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The Effects of Orthognathic Surgery on Pharyngeal Airway Dimensions and Quality of Sleep

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Abstract. *Orthognathic surgery has been associated with airway narrowing and induction of sleep-related breathing disorders. Therefore, the pharyngeal airway dimensions of 32 orthognathic surgery cases were prospectively investigated, and the relationship between the surgery and sleep quality assessed.*

Digitized lateral cephalometric radiographs were used to compare oropharyngeal airway morphologies before and after surgery. Patients were assessed in two main surgical groups based on sagittal jaw relationship. A questionnaire was used to assess changes in daytime sleepiness. The mandibular surgery cases were also assessed by overnight domiciliary sleep monitoring.

A significant decrease in the retrolingual airway dimension was found in all patients after mandibular setback surgery and a significant increase in this dimension after mandibular advancement. The questionnaire and sleep study revealed no significant changes in snoring incidence or apnoeic events after mandibular setback surgery. For the mandibular advancement group, a change in sleep quality was found, but only in cases with signs of a pre-existing sleep disorder.

Index words: Cephalometry, Orthognathic Surgery, Pharyngeal Airway, Sleep Apnoea.

Introduction

Surgical alterations in the position of the bony facial skeleton will inevitably affect the soft tissue–hard tissue relationships. However, an aspect of orthognathic surgery that is seldom considered is the effect of the skeletal movements on the pharyngeal airway. Changes in airway dimensions have been demonstrated after surgical repositioning of the mandible or maxilla (Riley *et al*., 1990; Yu *et al*., 1994), and case reports of mandibular setback surgery inducing sleep-related breathing disorders, such as obstructive sleep apnoea (OSA), have been associated with airway narrowing (Guilleminault *et al*., 1985; Riley *et al*., 1987). Conversely, the oro-pharyngeal effects of maxillo-mandibular advancement surgery have been used to advantage in the treatment of refractive sleep apnoea (Riley *et al*., 1993).

The prevalence of sleep apnoea is difficult to determine, but a recent extensive survey by Ohayon *et al*. (1997) in the UK recorded 3·5 per cent of 15–34-year-old males as sleep apnoeics. Therefore, it is not uncommon in the age range commonly associated with orthognathic procedures. Other workers have reported much higher prevalence figures and suggested that the condition is widely under-diagnosed. The Swedish Medical Research Council (1994) reported the prevalence of OSA in men at 17 per cent in the age range 30–40 years.

The hallmark of sleep apnoea is snoring, accompanied by periodic airway obstruction and cessation of breathing, resulting in arousal and sleep fragmentation, which produces excessive daytime sleepiness. This is usually progressive, with the patient falling asleep in ever more active situations, and related to an increase in automobile accidents (Findley *et al*., 1992). The condition is potentially life threatening and the consequent reduction in blood oxygen saturation can give rise to hypertension, and cardiac and pulmonary complications (Klitzman and Miller, 1994).

The resulting sleep disturbances can be assessed in various ways, but overnight monitoring by polysomnography provides the gold standard (Douglas *et al*., 1992). This is a combination of neurophysiological, respiratory, and cardiological tests, and is widely used in sleep research. However, it is complex, expensive, and not widely available. Therefore, many workers now use simpler methods to screen potential sleep apnoea subjects, involving only pulse oximetry and respiratory noise monitoring (Cooper *et al*., 1991; Smithson *et al*., 1995). An advantage of these mini-sleep studies is that they are suitable for domiciliary use, which more closely reflects the normal sleep environment of the subject (Stradling and Mitchell, 1989).

Several anatomical and physiological factors have been suggested as causes of sleep apnoea, but the disorder is likely to be due to inter-related factors, which in the presence of sleep and decreased muscle tone, lead to airway occlusion. Many studies have suggested differences in craniofacial structure in sleep apnoea subjects, such as mandibular deficiency, bimaxillary retrusion, reduced cranial base length, increased lower face height, elongated soft palate, large base of tongue, and inferior position of the hyoid bone (Rojewski *et al*., 1984; Lowe *et al*., 1986, 1995; Bacon *et al*., 1989; Battagel and L'Estrange 1996). Soft tissue imaging of airway structures has been used to identify sites of mechanical obstruction, and a reduced pharyngeal airway

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dimension is consistently reported in sleep apnoea subjects independent of the assessment technique used. However, the exact site of narrowing or obstruction is variable (Bohlman *et al*., 1983; Jamieson *et al*., 1986; Lowe *et al*., 1986; Bacon *et al*., 1989; Suto *et al*., 1993). Therefore, a structurally abnormal airway could serve as an anatomic substrate for the development of sleep apnoea.

