Original Article

Relationship between voice function and skeletal effects of rapid maxillary expansion

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ABSTRACT

Objective: To evaluate the effects of rapid maxillary expansion (RME) on the vocal quality, maxillary central incisors, midpalatal suture, and nasal cavity in patients with maxillary crossbite.

Materials and Methods: Coronal CT scans of 30 subjects (14 boys, 16 girls; mean age, 12.01 ± 0.75) were taken before RME (T0), and at the end of the expansion phase (T1). Voice samples of all patients were recorded with a high-quality condenser microphone (RODE NT2-A) on a desktop computer at T0 and T1. Statistical analyses were performed using a paired-sample *t*-test. The degree of association between the changes in the voice parameters and nasal width was assessed with Pearson's correlation.

Results: RME treatment produced a significant increase in the transverse dimensions of the midpalatal suture and nasal cavity between T0 and T1 ($P < .05$). The maximum F0 and jitter (%) results were shown to decrease statistically significantly from T0 to T1 ($P < .001$ and $P = .042$, respectively). Between T0 and T1, shimmer (%) and shimmer (dB) exhibited statistically significant increases ($P = .037$ and $P = .019$, respectively).

Conclusions: After RME therapy, voice quality differences were found to be associated with increases in nasal width. (*Angle Orthod.* 2018;88:202–207.)

KEY WORDS: Rapid maxillary expansion; Voice quality; Nasal width

INTRODUCTION

Rapid maxillary expansion (RME) is used in the orthopedic treatment of maxillary deficiency, preferably in growing patients. RME achieves expansion by providing pyramidal splitting in the maxilla just below the nasal valves at the level of the incisors. It is suggested that this results in an enlarged nasal cavity.[1–3] Although lateral and posteroanterior cephalometric radiographs are useful tools in assessing the nasal cavity, they can be insufficient for measuring nasal resistance, size of the airway and nasal space.[4–7] Anatomic structures including facial tissue and the nasal airway can be assessed accurately using three-dimensional computed tomography (CT).[8] CT scans were first used by Timms et al.[9] to assess osseous changes after RME. Garib et al.[10] found that screw activation of the nasal base was enlarged up to one-third on coronal CT images obtained 3 months after RME.

Voice formation is a complex physiological process involving interaction among respiration, the larynx, and downstream resonance systems.[11] Enlargement of the oral cavity and nasal cavity caused by RME can alter voice quality and resonance, which affect the acoustic parameters formed by vocal cord movements. The shape and size of the acoustic space may also have an impact on vocal quality and resonance.[12] Although it is suggested that enlargement of the upper respiratory tract influences vocal quality, the effect of RME on the nasal cavity and respiratory function is controversial.[4,13]

Standardized methods for objective analysis using acoustical indicators have been developed for sound analysis. Computer-assisted sound analyzers are valuable diagnostic tools providing objective, reproducible, and noninvasive acoustic measurements.

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Thus, pathological voice abnormalities can be distinguished from a healthy voice.[14] In the literature, there are a limited number of studies about the effects of RME appliances on vocal quality. In this study, the effects of dental and skeletal changes caused by RME on vocal quality were investigated. The hypothesis was that changes in nasal width caused by RME can alter voice quality.

MATERIALS AND METHODS

This was a prospective, clinical study. The treatment group included 30 subjects (16 females and 14 males, mean age: 12.01 $\pm$ 0.75) who required RME for unilateral or bilateral crossbite correction and orthodontic treatment. Inclusion criteria for selecting the treatment group were as follows: (1) transverse maxillary deficiency or unilateral or bilateral posterior crossbite, (2) Class I occlusal relationship, and (3) the patients were in an active growth period. Exclusion criteria were (1) previous orthodontic treatment, (2) history of nasal or pharyngeal surgery, (3) history of respiratory infection and dysphonia, (4) genetic disease, and (5) smoking.

