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Lateral cephalometric analysis of children with otitis media with effusion: A comparison with age and sex matched controls

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Abstract
Previous reports from this department have established significant differences in the morphology of the nasopharynx between patients with otitis media with effusion (OME) and normal controls. This study has used lateral cephalometric analysis to investigate these differences in greater detail.

Skeletal and soft tissue measurements were recorded in 50 patients with bilateral OME and were compared with 50 age and sex matched normal controls.

Various points were plotted enabling 23 different linear dimensions and three angles in and around the nasopharynx to be compared. The results show significant differences between the two groups in the skeletal and soft tissue dimensions of the nasopharynx. The children with OME have a smaller nasopharynx with a suggestion that this may be due to a difference both in the rate and timing of growth.

Introduction

Despite extensive research, the aetiology of otitis media with effusion (OME) remains uncertain although it is almost certainly multifactorial. Amongst the proposed aetiological factors is a variation in the skull morphology leading to a change in normal nasopharyngeal proportions. Several investigators have studied this particular aspect mainly by an analysis of lateral cephalometric radiographs. This technique ensures standardized positioning of the patient and therefore allows accurate comparisons to be made between different individuals.

The growth of the nasopharynx and its contents were described by Jeans *et al.* (1981) in a longitudinal study using lateral cephalometry. They found that the nasopharyngeal airway diminishes slightly from three to five years; there is then a gradual increase from five to nineteen years with a period from nine to thirteen where the growth is more rapid. The variations were due to a complex interaction of soft tissue growth and atrophy combined with an increase in area of the nasopharyngeal bony skeleton. The increase in soft tissue area reached a peak from three to five years and was largely due to adenoid growth.

Handelman and Osborne (1976) studied the pattern of nasopharyngeal growth from one to 18 years using annual lateral cephalmometric radiographs. They found the slowest period of bony nasopharyngeal growth to be between the ages of 4.5 and 6.5 years. At this time the nasopharyngeal airway was often at a minimum due to a simultaneous increase in adenoid size. They also showed that the increase in nasopharyngeal area was related to the descent of the hard palate from the sphenoid bone. This continued up to the age of 17 years in boys and 12 years in girls. Although this resulted in an increase in nasopharyngeal height, they found little change in sagittal depth which was well established by nine months of age.

Linder-Aronson (1970), using lateral cephalometry, made a comprehensive study of adenoid and nasopharyngeal size and their relation to nasal airflow. He found, as expected, the latter is proportional to the size of the nasopharyngeal airway. The area of the bony nasopharynx however, was only relevant to nasal airflow in children with small or moderate sized adenoids: if the adenoids were large then total obstruction occurred and if they were absent, then obstruction was not a problem. Further, children with otitis media and enlarged adenoids had the same airflow through the nose as children without otitis media but with small or absent adenoids.

Hibbert and Stell (1982), using plain lateral skull X-rays rather than cephalometry, compared the adenoid size in normal children and those with secretory otitis media and found no difference between the two groups. This was confirmed by Phillips *et al.* (1987) but that study also found palatal airway size to be significantly smaller in children with glue ear. The latter finding has subsequently been confirmed by Parker and Maw (1989).

Burwood *et al.* (1973) in a study of children with Down's syndrome showed a significant increase in the basal skull angle compared with normal children of a similar cranial capacity. Brown *et al.* (1989) in a further study of Down's children found that the occurrence of secretory otitis media correlated with a large sphenopalatine angle. The nasopharynx and associated airway was also reduced, although this did not correlate with the incidence of glue ear.

Studies based on radiographic analysis reflect growth in only two dimensions and therefore do not necessarily

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give a complete representation. Todd and Martin (1988) however, in a study of adult cadavers found that an increased length of the Eustachian tube was associated with a greater degree of pneumatization of the mastoid air cell system.

These findings suggest an association between nasopharyngeal morphology and the development of OME. The present study has looked more closely at the association of this condition and altered nasopharyngeal morphology and, in particular, the reason for the decrease in palatal airway as previously described (Phillips *et al.*, 1987; Parker and Maw, 1989). Lateral cephalometric radiographs from children with OME (patients) were studied and then compared with normal age and sex matched children (controls).

Material and methods

Measurements were taken on lateral cephalometric radiographs of 50 children aged between three years 11 months and six years 10 months with bilateral OME. The group comprised 25 males and 25 females with an even age distribution in both groups.