It is possible that orthognathic surgery, by altering facial skeletal anatomy, may induce a non-adaptive and unfavourable oropharyngeal change so promoting or exacerbating a sleep-related breathing disorder. Therefore, the aims of the present study were to prospectively examine airway dimensional changes in a group of orthognathic surgery patients, and to assess changes in sleep patterns in relation to the surgical procedures.

Subjects and Method

Subjects

Thirty-two adult Caucasians scheduled for elective orthognathic surgery were sequentially recruited from a London Hospital maxillofacial surgical unit over a period of one year. Afro-Caribbean subjects and patients with severe oro-facial abnormalities, such as cleft lip and palate, or a previously diagnosed sleep disorder were excluded from the study. The mean pre-operative age was 22·6 years (range 17·8–35·5), and the group included 14 males and 18 females. The patients were included in the study irrespective of the type of maxillo-mandibular surgery carried out. The sagittal skeletal relationship of the jaws, body mass index (weight/height^2), and basic demographic data were recorded (Table 1). A summary of the surgical procedures is shown in Table 2. All subjects underwent a period of fixed appliance orthodontics before and after surgery.

TABLE 1 *Demographic data (pre-op) and Epworth Sleepiness Scale (ESS) scores before and after surgery*

Variable	Subgroup	Mean ± SD	Range
Age (years)		22·6 (5·3)	17·8–35·5
Body mass index (kg/m^2)	Male	24·8 (2·2)	17·1–33·9
	Female	22·9 (2·2)	14·8–38·5
	Class II	21·1 (3·3)	14·8–26·1
	Class III	24·3 (5·2)	17·6–38·5
ESS score – Class II group	Pre-op	5·3 (3·2)	1–13
	Post-op	5·0 (4·1)	1–14
ESS score – Class III group	Pre-op	4·8 (2·9)	1–10
	Post-op	5·1 (2·7)	1– 9

n = 32: 14 male, 18 female; 12 Class II, 20 Class III.

TABLE 2 *Surgical case distribution (*n *= 32)*

Skeletal pattern	Surgery	Cases
Class II	Mandibular advance only	8
(*n* = 12)	Bimaxillary surgery	4
Class III	Mandibular setback	13
(*n* = 20)	Maxillary surgery only	7
	Bimaxillary surgery	11

Method

Questionnaire. This was used to assess the level of daytime sleepiness, and was based on the Epworth Sleepiness Scale described by Johns (1993). The subjects were asked to complete this by a single clinician prior to surgery and again at 6 weeks post-surgery (Table 1).

Cephalometry. Lateral cephalometric radiographs taken in natural head posture were used to assess craniofacial skeletal characteristics and pharyngeal airway dimensions shortly before and approximately 6 weeks after surgery. With the subject seated upright in the cephalostat, a thin layer of barium sulphate paste was painted onto the dorsum of the tongue in order to improve soft tissue identification (Hans and Goldberg, 1995). To standardize hyoid position, the radiograph was exposed at the end of expiration.

Radiographs were traced and 16 skeletal and 15 oropharyngeal soft tissue points identified (Figures 1 and 2). All tracings were analysed using a GTCO Accutab digitizer interfaced to a specialist software programme. The points were digitized twice in a predetermined sequence to a tolerance of 0·2 mm, and the soft tissue outlines of the oropharyngeal area, soft palate, and tongue were recorded (Figure 3). Calculations were made based on an automatic point matrix orientation of 7 degrees to the S–N line, and comprised 31 angular, linear, proportional, and area measurements (Tables 3–7).

Method error. Replicate tracing and digitization of 20 radiographs revealed a very low random error (Dahlberg, 1940). The largest error occurred in the variable upper incisor angulation to maxillary plane. The smallest Dahlberg value of 0·16 was recorded for SNB. Systematic error or bias was assessed using a one sample *t*-test at a significance level of 10 per cent (Houston, 1983). This revealed no significant systematic errors and acceptable reliability.

