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Changes in natural head position observed immediately and one year after rapid maxillary expansion

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SUMMARY Rapid maxillary expansion (RME) has been shown to increase nasal permeability and reduce nasal airway resistance. A number of studies have examined the relationship between RME and the change in airway resistance, or the relationship between airway resistance and natural head position (NHP). Few studies, to date, have examined the relationship between RME and the change in NHP resulting from the consequent change in airway resistance.

A sample of 43 adolescent patients with uni- or bilateral crossbite in the permanent dentition underwent RME as part of normal orthodontic treatment. Cephalograms in NHP were taken before, immediately after expansion, and one year after RME. No significant changes in the craniofacial angles were observed immediately after expansion. One year post-expansion, however, NSL/VER had reduced by 3.14 degrees ($P < 0.01$), OPT/HOR by 2.13 degrees ($P < 0.05$), and CVT/HOR by 2.55 degrees ($P < 0.05$).

The results of this study suggest an ongoing change in head posture possibly due to a change in the mode of breathing from oral to nasal as a result of RME, thereby contributing to a change in craniofacial development, supporting and adding to the soft tissue stretching hypothesis.

Introduction

The relationship between airway patency and the position of the head in relation to the true vertical and the cervical column has been the subject of interest to many researchers over the course of the last century. Airway patency is essential to life, and as respiration is a continuous activity, it is logical to postulate that it has some influence on post-natal growth and development of the craniofacial regions.

The environmental effect of respiration on craniofacial development has been extensively investigated by Linder-Aronson (1970, 1974, 1975) and other workers (Behlfelt *et al.*, 1989, 1990a,b) who demonstrated that patients with enlarged adenoids, tonsils, or other forms of airway obstruction differed in their craniofacial development compared with a normal sample of patients (i.e. those with no airway obstruction). Linder-Aronson (1975) showed that when adenoidectomy was performed, there was a trend towards normalization of the cephalometric variables in the surgery group towards those of the control group. This was ascribed to an improved mode of breathing.

Research by Solow and Tallgren (1971a,b, 1976), Solow and Krieborg (1977), Solow and Siersbæk-Nielsen (1986) and Solow and Sonnessen (1998) has elucidated this relationship to a much greater extent, and a hypothesis on the relationship between head posture and temporomandibular disorders has been developed (Solow and Sandham, 2002).

Natural head position (NHP) has been defined by Cole (1988) as 'the relationship of the head to the true vertical', while natural head posture was defined as 'the relationship of the head to the cervical column'. As a reproducible position, it is useful for making comparisons at different times for the same patient or comparing different patients cephalometrically. It is considered that NHP is established early in life and influenced by balance (the vestibular canals of the middle ear), vision (the need to maintain a horizontal visual axis) and proprioception from joints and muscles resulting from the erect posture. It has been found to have less variance than intracranial reference lines (Foster *et al.*, 1981). Lundström and Lundström (1992) advocated the use of NHP in cephalometry as they considered that this gave the patient a more natural appearance. The long-term stability of NHP has been investigated 3–6 months after the initial radiograph (Cooke and Wei, 1988), five years after (Cooke, 1990), and 15 years after (Peng and Cooke, 1999). Reproducibility seemed to deteriorate over time but to stabilize after 1 to 1½ years. Studies by Siersbæk-Nielsen and Solow (1982) and Sandham (1988) showed minor method errors between repeated radiographs taken on the same day.

NHP was first investigated in a meaningful way by Solow and Tallgren (1971a) and in numerous subsequent studies by the same researchers. It was found that the cranio-cervical relationship (the relationship of the neck to the head) had the greatest correlation with head posture, compared with any other cephalometric variables (Solow and Tallgren, 1971b, 1976). Based on these investigations, and the work of Linder-Aronson (1970, 1974, 1975) and others, Solow and Krieborg (1977) were the first to suggest an interaction between morphological change, airway patency, neuromuscular feedback, head posture, soft tissue changes, and differential forces on the facial skeleton (Figure 1).

