrease that occurs naturally in untreated patients,[27] the arches treated with RME-CFB effectively had maxillary arch perimeters that were 6.2 mm greater at the end of treatment than would have been expected if they were left untreated.

There was less mean treatment increase in maxillary arch perimeter seen in group CFB than that recorded for group RME-CFB (1.8 mm compared with 4.8 mm). It should be noted, however, that the majority of patients in group CFB still had their primary maxillary second molars intact (44 of 61), and thus a majority had leeway space available. Unfortunately, Kirjavainen et al[21] measured arch length and not arch perimeter, and thus, a direct comparison of the numeric values is difficult. Kirjavainen et al,[21] however, did record an increase in maxillary arch length of approximately 1.7 mm. After treatment, the RME-CFB group still had a net increase of 3.1 mm in arch perimeter, whereas group CFB showed no net gain. McNamara[26] reported a net increase of 4.3 mm, whereas McNamara et al[14] recorded an increase of three mm and Moussa et al[13] an increase of 1.6 mm in RME patients. Again, if the normal maturation process of a decrease in arch perimeter (−1.9 mm)[27] is considered, the maxillary arch perimeter for the RME-CFB group is five mm larger than in the untreated subjects.

The gain produced by treatment with RME is not transient and is stable long term after treatment. This long-term net increase in maxillary arch perimeter achieved with the RME-CFB protocol may help eliminate the need to extract in some patients with mild to moderate (<6 mm) amounts of crowding in the maxillary arch. This statement only pertains to the acquisition of available space necessary for alignment; however, it does not address the possible need to extract teeth for the correction of anteroposterior discrepancies.

Mandibular arch perimeter

The mean mandibular arch perimeter treatment gain of 1.5 mm produced by the RME-CFB maxillary expansion protocol was lesser than the values recorded by other investigations.[13,14,26] Moussa et al[13] reported a mean treatment increase of 2.7 mm, whereas McNamara indicated a mean treatment gain in mandibular arch perimeter of 2.9 mm (late-mixed dentition) in patients treated with an RME-fixed appliance protocol.[26]

In this study, mandibular arch perimeter did not decrease as much as it would have had these patients not received the maxillary expansion in combination with fixed appliance protocols.[26,27] In group RME-CFB, the maxillary expansion protocol, in combination with fixed orthodontic therapy, yielded enough additional space to provide a reasonably good resolution of the slight amount of mandibular crowding present in these patients.

TABLE 6. Descriptive Statistics for Between-observation Changes and Statistical Comparisons on T_1-T_2 and T_2-T_4 Changes[a]

