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RESEARCH ARTICLE

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EFFECT OF THE SURGICAL ASSISTED MAXILLARY EXPANSION ON THE AUDITORY APPARATUS

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ABSTRACT

Objectives: Surgically Assisted Maxillary Expansion (SAME) is a treatment method used to correct transverse deficiency in the maxillary arch. Various craniofacial areas especially in the areas of articulation of the maxilla could be affected. The purpose of this study was to evaluate the effects of SAME on auditory apparatus. **Materials and Methods:** A total of 17 patients with complete bone maturation were examined before maxillary expansion (T0), at completion of expansion (T1) and after the retention period (T2). Audiogram, tympanogram, physical exam, dental cast and radiograph evaluation were used to investigate the anatomical and physiological modifications after surgery. **Results:** In the audiogram of both ears, after SAME, 2000-4000Hz (T1-T2) frequency of the left ear was the only one not to show improvement. However, only 250-1000Hz and 1000-2000Hz were statistically significant ($p<0.005$). Tympanogram revealed no great alterations after the treatment for the membrane elasticity. No correlations were found between skeletal changes obtain by radiograph and dental cast measurements and the audiometric records ($p>0.005$). **Conclusions:** Positive effects of the SAME on the auditory apparatus were not as effective as for children. Mild changes on hearing capacity were not clinically effective.

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INTRODUCTION

Surgically Assisted Maxillary Expansion (SAME) is a treatment method used to correct transverse deficiency in the maxillary arch. This treatment also affects other structures such as the nasal cavity, maxillary sinus, and pharyngeal airways. Various craniofacial areas especially in the areas of articulation of the maxilla are also affected (Garrett *et al.*, 2008; Haralambidis *et al.*, 2009; Darsey, 2012; Zimring, 1965). Braun (1966) observed a correlation between hearing loss and maxillary constriction. According to Laptook (1981), the orthopedic effect of rapid maxillary expansion (RME) helps improve hearing levels in patients with maxillary deficiency. The effect of the expansion on the palatal and nasopharyngeal tissues improves the functioning of the pharyngeal ostia of the Eustachian tubes. Gray (1975) found that recurrent otitis media decreased remarkably in subjects treated with RME. Ceylan *et al*. (1996) performed RME on 14 children (11 girls and 3 boys, with average age of 12 years 11 months) with conductive hearing loss and maxillary deficiency.

The authors found that hearing levels significantly improved during the active expansion period and, although there was some loss in the hearing level after the retention period (about 4.5 months), it did not significantly affect the overall results. Taspinar *et al*. (2003) evaluated these effects over a 2-year period on 35 subjects and reported that RME had a positive effect on hearing levels. The results indicate that significant changes occur in both the hearing levels and air-bone gaps in both timing and frequency after the active treatment period (P < 0.001). For most patients (74%), these improvements were maintained two years after active treatment. Villano *et al*. (2006) evaluated 25 patients (15 girls and 10 boys, aged from 6 years 8 months to 8 years 2 months) with conductive hearing loss and maxillary constriction. After orthopedic expansion, the audiometric records indicated an improvement in hearing levels and, at the end of retention period, there was functional improvement in all patients at all frequencies. The limited data in the literature on this specific topic suggests the possibility of improving hearing levels by correcting palatal anatomy. However, none of these studies involved adults and none investigated the impact of surgical expansion on the auditory apparatus. Thus, the purpose of the present study was to evaluate the effects of SAME on auditory apparatus.

MATERIALS AND METHODS

The sample consisted of 17 patients (10 females and 7 males) who underwent SAME. Of the total number of patients, 3 had Angle class II and 14 had Angle class III, with an absolute discrepancy in the analysis of models. All surgeries were performed by the same surgeon, following the surgical technique described by Bays (1992). All subjects were informed as to the risks and benefits of the procedure and gave their consent for treatment. Each patient had severe maxillary arch constriction and high palatal vault. Age ranged from 16 to 45 years (mean of 30.5 years), with complete bone maturation. Each patient was examined for conductive hearing loss. 16 patients presented a minimal level of conductive hearing loss and only one had greater hearing loss. However, they did not know about these changes before initial audiogram.