Statistical analysis. The cephalometric data were analysed using SPSS PC+ (Norusis, 1986). The mean, standard deviation, range, and differences between the pre- and post-operative radiographs were calculated for 31 separate variables. These comprised 18 standard hard and soft tissue cephalometric measurements indicating the type and extent of surgical movements obtained, and 13 additional variables describing the effects on the oropharyngeal structures. Based on sagittal skeletal pattern, the data were divided into Class II and Class III groups, which were further divided depending on the specific surgery performed (Table 2). The changes induced by the surgery were assessed in each subgroup using the Wilcoxon signed ranks test.

Mini-sleep study. Sleep monitoring was performed during the pre-surgical orthodontic phase and approximately 1 month post-operatively for nine of the mandibular surgery cases. This involved unattended overnight pulse oximetry (Ohmeda, Biox 3740) and respiratory noise monitoring in the subject's home. The oximeter records oxygen saturation as a percentage value. The respiratory noise levels were assessed during sleep using a microphone connected to a noise level meter. Up to 8 hours of synchronized data were transferred to a portable microcomputer (Samsung notemaster 486C/25) in real time by an analogue-digital

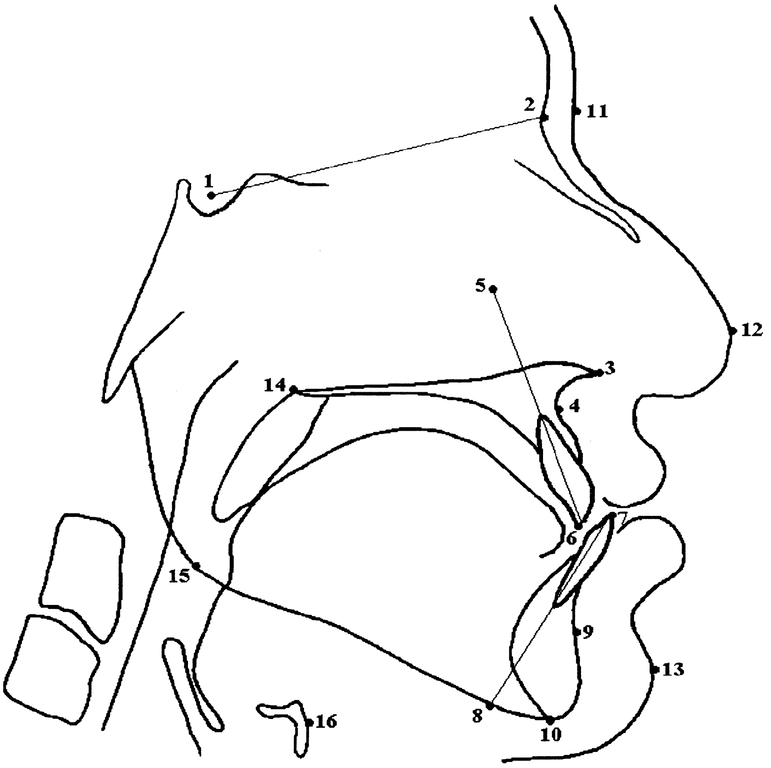

FIG. 1 Standard cephalometric points and measurements recorded (conforms to BSI, 1983). *Points:* 1, sella; 2, nasion; 3, anterior nasal spine (ANS); 4, point A; 5, upper incisor apex projection; 6, upper incisor tip; 7, lower incisor tip; 8, lower incisor apex projection to mandibular plane; 9, point B; 10, menton; 11, soft tissue nasion; 12, nasal tip; 13, soft tissue pogonion; 14, posterior nasal spine (PNS); 15, gonion; 16, anterior–hyoid bone. *Measurements:* gonion–menton; LAFH (menton–ANS); UAFH (nasion–ANS); LPFH (gonion–PNS); hyoid–ANS (horizontal measure); hyoid–gonion (vertical measure); soft tissue facial convexity (nasion–nasal tip–pogonion).

TABLE 3 *Craniofacial dimensions before and after surgery*. ***Class II group:*** *Mandibular advancement (*n = *12)*