Measures	Change T_1-T_2							Change T_2-T_3	
	CFB			CFB-RME			Anova significance	CFB (n = 61)	
	n	Mean	SD	n	Mean	SD		Mean	SD
Max. arch width (centroid)									
Intercanine	50	3.2	4.4	30	3.9	5.8	NS	−0.5	0.4
Interpremolar (first)	60	4.2	2.1	41	5.9	2.3	**	−0.3	0.3
Interpremolar (second)	56	4.2	2.4	39	6.5	2.2	**	−0.3	0.3
Intermolar (first)	61	4.0	2.3	41	6.1	2.3	**	−0.3	0.3
Max. arch width (lingual)									
Intercanine	50	1.8	4.2	30	2.8	5.3	NS	−0.8	0.7
Interpremolar (first)	60	3.5	2.1	41	5.3	2.0	**	−0.2	0.1
Interpremolar (second)	56	4.1	2.2	39	6.1	2.2	**	−0.3	0.2
Intermolar (first)	61	4.0	2.1	41	5.7	2.3	**	−0.5	0.7
Man. arch width (centroid)									
Intercanine	51	1.2	1.0	38	1.3	0.9	NS	−0.2	0.4
Interpremolar (first)	56	3.1	1.7	39	3.0	1.3	NS	0.0	0.4
Interpremolar (second)	59	2.9	1.7	39	2.9	1.4	NS	−0.3	0.5
Intermolar (first)	61	2.4	1.6	41	2.9	1.3	NS	0.1	0.4
Man. arch width (lingual)									
Intercanine	51	−0.2	1.5	38	1.7	0.0	NS	−0.2	0.5
Interpremolar (first)	56	2.7	1.9	39	2.4	1.6	NS	0.2	0.7
Interpremolar (second)	59	3.1	1.9	39	3.0	1.5	NS	−0.3	0.7
Intermolar (first)	61	2.3	1.5	41	2.8	1.6	NS	0.1	0.4
Max. arch depth									
Canine	50	−1.6	1.8	30	−1.1	2.0	NS	0.0	0.2
First premolar	60	−0.9	1.5	41	−0.5	2.0	NS	−0.3	0.5
Second premolar	56	−0.7	1.7	39	−0.4	2.0	NS	−0.5	0.4
First molar	61	−1.7	2.0	41	−0.9	2.1	NS	−0.6	0.5
Man. arch depth									
Canine	51	−0.5	1.0	38	0.0	1.0	NS	0.0	0.2
First premolar	56	−0.1	1.3	39	0.1	1.4	NS	−0.1	0.4
Second premolar	59	0.2	1.3	39	0.3	1.4	NS	−0.2	0.4
First molar	61	−1.1	1.5	41	−0.5	1.7	NS	−0.5	0.4
Arch perimeter									
Maxillary	61	1.8	3.4	41	4.8	4.5	**	0.7	0.7
Mandibular	61	0.6	2.9	41	1.5	2.6	NS	−1.0	0.7
Incisor irregularity									
Maxillary	50	−5.4	2.8	30	−5.0	3.3	NS	0.0	0.6
Mandibular	51	−2.7	1.9	38	−2.7	2.0	NS	0.0	0.7
Molar angulation (°)									
Maxillary	61	1.8	4.8	41	2.1	4.8	NS	0.3	3.0
Mandibular	61	−5.5	5.6	41	−7.5	5.1	NS	0.1	2.9

[a] CFB indicates cervical-pull facebow group; RME, rapid maxillary expansion; Max., maxillary; Man., mandibular; and NS, not significant.
* $P < .05$; ** $P < .01$.

The mean gain in mandibular arch perimeter produced by the CFB maxillary expansion protocol was only 0.6 mm. Kirjavainen et al,[21] who measured arch length rather than arch perimeter, reported a very minimal treatment gain of approximately 0.1 mm (average of males and females, anterior and posterior arch lengths). The potential leeway space available because of the presence of primary second molars (present in the majority of subjects), however, was not lost.

In group RME-CFB, the loss in mandibular arch perimeter after a 1.5-mm treatment gain yielded a postretention value that was essentially the same as the pretreatment value. Moussa et al[13] recorded a postretention value that was 0.6 mm less than the pretreatment value. McNamara,[26] however, described net gains in mandibular arch perimeter of 0.4 mm (late-mixed dentition) and 4.1 mm (early-permanent dentition) in patients treated with an RME-fixed appliance protocol five years postretention. Again, one possible explanation for this discrepancy is the difference in age of the patients at final measurement. As stated previ-

