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Electropalatographic and cephalometric assessment of tongue function in open bite and non-open bite subjects

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SUMMARY Anterior open bite (AOB) and tongue thrust swallowing are frequently associated, but the relationship between the two remains unclear. Electropalatography (EPG), which is used in speech pathology to measure dynamic tongue function for diagnostic, therapeutic, and research purposes, is a suitable technique for the investigation of this relationship.

The present clinical study examined the dentofacial pattern and tongue function in AOB and non-open bite children. EPG recordings of speech and swallowing, and lateral head radiographs were obtained from eight 10-year-old boys with tongue thrust swallowing behaviour and AOB, and from eight age-matched non-open bite controls.

Analysis of data from the two groups indicated that although differences were small, the open bite children displayed trends for longer face morphology and greater upper incisor proclination, less consistent production of closures during speech, a more posterior pattern of EPG contact, and relatively sparse EPG contact during swallowing.

The discovery of differing patterns of contact for the /ʤ/ and /ʧ/ phonemes indicates that these should be included when speech is used to test for the presence of fronted tongue behaviour.

Introduction

The use of many different definitions of anterior open bite (AOB) has resulted in wide variation in reported prevalence. However, a review of the literature indicates that, although there are racial differences, the condition probably affects less than 5 per cent of children (Kelly *et al.*, 1973; O'Brien, 1994). The aetiology remains uncertain (Pae *et al.*, 1997), but is thought to be multifactorial (Subtelny and Sakuda, 1964; Ngan and Fields, 1997). Differences in the composition of masticatory musculature (Sciote *et al.*, 1994), resting tongue posture (Proffit, 1975; Lowe and Johnston, 1979), tongue size (Turvey *et al.*, 1976), and functional activities such as digit sucking (Subtelny and Sakuda, 1964; Fields, 1993) are thought to be important aetiological factors. Myofunctional therapy, orthodontics and surgery have all been used to correct AOB, but although treatment is notoriously difficult, spontaneous closure is common (Gellin, 1966; Worms *et al.*, 1971), perhaps resulting from the development of normal swallowing activity, the transition to the permanent dentition, and the elimination of non-nutritive sucking activity. However, if anterior tongue posture persists after correction of the open bite, relapse is likely (Turvey *et al.*, 1976).

A wide variation in prevalence of tongue thrust swallowing has been reported, partly because of the profusion of definitions of abnormal tongue thrust behaviour (Andrianopoulos and Hanson, 1987). Tongue thrust swallowing is a normal feature of suckling, and also occurs during the transition between the deciduous and permanent dentitions, but usually ceases when normal incisor overbite is established. Lisping is often associated with tongue thrust swallowing, but many tongue thrust patients do not show altered sibilant production (Subtelny, 1965). As with AOB, the ætiology is uncertain, although genetic, functional, and pathological factors, and anterior open bite have been cited. Tongue thrust has been treated by orthodontic and surgical AOB closure, which may result in spontaneous correction of tongue thrust swallowing (Cleall, 1965; Tulley, 1969; Subtelny, 1970; Proffit and Mason, 1975; Turvey *et al*., 1976; Moyers, 1988; Proffit and White, 1991; Proffit and Ackerman, 1994), and with myofunctional therapy (Subtelny, 1965; Proffit and Mason, 1975; Andrianopoulos and Hanson, 1987), which aims to reposition the tongue tip posteriorly during speech and swallowing. However, the effects of myofunctional therapy have not been subjected to systematic analysis.

AOB and fronted tongue function are frequently associated, but despite many investigations, the relationship between the two is not completely understood. Although there is evidence that anterior tongue posture may prevent the eruption of the anterior teeth (Lowe and Johnston, 1979), other evidence suggests that tongue thrust swallowing is an adaptation to open bite which facilitates an anterior oral seal, rather than being its cause (Tulley, 1969; Subtelny and Subtelny, 1973; Wallen, 1974; Proffit and White, 1991).

Comparison of tongue function in children with and without AOB and tongue thrust swallowing might increase our understanding of the relationship between the two conditions. The intra-oral measurement of tongue position during function is difficult, but a reproducible method of measurement of tongue activity is necessary for such assessment. Currently available measurement techniques are either limited to being able to record static rather than dynamic information, such as the early 'wipe-off' palatograms, or interfere with function, as with electropalatography (EPG). In this technique an acrylic palatal base plate fitted with a number of electrodes (Figure 1) is used to record the location and timing of tongue contacts with the hard palate (or, more accurately, with the acrylic base plate) during continuous function (Hardcastle *et al*., 1991a,b). Each electrode is electrically connected to a personal computer containing an EPG3 interface card, which allows details of linguo-palatal contact for all electrodes to be stored to disk in real time.

