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Cranial base considerations between apnoeics and non-apnoeic snorers, and associated effects of long-term mandibular advancement on condylar and natural head position

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SUMMARY One hundred consecutively medically referred patients (58 apnoeic and 42 asymptomatic snorers) were reviewed cephalometrically at six-monthly intervals (6–30 months) following treatment for obstructive sleep apnoea (OSA) and/or habitual snoring by mandibular advancement. Eighty-seven males and 13 females (mean age 49 years, SD 8.5, range 33–74) were included in this study. Reference points and planes in the cranial base, nasopharynx, and mandibular condyle were digitized with a Reflex Metrograph and their means converted to linear and angular measurements.

No statistically significant differences were observed between the apnoeic and non-apnoeic groups in either their skeletal or cranial base measurements. All linear cranial base dimensions were, however, reduced in the apnoeic group, with the exception of the distance (S–SE). Following mandibular advancement, statistically significant changes were observed in vertical condylar position (Cd–vert) with changes occurring at 6 ($P < 0.012$), 18 ($P < 0.043$), and 24 months ($P < 0.007$). No changes in horizontal condylar position (Cd–horiz) were found. Significant changes were observed in natural head position (NHP) with a reduction from an extended (NSL–vert 99.7 degrees) to a more upright NHP (NSL–vert 93.0, $P < 0.001$).

Introduction

Abnormal craniofacial morphology has been extensively reported in patients presenting with obstructive sleep apnoea (OSA). Cephalometric radiographs have shown a number of skeletal and soft tissue abnormalities of the upper airway that predispose patients to pharyngeal occlusion, which are reported to be related to the severity of OSA. In particular, these include a decreased anterior cranial base length (S–N; Bacon *et al*., 1990; Andersson and Brattström, 1991; Zucconi *et al*., 1993), an acute cranial base angle (S–N–Ba degrees) (Steinberg and Fraser, 1995), and a decreased bony pharyngeal aperture and small oropharyngeal airway (Lowe *et al*., 1986; Bacon *et al*., 1990; Tangugsorn *et al*., 1995; Ono *et al*., 1996; Pracharktam *et al*., 1996; Pae *et al*., 1997). Although normal in all other respects, non-apnoeic snorers have also been shown to have smaller bony pharyngeal apertures (Zucconi *et al*., 1992; Johns *et al*., 1998). Conversely, there are reports that indicate that cephalograms of apnoeic patients and those of habitual snorers do not differ (Hochban and Brandenburg, 1994; Cistulli, 1996). Limited data suggest that ethnicity can play an important role in the cephalometric differentiation of patients with and without OSA (Sakakibara *et al*., 1999; Coltman *et al*., 2000; Liu *et al*., 2000), and that comparisons between apnoeic and non-apnoeic patients can only be made when ethnicity has been considered, as differences in cranial base dimensions can influence cephalometric values (Sassouni, 1962). The relationship between natural head position (NHP) and OSA has been demonstrated (Solow *et al*., 1993; Tangugsorn *et al*., 1995). OSA patients were found to exhibit an extended and forward NHP when compared with controls. Minor changes in NHP were initially caused by a cranial extension (NSL–vert; Woodside and Linder-Aronsen, 1979; Hellsing, 1989; Solow *et al*., 1996). These findings were not, however, substantiated by Özbek *et al*. (1998), who concluded that this difference was due to the inclusion of non-apnoeic snorers in their control group. To-date, only one cephalometric study has been undertaken to examine the effect of long-term mandibular advancement on the facial skeleton.

Bondemark (1999) cephalometrically investigated the effects of two years' treatment with a mandibular advancement appliance in 30 patients diagnosed with habitual snoring and/or OSA. That author found that a small forward and downward change in mandibular position was accomplished by a minor increase in mandibular length associated with a decrease in overjet of 0.4 mm and a 0.1-mm decrease in overbite. A change in mandibular posture was observed in 17 patients, whilst 13 subjects showed no change. Bondemark (1999) concluded that this change in mandibular position may be the result of condylar and/or glenoid fossa remodelling or a condylar positional change within the fossa as a compensatory reaction to mandibular advancement therapy. To the author's knowledge no cephalometric studies have been undertaken to determine the effect of long-term mandibular advancement on the upper facial skeleton and in particular its effect on condylar position and NHP. This investigation was therefore undertaken to investigate these issues.

