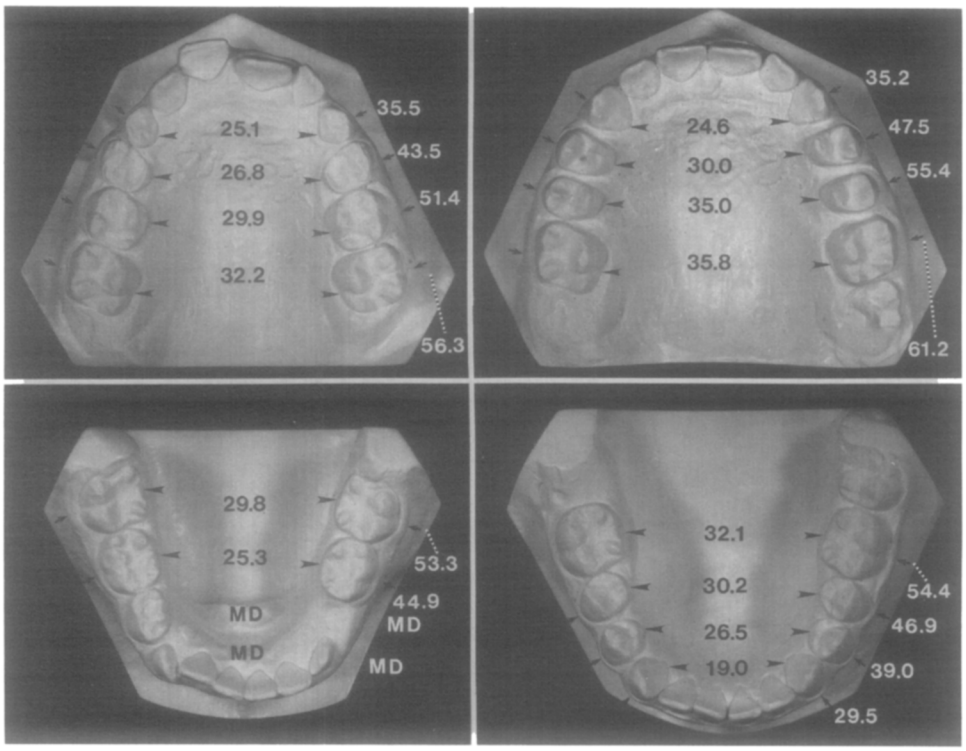

Fig. 4. Arch changes observed in an untreated boy over a period of 36 months. Initial records were taken when the patient was 9 years 11 months of age.

Table III. Maxillary alveolar expansion

	Control					*Fränkel*					
Region	*N*	$\bar{X}$	*S.D.*	*Min.*	*Max.*	*N*	$\bar{X}$	*S.D.*	*Min.*	*Max.*	*Sig.*
				Short-term (mm.) ($\bar{X}$ = 21 months)							
3-3	28	0.2	0.9	−1.3	2.3	22	1.3	1.4	−1.0	3.9	***
4-4	34	0.9	1.1	−1.6	3.0	35	3.8	1.7	0.0	8.6	****
5-5	42	0.7	0.9	−1.7	2.7	35	3.2	1.2	0.0	5.5	****
6-6	38	1.0	0.9	−0.7	4.0	37	3.2	1.4	0.5	7.0	****
				Long-term (mm.) ($\bar{X}$ = 41 months)							
3-3	9	0.7	1.0	−0.8	2.0	18	1.0	2.3	−2.6	6.9	NS
4-4	19	2.5	1.5	0.3	6.3	25	4.8	2.5	1.5	11.8	***
5-5	18	1.8	1.5	−0.3	5.9	28	4.3	2.3	1.4	12.9	***
6-6	18	1.9	1.3	0.3	5.6	29	4.4	2.0	1.7	12.5	***

NS = No significant difference between groups. *p < 0.05. **p < 0.01. ***p < 0.001. ****p < 0.0001.

groups became even more apparent when the long-term measurements were considered. In the control sample the average distance between the canines and between the first premolars did not increase during the 3½-year interval between the first and third sets of dental casts and approximately 1 mm. of arch expansion occurred posteriorly (Table II and Fig. 4). In contrast there was more than a 2 mm. average increase in intercanine distance and at least a 3.5 mm. increase in arch width between the remaining maxillary teeth in the treated group (Table II and Figs. 3, 5, and 6).