Variable	Pre-surgery Mean ± SD	Range	Post-surgery Mean ± SD	Range	Diff of mean	Stat sign.
Cranial base						
S–N (mm)	66·2 (3·1)	61·2–72·0	66·4 (3·1)	61·4–72·1	0·1	NS
Skeletal–maxilla						
SNA (°)	81·3 (5·8)	73·7–91·9	81·7 (4·7)	75·2–89·7	0·4	NS
A–S vertical (mm)	63·7 (7·2)	52·6–75·8	64·6 (5·5)	58·4–74·9	0·8	NS
Skeletal–mandible						
SNB (°)	73·0 (5·2)	64·6–78·9	76·9 (5·5)	67·6–85·1	3·94	**
B–S vertical (mm)	49·3 (11·5)	28·7–62·4	55. 7 (11·1)	35·9–71·8	6·4	**
Gonion–menton (mm)	63·7 (5·2)	54·4–73·4	64·7 (6·8)	51·5–74·1	0·9	NS
Intermaxillary						
ANB (°)	8·1 (3·1)	2·6–13·8	4·3 (3·9)	–1·7–10·3	–3·8	**
Max–mand plane angle (°)	27·8 (11·8)	12·6–47·9	28·6 (9·6)	16·9–46·7	0·9	NS
LAFH (mm)	58·8 (7·5)	50·3–74·3	62·5 (7·3)	52·9–74·8	3·8	**
UAFH (mm)	49·5 (3·9)	44·5–56·2	47·8 (3·6)	41·7–55·1	–1·7	NS
LPFH (mm)	30·9 (5·7)	16·4–36·8	31·6 (5·1)	20·9–38·1	0·7	NS
Hyoid						
Hyoid–ANS (horiz mm)	67·9 (7·1)	56·2–80·8	61·2 (8·9)	46·1–76·1	–6·7	**
Hyoid –gonion (vertical mm)	28·4 (9·1)	12·1–41·3	25·8 (7·7)	13·9–39·9	–2·6	NS
Dental						
UI–max plane (°)	113·7 (9·8)	97·5–129·2	110·9 (8·9)	96·4–123·2	–2·7	NS
LI–mand plane (°)	100·1 (9·4)	86·5–117·3	96·1 (6·9)	90·0–110·0	–4·0	*
Overjet (mm)	9·8 (3·6)	5·3–15·6	2·3 (1·3)	0·1–3·9	–7·5	**
Soft tissues						
Facial convexity (°)	124·2 (5·3)	114·9–133·1	129·2 (4·1)	119·8–134·4	4·9	**
Nasal tip–S vertical (mm)	94·1 (5·9)	84·2–102·7	94·9 (5·8)	84·4–102·8	0·8	NS

Statistical significance: *$P < 0{\cdot}05$; **$P < 0{\cdot}01$; ***$P < 0{\cdot}001$; NS, not significant.
For explanation of measurements and landmark points see Figure 1.