Electropalatography provides a convenient method of measuring dynamic tongue function. It is increasingly used in the diagnosis and treatment of speech disorders, and also as an investigative tool, although it has not been used widely in orthodontic research.

Figure 1 EPG plate. (Reproduced, with kind permission, from 'Electropalatographic and cephalometric assessment of myofunctional therapy in open-bite subjects', Cayley *et al.*, Australian Orthodontic Journal 2000, 16: 23–33.)

This study used electropalatographic and cephalometric evaluation to investigate differences in tongue function in open bite and non-open bite subjects, and to produce a core of experimental data for future research using this technique.

Subjects and Methods

The experimental group consisted of eight boys with a mean age of 9.93 ± 1.02 years (range 9.08–11.75 years), who had either an AOB, or an incomplete overbite of 3 mm or more, and exhibited a tongue thrust swallowing pattern with interposition of the tongue between the teeth. The control group consisted of eight boys with a mean age of 10.23 ± 0.53 years (range 9.35–10.84 years), who had no AOB or tongue thrust swallowing pattern.

The 62-electrode Reading EPG system, which is described in detail elsewhere (Hardcastle *et al*., 1989), was used in this investigation. EPG and 'dummy' plates were constructed for each child, and the children were requested to wear the trainer plate full time for 3 days prior to the EPG recording session to allow for speech accommodation.

Lateral head radiographs were available for all experimental children, and for six of the eight control children. The films were traced and measured with the aid of 400-mm $\times 2$ magnification loupes. The cephalometric landmarks and the angular and linear measurements are listed in Table 1. These variables were selected to facilitate comparison of the vertical and horizontal facial patterns and incisor relationships of the subjects. A diagrammatic representation of the landmarks, and angular and linear measurements can be found in Figure 2.

A phonetically balanced list of test words, which included a wide range of consonant articulations in initial, medial, and final positions within words, and in association with different vowels, was used to assess dynamic tongue activity during speech. These are set out in Table 2. Each child was asked to read the test words in groups of four into a microphone which was connected to a multiplexer, allowing EPG and audio data to be recorded simultaneously; a group was saved only if the words were read fluently and without mistakes. Recordings of the tongue activity during water and saliva swallowing were also made.

Differences between mean values of the cephalometric variables for the control group and the experimental group were compared using

Table 1 Cephalometric landmarks and measurements used in the study.

Landmark	Definitions	
S	Sella	The centre of the hypophyseal fossa (sella turcica)
N	Nasion	The fronto-nasal suture at its most superior point on the curve at the bridge of the nose
ANS	Anterior nasal spine	The most anterior point on the maxilla at the level of the palate
PNS	Posterior nasal spine	The most posterior point on the bony hard palate in the sagittal plane
A	Subspinale (Point A)	The most posterior point of the curve between ANS and supradentale
B	Supramentale (Point B)	The most posterior point of the bony curvature of the mandible below infradentale and above pogonion
Gn	Gnathion	The most anterior inferior point on the lateral shadow of the chin
Me	Menton	The lowest point on the symphyseal outline of the chin
Go	Gonion	The most posterior inferior point at the angle of the mandible
Is	Incision superius	The incisal tip of the most anterior maxillary central incisor
Ii	Incision inferius	The incisal tip of the most anterior mandibular central incisor
UIA		Upper incisor apex
LIA		Lower incisor apex
Ss	Stomion superius	The most inferior point on the upper lip
Si	Stomion inferius	The most superior point on the lower lip

Moyers (1988), and Enlow and Hans (1996).

Angular and linear measurements		
SN–MP	°	Cranial base to mandibular plane angle (Go-Gn)
SN–PP	°	Cranial base to palatal plane angle (ANS-PNS)
SNA	°	Antero-posterior position of maxilla to cranial base
SNB	°	Antero-posterior position of mandible to cranial base
ANB	°	Antero-posterior relationship between maxilla and mandible
N–PP	mm	Upper face height perpendicular to palatal plane
PP–Me	mm	Lower face height perpendicular to palatal plane
AFH	mm	Anterior face height (N-Me) perpendicular to palatal plane
Is–PP	mm	Distance from maxillary incisal edge to palatal plane perpendicular to palatal plane
Ii–MP	mm	Distance from mandibular incisal edge to mandibular plane along lower incisor axis
AOB	mm	Distance from mandibular incisal edge to upper incisor along lower incisor axis
U1–SN	°	Angle of maxillary incisor to cranial base
U1–PP	°	Angle of maxillary incisor to palatal plane
IMPA	°	Angle of mandibular incisor to mandibular plane
IIA	°	Inter-incisal angle
ILG	mm	Inter-labial gap perpendicular to palatal plane
NLA	°	Naso-labial angle

Owen (1984), Lopez-Gavito *et al*. (1985) and Proffit (1991).