Rapid maxillary expansion (RME) is a well-established technique for the correction of transverse discrepancies of the maxillary arch. Its mode of action relies on the separation of the two halves of the maxilla in order to achieve true skeletal or 'orthopaedic' expansion, followed by orthodontic alignment of the teeth. The use of RME to increase the patency of the nasal airway was advocated by Derichsweiler (1953) and Korkhaus (1960). Gerlach (1956) cautioned that while RME was useful for nasal stenosis, not every mouth breather could be treated in this way. Improved nasal airflow has been demonstrated in orthodontic patients after RME by Linder-Aronson and Aschan (1963), Hershey *et al.* (1976), and Loreille and Béry (1981) who demonstrated an average increase in nasal permeability of 13.6 per cent, and by Timms (1986), who, in a sample of 26 patients found an average 36.2 per cent decrease in nasal airway resistance after RME.

In the short-term, the results of RME in the transverse dimension have been documented by Cross and McDonald (2000), who showed that small, but statistically significant, increases in maximum nasal width took place, in agreement with previously reported studies. Long-term, the skeletal effects of RME have been described by Krebs (1964), who showed that rapid expansion of the maxilla as opposed to slow expansion (Skieller, 1964) resulted in a long-term increase in the width of the skeletal structures which was maintained with normal growth. Similar results have been reported by Cameron *et al.* (2002) and Baccetti *et al.* (2001).

It has been shown by Vig *et al.* (1980) that nasal obstruction results in elevation of the head relative to the cervical column and the true vertical in humans. Conversely, Wenzel *et al.* (1985) demonstrated an immediate drop in head elevation when a nasal decongestant was administered

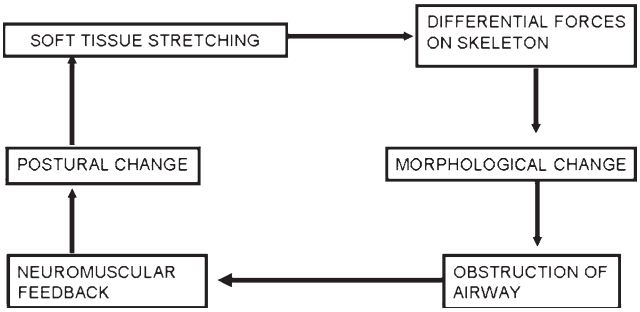

Figure 1 The soft tissue stretching hypothesis. (Reproduced from Solow, Kreiborg 1977 Soft tissue stretching: a possible factor in craniofacial morphogenesis. Scandinavian Journal of Dental Research 85: 505–507 with permission of Blackwell Publishing Limited.)

to a group of patients with nasal rhinitis, thereby improving airway patency.

Other factors that may influence head posture have been discussed by Wenzel *et al.* (1989), who, in a study of patients who had mandibular setback surgery for mandibular prognathism, showed that angulation of the cranial base to the cervical column increased by an average of 2.7 degrees. The nasopharyngeal airway size decreased following surgery, but the authors considered that a decrease in airway size on radiographs was not necessarily followed by an increase in airway resistance, and the degree of mandibular setback in many cases was only of the order of a few millimetres. It was postulated that psychosocial factors such as improved self-confidence may have stimulated patients into raising their heads, thereby reinforcing the changes in head posture arising from the biological changes.

While a number of investigations have shown a relationship between airway patency and head posture, and others a change in airway patency following RME, few studies, to date, have examined the changes in head posture that occur in the longer term as a result of reducing nasal airway resistance following RME. McDonald (1995) showed a number of changes in craniocervical angulation immediately after RME, but the trends and their significance were not assessed in the longer term.

From the foregoing, it is hypothesized that RME will result in increased nasal airway patency and reduced nasal airway resistance, which will lead to increased airway flow and alter craniocervical angulations. The objective of this study was to establish the changes in craniocervical angulations immediately after and one year following RME.

Subjects and methods

Ethical approval for this research was obtained from the Fife Health Board and the Clinical Research Ethical Committee of the Galway Regional Hospitals.

Patient selection

The patients in the test group were selected from the waiting list of a district general hospital. The criteria for inclusion were:

1. Between 10 and 16 years of age.
2. In good general and dental health.
3. Either (a) a bilateral crossbite in the buccal segments, or (b) a unilateral crossbite with displacement on closure.
4. A full permanent dentition in the maxillary arch, consisting of 654321/123456.
5. No history of surgery to the nasal, paranasal, or oral cavities.
6. No allergies, nasal decongestant medication, or history of nasal obstruction.