TABLE 6. Extended

Change T_2-T_3		Change T_3-T_4				Change T_2-T_4				
CFB-RME (n = 41)		CFB (n = 61)		CFB-RME (n = 41)		CFB (n = 61)		CFB-RME (n = 41)		Anova significance
Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
−0.6	0.4	−0.2	0.3	−0.3	0.3	−0.7	0.6	−0.9	0.7	NS
−0.6	0.5	−0.3	0.4	−0.3	0.5	−0.6	0.9	−0.9	0.7	NS
−0.6	0.5	−0.1	0.4	−0.2	0.5	−0.4	1.1	−0.8	1.2	NS
−0.6	0.4	−0.1	0.4	0.0	0.4	−0.4	0.8	−0.6	1.1	NS
−1.1	0.9	−0.5	0.8	−0.3	0.4	−1.3	1.2	−1.4	1.4	NS
−0.3	0.2	−0.1	0.7	−0.2	0.6	−0.3	0.9	−0.5	0.8	NS
−0.4	0.3	0.0	0.6	−0.2	0.6	−0.3	1.3	−0.6	1.3	NS
−0.6	0.9	0.0	0.6	0.2	1.2	−0.5	0.9	−0.4	1.9	NS
−0.2	0.5	−0.4	0.3	−0.4	0.5	−0.6	0.4	−0.6	0.6	NS
0.0	0.5	−0.5	0.5	−0.5	0.5	−0.5	0.6	−0.5	0.6	NS
−0.5	0.4	−0.4	0.4	−0.5	0.4	−0.7	0.6	−1.0	0.7	NS
−0.3	0.5	−0.2	0.4	−0.2	0.3	−0.1	0.7	−0.5	0.9	*
0.1	0.5	−0.5	0.5	−0.5	1.4	−0.7	0.9	−0.4	1.6	NS
0.0	0.9	−0.1	0.9	0.0	1.2	0.1	1.0	0.0	1.1	NS
−0.5	0.9	−0.3	0.5	−0.2	1.3	−0.6	0.7	−0.7	1.4	NS
−0.3	0.6	−0.2	0.4	−0.2	0.4	−0.1	0.7	−0.5	0.9	*
0.1	0.4	−0.1	0.3	0.0	0.4	−0.1	0.5	0.1	0.6	NS
−0.1	0.3	−0.1	0.4	0.0	0.3	−0.4	0.6	−0.1	0.5	NS
−0.3	0.5	−0.2	0.4	−0.1	0.4	−0.7	0.6	−0.4	0.5	NS
−0.4	0.6	−0.2	0.4	−0.1	0.3	−0.8	0.7	−0.5	0.8	NS
0.1	0.4	−0.1	0.3	−0.3	0.7	−0.1	0.4	−0.2	0.6	NS
−0.1	0.4	−0.1	0.4	−0.2	0.5	−0.2	0.5	−0.3	0.5	NS
−0.2	0.4	−0.3	0.4	−0.4	0.5	−0.5	0.6	−0.6	0.5	NS
−0.3	0.5	−0.3	0.4	−0.5	0.5	−0.8	0.6	−0.8	0.6	NS
−1.5	0.9	−0.5	0.7	−0.2	0.8	−1.7	1.1	−1.7	1.4	NS
−0.7	1.0	−0.7	0.7	−0.9	0.8	−1.7	0.9	−1.6	1.1	NS
0.1	0.6	0.1	0.7	0.4	0.7	0.1	0.9	0.5	1.2	NS
0.1	0.8	0.5	0.7	0.6	1.0	0.5	0.8	0.7	1.3	NS
0.7	3.2	−0.3	3.1	−0.1	3.1	0.0	3.7	0.6	3.7	NS
0.9	3.1	0.3	3.0	0.0	3.0	0.4	3.6	0.9	3.2	NS

ously, the postretention mandibular arch perimeter value was smaller than the pretreatment value in group CFB. However, the net loss (−1.1 mm) in this group did not equal the amount of leeway space potentially available for use in some patients.

Maxillary and mandibular incisal irregularity

In group RME-CFB, the mean treatment decrease of five mm in the maxillary incisor irregularity index is comparable to the 5.8-mm decrease reported by Moussa et al. The RME-CFB maxillary expansion protocol resolved the moderate amounts of crowding present in these patients at the start of treatment. In group CFB, the mean treatment decrease in maxillary incisor irregularity index was 5.4 mm. Kirjavainen et al[21] did not measure incisor irregularity, and thus, direct comparison of the treatment effects observed in this study is not possible.