After their first exam, all patients underwent a thorough clinical and medical history investigation and two instrument examinations by an otolaryngologist at three different times during treatment. First record (T0) was made prior to surgery; the second record (T1) was made after satisfactory expansion (approximately 18 days later); and third record (T2) was made after the retention period (six months later). The otolaryngological exams included: 1) An audiogram to examine auditory function; 2) A tympanogram to analyze variations in elasticity of the tympanic membrane related to the pressure changes in the external auditory tube (EAT). These are exams of choice for the auditory apparatus: the audiogram is a graph that assesses hearing capacity and sensitivity; the tympanogram, determines the mobility of the tympanic-ossicular system of the middle ear as a function of pressure variations in the EAT. Radiographic and dental cast records were also taken at the three different times. The distance between the jugular (left and right) and changes in the nasal cavity width in the posteroanterior cephalograms (P-A cephs) were used to evaluate skeletal changes (Figure 1). Dental cast measurements to evaluate changes in tooth position were performed at each evaluation time, using a digital sliding caliper. Intercanine widths were measured at the cusp tip. The inter-premolar width was measured between the cusp tips of the first premolars. The intermolar width was measured between the mesiovestibular cuspid of the upper first permanent molars. In order to calculate the width of the palate, a height 5 mm occlusal to the palatal depth marks noted above was conveyed on the lateral aspect of the palate on each side. The width between these scorings was measured. The depth of the palatal vault was determined by measuring the distance between the palatal depth and a straight wire laid across the occlusal surface of the first molar (Figure 2). Only one examiner made all measurements and he repeated it twice to give more accuracy for the results. Descriptive statistics, including mean and standard deviation values for the measurements, were calculated at each of the three evaluation periods separately. Data were evaluated using analysis of variance. The least square difference (LSD) test was used to determine when changes were significant. Correlations between skeletal/dental changes and audiometric values were analyzed using Pearson's correlation test. Significance was predetermined at the 0.05 confidence level.

RESULTS

In the audiogram of both ears, after SAME, 2000-4000Hz (T1-T2) frequency of the left ear was the only one not to show improvement. Highest variations occur between the second and final exam of both ears, however statistical significance were found only in the 250-1000Hz and 1000-2000Hz frequencies for the right ear (Table 1). Tympanogram results presented normal results in all patients, from these 12 (70.58%) on the right ear and 10 (58.82%) on the left ear showed an A curve type (standard model). The others presented Ad curve type (hipermobility of osseous-tympanum system) – 04 (23.52%) on the right ear and 07 (41.18%) on the left ear, while Ar curve type (rigidfy of osseous-tympanum system) was revealed only on the right side in one (5.88%) patient. The final evaluation revealed a discrete higher percentage of A curve type on the left ear – 12 (70.59%) and 05 (29.41%) with Ad type. On the right ear, the results did not show difference from the first exam – 12 (70.59%) with A type; 03(17.62%) with Ad type and 02 (11.76%) with Ar type (Table 2).