A total of 43 patients (25 females, 18 males) participated. The control sample comprised 36 subjects (24 females and

12 males), again all within the age group 10–16 years inclusive, who had been used in a previous study (McDonald, 1995). All subjects were of the same northern European racial background (white Caucasians) and represented the type of routine patients treated in most district general hospitals.

An historical control sample was used because it was not possible to obtain an untreated group and expose them to radiographs for comparison: a similar procedure was followed by Solow *et al*. (1993) in their study of sleep apnoea patients.

Full orthodontic records were obtained prior to treatment (T_1), consisting of study casts, clinical photographs, and radiographs. The lateral cephalometric headfilm was taken in NHP as described by Solow and Tallgren (1971a) and Siersbæk-Nielsen and Solow (1982), with a hanging chain over the radiograph to indicate true vertical.

The RME splint was constructed giving full cast metal coverage of the buccal teeth (654/456), occasionally covering 3/3 or 7/7 where necessary. A full permanent dentition was desirable to ensure coverage of permanent teeth as opposed to primary teeth in view of the total tooth coverage design of the splint, and to avoid traumatic exfoliation of primary teeth on removal. Generally, each screw had 40 turns available, with a total potential expansion of up to 10 mm. Occasionally, where the maxillary arch was very narrow, a smaller screw (25 turns) was used, followed by a second appliance to complete any further expansion. The appliance was cemented with glass ionomer cement and the patient or their parent instructed to turn the midline screw twice a day after meals.

Normally patients were reviewed after three weeks, but some required further activation of the appliance, or a new appliance, before the crossbite was sufficiently corrected. At this stage, a second headfilm in NHP was obtained (T_2). Orthodontic treatment proceeded normally and one year after cessation of maxillary expansion, a third lateral skull headfilm was obtained (T_3). At the end of orthodontic treatment the appliances were removed, final records obtained, and normal retention procedures instituted.

Cephalometric data

The cephalograms were traced onto acetate paper with a 3H pencil using a light viewing box. The shadow of the hanging chain indicated true vertical (VER) and this was traced on to the acetate sheet. The horizontal plane (HOR) was constructed by drawing a line perpendicular to the line VER. Of particular interest were the craniocervical angulations to the vertical and horizontal plane. The angulations shown in Figure 2 were traced.

Statistical analysis

The data were analysed using the Statistical Package for the Social Science (SPSS v.11, Chicago, Illinois, USA). Comparison of the control (McDonald, 1995) and test

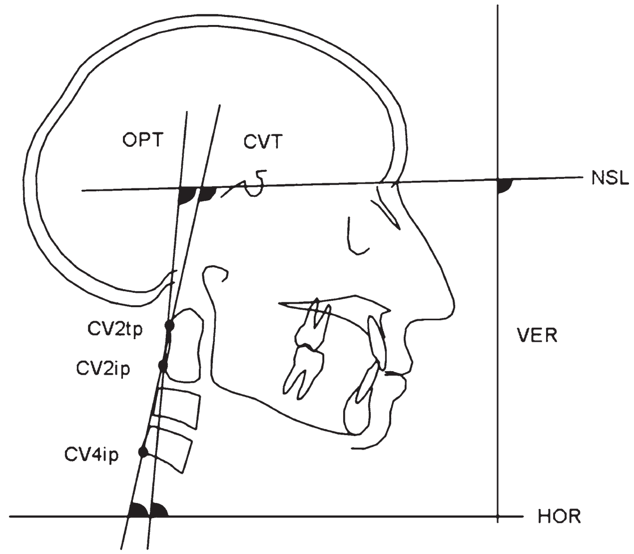

Figure 2 Craniocervical angulations used in this study. OPT/NSL: the angle formed by the line tangent to the odontoid process (CV2tp) through cv2ip (the most inferior and posterior point on the corpus of the second cervical vertebra), and the nasion–sella line. CVT/NSL: the angle formed by the line tangent to the odontoid process through cv4ip (the most inferior and posterior point on the fourth cervical vertebra), and the nasion-sella line. OPT/CVT: the angle between the odontoid process tangent through cv2ip and the tangent to the odontoid process through cv4ip. NSL/VER: the angle between the nasion–sella line and true vertical. OPT/HOR: the angle between the line OPT and true horizontal. CVT/HOR: the angle between the line CVT and true horizontal