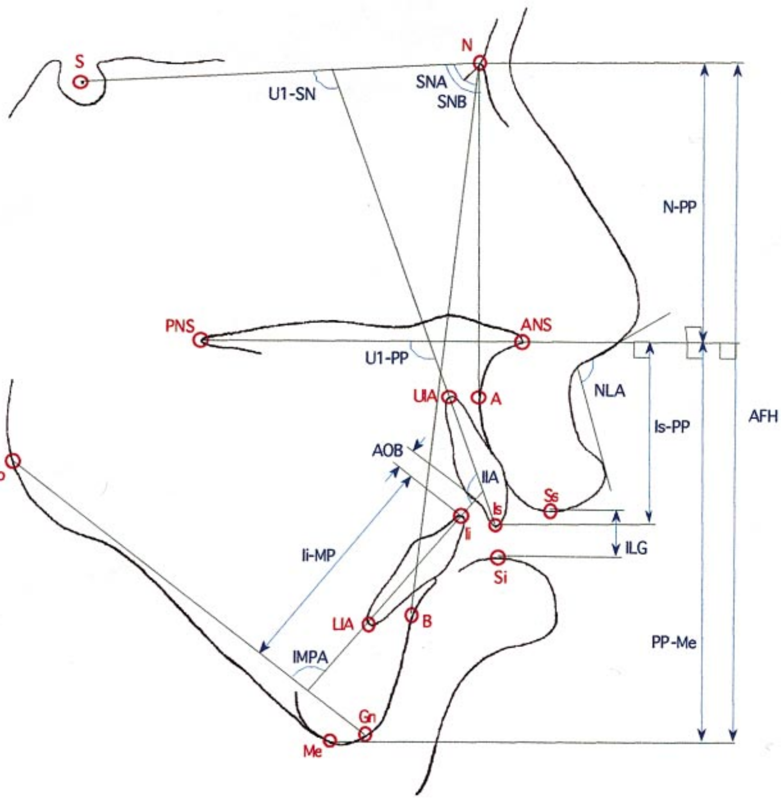

Figure 2 Cephalometric landmarks with linear and angular measurements. (Reproduced, with kind permission, from 'Electropalatographic and cephalometric assessment of myofunctional therapy in open-bite subjects', Cayley *et al.*, Australian Orthodontic Journal 2000, 16: 23–33.)

Table 2 Closures and words used in electropalatographic analysis.

Closures*				Whole words	
Alveolar		Palato-alveolar	Velar		
/t/ack	/d/redger	/tʃ/ain	/k/astle		
/t/eam	la/d/er	deck/tʃ/air	/k/lock	biscuit	razor
cock/t/ail	swor/d/	stre/tʃ/er	/k/itkat	box	saddle
s/t/retcher	threa/d/	wi/tʃ/craft	bo/k/s	castle	seesaw
sui/t/case	/l/eg	ca/tʃ/	co/k/tail	catch	shack
tro/t/er	c/l/ock	/dʒ/oke	de/k/chair	chain	shore
kitka/t/	s/l/ipper	dre/dʒ/er	suit/k/ase	clock	skate
squashki/t/	cocktai/l/		witch/k/raft	desk	slipper
star/t/	/n/ose		des/k/	door	star
/d/esk	chai/n/		mathsboo/k/	dredger	sword
/d/oor	bok/s/		ta/k/	feather	tack
			le/g/	flash	team
			tho/η/	joke	thong
				ladder	thread
				leg	tooth
				measure	tune
				nose	zip

*Closures selected for more detailed analysis are underlined.

Student's t-tests, with statistical significance predetermined at $P < 0.05$.

A radiographic error study showed that all linear measurements were reproducible to within 1 mm, and that, except for the naso-labial angle, for which the mean difference was 4.69 degrees, all other angular measurements were reproducible to within 2 degrees.