This project was approved by the Institutional Ethics Committee (reference number 4298783/050), and informed consent was obtained from the parents. The appliance was an acrylic split palate with a hyrax screw (Leone, Firenze, Italy) cemented in the midline. The appliance was activated with a quarter turn (0.25 mm per turn) twice a day until the suture had opened radiographically and continued until reaching 2–3 mm overexpansion. The same appliance was used as a passive retainer for 3 months so that bone formation at the suture level would occur and relapse of the expansion space at the incisors would be prevented.

Voice records and coronal CT scans of the patients were obtained before RME therapy (T0) and at the end of the expansion phase without the appliance in the mouth (third month of therapy: T1). Speech samples of all patients were recorded with a high-quality condenser microphone (RODE NT2-A) on a desktop computer (Intel Pentium 4, 3.2 GHz, 512 MB RAM). All recordings were performed in a quiet room in the Department of Otorhinolaryngology. A distance of 10 cm was maintained between the mouth and the headset microphone for each recording. The patients were asked to phonate the vowel /a/ at a comfortable habitus for at least 5 seconds. Voice samples were relayed directly to the computer, and the middle 3-second part was edited and analyzed with the updated Praat software program.[15] Mean F0, minimum F0, maximum F0, shimmer (a flickering or tremulous light), jitter (deviation from true periodicity of a presumably periodic signal), and noise-to-harmonic ratio (NHR) were evaluated and compared between T0 and T1. Their definitions are as follows:

- Fundamental frequency (F0; Hz): number of vibrations of the vocal fold per second[16]
- Jitter (%): cycle-to-cycle deviation in the fundamental frequency of a signal[17]
- Shimmer (%): variability of the peak-to-peak amplitude between adjacent cycles of vocal fold vibrations[18]
- NHR (dB): average ratio of the inharmonic energy (noise) to the harmonic spectral energy.[18]

Measurements on the coronal CT scans were made at the central incisors, midpalatal suture, and nasal cavity (Figure 1).

Statistical Analysis

All measurements were made by two operators and repeated 1 month later at the same console by the same operators to minimize T0–T1 repeated measures operator error and to maximize interrater reliability and thus reliability of the study itself. Systematic and random errors were calculated using Dahlberg's formula.[19] The range of measurement error was found to be from 0.05 to 0.28, which was not statistically significant. The Kolmogorov-Smirnov statistic was used to test whether the parameters were normally distributed. Statistical analysis was performed with MedCalc software (Version 10.1.6.0, Ostend, Belgium). Since the voice and CT parameters recorded before and after RME treatment were normally distributed, they were analyzed using a paired-sample *t*-test. A value of $P < .05$ was considered to be statistically significant. Pearson correlation was used to estimate the strength of the relationship between the increase in nasal width and voice quality at the end of expansion.

RESULTS

The age ranges of the patients are presented in Table 1. After a deep, comfortable inhalation, the /a/ vocalization was recorded for 5 minutes in patients at both T0 and T1. There were significant statistical differences between the T0 and T1 maximum F0, jitter (%), and shimmer (%) results ($P < .05$; Table 2).

A statistically significant change was found in all the tomography data evaluated in the T0 and T1 periods (Table 3). ICW and IAW increased by 2.46 mm and 2.96 mm, respectively. Anterior sutural width in the nasal and palatal region showed statistically significant increases (1.36 mm and 2.32 mm, respectively).

Among the voice parameters, Max F0 had the strongest correlation with ANW ($r = .477^{**}$), followed by shimmer ($r = .420^{*}$; Table 4).

