Effect of Rapid Maxillary Expansion on Voice

*Anthony T. Macari, †Georges Ziade, *Mohannad Khandakji, ‡Hani Tamim, and †Abdul-Latif Hamdan, *†‡*Beirut, Lebanon*

Summary: Objective. The purpose of this investigation is to evaluate the effect of rapid maxillary expansion (RME) on the fundamental frequency (F0) and formant frequencies F1–F4.

Study Design. Cross-sectional study.

Materials and Methods. A total of 14 consecutive patients between the ages of 9.6 years and 15 years with a constricted maxilla undergoing RME were included in this study. Measurements were made before (T1) and after treatment (T2). These included maxillary arch length, depth, width, and perimeter in addition to F0, habitual pitch, and formants F1, F2, F3, and F4 for the vowels /ɑ/, /i/, /o/, and /u/.

Results. There was a significant difference in the mean of F1/ɑ/ and F2/ɑ/ before and after treatment (*P* value of 0.04 and 0.013, respectively). It is worth noting that F1/ɑ/ decreased in 11 and F2/ɑ/ decreased in 10 of the 14 subjects.

Conclusion. The application of RME in the treatment of maxillary constriction leads to a significant lowering of the first and second formants for the vowel /ɑ/ in most subjects. Subjects undergoing rapid maxillary application should be aware of the potential change in voice quality especially in case of professional voice users.

Key Words: Maxilla–Formants–Fundamental frequency–Voice–Vowel.

INTRODUCTION

The larynx produces a spectrum of sound frequencies that are shaped and modulated by resonances within the vocal tract structures among which is the maxillary arch. The authors of this article have previously reported the association between craniofacial morphology and voice.[1,2] The results indicated that both mandibular and maxillary lengths inversely correlate with the fundamental frequency and the habitual pitch.[2] However, there was no correlation between the sagittal position of both maxilla and mandible and the fundamental frequency and habitual pitch. Similarly, in another investigation on the association between formant frequencies and length and sagittal projection of the maxilla and mandible, the authors have demonstrated “a significant negative association between F3, F4 and the length of both upper and lower jaw.”[2] Along the same line of investigation, Marunick et al have investigated the relationship between intraoral measurements (maxillary dental arch) and voice classification in nine professional female singers.[3] In Marunick et al’s study, the maxillary dental arch form, dimensions, and volume have been shown to be predictors of the different voice types (soprano, mezzo, and alto). Although no single dental cast measurement was a predictor for voice classification, palatal depth and volume gave optimal results according to which group each singer was classified.[3]

Studies on the impact of surgery of the orofacial and craniofacial structures on voice are few.[4,5] Adenoidectomy, tonsillectomy, inferior turbinectomy, septoplasty, and uvulopalatoplasty are surgeries carried out on soft tissues of the upper airway with resultant alterations in the resonant characteristics of the vocal tract.[4–6] The impact of these surgically induced alterations is at times a change in voice quality. Outcome measures used to report vocal changes are nasalance scores, formant frequencies, and formant amplitude.[4–8] Similarly, orthognatic surgery for the treatment of cleft palate, craniofacial anomalies, and malocclusion has also been expected to have an effect on voice.[4,5] These surgeries consist primarily of maxillary and mandibular osteotomies, distraction osteogenesis, and repair of cleft palate.

To the best of the authors’ knowledge, no previous study has examined the impact of rapid maxillary expansion (RME) on voice. RME is an accepted treatment modality for patients with constricted maxilla. Posterior crossbite because of constricted maxilla is a commonly encountered problem in orthodontics with an occurrence rate of 8% up to 22%,[9,10] making it one of the most prevalent malocclusion in both primary and mixed dentition.[10] RME is an orthodontic procedure used in patients with posterior crossbite with the purpose of widening the maxillary jaw and allowing better fit of the mandibular and the maxillary teeth.

The purpose of this investigation is to evaluate, in an orthodontic population, the effect of RME on voice parameters (fundamental frequency and formant frequencies F1–F4). Our hypothesis is that RME will impact voice by altering its resonant characteristics.