Dental cast analysis showed a reduction of 0.67mm ($p<0.05$) in the palatal depth from the initial evaluation (20.86 ± 2.58mm) to the final exam (20.19 ± 2.42mm). Palatal width presented an increase of 4.92mm ($p<0.05$) from the first evaluation (29,31 ± 4,26mm) to final exam (34,23 ± 3,77mm). Canine-canine distance showed an enlargement of 6.79mm ($p < 0,001$) with an average of relapse 2.54mm (37.40%) between maximum expansion and the third evaluation. Premolar-premolar distance presented an increase 7.52mm ($p < 0,001$) with a relapse of 1.48mm (19.68%). Molar-molar distance showed an enlargement of 7.42mm ($p < 0,001$) with a relapse of 1.45mm (19.54%) (Table 3). Cephalogram evaluation presented an increase of the maxilar width – 1.28mm and nasal width 0.69mm ($p<0.005$). In the final exam, a minimal relapse was observed, however without statistical significance. Mandibular width was only measured for magnification of the maxilo-mandibular discrepancy (Table 4). Table 5 illustrate the correlation between the audiogram results with palate depth, palate width and maxilar width. No statistical significance was found among skeletal changes and frequency variations found in the audiometry. This result suggests that may not exist proportionality between maxillary changes and increase of audiograms results.

Table 1. Statistical analysis of audiogram results during the different periods of evaluation

	Audiogram					
	Right Ear			Left Ear		
Evaluation	250•1000Hz Mean ± SD	1000•2000Hz Mean ± SD	2000•4000Hz Mean ± SD	250•1000Hz Mean ± SD	1000•2000Hz Mean ± SD	2000•4000Hz Mean ± SD
Preoperative (T0)	15.88 ± 24.83 $^{(A)}$	15.00 ± 27.73 $^{(A)}$	13.53 ± 28.10	11.47 ± 10.57	10.59 ± 10.74	10.88 ± 12.15
Postoperative (T1)	14.12 ± 25.14 $^{(AB)}$	12.94 ± 27.90 $^{(AB)}$	13.24 ± 27.89	11.47 ± 9.96	10.29 ± 10.23	9.71 ± 11.79
Final (T2)	10.59 ± 18.36 $^{(B)}$	9.71 ± 19.80 $^{(B)}$	9.71 ± 19.80	10.00 ± 11.59	9.71 ± 11.79	10.59 ± 14.02
P value	$p^{(1)} = 0.025$*	$p^{(1)} = 0.048$*	$p^{(1)} = 0.125$	$p^{(1)} = 0.439$	$p^{(1)} = 0.733$	$p^{(1)} = 0.651$
⌡ Differences						
T0 • T1	1.76 ± 4.66	2.06 ± 5.02	0.29 ± 5.14	0.00 ± 4.68	0.29 ± 4.13	1.18 ± 5.16
T0 • T2	5.29 ± 8.19	5.29 ± 9.10	3.82 ± 9.11	1.47 ± 6.06	0.88 ± 5.93	0.29 ± 6.72
T1• T2	3.53 ± 8.06	3.24 ± 9.00	3.53 ± 9.15	1.47 ± 5.52	0.59 ± 4.96	-0.88 ± 5.07

(*): Statistical significance • 5.0%. (1): ANOVA test for repeated values.

Table 2. Distribution of tympanogram curve types during the three phases of the study

Side	Curve type	Tympanogram curve Evaluation Period (T0)	Evaluation Period (T1)	Evaluation Period (T2)
RE	A	12 (70.58%)	14 (82.35%)	12 (70.58%)
	Ad	04 (23.52%)	02 (11.76%)	03 (17.64%)
	Ar	01 (5.88%)	01 (5.88%)	02 (11.76%)
LE	A	10 (58.82%)	12 (70.58%)	12 (70.59%)
	Ad	07 (41.18%)	04 (23.52%)	05 (29.41%)
	Ar	0 (0%)	01 (5.88%)	0 (0%)