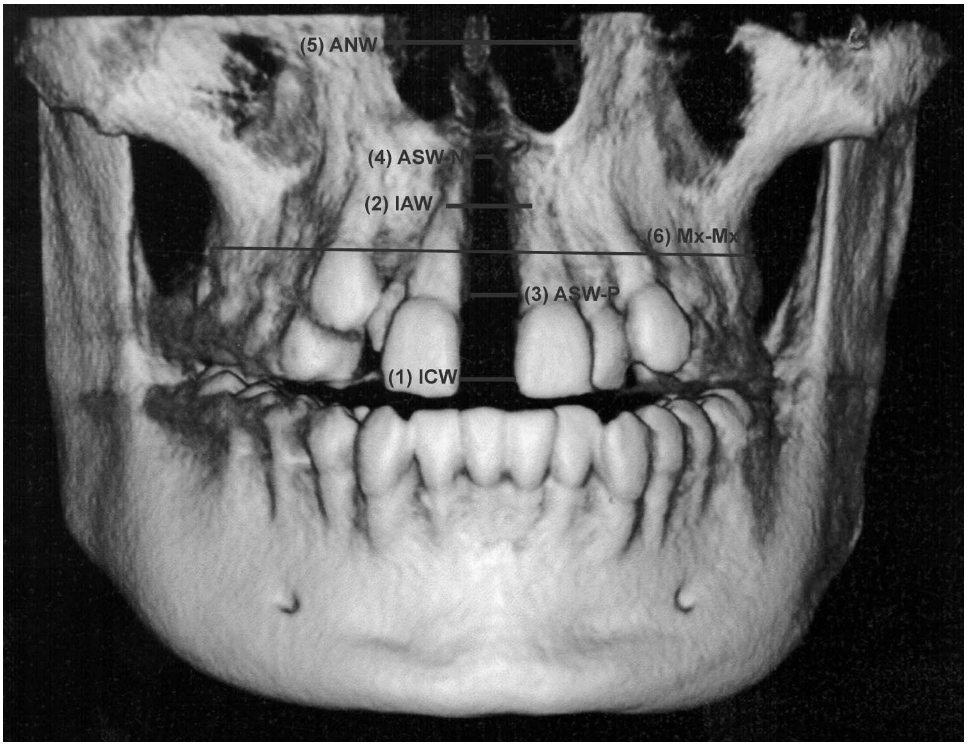

Figure 1. Measurements on the anterior scan: (1) interincisor crown width (ICW): shortest transverse distance between the mesial surfaces of the crowns of the maxillary central incisors; (2) interincisor apex width (IAW): transverse distance between the root apices of the maxillary central incisors; (3) anterior sutural width—palatal (ASW-P): shortest transverse distance at the level of the alveolar bone crest adjacent to the mesial surfaces of the roots of the maxillary central incisors was measured to determine the anterior width of the midpalatal suture in the palatal region; (4) anterior sutural width—nasal (ASW-N): at the ANS level, the shortest transverse distance between the mesial contour of each half segment of the maxilla; (5) anterior nasal width (ANW): transverse width between the most lateral point of each nasal cavity; (6) Mx-Mx: width of the skeletal base of the maxilla was recorded from right to left maxillary points.

DISCUSSION

The RME appliance used for midpalatal suture expansion acts on nasal volume by detaching the lateral walls of the nasal cavity during expansion of the nasal arch. By increasing the distance between the lateral walls of the nasal cavity, the cross-sectional area of the nasal passage and nasal cavity are enlarged, resulting in relief of respiration.[8] It has been suggested that an enlarged upper respiratory tract and skeletal changes resulting from expansion also affect voice quality.[13] In the literature, there is a paucity of information about the effect of RME on sound functions.[20] In this study, changes in voice quality and CT images before and after expansion were assessed in pediatric patients who underwent RME to investigate whether RME influenced voice quality.

The success of RME depends on a patient's age. For this procedure, the optimal timing is either the pubertal or prepubertal period. In mature patients, RME can cause severe pain, dental tipping, periodontal complications, and gingival recession in the posterior maxillary teeth.[21] Thus, the patients selected in this study were still growing.