MATERIALS AND METHODS

A total of 14 consecutive patients between the ages of 8 years and 15 years seeking orthodontic treatment using RME for a constricted maxilla at the Division of Orthodontics and Dentofacial Orthopedics at a university medical center were recruited for this study. All patients’ guardians have read and signed the consent form, which was approved by the internal review board of the university. Patients were excluded from the study if they presented with any history of respiratory infection, laryngeal manipulation, or dysphonia. The presence of dysphonia was ruled out by an expert speech language pathologist who performed later the acoustic analysis.

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From the *Department of Otolaryngology—Head and Neck Surgery, Division of Orthodontics and Dentofacial Orthopedics; †Department of Otolaryngology—Head and Neck Surgery; and the ‡Department of Internal Medicine, American University of Beirut Medical Center, Beirut, Lebanon.
Address correspondence and reprint requests to Abdul-Latif Hamdan, American University of Beirut Medical Center, P.O. Box 110236 Beirut, Lebanon. E-mail address: ah77@aub.edu.lb

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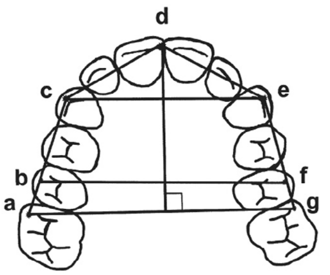

FIGURE 1. Arch length: distance from point d to line ag. Arch perimeter: ac + cd + de + eg. Arch width: distance between bf and ag.

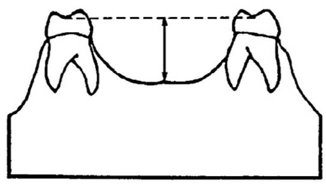

FIGURE 2. Arch depth.

Within an hour, before the initiation of the RME (T1) and after 2 weeks (T2) of active expansion, the following set of records was taken on all patients included in the study:

A. Maxillary alginate impressions were taken to perform dental models. Cast measurements included (Figure 1) (1) arch length—distance from midline perpendicular to the intermolar plane passing through the mesiobuccal cusps of the first molar; (2) arch perimeter—sum of distances of right and left buccal segments (from mesiobuccal cusps of first molars to the canine's cusp) and anterior segment of teeth (from canine's cusp to midline between central incisors); (3) arch width—measurement from mesiobuccal cusps of the right first molar to the left first molar; and (4) arch depth—distance from the intermolar line (through the mesiobuccal cusps of the first molars) to the palate (Figure 2).

B. Acoustic analysis using Visi-Pitch IV (model 3300; KayPENTAX, Montvale, NJ) was conducted between 2 and 5 pm to rule out the daily variations and time influence on the voice parameters. Using a condenser SM48 vocal microphone (Shure, Americas) coupled to the KayPENTAX Visi-Pitch IV 3950B), at a distance of 10–15 cm, the patient transmitted the vocal signal. The vocal signal was recorded directly into the system. The following measurements were included: (1) average fundamental frequency F_0 of the voice registered by asking the patient to pronounce continuously the vowel "ɑ" for 2 seconds at a comfortable pitch and loudness; (2) habitual frequency recorded by asking the patient to count from 1 to 10 in a normal voice; (3) formant frequencies recorded by asking each individual to pronounce and sustain, at a comfortable pitch and intensity level, the vowel sounds /ɑ/, /i/, /o/, and /u/. After the registration of each vowel, formant frequencies F1, F2, F3, and F4 were determined by placing the cursor in the middle of the formant band for consistency. Each singer was seated in a quiet room in front of a unidirectional condenser microphone at a constant mouth-to-microphone distance of 10 cm. Each singer was asked to phonate a sustained /ɑ/, /i/, and /u/ sound at a comfortable pitch and intensity level, both in a spoken manner and in a well-produced Middle Eastern style singing manner. Three consistent responses were recorded for each trial. Measures were made in real time and formant frequencies for singing groups across F1, F2, F3, and F4 were determined by using the Real-time Spectrogram of VP 3950 (Kay Elemetric Corporation, Lincoln Park, New Jersey). The cursor was placed at the centermost point of the steady-state formant band when looking at the spectrogram.

Statistical method

Means ± SD were used for continuous variables. For each subject, the parameters were collected before and after treatment, and the appropriate statistical analysis for small-size samples (Wilcoxon nonparametric paired test) was conducted. The analysis took into consideration the design (before and after) and modality of data collection (paired data). Differences were considered significant for $P < 0.05$. All analysis was conducted using IBM SPSS Statistics 22 (Chicago, IL).