The 50 radiographs used as controls were from a group of children who formed part of a longitudinal study of jaw development at King's College Hospital. These individuals who had no history of ear, nose or throat disease had serial lateral cephalograms taken annually between the ages of three and 19. The radiographs were matched for sex and age. Forty-nine were within one month and one was within three months.

Films were taken using a standard technique in both groups. The beam was centred on the external auditory meatus with the head in a true lateral position and the child breathing through the nose with a closed mouth. The average radiographic factors were 70 KV and 40 mA. The tube to film distance was five feet and the calculated magnification of the mid-line structures varies between1.067 and 1.092.

The 22 plotted points included both bony and soft tissue landmarks (Table I). Some of these are used in standard cephalometry whilst others were derived by creating horizontal and vertical grid lines. The horizontal grid line was drawn 7° below the sella nasion line with the vertical grid line at 90° based on the sella turcica. In all films used, the points were plotted using a GTCO Digitizer linked to an IBM/AT computer which also calculated the required lengths in millimetres and angles from the plotted points.

Some points were used to measure distances in and around the nasopharynx and others defined the angles between anatomical planes. The lengths and angles were therefore derived from points rather than being measured directly, the former method being less prone to error. This procedure was used for both patients and controls all the digitizing was done by the same investigator (I.M.S.). Twenty-three different lines and three angles were derived as defined in Table II and illustrated in Figures 1, 2 and 3.

Certain measurements relate only to bony parts, others involve soft tissues of the nasopharyngeal palate.

TABLE I

a	The most superior point of the nasopharynx on Line SP.
b	The most anterior point of the adenoid tissue in the nasopharynx.
d	The point on the antero-inferior surface of the adenoids nearest to the tip of the soft palate.
f	The point on the posterior wall of the oropharynx nearest to the tip of the soft palate.
g	The most inferior point of the soft palate.
h	The point on the superior surface of the soft palate nearest to point d.
i	The point on the inferior surface of the soft palate nearest to the dorsum of the tongue.
j	The point on the dorsum of the tongue nearest to the inferior surface of the soft palate.
k	The point on the horizontal axis line nearest to pm.
l	The point on plane SP created by a perpendicular from that plane passing through point s.
m	Basion—the lowest point on the anterior margin of the foramen magnum.
n	Nasion—the most anterior point of the frontonasal suture.
o	The point on the maxillary fissure nearest to point b.
r	The point on the incisal edge of the maxillary central incisor.
s	The centre of the sella turcica
t	The point at the tip of the mesial cusp of the upper first permanent molar or second deciduous molar if the former is absent
u	The most anterior part of the external ear canal marker.
w	The point on the line PP created by its transection with a perpendicular line from point u.
x	The point on line PV which is the shortest distance from u.
y	Point on the vertical grid line nearest to pm.
pm	Posterior nasal spine—The intersection between the nasal floor and the posterior contour of the maxilla.
am	Anterior nasal spine—The tip of the anterior nasal spine.
FIXED LINES AND PLANES (see Fig. 2)	
H	Horizontal grid line passing anteriorly from point s 7° below the line between sella and nasion.
V	Vertical grid line—passing perpendicular to line H from point s inferiorly.
SP	Sphenoid plane—A line passing between points m and a.
PV	A line perpendicular to the palatal line passing superiorly based on point pm.
OP	Line passing through points r and t.
PP	Line passing through points pm and am.

Statistical Methods

The study made a comparison of the skull dimensions between patients and controls and the questions addressed were as follows:

i. Do the selected lengths depend significantly on age for both controls and patients?
ii. do the lengths differ between controls and patients?
iii. Is the effect of age the same for both patients and controls?

The first question was answered by correlating all lengths with age for the controls and patients taken as separate groups. For the populations studied, which contained 50 individuals each, any $r > 0.2732$ is significant. In the case of the controls, there were ten lengths and one angle which correlated significantly with age. In decreasing order of importance these are: Line 15 ($r = 0.554$), Line 23 ($r = 0.485$) Angle 2 ($r = 0.438$), Line 9 ($r = 0.389$), Line 3 ($r = 0.373$), Line 18 ($r = 0.372$), Line 19 ($r = 0.364$), Line 14 ($r = 0.355$), Line 5 ($r = 0.338$), and Line 17 ($r = 0.290$). For the patients no lengths or angles had significant correlations with age.