Voice and speech represent a physiological continuum occurring as a result of interactions between the laryngeal respiratory and resonator systems.[22] In phonetics, vowels are simple sounds that can be more readily defined in an acoustical manner.[21] The RME appliance can not only cause alterations in speech but also affects the tongue posture and palatal volume.[1,23,24] Thus, voice recordings were performed without the appliance in the mouth.

The laryngeal voice was evaluated in the present study. The tongue position was low and back during phonation of the /a/ vocal, so the closure and constriction in the center of the vocal tract did not occur as in the other voices. The /a/ sound also constitutes the phonological core of many syllables.[24,25] Thus, only the vowel /a/, and not others, was measured.

Table 1. Demographic Data: Age (Years) of the Patients

	Age	
	Male (n = 14)	Female (n = 16)
Mean ± SD	12.06 ± 0,81	11.96 ± 0.78
range	10.5–13.4	9.5–13

Table 2. Comparison of Mean Values of T0 and T1 Voice Parameters

Parameters	n	T0 Mean ± SD	T0 Median	T0 Min–Max	T1 Mean ± SD	T1 Median	T1 Min–Max	*P*
Max F0 (Hz)	29	270.76 ± 78.29	264.35	129.15–467.28	234.12 ± 65.01	250.99	113.28–407.61	<.001*
Mean F0 (Hz)	29	224.32 ± 56.48	238.61	116.86–377.52	212.89 ± 57.25	232.75	92.05–319.26	.139
Jitter (%)	29	0.47 ± 0.20	0.41	0.22–0.94	0.39 ± 0.11	0.40	0.22–0.66	.042*
Shimmer (%)	29	4.13 ± 1.17	4.21	1.62–6.24	4.93 ± 1.74	5.01	2.30–9.11	.037*
Min F0 (Hz)	29	194.18 ± 64.57	223.08	75.52–310.87	185.38 ± 59.36	205.46	76.12–262.99	.574
Shimmer (dB)	29	0.38 ± 0.11	0.38	0.14–0.59	0.47 ± 0.19	0.45	0.20–0.96	.019*
NHR	29	0.0198 ± 0.0069	0.0185	0.0102–0.0356	0.0184 ± 0.0056	0.0193	0.0103–0.0329	.396

* $P < .05$, statistically significant.

In several studies, it has been confirmed that CBCT has high potential for evaluating maxillary structures due to its noninvasiveness, lower effective radiation dose, high accessibility, high accuracy, and good resolution.[10,26–28] However, no amount of radiation is really safe, so unnecessary exposure should be limited.[29] The CBCT (NewTom 3D, Giano, Verona, Italy) imaging system was used to obtain CBCT images assessed through the NNT viewer software program. The CT scans were taken with 0.300-mm axial thickness, 3 mA, and a low-dose protocol with 90 kV instead of the standard CT setting of 120 kV. In this study, X-ray emission time was kept at 3.6 seconds and the pretreatment and posttreatment scan had a smaller window to reduce the amount of radiation.

The distance between the maxillary incisors and the midpalatal suture and the width of the nasal cavity and maxillary base were assessed on CT images obtained at T0 and T1, allowing evaluation of the craniofacial changes resulting from RME. On the CT images, it was found that the distance between the roots and crowns of the maxillary incisors was significantly increased in the patients. The coronal CT images revealed that the midpalatal suture was opened by 1.37 mm in the nasal region and 2.32 mm at the palatal region, on average. In previous studies, similar findings regarding transverse changes in midpalatal sutures were observed.[30–32]

On the anterior CT images, the mean nasal and maxillary basal widths were significantly increased by 2.17 mm and 3.39 mm, respectively. The extent of expansion of the nasal cavity after RME was reported as 1.55 mm by Ballanti et al.,[32] 2.1 mm by Silva Filho et al.,[6] and 1.89 mm by Garret et al.[31]