Table 3. Dental cast analysis on the three periods of evaluation

	Dental cast measure				
Evaluation	Canine-canine Mean ± SD	Premolar-premolar Mean ± SD	Molar-molar Mean ± SD	Palate depth Mean ± SD	Palate width Mean ± SD
Preoperative (T0)	34.03 ± 3.00 $^{(A)}$	40.70 ± 2.98 $^{(A)}$	50.00 ± 4.06 $^{(A)}$	20.86 ± 2.58	29.31 ± 4.26
Postoperative(T1)	40.83 ± 3.98 $^{(B)}$	48.22 ± 3.93 $^{(B)}$	57.42 ± 4.48 $^{(B)}$		
Final (T2)	38.28 ± 3.09 $^{(C)}$	46.74 ± 3.70 $^{(C)}$	55.98 ± 3.80 $^{(B)}$	20.19 ± 2.42	34.23 ± 3.77
P value	$p^{(1)} < 0.001$*	$P^{(1)} < 0.001$*	$p^{(1)} < 0.001$*	$p^{(2)} = 0.013$*	$p^{(2)} < 0.001$*
⌡ Differences					
T1 • T0	6.79 ± 2.71	7.52 ± 2.58	7.42 ± 2.52		
T2 • T0	4.25 ± 2.23	6.04 ± 2.95	5.98 ± 2.69	-0.67 ± 0.99	4.92 ± 2.01
T2 • T1	-2.54 ± 1.74	-1.48 ± 1.79	-1.45 ± 2.34		

(*): Statistical significance • 5.0%. (1):ANOVA test for repeated measures. (2): Paired t-Student.

Table 4. Statistical analysis of radiographic results during the different periods of evaluation

	Radiographic measurements		
Evaluation	Maxilar width Mean ± SD	Nasal width Mean ± SD	Mandibular width Mean ± SD
Preoperative (T0)	61.93 ± 4.53 $^{(A)}$	34.73 ± 2.26 $^{(A)}$	84.79 ± 5.45
Postoperative (T1)	63.51 ± 4.81 $^{(B)}$	35.62 ± 2.30 $^{(B)}$	
Final (T2)	63.21 ± 4.79 $^{(B)}$	35.42 ± 2.66 $^{(B)}$	
P value	$p^{(1)} < 0.001$*	$p^{(1)} = 0.007$*	
⌡ Diferences			
T1 • T0	1.58 ± 1.43	0.89 ± 1.25	
T2 • T0	1.28 ± 1.59	0.69 ± 0.86	
T2 • T1	-0.30 ± 0.72	-0.20 ± 1.03	

(*): Statistical significance • 5.0%. (1): ANOVA test for repeated values.

DISCUSSION

The issue to be evaluated is how the controlled bone movement of the maxilla can improve hearing function. Laptook (1981), Wertz (1961), Starnbach (1964) suggest the response of soft tissues to the skeletal stimulus as an important factor in hearing gain. These authors affirm that the bone changes that take place in the oral cavity, oropharynx, nasal cavity and nasopharynx affect the conformation of the soft tissues adjacent to the facial skeleton. Ceylan (1996) states that improved air flow in the nasal cavity results in a gain in respiratory physiology and, consequently, a reduction in the accumulation of secretions in the nasopharynx and a lower incidence of upper airway infections and otitis media. Another explanation for the changes in hearing function following maxillary expansion is the anatomical theory. The musculature of the tensor and elevator of the palatine veil responsible for the opening and closing of the Eustachian tube in the region of the nasopharynx has its muscle origin near the ostium of the tube and the insertion of the fibrous portion of the soft palate attached to the bone portion of the palate. Furthermore, the tendons of this musculature are found lateral to the palatine aponeurosis formed by the fibrous portion of the soft palate with the bone portion of the palate (Byloff, 2004).

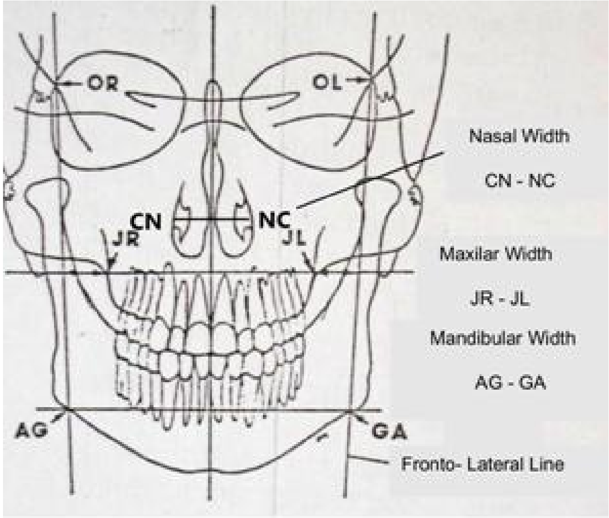

Figure. 1. Ilustrative model of the radiographic patterns used in the P-A cephalograms (BETTS, 1994) (1994)