Using computer software which was written for the purpose, details of the frequency of occurrence, duration, and average notional row number (ANR) of all closures, and ANR of whole words and swallows were extracted from the raw EPG data. The average notional row number is a nominal average representing tongue position, which is derived from the number of contacts per row over time, weighted towards the front of the palate.

Each word from each EPG recording session was examined for closures. A closure was defined as an EPG event in which continuous contact occurred from one side of the palate to the other, thus preventing the passage of air centrally. Examples of speech sounds involving closure are /ʤ/, the voiced, and /ʧ/ the voiceless initial palato-alveolar affricates in 'joke' and 'chain', respectively, and the velar stop /k/, as in 'suitcase'. The 42 closures identified are listed in Table 2.

A smaller set of closures was selected for more detailed analysis. These closures, which are underlined in Table 2, contained a variety of closure types, and included the most consistently produced examples of each type from both groups. From the raw EPG data, the duration of each closure, in milliseconds, was recorded. The front and rear rows involved in each 10-millisecond sample were noted, and used to calculate the ANR for each closure.

The 'whole word' mean ANR value for the 32 words listed in Table 2 was calculated. The EPG data for the saliva and water swallows were examined. The duration of the propulsive phase of each swallow, in milliseconds, was estimated. The propulsive phase was defined as the period from the beginning of the posterior extrusion of the bolus until maximum linguo-palatal contact was achieved. The ANR value for the propulsive phase of each swallow was calculated.

The EPG data, consisting of three repetitions of each closure, word, or swallow from the control group and the experimental group were compared to check for differences in tongue activity between the groups. Each closure, word, or swallow was recorded three times for each of the subjects resulting in 24 recordings at each recording session for each group. The data were analysed with a repeated measures ANOVA, with 'within child' factors of session and replication within session [Programme '5V' (unbalanced repeated measures, BMDP Statistical Software package, Release 7, University of California]. A compound symmetric error structure was assumed. As the number of values obtained for each EPG parameter was so large, statistical significance was predetermined at $P < 0.01$.

Results

Cephalometric data

The cephalometric values for the control group and experimental group are summarized in Table 3. The groups were similar for all cephalometric variables measured except for AOB, for which the difference between mean values reached statistical significance ($P < 0.05$). However, differences for SN–MP, PP–Me and AFH approached significance, perhaps indicating a trend towards longer face morphology in the experimental subjects. Similarly, increased values for U1–SN and U1–PP, and a lower value for the inter-incisal angle suggested a trend towards upper incisor proclination in the experimental children. Wide variation in the values of the soft tissue measurements was found for both groups.

Electropalatographic data

Table 4 shows the closures for which mean differences in frequency of occurrence for children in the two groups reached statistical significance ($P < 0.01$). Some recordings were unusable for analysis, for example, if the recording was longer than the maximum sampling time predetermined by the EPG3 software. The closure frequency excludes these recordings and represents the number of closures

Table 3 Mean cephalometric values for control and AOB groups (standard deviations in parentheses).

Variable	Control	AOB	Mean difference	t	Significance
SN–MP (°)	30.4 (4.3)	35.8 (3.7)	5.4	2.14	NS
SN–PP (°)	6.9 (1.9)	5.4 (3.1)	1.5	1.02	NS
SNA (°)	80.4 (1.4)	81.9 (4.3)	1.5	0.81	NS
SNB (°)	77.2 (1.7)	76.9 (3.4)	0.3	0.20	NS
ANB (°)	3.3 (2.1)	5.0 (2.3)	1.8	1.40	NS
N–PP (mm)	49.0 (2.3)	49.9 (1.6)	0.9	0.84	NS
PP-Me (mm)	59.8 (3.8)	64.2 (4.0)	4.4	1.86	NS
AFH (mm)	108.8 (5.8)	114.1 (4.0)	5.3	1.82	NS
Is–PP (mm)	26.8 (1.9)	28.1 (3.5)	1.3	0.82	NS
Ii–MP (mm)	35.6 (2.9)	37.1 (3.6)	1.5	0.87	NS
AOB (mm)	0.7 (0.8)	4.1 (1.4)	3.4	3.04	*
U1–SN (°)	103.8 (3.8)	109.6 (5.7)	5.8	1.89	NS
U1–PP (°)	110.7 (3.7)	115.0 (5.5)	4.3	1.56	NS
IMPA (°)	96.8 (3.1)	95.4 (7.4)	1.4	0.44	NS
IIA (°)	129.2 (4.3)	119.9 (8.2)	9.2	2.11	NS
ILG (mm)	0.9 (2.0)	2.0 (3.0)	1.1	0.77	NS
NLA (°)	114.4 (7.0)	108.9 (6.0)	5.5	1.49	NS

*$P < 0.05$; NS, $P > 0.05$ (not significant); $n = 14$.