group pre-treatment cephalometric data was performed using a one-sample *t*-test. Comparison of the pre-treatment age data and cephalometric angulations between the genders in the test group were examined using independent (two sample) *t*-tests. Craniocervical and craniovertical angulations pre-treatment (T_1), post-expansion (T_2), and one year post-expansion (T_3) were compared using repeated measures ANOVA. Normality of data was checked using the Kolmogorov-Smirnov and Shapiro-Wilk tests, while sphericity of the data was determined with Mauchly's test. Tests of within subject contrasts were performed to detect the population average that was significantly different, i.e. which of the readings for any particular cephalometric reading at a particular time was significantly different from the data obtained at the other time points.

Errors were analysed by retracing 15 per cent of the total sample at least two weeks after the initial tracing. Systematic errors were assessed using a paired *t*-test, and standard errors of the method. The coefficient of reliability was performed according to Houston (1983), and summary statistics of measurement error using the method of Bland and Altman (1986).

Results

Of the original 43 patients enrolled in the study who had a cephalometric radiograph taken at T_1, 41 (24 females, 17 males) had a cephalometric radiograph taken at T_2, and 39 (23 females, 16 males) had one taken at T_3. Therefore a total of four patient records (two females and two males) were unavailable at follow-up. On average, the time between T_1 and T_2 was 0.28 years (SD 0.12 years) and between T_2 and T_3 1.22 years (SD 0.35 years).

The average age for females at the start of treatment was 13.43 years (SD 0.8 years) while for males it was 13.34 years (SD 1.14 years). Using an independent samples *t*-test it was found that there was no statistically significant difference in age between the genders at the start of treatment (Table 1). The pre-treatment cephalometric variables for both genders were compared and only OPT/CVT (cervical lordosis) was found to be significantly different (difference = 1.91, P = 0.005); despite this, it was considered appropriate to combine the data for the genders. The average age for females in the control group was 12.71 years (SD 1.39 years) and for males 12.42 years (SD 1.20 years). The control group (McDonald, 1995) was, on average, one year younger than the test group (Table 1).

The cephalometric variables from the control group used by McDonald (1995) were compared with the test data at T_1 and were found to be virtually identical (Table 2) using a one-sample *t*-test.

Cephalometric data errors were examined as described in the previous section. The results are presented in Table 3. It was found that there was no significant systematic bias between the first and second readings using a Student's *t*-test. The coefficient of reliability (Houston, 1983) was between 0.92 and 0.99. The standard error of the method for repeated tracings ranged between 0.41 and 0.93 degrees. The accuracy of the tracings using Bland and Altman's method was found to be acceptable, in that over 95 per cent of the differences were within two standard deviations of the mean.

Tests of normality showed that the data were normally distributed, and Mauchly's test for sphericity was not violated. As these assumptions for parametric data had been met, repeated measures ANOVA was used to compare the data at the three time points.

The descriptive statistics for the craniocervical angulations are given for all subjects at the three time points in Table 4.

Table 1 Gender and age analysis: test and control groups.

	Test group			Control group (McDonald, 1995)		
	n	Mean	SD	*n*	Mean	SD
Females	25	13.43	0.8	24	12.71	1.39
Males	18	13.34	1.14	12	12.46	1.20
Total	43			36		

SD, standard deviation.

Table 2 Comparison of head posture in degrees between controls (n = 36) and test subjects (n = 43) at the start of treatment using a one-sample *t*-test.

	Control sample (McDonald, 1995)				Test sample before treatment				Statistical tests of difference			
	Mean	Minimum	Maximum	SD	Mean	Minimum	Maximum	SD	Difference	*t*	*P*	Significance
OPT/NSL	98.85	80.8	115.9	8.91	98.54	82.0	118.0	7.7	0.31	−0.263	0.794	ns
CVT/NSL	103.86	86.3	123.5	8.83	103.51	88.5	123.5	7.9	0.35	−0.287	0.775	ns
OPT/CVT	5.01	–3.77	13.79	4.17	4.97	1.0	8.5	2.27	0.04	−0.110	0.913	ns
NSL/VER	95.34	82.6	110.0	6.89	95.63	76.5	114.0	7.19	−0.29	0.269	0.789	ns
OPT/HOR	86.49	68.5	102.9	8.17	87.08	68.5	99.0	7.04	−0.59	0.553	0.583	ns
CVT/HOR	81.47	64.7	95.4	7.62	82.14	67.3	95.0	6.96	−0.67	0.635	0.529	ns

SD, standard deviation; ns, not significant.