The second question was studied by analysing the differences of the measurements for the matched pairs of controls and patients, and the results are shown in

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TABLE II

THOSE LINES FOUND TO BE IMPORTANT AND WHICH APPEAR IN TABLE III ARE IN ITALICS

Soft Palate		
Line No:		
1	g-pm	*Distance from tip of soft palate to postnasal spine.*
2	g-f	Shortest distance from g to posterior pharyngeal wall.
3	g-s	*Distance from sella to soft palate tip.*
4	i-j	Shortest distance between the inferior surface of the soft palate and the dorsum of the tongue.
5	g-am	Distance between points g and am.
Airway Space		
6	o-b	*Nasopharyngeal airway*—Smallest distance from posterior contour of maxilla to the anterior surface of the adenoids.
7	h-d	*Palatal airway*—the minimum distance between the postero-superior aspect of the soft palate and the antero-inferior surface of the adenoids.
Skeletal Assessment		
8	a-pm	*Nasopharyngeal height*—the distance between points a and pm.
9	pm-k	*Maxillary height*—minimum distance from pm to the horizontal grid.
10	pm-y	Antero-posterior position of maxilla—minimum distance from pm to vertical grid.
11	am-pm	Depth of maxilla-distance between anterior and pm.
12	s-1	*Depth of the basisphenoid bone*—distance from s to inferior surface of basisphenoid at point 1 on the line SP taken as a perpendicular to that plane.
13	pm-t	Distance between postnasal spine and t.
14	am-t	*Distance between points am and t.*
15	r-t	Distance between r and t.
16	am-r	Distance between am and r.
17	s-n	Distance between sella and nasion
18	n-m	Distance between basion and nasion
19	m-s	*Distance between basion, sella and height of clivus*
20	u-w	Distance between points u and w
21	u-x	Distance between u and x
22	u-pm	Distance between u and postnasal spine
23	s-pm	*Distance between sella and postnasal spine*
Angles (see Fig. 3)		
Angle 1		*Angle between anterior skull base and basisphenoid Nasion-sella-basion.*
Angle 2		Angle between occlusal and palatal lines (OP and PP).
Angle 3		Angle between hard and soft palate ANS-PNS-tip of soft palate.

Table III. In this table, the most important (ten lengths and one angle) are listed in decreasing order of significance. Included in the table is *t*-value, the corresponding *P*-value, the mean differences, the standard deviation and the standard error of the differences and the confidence interval for the mean.

The third question above is addressed by using a generalized linear model to compare the slopes of the regression lines, for the six lengths which give F values which are significant at the 95% level from this analysis. These are listed in decreasing order of importance in Table IV, which also shows the coefficients of the regression lines for both controls and patients. The regression lines may be plotted and it can be seen that with the single exception of Line 19, the lines for controls and patients intersect within the age range of interest, namely four years to seven years, in such a way that at the lower age limit, controls are shorter than patients but at the upper age limit the lengths for patients are shorter than the controls. In the case of Line 19, the two regression lines are nearly parallel and patients are less than controls over the whole range by a significant amount.

The standard deviation, for the controls and the patients, of the lines in Table IV are also shown. It can be seen that the variability of the controls and the patient data are almost the same: in fact, for lines 3 and 23 the $SDp < SDc$ whereas for the others the situation is reversed. Hence the explanation of the fact that $Sp < Sc$ for all these lines is not due to greater variability of patient data.

It is unlikely that the observer who digitized *all* the data could have consciously biased the lengths because he digitized *points*—from which the lengths were derived. At the time the digitization was done, no indication was available as to which lines would prove to be significantly different between controls and patients. We believe that we have highlighted genuine differences.

The statistical results can be interpreted as follows:

Soft tissue measurements

Palatal Airway. Line 7 (h–d)

The airway is larger in the controls. With increasing age, the airway increases in the controls but decreases slightly in cases with OME.

Nasopharyngeal Airway. Line 6 (o–b)

Once again the distance is greater for the controls.