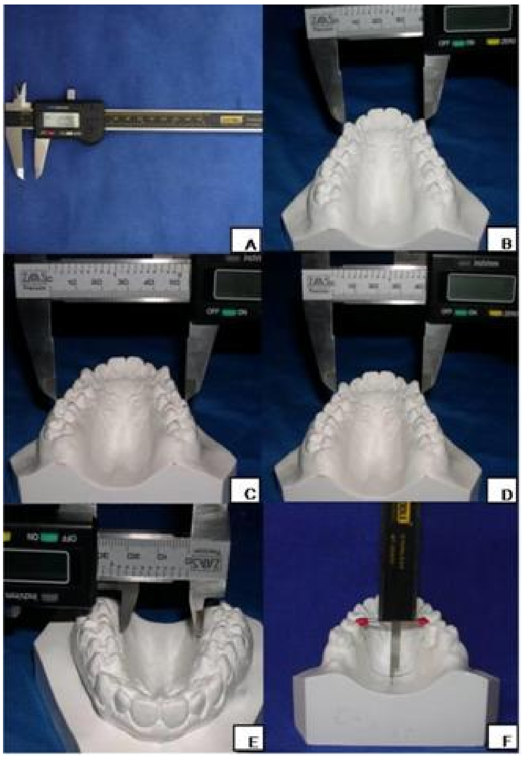

Figure. 2 . (A) - Digital caliper (Starrett ®), (B) – Canine-canine distance, (C) – Molar-molar distance (D) – Premolars-premolars distance, (E) – Palate width (F) – Palate depth