Table 3 Method errors (*t*-test, coefficient of reliability and random error).

	t	*P*	Significance	Coefficient of reliability	Standard error of the method (degrees)
OPT/NSL	−0.147	0.884	ns	0.98	0.77
CVT/NSL	−0.032	0.975	ns	0.99	0.71
OPT/CVT	0.341	0.367	ns	0.92	0.59
NSL/VER	−0.011	0.992	ns	0.99	0.53
OPT/HOR	0.162	0.872	ns	0.98	0.93
CVT/HOR	0.076	0.939	ns	0.99	0.41

Method errors were assessed by retracing a random selection of 15 per cent of the total number of cephalometric radiographs (18 in total).
ns, not significant.

Table 4 Changes in craniocervical angles over the course of treatment.

	Time	*n*	Mean	SD	SE	95% confidence interval for mean		Minimum	Maximum
						Lower bound	Upper bound		
OPT/NSL	T_1	43	98.54	7.7	1.17	96.17	100.91	82.0	118.0
	T_2	41	98.98	7.81	1.22	96.52	101.44	83.5	123.0
	T_3	39	97.54	7.69	1.23	95.05	100.03	77.0	115.0
CVT/NSL	T_1	43	103.51	7.91	1.21	101.08	105.95	88.5	123.5
	T_2	41	104.37	7.84	1.23	101.9	106.85	87.5	125.0
	T_3	39	102.94	7.68	1.23	100.45	105.45	85.0	120.0
OPT/CVT	T_1	43	4.97	2.27	0.35	4.27	5.67	1.00	8.5
	T_2	41	5.40	2.53	0.40	4.60	6.20	0.50	10.5
	T_3	39	5.40	2.68	0.49	4.54	6.27	-0.50	13.0
NSL/VER	T_1	43	95.64	7.19	1.10	93.42	97.85	76.5	114.0
	T_2	41	95.43	7.14	1.11	93.18	97.68	82.6	112.5
	T_3	39	92.50	6.69	1.07	90.33	94.67	80.5	104.0
OPT/HOR	T_1	43	87.08	7.04	1.07	84.92	89.25	68.5	99.0
	T_2	41	86.55	7.64	1.19	84.14	88.96	64.5	99.0
	T_3	39	84.95	6.51	1.04	82.84	87.06	71.0	99.0
CVT/HOR	T_1	43	82.14	6.96	1.06	80.0	84.29	67.3	95.0
	T_2	41	81.16	6.82	1.06	79.01	83.31	63.0	95.0
	T_3	39	79.59	5.71	0.91	77.74	81.43	67.5	88.0

SD, standard deviation; SE, standard error.

The craniocervical angles, OPT/NSL and CVT/NSL, both increased very slightly between T_1 and the immediate post-expansion period, T_2, but then declined when measured at follow-up (T_3). OPT/NSL increased from 98.54 degrees at T_1 to 98.98 degrees at T_2, an increase of 0.44 degrees, but then declined at T_3 to a value of 97.64 degrees, which resulted in an overall decrease of 1.0 degree over the course of the study (Table 4 and Figure 3). The angle CVT/NSL showed an increase from 103.51 degrees to 104.37 degrees before declining to 102.94 degrees over the same period (Table 4 and Figure 3). The overall decrease of 0.57 degrees was less than that for OPT/NSL. Neither of the changes in these two angulations were found to be statistically significant (Tables 5 and 6)

The cervical lordosis angle, OPT/CVT, showed a pre-treatment (T_1) value of 4.97 degrees (SD 2.27 degrees) which increased to 5.4 degrees (SD 2.53 degrees) at T_2, and remained unchanged at T_3 (SD 2.68 degrees) (Table 4 and Figure 3). The average change between the beginning and end of the study was an increase of 0.43 degrees. This change was not statistically or clinically significant (Tables 5 and 6).