CEPHALOMETRIC LANDMARKS

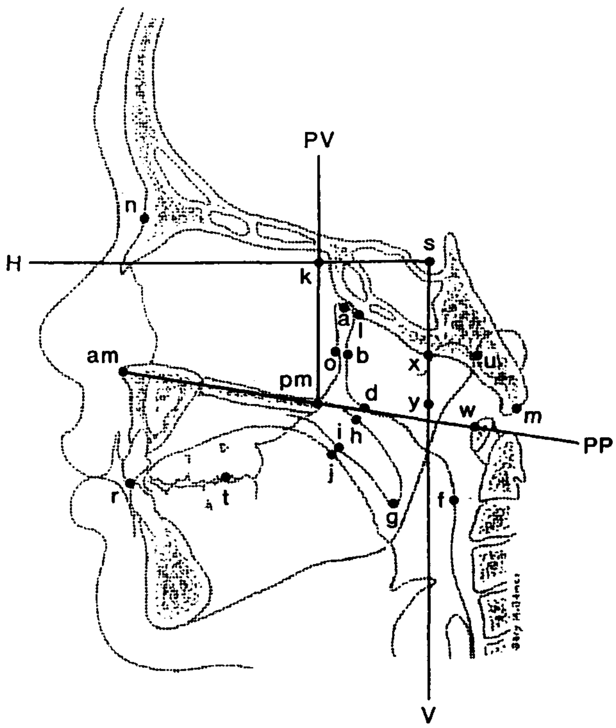

FIG. 1

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FIXED LINES & PLANES

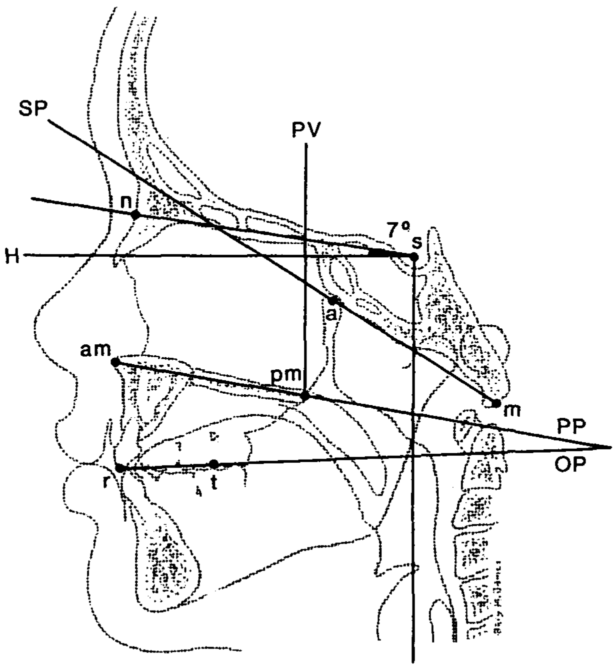

FIG. 2

However, with age, there is a paradoxical decrease in the controls and a slight increase in the patients but throughout the age range controls are larger than the patients.

Distance from Sella to tip of the Soft Palate. Line 3 (g–s)

The mean distance in the controls is greater than that in the patients. The distance increases with age for controls whereas it decreases in those with OME.

MEASURED ANGLES

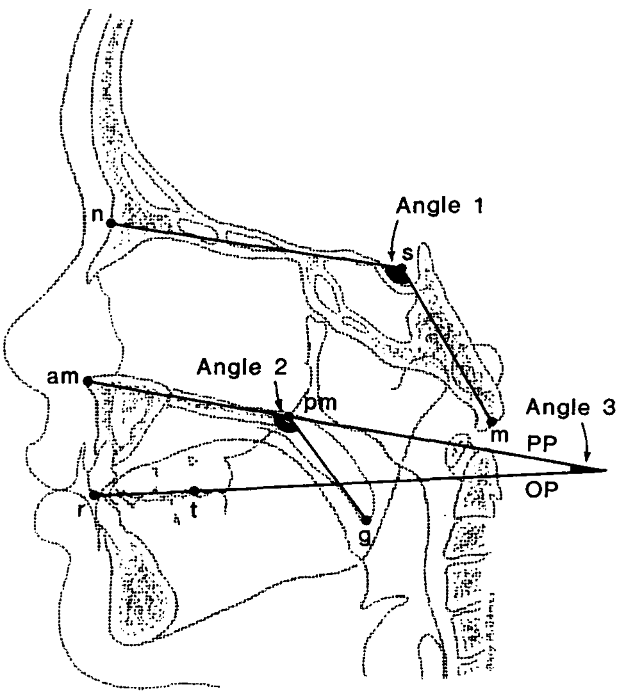

FIG. 3

Soft Palate length. Line 1 (pm–g)

The length of the soft palate is significantly greater in the controls compared to the patients. Again with age, the length increases in the controls but decreases in those with OME and this is similar to the palatal airway (Line 7).