Table 4 Statistically significant differences in closure frequency between groups.

Location	Closure	Frequency (%)		Mean difference	Significance
		Control	AOB	(SE)	
Alveolar	/t/eam	100.00	79.17	20.83 (7.65)	*
	swor/d/	83.33	50.00	33.33 (12.78)	*
Velar	/k/astle	95.83	54.17	41.67 (13.20)	*
	/k/lock	79.17	37.50	41.67 (15.44)	*

*$P < 0.01$, $n = 16$.

that were actually made as a percentage of the usable words. As can be seen from the table, of the 42 closures examined, mean differences for only /t/eam, swor/d/, /k/astle, and /k/lock reached statistical significance, and these four closures were all made more often in the control group, indicating more consistent production of closures in the non-open bite group. All initial and final closures, and velar medial closures for which differences were greater than 5 per cent were made more frequently by the control subjects. For alveolar and palato-alveolar medial closures, no clear pattern was discernible in differences between the groups. For many closures the standard error was high compared with the mean difference. This indicates high variability in the occurrence of closures and is reflected in the small number of differences that reached statistical significance.

Figure 3 shows the palatograms and mean ANR values for both groups for the eight closures selected for more detailed analysis. Although no differences in ANR reached statistical significance, differences for four closures, /l/ and /n/, and /tʃ/ and /dʒ/, almost did. For these closures and, in fact, for all eight except 'suit/k/ase', mean ANR values were higher in the experimental group, indicating a trend towards more posterior palatal contact. Examination of the palatograms in Figure 3 also suggests a more posterior pattern of contact in the experimental group for the seven closures, and also for 'suit/k/ase'.

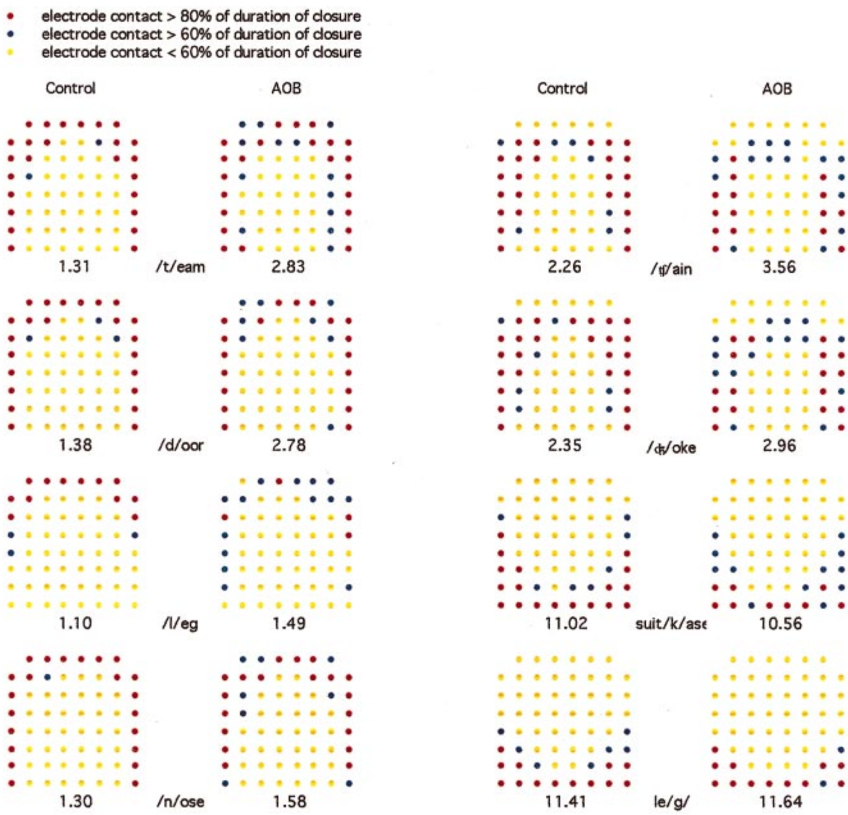

Figure 3 Palatograms and mean ANR values for eight selected closures for control and AOB groups.

Table 5 Statistically significant differences in mean ANR of whole words for control and AOB groups (standard errors in parentheses).