RESULTS

Demographic data

Fourteen subjects were enrolled in this study: seven males and seven females. The mean age of the 14 subjects was 11.64 ± 1.69 with a range of 8–15 years.

Maxillary arch measurements

Four arch measurements were considered for this study, namely the width, length, depth, and perimeter of the maxillary arch. The means of these parameters for 14 subjects before and after surgery are listed in Table 1.

Means of fundamental frequency and habitual pitch before and after surgery

The means of F0 and habitual pitch before surgery were 218.9 Hz and 214.3 Hz, respectively. The means postoperatively were 220.5 Hz and 212.6 Hz, respectively. There was no significant difference in the means before and after surgery. Even when stratified by gender, there was still no significant difference before and after the treatment. There was also no significant difference in the means of any of the remaining acoustic variables before and after surgery (Table 2).

Means of formants F1–F4 before and after RME

There was a significant difference in the mean of F1/ɑ/ and F2/ɑ/ before and after the surgery (*P* value of 0.04 and 0.013, respectively). It is worth noting that F1/ɑ/ decreased in 11 of the 14 subjects and similarly F2/ɑ/ decreased in 10 and remained the same in two of the 14 subjects (Figure 3 and Figure 4).

There was no significant difference in any of the other formants F1, F2, F3, and F4 for the vowels /i/, /o/, and /u/ (Table 3).

TABLE 1.
Maxillary Arch Measurements Before and After Treatment

Name	Pre Surgery Arch Width (mm)	Pre Surgery Arch Depth (mm)	Pre Surgery Length (mm)	Pre Surgery Perimeter (mm)	Post Surgery Arch Width (mm)	Post Surgery Arch Depth (mm)	Post Surgery Length (mm)	Post Surgery Perimeter (mm)
Subject 1	50.38	18.9	29.85	79.59	54.13	18.38	28.47	84.45
Subject 2	52.49	19.76	29.09	87.76	59.45	18.37	29.89	90.21
Subject 3	49.19	17.78	28.94	80.9	52.88	18.13	27.74	79.27
Subject 4	46.72	17.5	28.12	75.33	50.59	17	27.35	75.42
Subject 5	49.66	18.84	23.72	73.5	55.43	19.63	23.8	80.79
Subject 6	50.99	18.21	23.56	74.15	55.64	18	23.27	78.01
Subject 7	52.77	21.56	33.81	88.88	55.47	21.5	32.08	88.48
Subject 8	45.59	17.25	23.44	74.74	49.38	16.27	22.9	70.77
Subject 9	53.55	15.15	27.56	83.32	54.8	14.95	26.8	82.3
Subject 10	50.69	17.7	23.58	73.11	55.84	16.58	23.82	79.54
Subject 11	46.8	17.4	29	84.7	51.1	18.9	24.25	79.9
Subject 12	49.63	18.29	30.24	84.68	53.99	17.8	28.88	86.46
Subject 13	48.39	16.81	28.67	82.28	52.37	16.67	28.5	87.32
Subject 14	46.75	20.64	26.7	74.84	50.02	22.1	26.55	76.03
Mean ± SD	49.5 ± 2.5	18.3 ± 1.6	27.6 ± 3.1	79.8 ± 5.5	53.6 ± 2.8	18.2 ± 2.0	26.7 ± 2.8	81.4 ± 5.5

The correlation between the difference in arch measurements and the difference in the four formants for the vowels /ɑ/, /i/, /o/, and /u/

There was a positive and moderate correlation for F1/ɑ/ and arch perimeter and F2/u/ and arch width (r = 0.56 and 0.59, respectively). There was also a negative and strong association between F4/o/ and arch width and F4/u/ and arch depth (r = –0.80 and –0.71) (Table 4).

DISCUSSION

Formant frequency represents a major attribute of one's identity. Not only does it reflect cross-cultural and racial differences but also has been associated with various body measurements and morphologic features, among which are cranial circumference, head-to-shoulder ratio, chest circumference, and waist-to-hip ratio.[11] On the other hand, there has been a debate on the relation between body weight and formants with a major dispute whether heavy individuals compared with normal individuals have lower speaking frequencies.[12,13] Despite the debate on the correlation between speaker's weight, and formant frequencies and their interspace, there is a consensus that formants vary with the shape, configuration, and dimensions of the vocal tract, part of which is the orofacial and craniofacial morphology.[14,15] The effect of different vocal tract configurations on formants has intrigued the authors of the present article to investigate the effect of RME on formant frequencies and their dispersion.