Bony measurements

Height of Clivus. Line 19 (m–s)

This is smaller in the patient group than in controls but the size increases at nearly the same rate, in both groups with increasing age.

Depth of the Sphenoid. Line 12 (s–l)

The mean length is again less in the patient group. With age, the measurement increases slightly in controls but decreases slightly in the patients.

Nasopharyngeal Height. Line 8 (a–pm)

The controls increase significantly with age and the patients do so less rapidly. At the lower age limit controls are less than patients but at the upper limit the position is reversed.

Angle between the anterior Skull Base and Basisphenoid. Angle 1

The angle was greater in patients than the controls. With age, there was a decrease in size in controls and an increase in size for patients.

Distance from Horizontal Plane to Postnasal Spine Line 9 (pm–k)

The distance is greater in controls and with age there is a significant increase in the controls and a slight decrease in the patients.

Sella to Postnasal Spine. Line 23 (s–pm)

This is greater in controls in which there is an increase with age. Whereas no increase occurs with age in the patients. The changes are similar to those seen in Lines 8 and 12.

Distance between anterior Nasal Spine and Upper First Permanent Molar or Second Deciduous Molar (Line 14 (am–t)

In the controls there is a significant correlation with age and the controls are all *less* than the patients, the rate of increase for patients is less than for controls. This line is the only one which behaves in this way.

Figure 4 illustrates the main soft tissue and bony measurements which show differences between controls and patients with OME, excluding Line 23 which is the sum of lines 12 and 8.

Discussion

The normal growth of the maxilla has been exten-

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TABLE III

DIFFERENCE BETWEEN CONTROLS AND PATIENTS WITH OME. T-TEST APPLIED TO LENGTH DIFFERENCES OF MATCHED PAIRS. THE DIFFERENCE IS POSITIVE IF CONTROL EXCEEDS PATIENT.

	t	P	mean of differences	st dev	st err	Confidence Interval
Soft Tissue Measurements						
Line 7	5.45	0.0	2.34	3.03	0.43	1.47 to 3.20
Line 6	4.54	0.0	1.13	1.76	0.25	0.63 to 1.63
Line 3	4.08	0.0	3.48	6.04	0.85	1.77 to 5.20
Line 1	2.34	0.023	2.03	6.06	0.87	0.29 to 3.77
Bony Measurements						
Line 19	3.75	0.001	1.84	3.46	0.49	0.85 to 2.82
Line 12	3.00	0.004	1.10	2.58	0.37	0.36 to 1.83
Line 8	2.70	0.010	1.13	2.95	0.42	0.29 to 1.97
Angle 1	−2.41	0.020	−3.26	9.56	1.35	−5.97 to −0.55
Line 9	2.33	0.024	1.07	3.24	0.46	0.15 to 1.99
Line 23	2.10	0.041	0.96	3.23	0.46	0.04 to 1.88
Line 14	−2.04	0.047	−1.52	5.27	0.75	−3.02 to −0.02

sively studied and general trends of growth are now well recognized. The overall pattern of sagittal growth in the facial skeleton can be regarded as downwards and forwards by a process of continuous bony re-modelling.

Each bone shows fields of resorption and deposition which vary between individuals in amount, rate and timing. In this way the differences appear not only in overall bony morphology but also in the rate of change by which these differences occur. To a large extent these variations are genetic although they are thought to be affected by functional changes in the soft tissue relationships (Enlow, 1975).

The results of this study show that patients with OME have significant reduction in certain skeletal and soft tissue dimensions in the nasopharynx and further may show a reduced or delayed rate of localized skull growth. The differences between the controls and patients will be discussed with references to established data of normal human skeletal growth.

Soft tissues

These measurements involve soft tissues within the nasopharynx, either in relation to the soft palate or the adenoid tissue but only the palatal airway (Line 7) relates to a measurement between two adjacent soft tissues. The remainder relate to a soft tissue measurement taken from a bony point. However, the palatal airway itself may reflect not only the bony confines in which the adenoid tissue is located but also the bony attachment and disposition of the musculature of the soft palate. The difference in size of the palatal airway confirms the original findings of Phillips *et al.* (1987) and confirms the significantly smaller airway found in patients with OME. From the present study it appears to be mainly due to the reduced vertical height of the nasopharynx (Line 8), but may in part be due to the change in length of the soft palate (Line 1). The result is a soft palate which is positioned relatively higher in the nasopharynx and therefore nearer the adenoid bed, thus reducing the palatal airway.