Maxillary alveolar expansion. Alveolar measurements were made 4 mm. below the gingival margin. In the short-term sample, the control subjects showed a modest amount of alveolar expansion ranging from 0.2 mm. in the canine region to 1.0 mm. in the first premolar region (Table III and Fig. 2). The amount of alveolar expansion in the short-term Fränkel group was, on the average, slightly greater than the amount of dental expansion, particularly in the premolar and molar regions (Fig. 3). In the long-term groups the amount of alveolar expansion in the control group was sig-

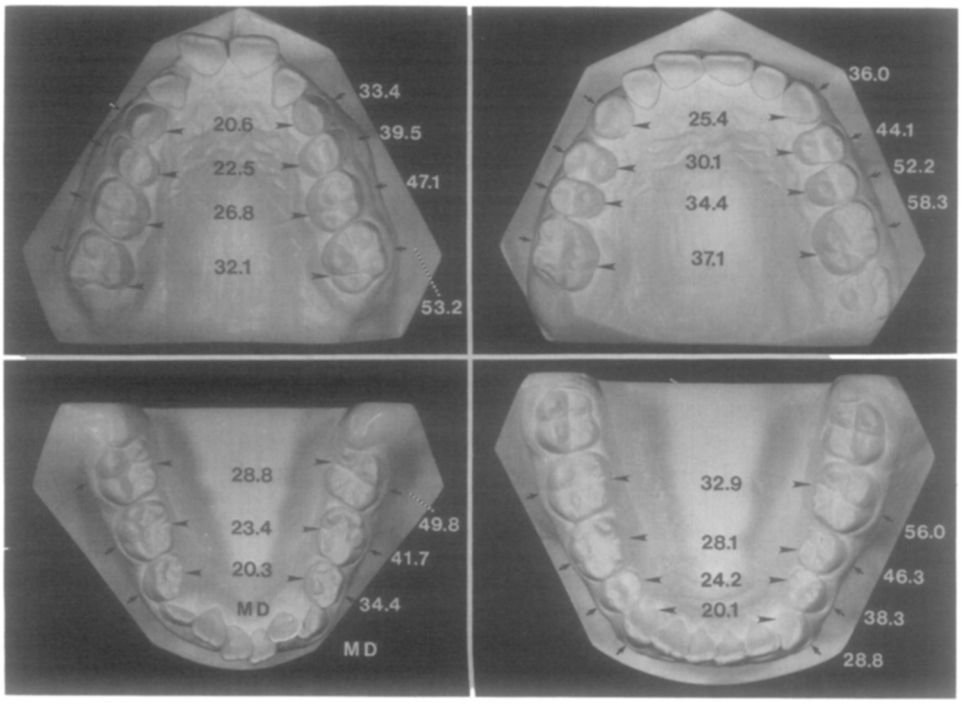

Fig. 5. Arch changes observed in a female patient treated with a Fränkel appliance for 36 months. Initial records were taken when the patient was 9 years 9 months of age; the second set of records was taken when the patient was 12 years 10 months of age.