Both these theories offer responses to the improvement in hearing function. However, the evaluation instrument employed in these studies only measures the auditory physiology in the different evaluation intervals and does not detail an anatomical analysis of these structures in the post-operative period. After their visit to the otolaryngologist, no pathology was observed that would contraindicate the treatment. Rhinoscopy revealed that six patients had a deviated septum and five patients had hypertrophy of the inferior nasal conchae. In the sample, only one patient reported having nasal breathing, whereas nine reported having mixed breathing and seven reported having mouth breathing. Laptook (1981) describes “skeletal development syndrome” with the following findings: (1) maxillary atresia; (2) high-arched palate; (3) hypertrophy of the nasal conchae reducing the size of the nasal cavity; (4) bilateral posterior crossbite associated to the high-arched palate; (5) elevated floor of the nasal fossa; and (6) mouth breathing. These common findings of transverse deformity result in a reduction of nasal permeability and an increase in nasal resistance to air flow, which directly affects gathering air through the nose. Recent studies have demonstrated that there is an improvement in nasal breathing after surgical-orthodontic treatment resulting from the gain in volume of the nasal cavity and reduction in nasal resistance (Taspinar *et al*., 2003). During the post-operative evaluation, no alteration was identified in the physical exam of the nose, mouth and ears, with the exception of one patient. In this case series, the otolaryngological exam and cephalometric radiographs revealed that the anterior portion of the septum did not accompany either of the two maxillae during the movement of the bone segments. Schwarz (1985) reports a similar finding. The analysis of dental casts is one of the tools used to quantify the expansion between the different tooth groups and assess the stability of the procedure. The present study found a transverse increase of 7.42 ± 2.52 mm in the molar region ($p<0.001$). This result is compatible with the papers consulted by Pogrel *et al*. (1992); Bays (1992); Anttila (2004); Chamberland (2008); Trefny *et al*. (2016). The inter-canine distance increased by 6.79 ± 2.71 mm ($p<0.001$), which is similar to the studies referenced by Bays (1992); Bylof (2004); Anttila (2004); Trefny *et al*. (2016). The increase in the pre-molar distance was 7.52 ± 2.58 mm ($p<0.001$), which is also compatible with previous studies by Byloff (2004); Anttila (2004); Trefny *et al*. (2016). SAME has a relapse ranging from 4 to 50%. In the region of the upper molars, nine studies present the following percentages: Pogrel *et al*. (1992), Bays (1992); Anttila (2004); Chamberland and Proffit (2008). In the present study, loss in the molar region was 19.54%, which is compatible with the literature. Regarding the loss of the inter-canine distance, the literature reports the following percentages: Bays (1992) – 9%; Anttila (2004) – 6%; Freitas (2008) – 23%. A higher inter-canine distance loss rate was found in the present study (37.40%), however, there was also a greater expansion (6.79 ± 2.71 mm) in relation to the literature consulted, with a final expansion of 4.25 ± 2.23 mm in the canine region, which is similar to the expansion reported in previous studies. Few studies present the measurements and relapse in the premolar region, even though these teeth serve as anchorage for the expander apparatus, together with the molars and canines. Byloff (2004) describe a loss of 33%; Anttila (2004) describe 12% and the degree of loss in the present study was 19.68%. There are some errors in the methodology of the analysis of plaster models that contribute toward a discrepancy in loss rates. Most studies take measurements at the beginning of treatment, after orthodontic retention and at a late follow up examination. However, the results would be more reliable if the measurements were taken during maximal expansion, which would be when the Hyrax apparatus is locked. From this point, late post-operative evaluations would be carried out with a minimum of four to six months following maximal expansion, the post-expansion retention period and when the orthodontic apparatus is installed. Only three studies employ this methodology: Byloff (2004), Chamberland (2008) and Freitas (2008).

The depth of the palate is a measurement that tends to diminish, as the horizontal process of the palatine bone is positioned downwardly following the procedure. The present study found a reduction of 0.67 mm in the height of the palate ($p<0.005$), which is lower than that described in previous studies: Caubi (2008) – 1.35 mm; Northway (1997) – 1.9 mm. The width of the palate tends to increase as a result of the lateral movement of the palatine alveolar process, which, in the present study, was an increase of 4.92 mm ($p<0.005$) on the final evaluation. This finding is similar to that described by Northway (1997), who found a 4.9 mm increase in palate width. Both width and depth of the palate achieved statistically significant differences. Studies on surgically-assisted maxillary expansion classically assess the efficacy of the procedure through the evaluation of plaster models. However, this analysis is restricted to the positioning of the teeth. This model reference means that the expansion and relapse are exclusively evaluated the dental movement and there is no assessment tool for skeletal movement. In the present study, postero-anterior cephalometric radiograph revealed an increase of 1.58 ± 1.43 mm in maxillary width between the beginning of treatment and maximal expansion ($p<0.005$), with a loss of 0.30 ± 0.72 mm at the final evaluation. Only three previous studies evaluated skeletal alterations following expansion surgery: Berger *et al.* (1998) report an increase of 3 mm in maxillary width, with a loss of 0.67 mm; Byloff (2004) report a gain of 1.31 mm and loss of 0.4 mm; Chamberland (2008) obtained 3.49 ±1.37 mm in skeletal expansion, with no loss during the follow up. Regarding nasal width, the present study found an increase of 0.89 ± 1.25 mm ($p<0.005$), with a loss of 0.20 ± 1.03 mm on the final evaluation. Berger *et al.* (1998) report an increase of 1.72 mm during the expansion and a loss of 0.41 mm during follow up. Chamberland (2008) found a variation in nasal width between 1.5 and 2.0 mm between evaluation intervals. Cephalometric tracings for postero-anterior radiographs are not standardized in these works; most of these authors used the analysis described by Betts (1994). However, not all the studies followed this procedure, which affects the analysis of the results. The extreme complexity of the nasal airway shape makes it difficult to reliably assess ventilation and possible modification of the nasal airway after SAME. However, the improvement in ventilation can be detected with computational fluid dinamycs (Iwasak *et al.*, 2012). In the audiometric evaluation, most of the patients exhibited minimal level of conductive hearing loss and only one had a moderate degree of hearing loss in the left ear and severe sensorial-neural loss in the right ear. After surgery, there was a reduction in the decibel level on all frequences studies in both the right and left ear between the initial evaluation and the evaluation at maximal expansion. Thus, the patients exhibited a quantitative improvement in auditory function following the procedure. However statistical significance were found only in the 250-1000Hz and 1000-2000Hz frequencies for the right ear. Even without showing relevant quantitative results, a subjective analysis can be made to assess if qualitative improvement occurs.