Word	Mean ANR		Mean difference	Significance
	Control	AOB		
desk	6.24 (0.19)	7.02 (0.18)	0.79 (0.26)	*
tune	5.98 (0.20)	6.94 (0.20)	0.96 (0.29)	*
tooth	5.89 (0.19)	6.88 (0.19)	0.99 (0.26)	*
zip	5.65 (0.29)	6.87 (0.29)	1.22 (0.41)	*
measure	6.77 (0.36)	8.10 (0.36)	1.33 (0.51)	*

*$P < 0.01$, $n = 16$.

For 23 of the 32 words examined, mean ANR values were higher in the experimental group, but differences reached significance only for ‘desk’, ‘measure’, ‘tooth’, ‘tune’, and ‘zip’ ($P < 0.01$), indicating a more anterior pattern of palatal contact for these words in the control group children. Table 5 summarizes the mean ANR values for these five words.

Table 6 shows the mean ANR values for the control and the experimental group for the saliva and water swallows. The difference of 0.49 ± 0.16 between the groups for water swallowing was statistically significant ($P < 0.01$), indicating more anterior palatal contact in the control group. The difference for the saliva swallowing was also in the same direction, but failed to reach significance.

Table 6 Mean ANR of saliva and water swallows for control and AOB groups (standard errors in parentheses).

Word	Mean ANR		Mean difference	Significance
	Control	AOB		
saliva	4.70 (0.15)	5.01 (0.15)	0.31 (0.21)	NS
water	4.69 (0.11)	5.18 (0.12)	0.49 (0.16)	*

NS, $P > 0.01$ (not significant); $*P < 0.01$, $n = 16$.

Palatograms of the saliva and water swallows are reproduced in Figure 4. From these it can be seen that in the experimental children there was relatively sparse contact for both swallows. In the water swallows, none of the electrodes were contacted for more than 90 per cent of the duration of the swallows, and the distribution of the blue electrodes (indicating 75 per cent contact) follows no obvious pattern. In the saliva swallows, peripheral contact occurred for more then 75 per cent of the duration of the swallows, and a posterior palatal bolus cavity is discernible. Palatograms of the control group swallows, on the other hand, showed a high percentage of lateral and anterior contact, with a well-defined posterior palatal bolus cavity.

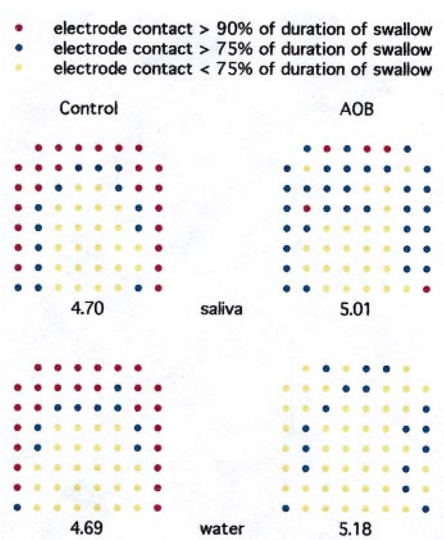

Figure 4 Palatograms and mean ANR values for saliva and water swallows for control and AOB groups.

The evidence from the palatograms and the numerical ANR data both support the finding that a more anterior pattern of contact was made by the control subjects.

Discussion

This study used cephalometry and electropalatography to compare an experimental group of 9–11-year-old male AOB children with a group of non-open bite controls of similar age.

Although EPG has been used as a diagnostic, therapeutic and research tool in various situations (Gibbon and Hardcastle, 1987; Fletcher *et al.*, 1991; Hardcastle *et al.*, 1991a,b), to date it has not been applied specifically to AOB patients; neither has it been used to compare two groups of subjects with potential differences in linguo-palatal function. EPG has been applied, however, to the quantification of tongue contact patterns during swallowing and has been shown to be potentially useful in this area (Chi-Fishman and Stone, 1996). Unfortunately, this research was published too late to have been useful during the planning of the present study.

Spontaneous closure of AOB occurs in approximately 80 per cent of 10–12-year-old children (Worms *et al.*, 1971). Recruitment of experimental subjects was difficult and, therefore, there was no control group of AOB children to assess how much closure of AOB would have occurred without therapeutic intervention; the (non-open bite) control group was used for this purpose. However, growth changes and alterations in incisor position in the experimental and control group subjects may well have been different.