The craniovertical angle, NSL/VER, gave an average value of 95.64 degrees (SD 7.19 degrees) at T_1, which declined slightly to 95.43 degrees (SD 7.14 degrees) at T_2. When examined at T_3 the angulation was found to be 92.5 degrees (SD 6.69 degrees) (Table 4 and Figure 3). Between T_1 and T_2 there was a decrease of 0.21 degrees, followed by a further decrease of 2.93 degrees at T_3, giving an overall reduction for NSL/VER of 3.14 degrees over the course of the study. This change was found to be statistically significant (P = 0.005, Table 5), with the most significant changes taking place between T_2 and T_3 (P = 0.001, Table 6).

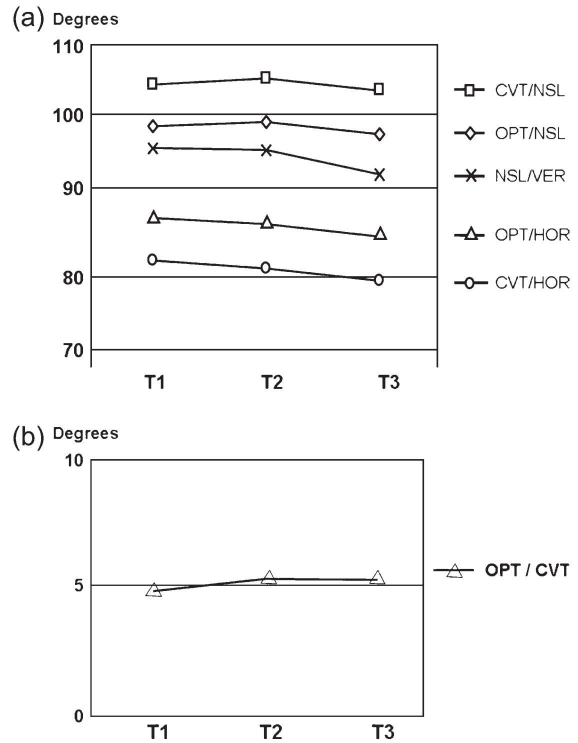

Figure 3 Changes in (a) craniocervical angles OPT/NSL, CVT/NSL, NSL/VER, OPT/HOR and CVT/HOR, and (b) angle OPT/CVT, over the course of the study.

The first cervicohorizontal angle, OPT/HOR, showed an average value of 87.08 degrees (SD 7.04 degrees) prior to

Table 5 ANOVA (General Linear Model Repeated Measures) for all cephalometric variables.

	Value range	F	Hypothesis degrees of freedom	Error degrees of freedom	*P*	Significance
OPT/NSL	0.052–0.948	1.021	2	37	0.37	ns
CVT/NSL	0.070–0.930	1.394	2	37	0.261	ns
OPT/CVT	0.047–0.953	0.942	2	37	0.399	ns
NSL/VER	0.246–0.754	6.039	2	37	0.005	**
OPT/HOR	0.151–0.849	3.302	2	37	0.048	*
CVT/HOR	0.181–0.819	4.084	2	37	0.025	*

*$P \leq 0.05$; **$P \leq 0.01$.
ns, not significant.

Table 6 Tests of within-subjects contrasts.

Source	Time	Type III sum of squares	Degrees of freedom	Mean square	F	*P*	Significance
Time	OPT/NSL3 v. data at T_2 and T_3	22.09	1	22.09	1.19	0.283	ns
	OPT/NSL1 v. OPT/NSL2	11.63	1	11.63	0.52	0.477	ns
	CVT/NSL3 v. data at T_2 and T_3	14.46	1	14.46	0.72	0.401	ns
	CVT/NSL1 v. CVT/NSL2	34.91	1	34.91	1.42	0.241	ns
	OPT/CVT3 v. data at T_2 and T_3	0.138	1	0.138	0.5	0.824	ns
	OPT/CVT1 v. OPT/CVT2	5.7	1	5.7	1.89	0.177	ns
	NSL/VER3 v. data at T_2 and T_3	297.14	1	297.14	12.32	0.001	***
	NSL/VER1 v. NSL/VER2	5.1	1	5.1	0.19	0.667	ns
	OPT/HOR3 v. data at T_2 and T_3	163.9	1	163.9	6.71	0.014	*
	OPT/HOR1 v. OPT/HOR2	25.44	1	25.44	0.83	0.368	ns
	CVT/HOR3 v. data at T_2 and T_3	187.22	1	187.22	7.97	0.008	**
	CVT/HOR1 v. CVT/HOR2	58.83	1	58.83	2.27	0.14	ns