Regarding the tympanometric curves, no significant alterations were seen between the initial evaluation and subsequent evaluations. At the final evaluation, there was a discretely greater percentage of exams with a type A curve in the left ear and the maintenance of the results in the right ear. Assessing the records of the stapedic reflex, there was a discrete improvement in the contralateral reflexes of the right ear, whereas the results on the left side (both contralateral and ipsilateral) remained similar to those of the initial exam. These results partially corroborate the literature available on children. Ceylan (1996), Taspinar (2003) and Vilano (2006) report a greater percentage of improvement. Ceylan (1996) describes a study with no long-term follow up and a slight relapse on the final evaluation. Taspinar (2003) and Vilano (2006) carried out a two-year and an eight-month follow up, respectively, with no signs of relapse in hearing gain after maximal maxillary expansion. There were no statistically significant correlations of dental alterations (obtained from the variations in the measurements on the plaster models) and skeletal alterations (determined through radiographic assessment) with variations determined by the audiometric exams. This result does not support the hypothesis of anatomical correction defended by studies carried out on children. No other study has used the available assessment tools for maxillary expansion (analysis of radiographs and plaster models) in order to relate changes in the upper arch to audiometric exams that quantify hearing function. There are a number of theories on the disparity in the results of studies on children and those on adults. One of the possible explanations is due to the fact that the auditory tube in adults has a 45° inclination. Thus, gravity assists in the drainage of the secretions. In children, the auditory tube has a 10° inclination, it is practically flat. With Rapid Palatal Expansion, the tube gains greater inclination, which helps to retain less secretions. Another fact is due to the auditory tube being broader in children and has a less rigid cartilaginous portion. Concluding, anatomically the lower positioning of the palate and opening of the nasal cavity following maxillary expansion is more beneficial to children than adults (Gray, 1975; Chamberland, 2008; Ehler, 2005). On the other hand the results of the studies would be more promising if the sample were composed by adults patients with otitis media and palatal vault.

Conclusion

Surgical assisted maxillary expansion can result in mild changes in hearing sensitivity, however these changes were clinically insignificant.

Figure. 1 – Ilustrative model of the radiographic patterns used in the P-A cephalograms (BETTS, 1994) (1994)

Figure. 2 – (A) - Digital caliper (Starrett ®), (B) – Canine-canine distance, (C) – Molar-molar distance (D) – Premolars-premolars distance, (E) – Palate width (F) – Palate depth

Compliance with Ethical Standards

Conflict of Interest: All the authors declare no conflicts of interest

Funding: No funding

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards

Informed consent: Informed consent was obtained from all individual participants included in the study

Abbreviations

Surgically Assisted Maxillary Expansion (SAME)
Rapid Maxillary Expansion (RME)
External Auditory Tube (EAT)
Least Square Difference (LSD)

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