The nasopharyngeal airway (Line 6) was greater in controls than in those with OME. This supports the findings of the study by Hibbert (1979) who studied children in the wider age range of two years 11 months to 10 years 10 months, and is supported by cranial base measurements made by Todd *et al.* (1989). Jeans *et al.* (1981) have shown that the outline of the normal adenoid tissue is variable with age. Paradoxically in the present study there was a decrease in the nasopharyngeal airway in controls with increasing age, compared with a slight increase found as patients with OME grew older. A finding only seen in one other measurement, namely the angle between the anterior skull base and basisphenoid (Angle 1).

The normal increase in size from the sella to the tip of

TABLE IV

COMPARISON OF THE SLOPES OF THE REGRESSION LINES FOR CONTROLS WITH PATIENTS.

	F	P	Cc*	Sc†	SDcø	Cp	Sp	SDp
Soft tissue measurements								
Line 3	4.85	0.010	44.8	2.029	4.78	56.2	−0.661	3.92
Bony Measurements								
Line 23	8.76	0.000	32.8	1.679	3.04	41.1	0.009	2.20
Line 19	4.53	0.013	33.6	1.022	2.47	33.1	0.794	2.94
Line 9	3.72	0.028	30.5	1.025	2.32	35.2	−0.031	2.44
Line 8	3.51	0.034	16.3	1.187	2.73	21.1	0.116	2.95
Line 14	3.27	0.042	25.5	1.436	3.56	33.4	0.289	3.65

*Cc is the constant in regression line of controls.
†Sc is the slope of regression line of controls.
øSDc is the standard deviation of the controls.
Cp, Sp and SDp corresponding quantities for patients.
There were no significant differences of the slopes for Controls and Patients in Lines 7, 6, 1 and 12 and Angle 1.

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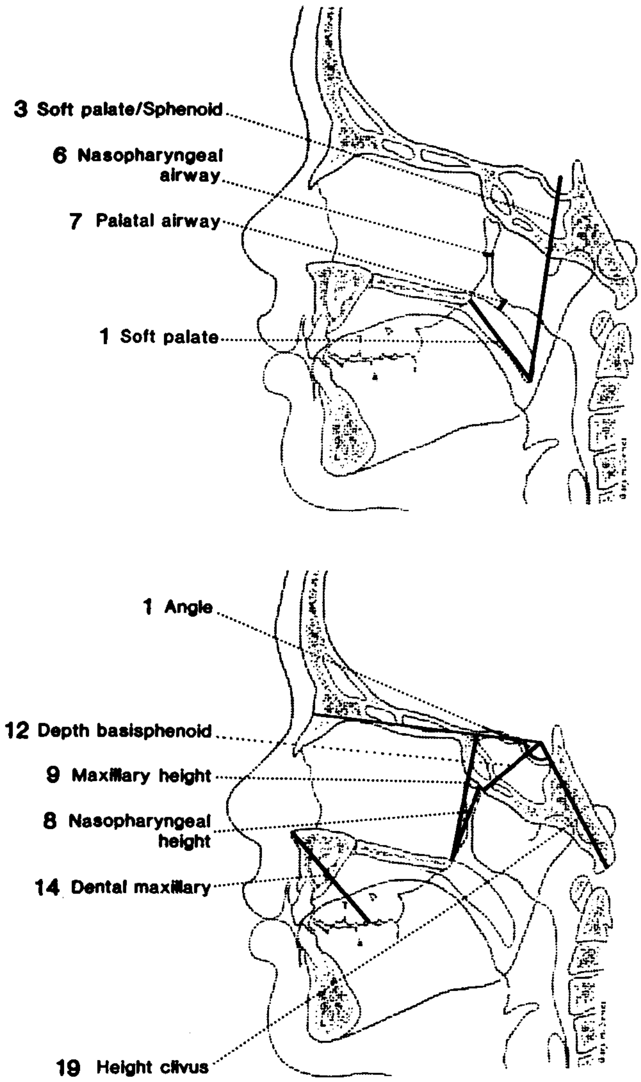

FIG. 4

the soft palate (Line 3) is due to an increase in height of the sphenoid and nasopharynx and also in length of the soft palate itself. Knott (1971) has shown that the major part of the sphenoid growth anteriorly is completed by the age of six years. This suggests that the increase is mainly a function of maxillary and soft palate growth since there is little change in height of the sphenoid in either controls or patients as shown in Line 12.