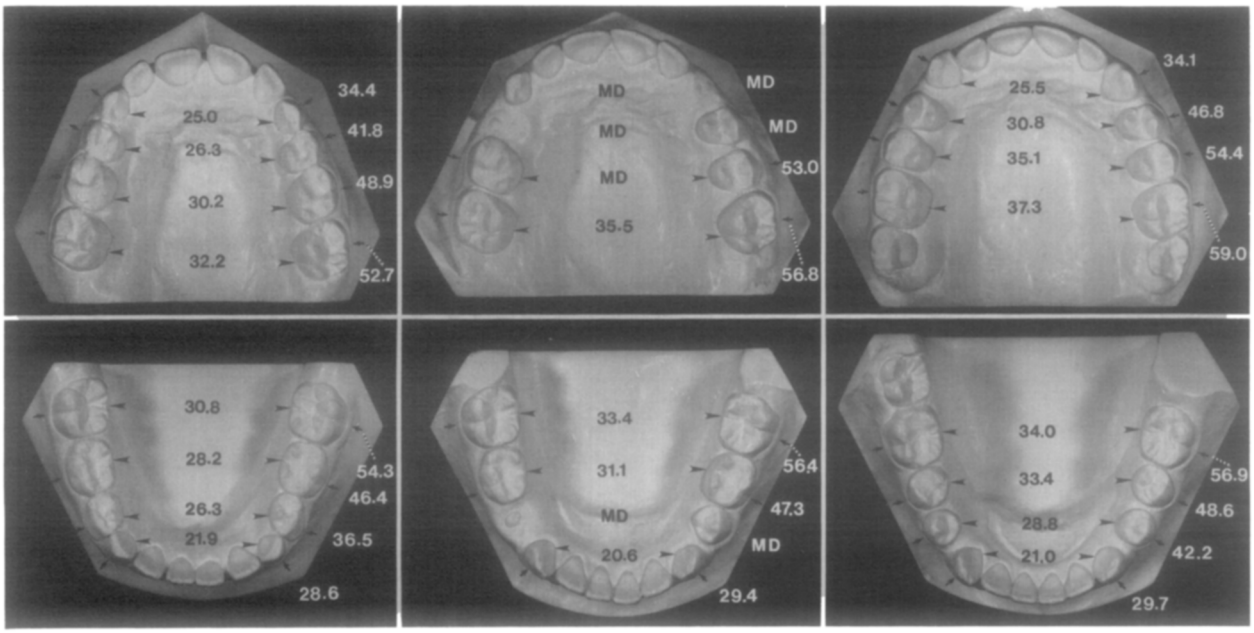

Fig. 6. Arch changes observed in a female patient treated with the Fränkel appliance for 45 months. Initial records were taken when the patient was 10 years 3 months of age; the second set was taken when the patient was 14 years of age. The patient wore the functional regulator only during the night as a retainer during the last year of treatment.

Table IV. Mandibular dental expansion (lingual)

Region	Control					Fränkel					
	N	$\bar{X}$	*S.D.*	*Min.*	*Max.*	*N*	$\bar{X}$	*S.D.*	*Min.*	*Max.*	*Sig.*
					Short-term (mm.) ($\bar{X}$ = 21 months)						
3-3	17	−0.1	0.7	−1.3	1.1	16	1.0	1.2	−1.3	2.5	***
4-4	30	0.4	1.2	−1.5	3.6	25	2.4	1.3	−0.7	5.5	****
5-5	39	0.7	0.9	−1.0	2.7	35	2.7	1.4	0.9	5.9	****
6-6	42	0.6	1.7	−1.3	4.1	36	1.9	1.3	−1.5	5.4	****
					Long-term (mm.) ($\bar{X}$ = 41 months)						
3-3	14	−0.4	1.3	−2.2	2.2	15	0.9	1.8	−2.5	3.7	NS
4-4	15	1.2	1.6	−2.3	3.4	22	3.3	1.9	0.7	8.0	**
5-5	17	1.4	1.5	−1.2	4.8	30	3.8	2.2	1.1	11.4	**
6-6	22	1.0	1.5	−0.9	5.7	28	2.7	1.6	0.5	6.8	***

NS = No significant difference between groups. *p < 0.05. **p < 0.01. ***p < 0.001. ****p < 0.0001.

Table V. Mandibular alveolar expansion

Region	Control					Fränkel					
	N	$\bar{X}$	*S.D.*	*Min.*	*Max.*	*N*	$\bar{X}$	*S.D.*	*Min.*	*Max.*	*Sig.*
					Short-term (mm.) ($\bar{X}$ = 21 months)						
3-3	24	0.6	1.3	−2.3	2.5	19	2.3	2.3	−1.0	9.4	**
4-4	31	1.6	1.3	−2.2	4.1	28	2.7	2.1	−0.2	7.0	**
5-5	38	0.8	1.8	−1.4	5.2	37	2.1	1.5	−1.1	6.0	****
6-6	30	0.0	0.7	−1.5	1.3	34	1.4	1.3	−1.4	5.0	***
					Long-term (mm.) ($\bar{X}$ = 41 months)						
3-3	13	1.0	1.1	−1.4	2.3	18	2.1	1.6	−0.1	5.2	**
4-4	17	2.3	1.4	0.0	4.9	25	3.8	1.9	−0.1	8.2	*
5-5	19	1.0	2.4	−1.4	5.2	31	2.7	1.9	−0.8	7.8	***
6-6	18	0.3	0.7	−0.9	1.5	27	2.0	1.9	−1.9	6.2	***

NS = No significant difference between groups. *p < 0.05. **p < 0.01. ***p < 0.001. ****p < 0.0001.

nificantly greater than the average amount of dental expansion, ranging from 0.7 to 2.5 mm. (Table III and Fig. 4). However, the subjects treated with the Fränkel appliance showed two to three times as much alveolar expansion as did the control subjects (Table III and Figs. 3, 5, and 6), with more than 4 mm. of arch expansion occurring in the premolar and molar regions.

Mandibular dental expansion. During the 21-month short-term control period, there was very little increase in interdental dimension in the control group, with no average change in intercanine dimension and only a slight (0.5 mm.) change posteriorly (Table IV and Fig. 2). In contrast, there was an average of 1 mm. increase in intercanine distance in the Fränkel group and a 1.9 to 2.7 mm. increase posteriorly (Fig. 3).