Subjects and methods

Sample

One hundred consecutively treated medically referred patients using a mandibular advancement appliance for OSA and/or habitual snoring were included in this study. Fifty-eight patients were referred from the Tom McKendrick Sleep Laboratory, Dunedin Hospital, for the treatment of mild to moderate OSA, six patients in this group were non-compliant with nasal continuous positive airway pressure. The remaining 42 subjects were referred for the treatment of non-apnoeic snoring. Only patients who stated that they wore the appliance seven nights per week (for a minimum of 5–6 hours per night) were included. A total of 114 patients were initially contacted; 13 subjects were excluded as they did not wear the appliance on a regular basis, one patient declined to be in the study. Overall, 87 males and 13 females were included, mean age 49 years (SD 8.5), range 33–74 years. The mean age for males was 48 years (SD 8.3) and for females 51 years (SD 10.2).

The mandibular advancement splint used was non-adjustable and had full occlusal coverage (Robertson, 1997). Mandibular advancement was established at 75 per cent of maximum protrusion as determined by the George-gauge (range 3–14 mm; George, 1992).

Cephalograms

A cephalogram was taken for all patients at their initial consultation. Following insertion of the mandibular advancement splint, review cephalograms were taken without the appliance *in situ*, at six-monthly intervals from 6 to 30 months. Only one review cephalogram was taken for each patient. Prior to insertion of the appliances all patients were randomly assigned to a six-month review period (each period consisting of 20 patients). Cephalograms were taken with the subjects seated, with maximal intercuspation of the teeth, the lips in light contact and in NHP as described by Moorrees and Kean (1958). All cephalograms were taken in the afternoon by the same operator. Rare earth intensifying screens were used to obtain maximum detail. Exposure was adjusted for each patient, but generally 85 KVP and 15 MA was used at 1.0-second exposures. Prior to exposure all patients were clinically examined by the author to check for occlusal discrepancies between centric occlusion (CO) and centric relation (CR).

Cephalometric measurements

Reference points and planes (Figure 1) were identified and transferred to mylar film. The co-ordinates of each point on the tracings were recorded twice with a Reflex Metrograph (Scott, 1981) and the mean values converted to linear and angular measurements.

The *t*-test for paired data was used to compare all measurements between the before (T1) and after treatment (T2) groups; a value of $P < 0.05$ was regarded as significant. To determine the error of the method, double determinations were taken of 10 randomly selected cephalograms and compared using Dahlberg's (1940) formula. The error in the linear measurements fell within the range 0.20–0.47 mm, and in the angular measurements 0.21–0.79 degrees. There were no statistically significant differences between the duplicate measurements.

Because no lead wire was used during exposure to indicate the true vertical on the cephalogram, the right-hand border of the cephalogram was used as the vertical reference line (Tallgren and Solow, 1987). The head position in relation to the vertical was expressed by the angle (NSL–vert).

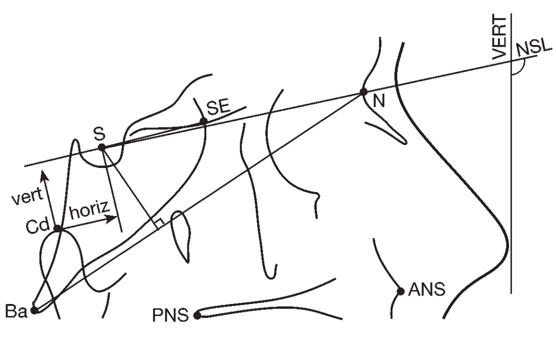

Figure 1 Reference points and planes used in this study. Ba (basion), lowest point on the anterior margin of foramen magnum; Cd (condylion), most superior point of the condylar head; N (nasion), anterior point of the intersection between the nasal and frontal bones; PNS (posterior nasal spine), most posterior point of the bony hard palate in the mid-sagittal plane; S (sella), mid-point of the concavity of the sella turcica; SE (spheno-ethmoidal registration point), the point of intersection between the greater wings of the sphenoid and the anterior cranial base; Cd vert, the vertical distance between the mandibular condyle and an extension of the line S–SE; Cd horiz, the horizontal distance between Cd to a line perpendicular to the line S–SE through S; S–SE, cranial base reference plane; NSL, nasion–sella line (N–S); VERT, true vertical, right hand border of cephalogram; S perp N–Ba (sella vertical position), the perpendicular distance between sella and N–Ba.