The growth and therefore the length of the soft palate (Line 1) in a normal individual is partly determined by the size of the nasopharyngeal outlet. It is reduced in those with OME and with age there is a decrease in length in cases with OME compared with an increase found in controls. Perhaps this indicates either a different rate of growth or a muscular re-alignment of the palate in OME cases, possibly in relation to altered nasoharyngeal pressure changes.

Bony Changes

The remaining measurements showing significant differences between the two groups were of purely skeletal dimensions or in relation to position of the lower jaw.

Unlike the anterior segment, the posterior part of the sphenoid bone (Line 19) normally increases in length between the ages of 6 and 12 years (Knott, 1971), by an average of 1 mm per year. Both OME patients and controls achieve this rate of growth although overall the patients are significantly smaller in this dimension. Knott's work (1971) confirmed the growth of the anterior part of the sphenoid (Line 12) was largely complete by the age of six years. In our study, the anterior sphenoid is smaller in the patients than in the controls and with increasing age there is little growth in either group.

The height of the nasopharynx (Line 8) and the maxillary height (Line 9) are both reduced in patients with OME and there is little or no growth with age, whereas a significant rate of growth occurs in controls. These changes are similar to those of the sella to postnasal spine measureents (Line 23). They may reflect reduced maxillary and to a lesser extent sphenoid sinus growth which also may in part account for the change found in Angle 1.

These results suggest that patients with OME have a smaller nasopharynx, with in some areas, a delay in the normal rate of growth compared with controls. The changes may be due to some alteration in general growth pattern of the skull base, but they may relate to reduced pneumatization of the maxilla. They may also be due to reduced growth and pneumatization of the sphenoid. The parallelism between Eustachian tube obstruction and pneumatization of the mastoid air cell system with ostial obstruction of the maxillary and sphenoid sinuses and pneumatization of those bones calls for further investigation. Finally, some of the changes may be related to dental development.

The effect of these changes is to reduce the overall area of the nasopharyngeal airway. Linder-Aronson (1970) has shown that the nasal airflow in patients with otitis media is not significantly different compared to controls with small or no adenoids.

In considering nasal airflow:

$$V \times A = \text{a constant (Swift, 1982)}$$

(where V = average velocity in m/sec A = cross sectional area)

Consequently if the nasopharyngeal area is decreased then the velocity of the air must increase if nasal airflow is to remain constant. Further, according to Bernouilli's equation:

$$P + dV/2 = \text{a constant}$$

(where P = pressure d = density of the gas and V = velocity)

With an increase in velocity, there will also be a reduction in nasopharyngeal pressure.

The equalization of pressure between the nasopharynx and middle ear is thought to occur only when the Eustachian tube is opened by contraction of the soft palate musculature. Middle ear pressure under normal circumstances is thus considered to be equal of that of the nasopharynx. A negative middle ear pressure is generally believed to occur as a result of Eustachian tube malfunction which prevents this normal ingress of air. This traditionally held view is being challenged by recent findings of a positive pressure within the middle ear under normal circumstances. The positive pressure can occur with sleep and appears to be related to an increase in carbon dioxide possibly generated by the middle ear mucosa (Buckingham, 1989; Herglis and Magnusson,

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1989). These studies also suggest that tympanic membrane retraction may be associated with an abnormally patent, rather than obstructed Eustachian tube (Magnusson, 1989; Falk and Magnusson, 1989). A negative nasopharyngeal pressure could thus lead to a similar state in the middle ear without the need for soft palate contraction. This would also confirm the work of Holborrow (1970) who showed that because of anatomical factors, Eustachian tube closure up to the age of seven years is less efficient when compared to the adult.

Conclusion

The natural history of otitis media with effusion is one of spontaneous resolution in the majority of cases by the age of ten years. The present study has shown that the nasopharynx is smaller in these children up to the age of seven years. As a result a negative pressure may be generated within the nasopharynx which, in the presence of an abnormally patent Eustachian tube, could be transmitted to the middle ear.

Further studies are required to measure airway pressures and also to compare nasopharyngeal size at an older age, to determine if this deficit is ultimately corrected. Should that be the case, it would confirm that rather than having a smaller nasopharynx, children with OME experience a delayed rate of growth within the nasopharyngeal tissues.

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