Similar findings were observed in the analysis of the long-term cases (Figs. 3 to 6). A 1.0 to 1.4 mm. increase in arch dimension was observed in the premolar and molar regions of the control group. Two to three times more arch expansion occurred in those cases treated with the Fränkel appliance, with averages of 2.7 to 3.8 mm. All comparisons between the mandibular dental expansion value were statistically significant except for a long-term comparison between the increases in intercanine dimension. Although the intercanine distance decreased, on the average, in the control group and increased by approximately 1 mm. in the treated group, these values were not statistically different.

Mandibular alveolar expansion. The amount of alveolar expansion in the short-term control sample was variable, depending upon the subject and the region in the dental arch considered (Table V). Less change occurred adjacent to the lower first molar than in any other region. A similar finding was observed in the Fränkel subjects, although the magnitude of change was greater. The amount of change adjacent to the lower first molar was 1.4 mm., with at least 2 mm. occurring in more anterior regions. The amount of alveolar expansion was approximately the same as the amount of dental expansion.

Similar findings were observed when the long-term treated sample was compared with the corresponding control group (Figs. 3 to 6). The amount of alveolar expansion was greater in the treated group, and in both

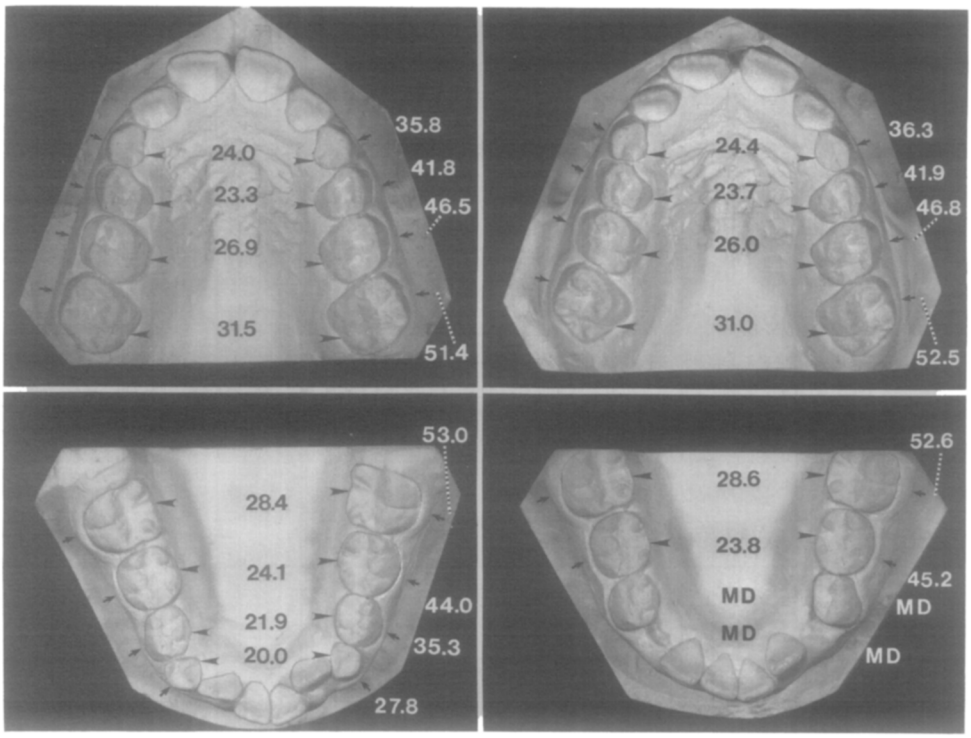

Fig. 7. Arch changes observed in an untreated male patient during a period of 23 months. The initial records were taken at 9 years 2 months of age; the second set at 11 years 1 month of age. This patient was placed in the narrow subgroup.