Results

After adjusting for age and sex (ANOVA), no statistically significant differences were found between the apnoeic and non-apnoeic snoring groups in relationship to their skeletal classifications (Table 1). Female patients in both groups had, however, statistically significantly smaller overall linear skeletal measurements when compared with their male counterparts. No differences were observed when angular measurements were considered.

Overall, 39 per cent of the total sample presented with a Skeletal I facial pattern, 47 per cent Skeletal II, and 14 per cent Skeletal III (Table 1).

Although most cranial base linear dimensions were reduced in the apnoeic group (Table 2) no statistically significant differences were observed between patients with documented OSA and those presenting with asymptomatic snoring. The only linear measurement not reduced in the apnoeic group was the distance (S–SE). Differences in linear measurements between apnoeic patients and non-apnoeic snorers, therefore, do not include that aspect of the anterior cranial base from sella to the intersection of the

Table 1 A comparison of the skeletal classifications of apnoeic and non-apnoeic snorers.

	Skeletal classification			Row total
	I	II	III	
Snorers	16	20	6	42
Apnoeics	23	27	8	58
Total	39	47	14	100

Chi-square	Value	DF	Significance
Pearsons	0.02533	2	0.98742

Skeletal classification (Tulley and Campbell, 1970).
Skeletal I (ANB difference 1–3 degrees).
Skeletal II (ANB difference >3 degrees).
Skeletal III (ANB difference <1 degrees).

Table 2 Cranial base and nasopharyngeal measurements of apnoeics and non-apnoeic snorers.

	Non-apnoeic snorers		Apnoeics		Mean difference	*P*
	Mean	SD	Mean	SD		
Linear (mm)						
N–Ba	112.45	5.39	111.48	5.47	0.97	0.382
S–N	75.47	3.85	74.84	3.72	0.63	0.409
S–Ba	50.50	3.54	49.66	3.83	0.83	0.269
N–Cd	91.46	4.75	90.42	5.14	1.04	0.307
S–SE	26.70	2.53	26.97	2.67	–0.26	0.615
S–Cd	24.02	3.83	22.88	3.20	1.14	0.109
Cd–vert	18.40	4.52	17.02	3.60	1.37	0.095
Cd–horiz	14.85	3.81	14.75	3.39	–0.10	0.891
S perp–N–Ba	27.50	3.29	26.78	3.67	0.73	0.316
Ba–PNS	45.88	4.16	44.56	4.73	1.32	0.152
Angular (degrees)						
N–S–Ba	125.5	5.6	126.3	6.3	–0.8	0.520
N–S–Cd	125.9	8.7	127.2	8.5	–1.2	0.481
NSL–vert	97.8	14.4	101.0	14.0	–3.2	0.275

sphenoid and jugum. No significant differences were observed between angular measurements (Table 2); however, apnoeics tended to have a greater cranial extension (NSL–vert 101.0 degrees) compared with non-apnoeic snorers (NSL–vert 97.8 degrees).

As no statistically significant differences were observed between the apnoeic and non-apnoeic groups, both groups were combined to investigate the effect of long-term mandibular advancement on the upper facial skeleton and in particular the relationship of the mandibular condyle to the cranial base. Significant differences were observed in condylar position relative to sella (S–Cd, $P < 0.001$; Table 3). Further analyses of condylar position were

Table 3 Cranial base and nasopharyngeal dimensions before (T1) and after (T2) treatment.