The results of this study clearly indicate that RME results in a significant drop in F1/ɑ/ and F2/ɑ/ (*P* value of 0.04 and 0.013,

TABLE 2.
Acoustic Parameters Before and After Treatment

Variables	Mean ± SD (N = 14) Before Treatment	Mean ± SD (N = 14) After Treatment	*P* Value
Fundamental frequency (F0) (Hz)	218.9 ± 44.2	220.5 ± 51.4	0.73
Habitual frequency (Hz)	214.3 ± 46.4	212.6 ± 47.5	0.55
Jitter (%)	1.3 ± 0.7	1.4 ± 0.8	0.59
Shimmer (%)	5.1 ± 2.1	5.1 ± 1.6	0.93
Noise to Harmonics ratio	0.2 ± 0.03	0.1 ± 0.04	0.35
Voice Turbulence Index	0.07 ± 0.04	0.06 ± 0.02	0.19

TABLE 3.
Formant Frequencies for the Vowels /ɑ/, /i/, /o/, and /u/ Before and After Treatment

Formants (Hz)	Formant Frequency (Mean ± SD) Before Treatment	Formant Frequency (Mean ± SD) After Treatment	*P* Value
F1ɑ	823.0 ± 108.9	758.8 ± 151.6	0.04*
F1i	502.4 ± 77.5	501.1 ± 88.8	0.89
F1o	562.4 ± 96.9	518.0 ± 103.9	0.11
F1u	450.2 ± 111.4	476.9 ± 77.2	0.51
F2ɑ	1461.9 ± 143.8	1332.5 ± 173.5	0.013*
F2i	2739.7 ± 162.2	2684.2 ± 264.8	0.94
F2o	1135.9 ± 119.1	1118.1 ± 117.3	0.21
F2u	997.4 ± 154.3	1015.1 ± 162.2	0.60
F3ɑ	3166.7 ± 276.9	3016.9 ± 504.8	0.45
F3i	3438.4 ± 287.4	3401.7 ± 389.0	0.57
F3o	3087.9 ± 337.3	3144.4 ± 304.8	0.25
F3u	3086.5 ± 226.1	3132.2 ± 304.9	0.21
F4ɑ	4022.9 ± 244.6	3976.2 ± 235.3	0.93
F4i	4177.1 ± 145.6	4136.0 ± 219.7	0.59
F4o	4027.4 ± 270.3	4050.6 ± 157.8	0.83
F4u	4077.9 ± 197.8	4115.3 ± 250.6	0.33

* Statistically significant.

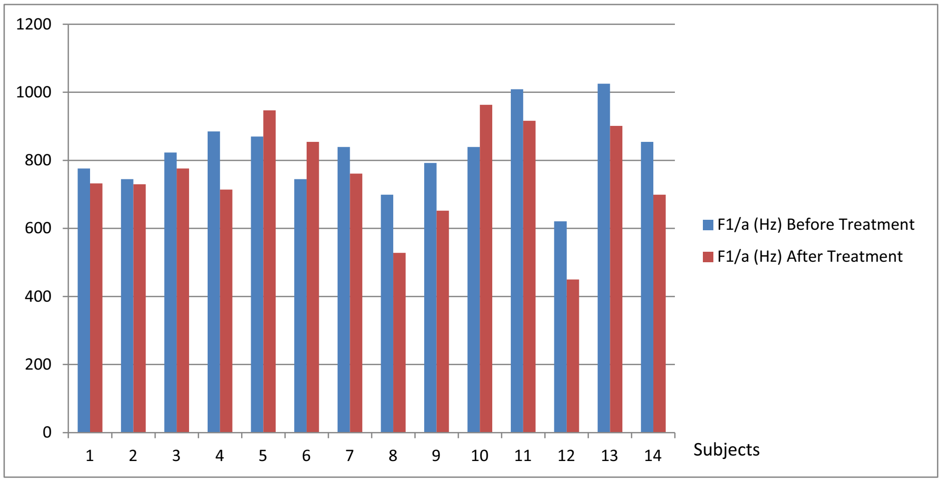

FIGURE 3. F1/a/ before and after treatment in subject 1 to subject 14.

respectively). More so, the association between the difference in arch measurements and the difference in the four formants for the vowels /ɑ/, /i/, /o/, and /u/ revealed a positive and moderate correlation for F1/ɑ/ and arch perimeter and F2/u/ and arch width ($r = 0.56$ and 0.59, respectively). There was also a negative and strong association between F4/o/ and arch width and F4/u/ and arch depth ($r = -0.80$ and -0.71).