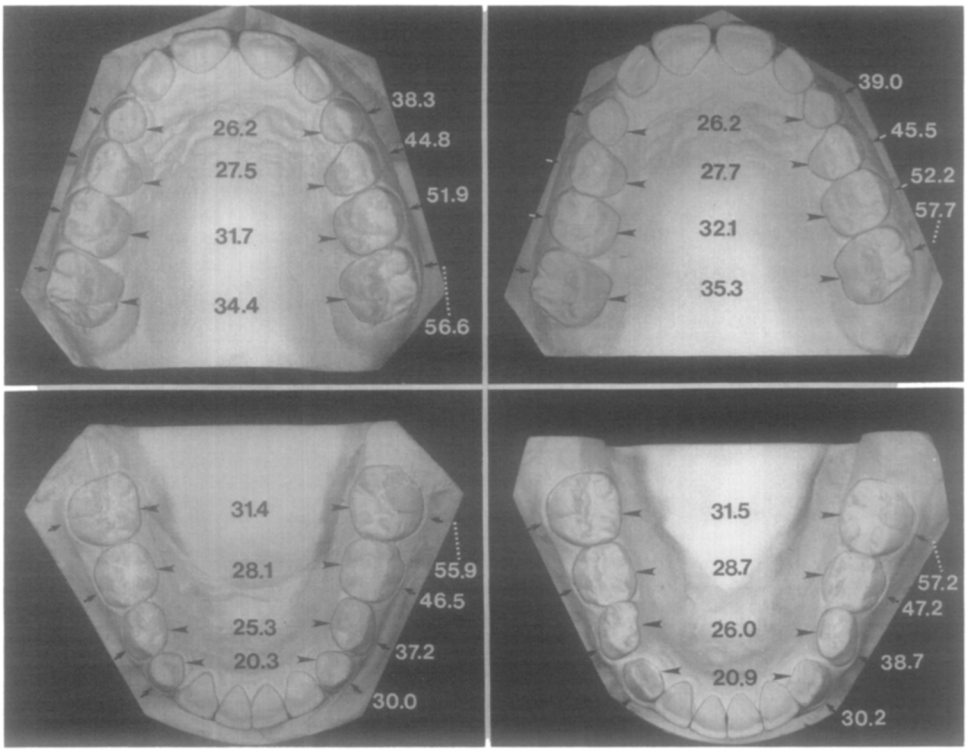

Fig. 8. Arch changes observed in an untreated boy during a period of 24 months. The initial records were taken at 9 years 11 months of age; the second set of records was taken at 11 years 11 months of age. This patient was placed into the wide subgroup.

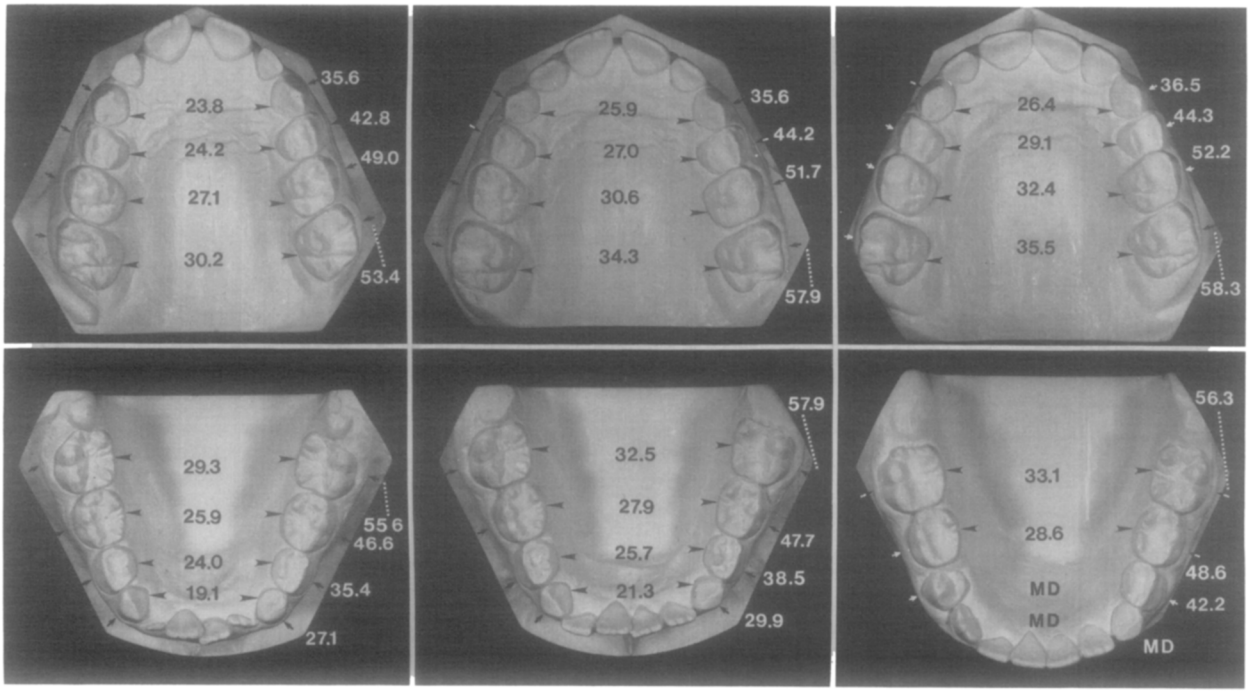

Fig. 9. Arch changes observed in a patient treated with a Fränkel appliance for 33 months. The initial records were taken at 9 years 2 months of age; the second set at 10 years 8 months of age; the third set at 11 years 11 months of age. The initial records indicated placement in the narrow subgroup.