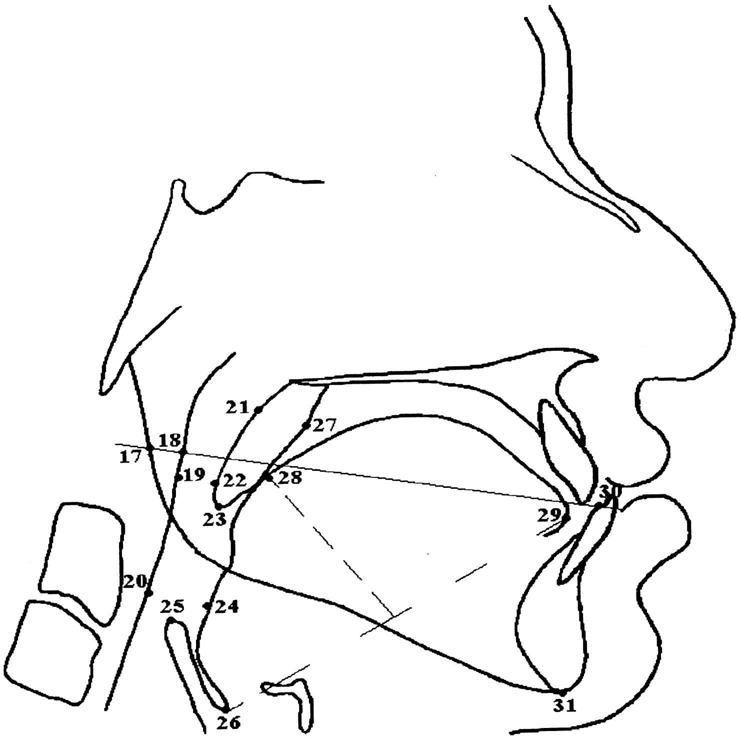

FIG. 2 Oropharyngeal cephalometric points and measurements. *Points:* 17, intersection of occlusal plane with ascending ramus; 18, occlusal plane with posterior pharyngeal wall (ppw); 19, point on ppw (narrowest palatal airway); 20, point on ppw (narrowest lingual airway); 21, soft palate thickest dimension (nasal surface); 22, point on soft palate (narrowest palatal airway); 23, tip of soft palate; 24, point on tongue (narrowest lingual airway); 25, tip of epiglottis; 26, vallecula; 27, soft palate thickest dimension (oral surface); 28, tongue thickness (perpendicular to line from vallecula to tongue tip); 29, tip of tongue; 30, intersection of occlusal plane with lower incisor; 31, most inferior point bony chin. *Measurements:* intermaxillary space length (ppw–lower incisor – point 30–18); soft palate depth (horizontal measure PNS–point 23); soft palate thickness (point 21–27); soft palate length (PNS–point 23); palatal angle (maxillary plane–soft palate length).

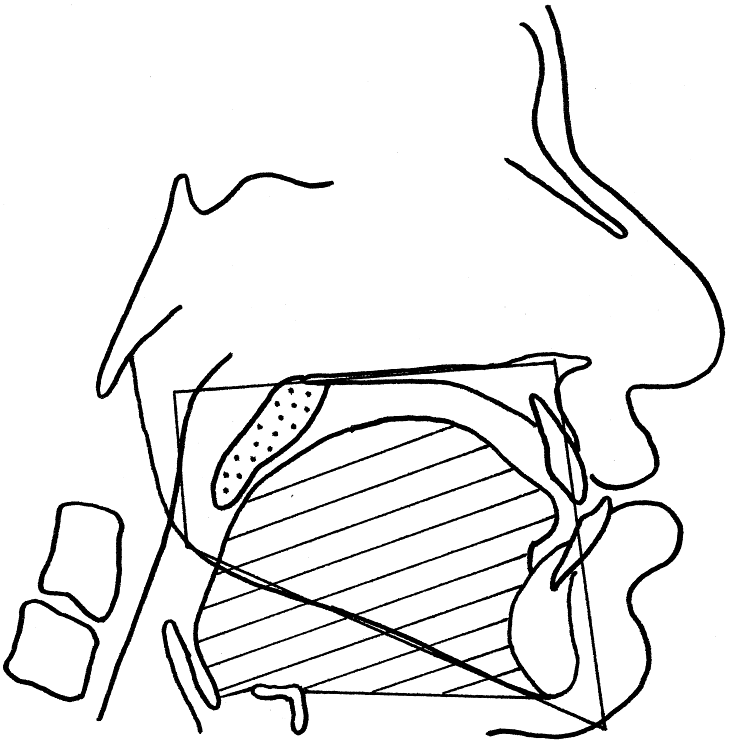

FIG. 3 Oropharyngeal area measurements and intermaxillary space. Intermaxillary space (IMS) is delineated by the trapezium drawn through the maxillary and mandibular planes, the posterior pharyngeal wall and the lingual gingival aspect of the lower incisor (method of Vig and Cohen, 1974). Tongue proportion is tongue area (shaded lines) as a percentage of IMS.

converter (ADC PL4.02) for analysis using a specialist software programme (Picolog, Pico Technology Ltd). All subjects were asked to refrain from alcohol and to standardize the microphone position and their sleeping arrangements as much as possible on the two occasions. This method is similar to that described by Smithson *et al.* (1995).

Statistical analysis. The sleep study data were reduced to 5 main oxygen saturation and sound variables for statistical analysis. Mean and minimum oxygen level, and number of desaturations of 4 per cent or greater were calculated (Stradling and Crosby, 1991). In addition, the 95 and 5 percentile levels for the respiratory noise data were assessed. These values correspond to the background room noise level (L95) and the loudest respiratory noise levels (L5), respectively (Smithson *et al*., 1995). The Wilcoxon signed ranks test was used to evaluate differences between the pre-operative and post-operative variables.

Results

The height, weight, and body mass indices (Table 1) were within normal limits for both male and female groups (Davies and Stradling, 1990).

Questionnaire

Prior to surgery, nine patients were self-reported snorers and these subjects tended to have higher Epworth sleepiness scale (ESS) scores than the non-snorers. However, overall the pre-surgical ESS scores were low and quite variable, and after surgery demonstrated no clear pattern of change in either the Class II or Class III surgical groups (Table 1).

Cephalometry

The subjects were divided into Class II and Class III groups for assessment of surgical effects on craniofacial anatomy.