*$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$.

expansion at T_1 (Table 4). At T_2 this value decreased to 86.55 degrees (SD 7.64 degrees) and at T_3 the average was 84.95 degrees (SD 6.51 degrees). The average decrease in OPT/HOR between T_1 and T_2 was 0.53 degrees, and between T_2 and T_3 was 1.6 degrees, with an overall decrease of 2.13 degrees over the course of the study (Table 4 and Figure 3). This change was found to be statistically significant (*P* = 0.048, Table 5), with the value at T_3 statistically significantly different from that at T_1 and T_2 (*P* = 0.014, Table 6)

The second cervicohorizontal angle, CVT/HOR, showed an average pre-treatment value of 82.14 degrees (SD 6.96 degrees) prior to expansion, with a value at T_2 of 81.16 degrees (SD 6.82 degrees) and at T_3 of 79.59 degrees (SD 5.71 degrees) (Table 4 and figure 3). The decrease between T_1 and T_2 was 0.98 degrees, and between T_2 and T_3 1.57 degrees. The overall decrease between T_1 and T_3 was 2.55 degrees, which was found to be statistically significant (*P* = 0.025, Table 5). The value at T_3 was found to be statistically significant from that at T_1 and T_2 (*P* = 0.008, Table 6).

Discussion

This study has shown that a number of significant changes in craniocervical and craniovertical angles take place consequent to RME. The trends and directions of these changes are those that would be expected from a widening of the nasal airway, an improvement in nasal airway permeability, and a subsequent change in head posture, in accordance with the hypothesis of Solow and Krieborg (1977).

The craniocervical angles, OPT/NSL and CVT/NSL, both showed a very slight initial increase immediately after RME, which could possibly be attributed to the transient bite opening effect of the RME splint on the occlusion. This slight increase could also be explained by either (a) an elevation of the nasion–sella line (NSL) due to the head elevating upwards, or (b) a decrease in the cervicohorizontal angles (OPT/HOR and CVT/HOR) with the angle NSL/VER remaining constant. Daly *et al.* (1982) showed that by fitting a bite opening appliance, head extension or elevation could occur.

Overall, the angles, OPT/NSL, CVT/NSL, and OPT/CVT, showed no statistically significant changes over the course of the study, although the trend suggests that these angulations may continue to change with time. All six angles examined (apart from OPT/CVT) decreased one year after RME, with the greatest changes taking place between T_2 and T_3, the period between the end of initial expansion and the follow-up one year after expansion. This suggests that it takes some time for the physiological chain of events that governs the relationship between airway patency and morphological change to occur, which is in agreement with Linder-Aronson (1970, 1974, 1975). Three of these angles, NSL/VER, OPT/HOR and CVT/HOR, showed statistically significant changes at the 5 per cent level, which could be ascribed to the effect of RME increasing nasal airway patency, given the overall stability of NHP over time as shown by Peng and Cooke (1999).

In the case of NSL/VER, which describes head elevation to the true vertical, the decrease in this angle would reflect the increased airway patency as a result of RME, which was also observed by Wenzel *et al.* (1985). In the current study, the decrease was an average of 3.14 degrees ($P = 0.005$). This is a statistically significant change and it is possible this will continue with subsequent growth.