The cephalometric results confirm that the experimental group was different from the control group. Although AOB was the only variable that was statistically significantly different between the control and experimental groups, several measurements of vertical facial height almost reached statistical significance. As can be seen from Table 3, differences between the groups for SN–MP, AFH and PP–Me approached statistical significance, indicating a trend towards a longer facial morphology in the experimental group. It should be noted, however, that in the cephalometric error study, SN–MP and PP–Me were the least reproducible of the cephalometric measurements used. Nonetheless, the association of these morphological features with AOB has been reported previously (Lopez–Gavito *et al*., 1985).

From Table 3 it can also be seen that differences between mean values of U1–SN, U1–PP and IIA between the groups were high, but again, the differences were not statistically significant. Table 7 shows the mean values and standard deviations for U1–SN and IIA from the long-faced group in the University of Iowa longitudinal facial growth study (Bishara and Jakobsen, 1985) and from the two groups in the present investigation. The mean anterior face height for the Iowa long-faced group was similar to that of the control group in the present study, but was 6 mm less than the mean of the experimental group, thus placing the latter well into the long-faced category in the Iowa study. From the table, it can be seen that the mean value for U1–SN for the control group was 3.1 degrees higher than that found in the Iowa long-faced group. However, for the present experimental group, the mean U1–SN was almost 9 degrees higher than that of the Iowa long-faced group. Similarly for the IIA, the mean value for the control group from the present study is comparable with values from the Iowa study, whereas the mean value for the AOB group was almost 10 degrees lower than the long-faced Iowa group. This evidence may indicate a trend towards greater upper incisor proclination in AOB subjects, which has also been reported in mouth-breathers with enlarged tonsils (Behlfelt, 1990). Forward resting tongue posture, which was also noted by Behlfelt, could account for this phenomenon and it may be that, if the sample group had been larger, these small differences may have reached statistical significance.

Table 7 Mean U1–SN and IIA values from Iowa Growth Study* and present study (standard deviations in parentheses).

	Iowa study*	Present study	
	Long faced	AOB	Control
U1-SN (°)	100.7 (7.0)	109.6 (5.7)	103.8 (3.8)
IIA (°)	129.5 (7.8)	119.9 (8.2)	129.2 (4.3)

*Bishara and Jakobsen (1985).

Wide variation between individuals has been found in tongue contact during speech using both conventional palatography (Allen, 1958) and EPG (Hamlet *et al*., 1986; Lundqvist *et al*., 1995). In the present study, similar inter-individual variation may have been present in all EPG parameters measured. However, in order to reduce the amount of information, the EPG data was pooled and analysed for whole groups of subjects, so that inter-individual variation was masked. Although such loss of information on individual variation has been regarded as a contra-indication to the pooling of EPG data from different individuals (Hamlet *et al*., 1986), it has nevertheless been used elsewhere (Dagenais *et al*., 1994), and may be seen as a further EPG data reduction method.

Close examination of the palatographic and numerical data obtained from the control and experimental groups for the palato-alveolar affricate phonemes, /tʃ/ and /dʒ/, (see Figure 3 and Table 8) indicates that the differences between the groups, although small, were sufficiently large to constitute a distinguishing feature between the groups. As can be seen from Table 8, the mean values for duration and ANR of the /tʃ/ and /dʒ/ closures were higher in the experimental children. These findings may indicate a more ponderous execution of these sounds with a noticeably different pattern of tongue activity, which confirms the impression that it is, indeed, possible to detect these differences clinically in open bite children.

Table 8 Mean duration and ANR values for control and AOB groups for /tʃ/ and /dʒ/ closures.

Group	Mean duration (ms)		Mean ANR	
	Control	AOB	Control	AOB
/tʃ/	79.1	111.2	2.26	3.56
/dʒ/	92.3	116.5	2.35	2.96

However, the predictive value of these sounds remains to be systematically tested. With this caveat, it is nonetheless suggested that the /tʃ/ and /dʒ/ phonemes may be of assistance in the diagnosis of tongue thrust, and should be included in any list of test words used for this purpose. In the other closures examined in detail, no general distinguishing characteristics were found, and any useful diagnostic information contained in the whole word data may have been masked by the presence of other phonemes within the words.