These findings corroborate the results of previous studies on the association between vocal tract morphology and voice in normal individuals of different ages and gender. Based on the source-filter theory, formant frequencies are intimately related to the morphology of the epilaryngeal tube, pharynx, and vocal tract; variation in morphology markedly impacts the position of these formants and their dispersion.[16] This is evidenced by the lower formants and the smaller interspace difference observed in male subjects compared with females, and similarly by the presence of higher formants in children compared with adults.[17,18] The radiologic investigation by Fitch and Giedd using magnetic resonance imaging further highlights the differences in vocal tract morphology including oral and pharyngeal cavity among men and women.[19] These differences were attributed to vocal tract remodeling mainly after puberty.

That being said, alteration in the configuration of the vocal tract can result in changes in voice quality and timbre. Whereas both epilaryngeal and pharyngeal cross sections may relate to clustering of F3–F5, F3 is more sensible to the cavity between the tongue and the teeth and F1 and F2 are most affected by the position of the tongue.[19] This is demonstrated in the singing voice where lowering of the laryngeal framework results in lengthening of the vocal tract and deepening of the voice, whereas a rise in the laryngeal framework results in an increase in F0. In fact, the shape of the vocal tract is also modified dynamically with regard to pitch, loudness, and/or special formant settings for each vowel differently. This has been substantiated radiologically by magnetic resonance imaging where significant oral and pharyngeal changes were noted when singers reached fundamental frequencies that were approximate to the first formant, namely widening of the pharyngeal inlet with both jaw and lip opening.[20] In this investigation by Sundberg, the subjects sang a scale using the vowel /ɑ/. In another study by Samlan and Kreiman[21] on the influence of changes in epilaryngeal area on voice using a kinematic vocal tract model, the results indicated that epilaryngeal constriction and expansion caused salient

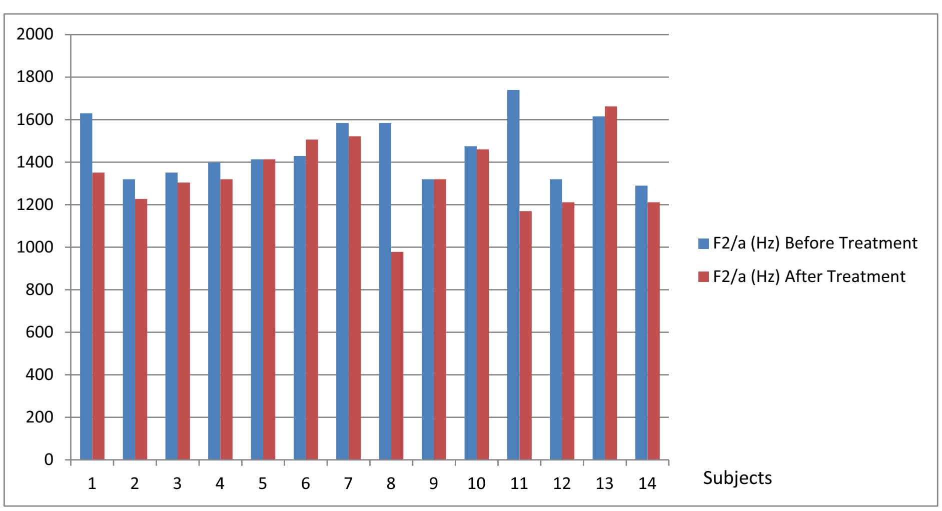

FIGURE 4. F2/a/ before and after treatment in subject 1 to subject 14.