All patients (*n* = 100)	T1		T2		Mean difference	*P*
	Mean	SD	Mean	SD		
Linear (mm)						
N–Ba	111.88	5.43	111.95	5.48	–0.07	0.700
S–N	75.10	3.77	75.00	3.76	0.10	0.324
S–Ba	50.01	3.72	50.17	3.54	–0.16	0.356
N–Cd	90.85	4.99	90.94	4.92	–0.09	0.607
S–SE	26.86	2.60	26.83	2.51	0.03	0.702
S–Cd	23.35	3.50	23.97	3.48	–0.62	0.001*
Cd–vert	17.61	4.05	18.43	3.85	–0.82	0.000*
Cd–horiz	14.79	3.56	14.88	3.55	0.09	0.607
S perp–N–Ba	27.08	3.52	27.10	3.39	–0.02	0.836
Ba–PNS	45.10	4.53	45.04	4.18	0.06	0.763
Angular (degrees)						
N–S–Ba	125.9	6.0	126.0	5.9	0.1	0.832
N–S–Cd	126.6	8.6	125.6	8.2	1.0	0.026*
NSL–vert	99.7	14.2	93.0	18.0	6.7	0.001*

*Significant difference between groups.

made in the vertical (Cd–vert) and horizontal (Cd–horiz) planes relative to the cranial base reference line (S–SE). No statistically significant changes were found for the horizontal aspect (Cd–horiz), but significant changes were observed in the vertical aspect (Cd–vert, mean diff 0.82 mm, $P < 0.001$), when all patients were compared (Table 3). Likewise, a small but statistically significant change was observed in the angle N–S–Cd degrees ($P < 0.026$). This was thought to be related to a change in the vertical position of condylion. A statistically significant change in NHP was also observed, with a reduction of (NSL–vert) from 99.7 to 93.0 degrees ($P < 0.001$). This resulted in a change in head posture from an extended to a more upright NHP (Table 3).

Following comparison of all patients at T1 and T2, a one-way analysis of variance followed by Duncan's multiple range test was used to determine whether initial differences existed between any group prior to treatment with a mandibular advancement appliance. No differences were found. Further analysis of the data was then undertaken to determine at which time interval changes occurred.

Changes in condylar vertical position relative to length of treatment are given in Table 4. Condylar displacement was first observed at 6 ($P < 0.012$), at 18 ($P < 0.043$), and 24 months ($P < 0.007$). Although changes occurred at 12 and 30 months, these differences did not reach a statistical level of significance. Further evaluation of the data by analysis of covariance was then carried out to determine whether changes were progressive with continuing treatment. After adjusting for time no statistically significant differences were observed in condylar vertical position between any of the groups.

Conversely, continuing changes in NHP occurred between 12 and 30 months ($P < 0.019$), and 18 and 30 months ($P < 0.008$); however, as no other inter-group changes were found these findings were considered inconclusive.

Discussion

All patients in this study were referred for treatment of mild to moderate OSA and/or non-apnoeic snoring. Historically, the differentiation between these two groups has caused some debate especially at the lower end of the spectrum. The minimal diagnostic criteria for OSA has been defined as an apnoea-hypopnoea index (AHI) of 5 or greater with daytime hypersomnolence (Young *et al.*, 1993). Based on epidemiological evidence (Engleman *et al.*, 1997, 1999; Young *et al.*, 1997) the American Academy of Sleep Medicine Task Force (1999) defined mild OSA as an AHI of 5–15 events per hour, moderate OSA 15–30 events per hour, and severe OSA greater than 30 events per hour. Morbidity associated with OSA with AHI values as low as 5 has been reported (Peppard *et al.*, 2000), likewise simple snoring has been reported as being the beginning of sleep-disordered breathing with a significant risk for elevated blood pressure (Young *et al.*, 1996). The differentiation between patients with OSA and those with non-apnoeic snoring is undoubtedly difficult and is arbitrarily based on a diagnostic cut-off value (AHI > 5 <) with or without associated daytime symptoms. Nonetheless, the diagnostic criteria used

Table 4 Changes in vertical condylar position relative to length of treatment.

Months	Before treatment (T1)		After treatment (T2)		*P*
	Mean	SD	Mean	SD	
6	16.82	3.46	17.89	3.54	0.012*
12	17.83	5.49	18.10	5.51	0.582
18	17.48	3.47	18.41	3.64	0.043*
24	18.05	3.58	19.07	3.24	0.007*
30	18.21	4.30	18.92	3.29	0.198

*Significant difference between groups.

in this study to differentiate patients presenting with OSA and those with non-apnoeic snoring are in accordance with current international recommendations (American Academy of Sleep Medicine Task Force, 1999).