Table VI. Maxillary dental expansion (lingual) in narrow and wide arches

	Control								*Fränkel*							
	Narrow			*Wide*					*Narrow*			*Wide*				
Region	*N*	$\bar{X}$	*S.D.*	*N*	$\bar{X}$	*S.D.*	*t test*	*Sig.*	*N*	$\bar{X}$	*S.D.*	*N*	$\bar{X}$	*S.D.*	*t test*	*Sig.*
							Short-term (mm.)									
3-3	14	0.2	0.9	14	0.6	1.9	0.39	NS	9	2.0	2.0	12	1.5	1.1	0.28	NS
4-4	17	0.0	0.5	16	0.1	1.1	0.93	NS	15	3.6	1.3	18	2.9	1.8	0.13	NS
5-5	18	0.4	0.7	22	0.4	0.8	0.99	NS	14	3.3	1.2	19	2.8	1.2	0.21	NS
6-6	18	0.2	0.9	22	0.5	1.1	0.57	NS	15	3.2	1.1	19	2.9	1.5	0.43	NS
							Long-term (mm.)									
3-3	1	4.0	NS	7	0.0	1.2	0.71	NS	9	2.9	1.0	9	1.2	1.0	0.001	***
4-4	5	0.4	0.5	13	−0.2	1.2	0.48	NS	12	4.4	2.3	12	2.7	1.9	0.01	**
5-5	6	0.7	0.5	13	1.0	1.0	0.67	NS	14	5.0	2.7	13	3.6	1.5	0.05	*
6-6	6	0.1	1.0	14	1.0	1.3	0.31	NS	14	4.7	3.0	14	3.8	1.3	0.09	NS

NS = No significant difference between groups. *p < 0.05. **p < 0.01. ***p < 0.001. ****p < 0.0001.

groups the amount of expansion was greater in the premolar region than in the molar region.

Arch expansion versus initial arch width

In order to determine whether or not arches that are narrow at the beginning of treatment expand more than those that are wide, both the control and the treated samples were divided into narrow and wide subgroups. After consideration of a number of measures, the groups were arbitrarily divided on the basis of the transpalatal width between the upper first primary molars as measured on the initial set of study models. This particular measurement was chosen because it was thought that the width of the deciduous first molar was more sensitive to changes in arch form than the maxillary first permanent molar was, particularly in the case of tapered arches. Those cases which had a transpalatal width of less than 24.5 mm. were placed in the narrow group (Fig. 7) and those cases which had a transpalatal width of 24.5 mm. or greater were placed in the wide group (Fig. 8).