In the current study, voice recordings were obtained at T0 and T1 and analyzed by Praat software, which produces reliable and objective outcomes. The computer-assisted acoustic analysis software that was used has the advantages of being easy, rapid, and noninvasive in pediatric patients.[13]

Variations in the size and morphology of the voice system can lead to modifications in acoustic and perceptive assessments, particularly in formant frequencies.[33] Although there are five formants for each vowel, two formants, namely F1 and F2, are most commonly used as indicators of vocal quality.[34] Yurttadur et al.[20] detected a decrease in the F1 and F2 frequencies after removal of the RME appliance. Sari et al.[21] suggested that vowels were affected by the size of the anterior oral cavity in patients who underwent surgically assisted RME. In a study on a pediatric population by Macari et al.,[35] it was found that RME significantly decreased F1α and F2α parameters, leading to the conclusion that RME has an influence on the voice. In a study on children with Down syndrome, a decrease was observed in F0 frequency for the vowels *a, i, e,* and *u* after expansion with RME. In the current study on pediatric patients, no significant difference was observed in the mean F0 frequency, while a significant decrease was observed in the maximum F0 frequency after application of the RME appliance.

In the current study, the finding that the jitter percentage was significantly decreased while the shimmer percentage was significantly increased indi-

Table 3. Statistical Comparison of Measurements Made on the Computed Tomography (CT) Scans at T0 and T1 With Paired *T*-Test

Parameters	n	T0 Mean ± SD	T1 Mean ± SD	Comparison of Means T0 vs T1	*P*
ICW	29	0.39 ± 0.41	2.85 ± 1.19	2.46*	.000
IAW	29	4.60 ± 1.93	7.56 ± 2.16	2.96*	.000
ASW-P	29	0.58 ± 0.62	2.90 ± 1.30	2.32*	.000
ASW-N	29	0.35 ± 0.19	1.72 ± 0.84	1.36*	.000
ANW	29	17.17 ± 1.53	19.34 ± 1.77	2.17*	.000
Mx-Mx	29	45.65 ± 2.60	49.04 ± 2.71	3.39*	.000

* $P < .05$, statistically significant.

Table 4. Pearson Correlation Coefficients Between Increase in Nasal Width and Changes in Voice Parameters at End of Expansion

	ANW Coefficients (*r*)	*P*
FO	0.064	.74
MinFO	0.131	499
MaxF0	0.477**	.009
Jitter	0.071	.713
Shimmer	0.420*	.023

* Significant at $P = .05$; ** significant at $P = .01$.

cates that RME significantly changed voice quality. It is suggested that jitter and shimmer values are associated with resistance of the laryngeal airway and incomplete velopharyngeal closure.[36] Liberman et al.[37] suggested that the jitter percentage is increased in pathological sounds. In a study on patients aged 12 to 17 years, Yurttadur et al.[20] applied RME and found that it did not cause significant changes in F0, jitter or shimmer percentages, NHR, APQ, or RAP parameters because it did not change the voice quality or resonance. It is hypothesized that the broader age interval in that study explains the differences in outcomes.

Pearson's correlation coefficient was used to assess the associations between significant enlargements in the nasal cavity after RME and gathering of sound data. The finding of a strong correlation favors the hypothesis that alterations in voice quality result from increased nasal width. These results indicate that RME can change vocal quality, so it would be useful to inform patients and families of this possibility.

One limitation of this study was the absence of a control group, because of the ethical sensitivity to delay the treatment of children with functional crossbite. Therefore, not only treatment also growth might have played a role in the study results.

CONCLUSIONS

- At the end of RME therapy, the transverse dimensions of the midpalatal suture showed statistically significant increases in all patients because of suture opening.
- A significant amount of expansion of the nasal cavity and skeletal base of the maxilla was observed on the anterior CT scan.
- Significant changes were obtained in the vocal parameters of max F0, jitter (%), and shimmer (both % and dB).
- The changes in voice parameters were found to be significantly correlated with the increase in nasal cavity width.

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