In group RME-CFB, the mean mandibular incisor irregularity index decrease of 2.7 mm is comparable to the 2.8-mm decrease reported by Moussa et al.[13] The patients in this study had mild amounts of crowding, as represented by the initial irregularity index (Table 4). It is clear, however, that the RME-CFB maxillary expansion protocol in combination with fixed orthodontics successfully resolved the mild amount of crowding present at the start of treatment. In group CFB, the mean treatment decrease in mandibular incisor irregularity index also was 2.7 mm. Again, the study conducted by Kirjavainen et al[21] did not measure incisor irregularity.

In both groups, RME-CFB and CFB, during the posttreatment period, the mean maxillary incisor irregularity increases of 0.5 and 0.1 mm, respectively, and the mean mandibular incisor irregularity increases of 0.7 and 0.5 mm, respectively, are comparable to the 0.8-mm increases reported by Moussa et al.[13] These changes in maxillary incisor irregularity during the posttreatment period are similar to those that might have occurred naturally with increasing age.[27,28] The prolonged retention period most likely played a role in the somewhat greater stability, compared with that reported in the literature.

Expansion with the RME-CFB protocol compared with the CFB protocol

The results of this study indicate that the stability of the widening achieved with the Haas-type expander was not statistically different compared with the stability of the expansion achieved with the expanded inner bow of a facebow. Previous investigations have demonstrated that RME appliances produce orthopedic expansion that is stable after retention when used at an age before sutural ossification occurs.[13–15,26] With four and 6.1 mm of intermolar expansion for groups CFB and RME-CFB, respectively, the loss in this dimension was only 0.4 and 0.6 mm 10 years after active treatment ended. In both groups, 90% of the total intermolar expansion was maintained. These losses in the transverse dimension were minor and represent good long-term stability.

The literature also demonstrates the long-term instability of any significant amount of orthodontic expansion (tooth tipping). If tooth tipping had occurred with facebow treatment, it is anticipated that there would be more maxillary first molar tipping (as indicated by a change in molar angulation) during the treatment phase followed by a rebound in the posttreatment phase. In fact, there was no statistical difference in maxillary molar angulation between the two groups during the treatment (T_1-T_2) or posttreatment (T_2-T_4) intervals. In this study, the net maxillary intermolar increase in group CFB was 3.6 mm, arguably clinically significant. The maxillary intermolar increase is much greater than the one mm net maxillary intermolar expansion, achieved with orthodontic-type forces, reported in the literature.[29,31,34,41]

The amount of mandibular intermolar width that is gained at the end of the long-term observation interval is the same for the RME and facebow groups (2.4 mm). As for the increases in arch perimeters, however, the facebow protocol is not able to induce any favorable increase in either maxillary or mandibular arch perimeters in the long term, whereas the significantly larger postexpansion gain in the RME group (4.8 vs 1.8 mm in the facebow group) leads to a clinically significant outcome in the long term (3.1 mm).

CONCLUSIONS

- The RME-CFB protocol produced a greater increase in maxillary arch width (6.1 mm) than did the CFB protocol (4 mm).
- The RME-CFB protocol provided more net maxillary arch perimeter increase than did expansion with an inner bow of a cervical facebow. The RME-CFB group had three mm more maxillary arch perimeter 10 years after treatment completion than did the CFB group.
- The stability of expansion achieved with an inner bow of a facebow is equal to that achieved with a Haas-type RME appliance, especially when a similar fixed appliance protocol follows expansion. Both expansion protocols retained 90% (5.5 in mm group RME-CFB; 3.6 mm in group CFB) of the initial intermolar expansion 15 years after expansion therapy. The expansion produced by both protocols does not appear to induce orthodontic tipping of anchor teeth.
- Maxillary expansion by either method exerted only a modest effect on mandibular arch perimeter. Neither method produced a net postretention increase. Mandibular arch perimeters, however, were greater than they would have been had these patients not been treated.

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