The neck extension that has taken place (i.e. in the angles OPT/HOR and CVT/HOR) is of interest. This type of forward neck posture is associated with patients with smaller nasopharyngeal dimensions (Solow *et al.*, 1984), and obstructive sleep apnoea/hypopnoea (OSAH) (Solow *et al.*, 1993). The average value for OPT/HOR in the OSAH cases was found to be 81 degrees compared with a range in control samples of 83.6 to 90.4 degrees, indicating neck extension, while OPT/NSL was approximately 10 degrees higher, indicating head elevation. These increased angulations were considered to be a compensatory mechanism serving to maintain airway adequacy in sleep apnoea patients (Solow *et al.*, 1996). Conversely, Özbek *et al.* (1998), found an increase in OPT/HOR and CVT/HOR in patients with OSAH. Achilleos *et al.* (2000a) in a study of patients who had mandibular advancement for retrognathism, showed that the angles, OPT/HOR and CVT/HOR, both increased (i.e. the neck became more flexed and upright) by approximately 6 degrees. The average pharyngeal airway space had increased in the sagittal dimension, and the authors considered that mandibular advancement osteotomy could increase airway patency and be a treatment approach for sleep apnoea patients. Robertson (2002) in just such a study of mandibular advancement surgery for OSA, found a decrease in the angle NSL/VER from 99.7 to 93.0 degrees, a decrease of 6.7 degrees, consistent with an increased airway patency. In a further study, but this time of patients who had mandibular setback surgery, Achilleos *et al.* (2000b) found that while the angles, OPT/HOR and CVT/HOR, showed no significant changes, OPT/NSL and CVT/NSL had both increased significantly, while the airway space had decreased, indicating cervical hyperflexion at follow-up. No significant changes were found in the cervico horizontal angle, CVT/HOR.

In the present study, it was assumed that the nasal airway has become more patent as a result of RME, but the angulations, OPT/HOR and CVT/HOR, decreased rather than increased. The pharyngeal airway dimensions have not been affected, as would occur in mandibular surgery, and this finding may reflect a change that is associated with nasal airway resistance alone, rather than pharyngeal airway resistance.

The effect of RME on the cervico-horizontal angles appears to be somewhat more immediate than that on the angle NSL/VER, and this finding is significant in view of the fact that the structures that form the neck are more remote from the site of expansion. In the study by Solow *et al.* (1996) on sleep apnoea patients, it was considered that neck extension resulted in the more caudal portion of the nasopharyngeal airway (that area most remote from the point of rotation of the head, the atlanto-occipital axis) becoming wider, thereby allowing a more patent airway in OSAH patients. Hellsing (1989) in a study of 20 adult patients showed that extending the head 20 degrees resulted in an increase in the cross-sectional area of the pharyngeal airway.

If airway patency has improved at the nasal level due to RME, with the nasal dimensions having increased and the nasopharyngeal dimensions remaining the same, this increased airflow may result in a small but significant increase in airway resistance at the nasopharyngeal level, thereby leading to the neck inclining forward to widen the airway at this level. The upper and lower airway resistances then resume a state of 'dynamic equilibrium' between them.

While the present study did not attempt to quantify nasal airway resistance using either rhinomanometric or other methods, the reduction in head elevation in relation to the vertical (NSL/VER) would be expected from the increase in nasal permeability, while the results for the cervico-horizontal angles (OPT/HOR and CVT/HOR) suggest a change in airway resistance at the level of the lower airway.

Conclusions

1. RME was found in this study to have no immediate significant effect on the relationship of the head to the true vertical, the cervical column, or the horizontal, as measured on cephalometric radiographs in NHP.
2. One year after expansion, a statistically significant reduction in the relationship of NSL to true vertical (NSL/VER) from 95.64 to 92.5 degrees, a difference of 3.14 degrees ($P < 0.01$), was found. This finding indicates a reduction in head elevation and is consistent with improved nasal respiration.
3. The relationship of the cervical column to the horizontal (OPT/HOR and CVT/HOR) also changed significantly one year after RME. OPT/HOR reduced from 87.08 to 84.95 degrees, a difference of 2.13 degrees ($P < 0.05$), while CVT/HOR reduced from 82.14 to 79.59 degrees, a reduction of 2.55 degrees ($P < 0.05$). The net result was a more forward inclination of the cervical spine and a slight (non-significant) increase in cervical lordosis.

4. The increased forward inclination of the cervical spine seen in patients one year after RME in the present study suggests that the increase in nasal permeability and consequent increased nasal airflow may result in a small temporary increase in pharyngeal airway resistance. In order to compensate for this, the neck inclines forward to increase the cross-sectional area of the pharynx.
5. The clinical significance of the findings of this study is that RME causes a reduction in nasal airway resistance, which in turn results in a reduction in head elevation which is likely to have an effect on soft tissue stretching. Such a change would be beneficial for a patient who suffers from nasal airway obstruction and who has a higher facial vertical dimension as a result. By changing the mode of breathing early in adolescence, a tendency towards normalization of the craniofacial dimensions can occur with growth. The change in neck inclination may continue to alter and be of clinical significance.

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