Maxillary expansion. There was no statistical dif-

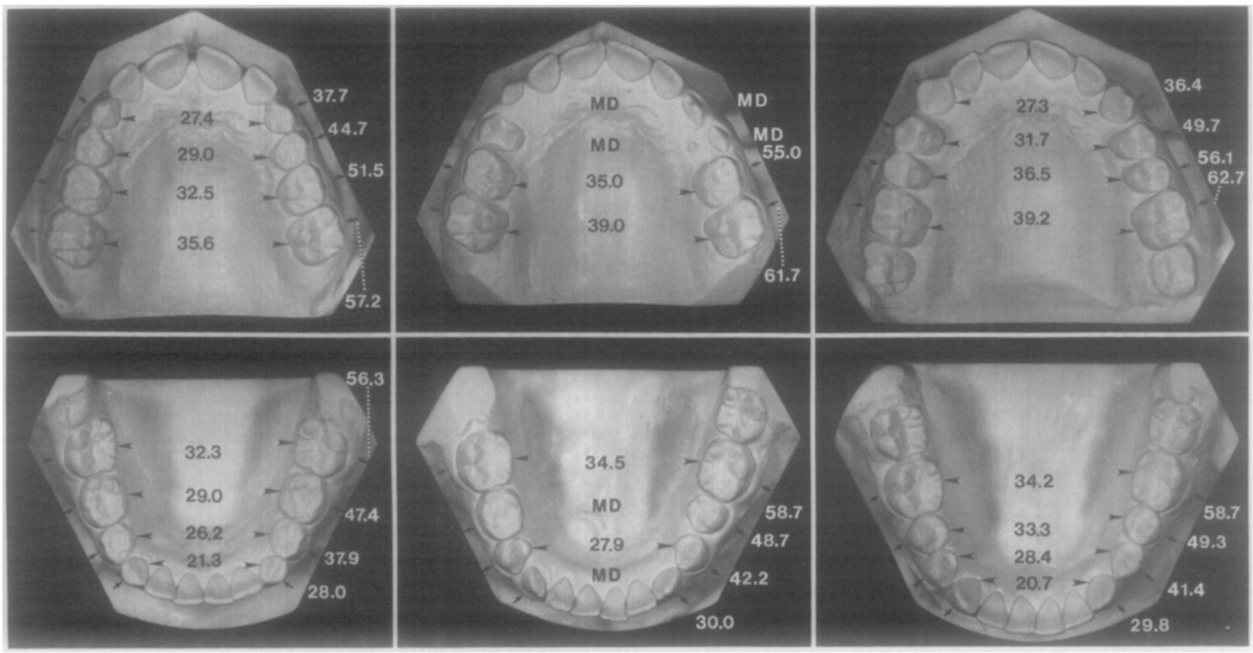

Fig. 10. Arch changes observed in a male patient treated with the Fränkel , appliance. Initial records were taken at 10 years 4 months of age; the second set at 12 years 1 month of age; the third set at 13 years 6 months of age. This patient was classified in the wide subgroup.

Table VII. Mandibular dental expansion (lingual)

	Control								*Fränkel*							
	Narrow			*Wide*					*Narrow*			*Wide*				
Region	*M*	$\bar{X}$	*S.D.*	*N*	$\bar{X}$	*S.D.*	*t test*	*Sig.*	*N*	$\bar{X}$	*S.D.*	*N*	$\bar{X}$	*S.D.*	*t test*	*Sig.*
							Short-term (mm.)									
3-3	7	−0.1	0.8	9	−0.6	0.6	0.86	NS	4	1.2	1.3	10	1.1	1.3	0.92	NS
4-4	14	0.5	1.2	16	0.3	1.1	0.69	NS	11	2.1	1.1	13	2.7	1.5	0.26	NS
5-5	18	0.5	0.9	20	0.8	0.9	0.41	NS	14	2.6	1.4	19	3.0	1.3	0.30	NS
6-6	18	0.3	0.9	22	0.8	2.2	0.31	NS	14	2.1	1.3	19	1.9	1.3	0.66	NS
							Long-term (mm.)									
3-3	2	−1.2	0.1	11	−0.1	1.3	0.39	NS	6	1.0	2.1	9	0.9	1.6	0.85	NS
4-4	3	1.8	1.0	11	1.2	1.6	0.61	NS	12	3.2	1.6	10	3.4	2.0	0.83	NS
5-5	5	1.7	1.6	12	1.3	1.5	0.75	NS	15	3.7	2.7	14	3.8	2.2	0.85	NS
6-6	6	0.5	0.8	15	0.9	1.1	0.55	NS	14	3.0	1.9	13	2.3	1.1	0.20	NS

NS = No significant difference between groups. *p < 0.05. **p < 0.01. ***p < 0.001. ****p < 0.0001.

ference in expansion between the narrow and wide subgroups in the control sample (Table VI), although on the average there was a slightly greater amount of arch expansion in the wide group at both the short-term and long-term intervals. However, in the analysis of the maxillary dental expansion in the cases treated with the Fränkel appliance, there was a trend toward larger increments of arch expansion in the narrow subgroup (Fig. 9) than in the wide subgroup (Fig. 10). In the analysis of the long-term results, there was a significantly larger expansion in the narrow subgroup than in the wide subgroup in three of the four lingual measurements considered. For example, the average amount of intercanine expansion was 2.9 mm. in the narrow group and 1.2 mm. in the wide group (Table VI). The maxillary premolar region demonstrated about 1.5 mm. greater arch expansion in the narrow group than in the wide group. In the consideration of the short-term values, in each instance the average value was greater in the narrow group than in the wide group, although perhaps sample size prohibits determination of a clear statistical significance.

The findings for the maxillary alveolar expansion were similar to those cited for the maxillary dental expansion and will not be described in detail here.

Mandibular expansion. In contrast to the findings

reported above for the maxilla, no statistical difference could be determined for the mandibular arch between the narrow and wide subgroups in either the control or the treated group at either the short-term or long-term intervals (Table VII). Although the sample sizes for the subgroups were of necessity relatively small, no trend toward more expansion in the narrow treated group was observed. In fact, the average expansion of teeth in the treated wide subgroup was greater than in the treated narrow subsubgroup approximately one half of the time.

The findings for the mandibular alveolar expansion also revealed no significant differences in the subgroups of either the treated or the control samples.

DISCUSSION

The results of this study indicate that expansion of the maxillary and mandibular dental arches occurs routinely when a functional regulator (FR-1 or FR-2) is conscientiously worn by the patient. The expansion is not limited to a particular region of the dental arch, although in absolute terms the greatest amount of expansion occurred in the premolar and molar regions while a lesser amount occurred in the canine region.