TABLE 4.
Association Between the Difference in Arch Measurements and the Difference in Formants F1, F2, F3, and F4 for the Vowels /ɑ/, /o/, /i/, and /u/

	Difference in Arch Width		Difference in Arch Depth		Difference in Arch Length		Difference in Arch Perimeter	
	P Value	r coefficient	*P* Value	r coefficient	*P* Value	r coefficient	*P* Value	r coefficient
Difference voice F1ɑ	0.08	r = 0.48	0.74	r = –0.10	0.20	r = 0.36	0.04	r = 0.56
Difference voice F1i	0.53	r = 0.19	0.50	r = 0.20	0.32	r = –0.29	0.87	r = –0.05
Difference voice F1o	0.54	r = –0.18	0.09	r = 0.47	0.27	r = –0.32	0.71	r = 0.11
Difference voice F1u	0.15	r = 0.43	0.82	r = 0.07	0.24	r = 0.35	0.77	r = 0.09
Difference voice F2ɑ	0.91	r = 0.03	0.69	r = 0.12	0.37	r = 0.26	0.45	r = 0.22
Difference voice F2i	0.70	r = 0.11	0.11	r = –0.45	0.97	r = –0.01	0.46	r = –0.21
Difference voice F2o	0.83	r = 0.06	0.79	r = 0.08	0.16	r = 0.40	0.06	r = 0.52
Difference voice F2u	0.04	r = 0.59	0.41	r = –0.25	0.45	r = 0.23	0.03	r = 0.59
Difference voice F3ɑ	0.25	r = –0.33	0.95	r = –0.02	0.19	r = –0.38	0.84	r = –0.06
Difference voice F3i	0.14	r = 0.41	0.16	r = –0.39	0.55	r = 0.18	0.50	r = 0.20
Difference voice F3o	0.24	r = –0.34	0.49	r = 0.20	0.63	r = –0.14	0.52	r = 0.19
Difference voice F3u	0.52	r = –0.20	0.65	r = –0.14	0.54	r = –0.19	0.72	r = 0.11
Difference voice F4ɑ	0.58	r = –0.16	0.39	r = 0.25	0.58	r = 0.16	0.94	r = 0.02
Difference voice F4i	0.99	r = 0.006	0.56	r = 0.21	0.16	r = –0.48	0.10	r = –0.55
Difference voice F4o	0.001	r = –0.80	0.36	r = 0.27	0.14	r = –0.41	0.35	r = –0.27
Difference voice F4u	0.99	r = 0.006	0.006	r = –0.71	0.84	r = –0.06	0.41	r = –0.25

differences in voice quality and were similar for /ɑ/ and /i/ and different for /u/. Subsequently, for each vowel, the vocal tract assumes a different shape. That being said, we can deduce that the changes in the formants for the vowel/ɑ/ may not be necessarily accompanied by similar changes in the remaining vowel.

The results of this current investigation also corroborate the findings of numerous investigations on the effect of vocal tract surgery on voice and formant frequencies.[4–8]

Orthognathic surgery, be it distraction osteogenesis or maxillofacial osteotomies, has been shown to affect speech, velopharyngeal function, and fundamental frequency.[7,8] The effect of orthognathic surgery on voice has been attributed to changes in the position of the hyoid bone and orofacial structures, which constitute a major component of the resonating system. Surgeries of the upper airway such nasal surgery, uvulopalatopharyngoplasty, and tonsillectomy with or without adenoidectomy have all been proven to affect to a minor extent variant formant frequencies with conflicting results.[22,23] The effect has been attributed to changes in the acoustic surface area induced by surgery and hence to alterations in the resonant characteristics of the resonators and their coupling effect in transmitting sound. The anatomical alterations following extirpation of soft tissues can also affect vocal tract resonance by inducing changes in the dynamic behavior of the vocal tract muscular wall. Chuma et al have shown an increase in F2/i/ and /ɑ/ and a decrease in F1/o/ following tonsillectomy and adenoidectomy.[7] Similarly, Kazi et al have demonstrated acoustic changes following partial glossectomies in 26 male patients with oropharyngeal cancer.[6] Their results indicated a significant change in F2 and F3 and no change in F1 in female patients compared with controls and an increase in the mean F1 formant in males. The conclusion was that partial glossectomy for patients with oropharyngeal cancer can alter formant frequencies.[6]

CONCLUSION

RME has an impact on voice. In the pediatric population, the results of this investigation clearly indicate that the application of the palatal expander in the treatment of maxillary constriction leads to a significant lowering of the first and second formants for the vowel /ɑ/ in most pediatric subjects. Subjects with constricted maxilla undergoing rapid maxillary application should be aware of the potential change in voice quality.

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