Examination of the palatographic and numerical data for the control and experimental groups indicates that there were some differences between the two groups. These differences, although small, were evident in the data from closures, words, and swallows, and indicated a trend for more posterior palatal contact in the experimental subjects. This finding has not been reported before, but would seem to contradict the hypothesis that during swallowing, the tongue adapts to the presence of the AOB by functioning more anteriorly (Wallen, 1974). However, the front of the EPG plate only extends to the palatal gingival margins of the upper incisors and cannot, therefore, quantify tongue function beyond this limit. It may be, therefore, that the tongue does protrude to effect an anterior oral seal, but the EPG system fails to register its position.

The production of the alveolar and palato-alveolar closures normally involves the apical region or tip of the tongue, and the area of contact is small. From the palatograms in Figure 3, it can be seen that in the control group, the midline anterior contact for these closures was confined to a single row, whereas the children in the experimental group exhibited a deeper pattern of midline anterior contact. In accordance with Wallen's hypothesis, this may be because the tongue was protruded into the open bite; consequently, a more posterior part of the dorsal surface of the tongue, the laminal region, was brought into contact with the palate during the production of these sounds. The laminal region of the tongue, which is also known as the blade, is larger than the tip, and would therefore be expected to produce a larger EPG contact area; this can be seen in the palatograms of the /tʃ/ and /dʒ/ phonemes from the AOB group in Figure 3. The higher mean ANR values found in the experimental subjects suggest that the AOB children had a more posterior contact pattern. However, the deeper anterior contact pattern found in the experimental subjects may account for these higher values. Thus, although the tongue is protruded into the open bite, and is actually positioned anteriorly, the deep EPG contact pattern associated with lamino-palatal contact in the anterior region results in a higher mean ANR, implying a more posterior pattern of contact in the AOB subjects. It appears that palatographic representation of EPG data may be more informative than numerical ANR values.

For the velar closures, /k/ and /g/, the palatograms show a more posterior pattern of contact in the experimental group subjects. While a more posterior contact pattern is normally associated with a higher ANR value, this may not be true for velar closures if linguo-palatal contact occurs behind the posterior border of the EPG plate. In this case, some linguo-palatal contact at the posterior limit of the closure may not be registered, resulting in an artificially low ANR value.

Although the differences in mean ANR values between the two groups were small and failed to reach significance, the value for the experimental group was higher for the /g/, and lower for the /k/ closure. The reason for these contradictory ANR values is not clear, but other factors, such as the pattern of lateral contact, the balance between anterior and posterior contact, and the effect of different percentages of contact can influence the mean ANR value. As suggested above, the palatogram may be more useful than the numerical ANR value.

Palatograms of the swallows in Figure 4 show relatively sparse patterns of contact in the experimental children compared with the control subjects, in whom a stronger pattern of peripheral contact, and a well defined posterior palatal bolus cavity were found. It is feasible that the sporadic contact pattern seen in the experimental subjects may be caused by reduced linguo-palatal pressure. Although some workers have found increased tongue pressure during swallowing in AOB patients (Kydd *et al*., 1963), others have shown that some tongue thrusters exhibit little or no pressure, whereas others use very heavy linguo-palatal pressure during swallowing (Proffit *et al*., 1969). There was also some evidence of less consistent production of closures by the experimental subjects. Although the reason for this is not clear, it is possible that this also results from reduced linguo-palatal pressure during function.

One aim of the present investigation was to produce a core of experimental data and this was achieved. Great potential remains for further analysis of both the cephalometric and EPG data. Further analysis of the differences between groups for the /tʃ/ and /dʒ/ phonemes, and for other sounds not analysed in detail in the present study would provide a greater insight into differences between open bite and non-open bite children.

Conclusions

Comparisons of the cephalometric data indicated a trend towards longer face morphology and upper incisor proclination in the experimental subjects.

Comparisons of the EPG data indicated a trend for more consistent production of closures in the control group, with high variability in the occurrence of closures in both groups.

Analysis of a subset of eight closures indicated a trend in the ANR and palatographic data towards more anterior linguo-palatal contact in the control subjects, a different pattern of anterior contact for the palato-alveolar closures, /tʃ/ and /dʒ/, in the two groups, and similar variability in duration, ANR, and closure index values for both groups. These results suggest that the /dʒ/ and /tʃ/ phonemes should be included when speech is used to test for the presence of fronted tongue behaviour.

Analysis of the EPG data for whole words and swallows indicated that the control subjects showed a more anterior pattern of palatal contact. During swallowing, the experimental children displayed relatively sparse patterns of EPG contact compared with the control subjects, in whom stronger peripheral contact, and a well-defined posterior palatal bolus cavity were found. For water swallows, the difference in mean ANR values between the groups reached statistical significance ($P < 0.01$).

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