It is clear that the expansion observed in the treated cases is several times greater than that observed in the untreated controls. The maxillary expansion observed in the treated cases did not appear to be a simple tipping of the teeth laterally, as would occur with a finger-spring appliance. Although no specific quantification of crown orientation was made in this study, visually the treated cases in this sample appeared to demonstrate primarily a bodily movement of the buccal segment laterally, presumably as the teeth migrated vertically.

Visual inspection of the mandibular casts indicated that more uprighting of teeth occurred in the lower arch than in the upper arch. Van der Linden and Duterloo[19] note that the lower dentition erupts in a more lingual direction than does the upper dentition. Fränkel[11] states that the uprighting of the teeth in the lower buccal segments may be a result of the diminished resistance of the associated soft tissues. Because of the uprighting mechanism in the lower arch, Fränkel states that there is less alveolar expansion in the lower arch than in the upper arch. Also, it should be noted that the vestibular shields are held 3.0 mm. away from the maxillary alveolus but only 0.5 mm. from the mandibular alveolus at the depth of the sulcus. Thus, there is little, if any, soft-tissue stretch in the mandible.

In this study we noted less mandibular alveolar expansion than dental expansion in the second premolar and first permanent molar regions (as Fränkel suggests) but more alveolar expansion than dental expansion in the first premolar and canine areas. This difference in response according to the region of the mandible considered may be due to the bone architecture of the alveolus, which is thicker posteriorly than anteriorly.

Few studies which consider arch expansion produced by wearing the Fränkel appliance have been published previously. Mosch[10] reports average increases of 4.4 to 4.7 mm. of arch expansion in 400 patients treated in Fränkel's clinic for 17 to 23 months. The amount of expansion observed in our short-term group was approximately 3.0 mm. (Table II). However, the long-term results were much closer to the findings of Mosch in that the average values for the premolar and molar measurements were 3.5 to 4.2 mm. (Table II). The differences between the expansion in those patients treated in Fränkel's clinic and the expansion observed in this study may have been partly due to appliance design.

Most of the treated patients in this study represent initial efforts in using the Fränkel appliance. During Professor Fränkel's visits to the United States, he had an opportunity to review the patients in our practices currently under treatment. One of his most frequent criticisms of the appliances he saw was of an underextension of the vestibular shields into the vestibular fold. He theorizes that an underextension of the vestibular shields will not result in tension on the periosteum and thus will result in less expansion of the dental arches. The results of this study seem to support that hypothesis, although this must be tested in a population of treated cases in which there is adequate extension of the shields. (The current theories and concepts of vestibular extension, as well as other clarifications of appliance design, are discussed by McNamara and Huge.[26])

What are the clinical implications of the expansion produced by the Fränkel appliance? When a treated group is compared with an untreated Class II control group, it is clear that significant expansion is produced by wearing the appliance. However, it is also clear that the Fränkel appliance is not a panacea for severely crowded cases, particularly if the lower permanent canines have erupted. In this sample, the average increase in intercanine width was approximately 1 mm., with a maximum of 3.7 mm. (Table IV). This was not statistically different from the control group. If incisor crowding is present and the incisors have a normal axial inclination and position anteroposteriorly, a dramatic uncrowding of the incisors is not to be expected. Most of the expansion occurs in the premolar and molar regions. This expansion produced by the functional regulator can be sufficient to make a borderline extraction case treatable without removal of permanent teeth. We have often observed 6 to 10 mm. of maxillary arch expansion, particularly in those cases that were con-

sidered narrow at the beginning of treatment. The current study also has shown that in the maxilla narrower arches tend to expand more than wider arches.

SUMMARY AND CONCLUSIONS

Sixty treated and forty-seven untreated Class II, Division 1 patients were examined in this study. The patients in the former group were treated with the functional regulator of Fränkel (FR-1 or FR-2), while patients in the latter group were not treated but were of similar ethnic and skeletal composition. Sequential dental casts of the treated and untreated groups were examined, and the changes in lingual, buccal, and alveolar arch widths were compared.

The results of this study indicate that expansion of the maxillary and mandibular dental arches and their supporting structure occurs routinely when a functional regulator (FR-1 or FR-2) is conscientiously worn by the patient. The expansion is not limited to a particular region of the dental arch, although in absolute terms the largest expansion values occur in the premolar and molar regions, while lesser values were recorded in the canine region. In addition, this study indicates that in the maxilla narrower arches tend to expand more than wider arches.

The question of stability will be covered in a future article.

It is the responsibility of the clinician to evaluate the efficacy of this expansion and to apply this treatment approach in those cases where it is indicated.

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