As well as polysomnography to evaluate patients with sleep-disordered breathing, cephalometry has shown a number of skeletal abnormalities of the cranial base and nasopharynx that many consider to be related to the onset and severity of OSA. Decreased anterior cranial base length (Bacon *et al*., 1990; Tangugsorn *et al*., 1995) and an acute cranial base angle (S–N–Ba; Jamieson *et al*., 1986; Andersson and Brattström, 1991; Steinberg and Fraser, 1995), along with a reduced nasopharynx (Ba–PNS; Zucconi *et al*., 1992; Ono *et al*., 1996; Pae *et al*., 1997) have been reported. Conversely, no such differences in these dimensions have been reported in the differentiation of mild apnoeics to non-apnoeic snorers. In agreement with the findings of Johns *et al*. (1998), although trends suggest a shortening of cranial base dimensions, no statistically significant differences were found between mild apnoeics and non-apnoeic snorers in the present study.

A cautionary note should be given, however, to the interpretation of some of these findings of cranial base discrepancies between patients with documented OSA and those without reported by others. It is important that cephalometric ethnic differences are considered.

In a cephalometric comparison of Chinese and Caucasian patients with OSA matched for age, gender, and skeletal patterns, Liu *et al*. (2000) reported that the Chinese groups revealed more underlying craniofacial skeletal discrepancies with significantly smaller maxillae and mandibles, and in particular steeper and shorter anterior cranial bases. These authors concluded that such cephalometric differences may indicate the need to consider ethnicity when planning treatment of OSA. It is therefore important that inter-racial differences are taken into account when cranial base measurements are used in the diagnosis of patients with OSA. In the present study, all patients were of Caucasian origin. Another cause of concern relates in part to the variability of nasion. For example, in a comparison of Caucasian and Chinese males, nasion is on average higher in Chinese by 4 mm (Sassouni, 1962). Likewise, nasion is higher in Negroes by 2 mm when compared with Caucasians (Sassouni, 1962). Binder (1979) found that an antero-posterior displacement of nasion of 5 mm or more resulted in a 2.5-degree deviation in the ANB angle. It can be concluded, therefore, that the relative position of nasion can influence any cephalometric measurement incorporating this landmark if ethnicity is not accounted for. In lieu of these findings, the cranial base dimension (S–SE) was used as the major cranial base reference line to compare condylar position before (T1) and after (T2) mandibular advancement.

This dimension (S–SE) is considered to be unchanged from adolescence (Ford, 1958) and is regarded as one of the most stable landmarks in the facial skeleton (Johnston, 1996). Of note (S–SE) was the only cranial base linear dimension that was not reduced when apnoeic patients were compared with asymptomatic snorers. Overall, although all cranial base and nasopharyngeal dimensions were reduced in the apnoeic group, these were not statistically significant. These findings may be related to the severity of OSA in the symptomatic group, as only patients with documented mild to moderate OSA were referred for management of their condition with mandibular advancement. Steinberg and Fraser (1995) investigated the cranial base length and flexure in adult patients with documented OSA with asymptomatic snorers and observed that the cranial base flexure was significantly more acute in the apnoeic group ($P < 0.001$). No cranial base length differences were observed. Steinberg and Fraser (1995) considered that an acute cranial base angle played a role in the development of OSA by the anterior repositioning of the posterior pharyngeal wall with a consequential decrease in pharyngeal airway dimension. These authors concluded that cranial base length abnormalities were not common in patients with airway problems and, as a consequence, did not play a role in the aetiology of OSA.

In the present study no angulation differences in cranial base flexure were observed between the non-apnoeic and apnoeic groups (Table 2).

In agreement with the findings of Johns *et al.* (1998), however, differences were observed in nasopharyngeal depth (BA–PNS) and, although not statistically significant, this dimension recorded one of the greatest mean differences (1.32 mm) between the apnoeic and non-apnoeic groups. As many (Bacon *et al.*, 1990; Tangugsorn *et al.*, 1995; Ono *et al.*, 1996; Pracharktam *et al.*, 1996; Pae *et al.*, 1997; Özbek *et al.*, 1998; Johnston and Richardson, 1999) consider a reduced bony nasopharyngeal aperture to be significant in the patency of the upper airway, a difference in this dimension may well be a major factor in the differentiation between apnoeic and non-apnoeic snoring patients.

Following treatment with a mandibular advancement appliance statistically significant changes were found in condylar vertical position (Table 4) at 6 ($P < 0.012$), 18 ($P < 0.043$), and 24 months ($P < 0.007$). Although changes in condylar position occurred at 12 and 30 months, these changes did not reach a level of statistical significance. After adjusting for time by analysis of covariance, changes in condylar vertical position were not progressive with ongoing treatment. These findings may indeed be related to the fact that a non-adjustable mandibular advancement appliance was used in this study.

Studies investigating the effect of long-term mandibular advancement on the facial skeleton have been limited. Bondemark (1999) observed a forward and downward change in mandibular posture after two years' nocturnal treatment with a mandibular advancement appliance. He speculated that this may be the result of condylar or glenoid fossa remodelling as a compensatory reaction or, indeed, a functional adaptation in mandibular position. In the present study, as statistically significant changes in condylar vertical position were observed as early as 6 months with mandibular advancement, these changes are unlikely to be related to glenoid fossa or condylar remodelling, but repositional changes of the head of the mandibular condyle.

As reported previously (Robertson, 2001), in this present study treatment was discontinued for one patient due to adverse occlusal changes. This patient after 30 months of mandibular advancement treatment had developed a 5-mm posterior open bite resulting in severe incisal wear due to a marked proclination of the lower incisors and a retroclination of the upper incisors. Transcranial temporomandibular radiographs of this patient showed a marked postero-superior increase in joint space between the head of the mandibular condyle and the glenoid fossa. No bony remodelling of the fossa was observed radiographically. Posterior contact of the molars was re-established, but only after mandibular advancement therapy had been discontinued for 9 months. Angulation changes of the incisors were, however, permanent and required corrective orthodontic treatment. The patient was subsequently well controlled with the use of a tongue stabilizer. In light of the reversibility of these changes it can be assumed that in this case occlusal changes were related to condylar repositioning, and not to growth modification of the condylar head or glenoid fossa.

Previous studies of the interactions between airway adequacy and head posture have demonstrated that minor changes in NHP lead to a changed mode of breathing that is caused by cranial extension (NSL–vert; Hellsing, 1989; Solow *et al.*, 1993; Tangugsorn *et al.*, 1995; Özbek *et al.*, 1998). These findings are in accordance with the present study and, although not statistically significant, all apnoeic patients had an extended NHP when compared with non-apnoeic snorers (mean difference 3.2 degrees). Many investigators have, however, noted marked differences in NHP in so-called 'normals' (Solow and Tallgren, 1971; Foster *et al.*, 1981; Leitao and Nanda, 2000). However, Özbek and Koklu (1993) considered that alternations in the variable (NSL–vert) could be explained by the inter-individual variability of the vertical position of sella. In the present study, the vertical position of sella was investigated relative to the cranial base reference line Ba–N (S perp N–Ba; Table 2). No statistically significant differences were observed in sella vertical position between the apnoeic and non-apnoeic groups. To the author's knowledge, no study has been undertaken that has investigated changes in NHP associated with long-term mandibular advancement. A reduction from an extended NHP (NSL–vert 99.7 degrees) to a more upright 'normal' NHP (NSL–vert

93.0 degrees) may indeed be an indication of improved upper airway function. Owing to the individual variability of NHP, these changes were only significant, however, when the entire sample ($n = 100$) was compared (Table 3).

Conclusions

No statistically significant differences in cranial base or nasopharyngeal dimensions between patients with OSA and those with asymptomatic snoring were found in this investigation. This may in part be related to the severity of the patients referred for treatment with a mandibular advancement appliance. Changes observed in vertical condylar position (Cd–vert) following long-term mandibular advancement are thought to be related to changes in mandibular position reported by others (Bondemark, 1999). Although not confirmed by polysomnography, changes in NHP from an extended to a more upright position may be coincidental with improved upper airway function following long-term mandibular advancement.

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