Skeletal changes: Class II group. All 12 patients in the Class II group (Table 3) underwent sagittal split mandibular advancement osteotomies. The range of surgical movement was 5–11 mm. The effects of surgery on the facial tissues for the Class II cases are described in Table 3. Significant skeletal differences were found following surgery for SNB, ANB, facial convexity, B to S vertical, hyoid to anterior nasal spine (ANS), and lower anterior face height (LAFH). The overjet decreased considerably from a mean of 9·8–2·3 mm.

Skeletal changes: Class III group. The Class III group was more heterogeneous (Table 2); therefore, not all subgroups are reported. The main surgical divisions were:

(1) mandibular set backs (13 patients, 11 of whom had an associated maxillary advancement);
(2) maxilla only surgery (seven patients);
(3) a group containing all the maxillary procedures (18 patients).

The effects of bimaxillary surgery on the facial skeletal landmarks are shown in Table 4. Statistically significant

TABLE 4 *Craniofacial dimensions before and after bimaxillary surgery.* ***Class III group****: mandibular setback (13)/maxilla advancement (11)*

Variable	Pre–surgery Mean ± SD	Range	Post–surgery Mean ± SD	Range	Diff of mean	Stat sign.
Cranial base						
S–N (mm)	64·6 (2·6)	59·6–68·7	64·5 (2·8)	59·4–68·8	–0·1	NS
Skeletal–maxilla						
SNA (°)	78·5 (2·9)	73·8–85·1	82·3 (2·9)	78·3–86·5	3·9	**
A–S vertical (mm)	59·3 (3·5)	55·1–65·6	63·4 (3·7)	58·5–71·0	4·0	**
Skeletal–mandible						
SNB (°)	82·0 (4·1)	77·2–89·2	78·6 (3·5)	75·2–85·8	–3·4	**
B–S vertical (mm)	62·2 (7·9)	50·4–74·8	56·4 (6·5)	48·6–66·5	–5·8	**
Gonion–menton (mm)	70·2 (7·4)	60·6–82·1	64·6 (4·2)	56·7–72·4	–5·6	*
Intermaxillary						
ANB (°)	–3·2 (2·9)	–8·2–1·3	3·0 (2·7)	–1·3–7·0	6·2	**
Max–mand plane angle (°)	32·6 (4·9)	22·8–38·0	33·4 (4·2)	26·8–38·6	0·9	NS
LAFH (mm)	69·2 (7·7)	56·7–89·4	67·3 (6·4)	56·1–82·9	–1·9	**
UAFH (mm)	50·9 (3·2)	44·2–55·2	50·0 (3·1)	44·8–55·8	–0·9	NS
LPFH (mm)	33·1 (4·3)	27·5–41·0	34·6 (6·9)	22·1–47·5	1·5	NS
Hyoid						
Hyoid–ANS (horiz mm)	57·6 (7·3)	48·8–73·3	62·2 (6·5)	50·5–76·3	4·6	NS
Hyoid–gonion (vertical mm)	30·9 (9·4)	17·5–49·3	30·9 (9·2)	15·1–50·3	–1·1	NS
Dental						
UI–max plane (°)	112·1 (8·1)	95·3–128·8	112·8 (6·7)	99·1–128·1	0·7	NS
LI–mand plane (°)	87·7 (7·2)	75·8–100·1	86·3 (7·8)	72·9–98·3	–1·4	NS
Overjet (mm)	–6·1 (3·9)	–14·9–1·5	2·8 (1·5)	0·6–6·3	8·9	**
Soft tissues						
Facial convexity (°)	138·6 (4·7)	129·6–146·9	131·3 (3·2)	125·5–137·6	–7·3	**
Nasal tip–S vertical (mm)	93·1 (3·5)	86·3–98·5	94·1 (3·8)	87·5–100·5	1·0	*

Statistical significance: *$P < 0{\cdot}05$; **$P < 0{\cdot}01$; ***$P < 0{\cdot}001$; NS, not significant.
For explanation of measurements and landmark points see Figure 1.

increases in SNA and A point to sella vertical distance illustrate the surgical advancement of the maxilla. Retrusion of the mandible produced a decrease in SNB, B point to sella vertical, and gonion to menton distance. The mean surgical change in ANB was 6·2 degrees.

Oropharyngeal changes: Class II group. The oropharyngeal measurements applied are illustrated in Figures 2 and 3. Following advancement surgery in the Class II group, the minimum palatal airway dimension increased significantly ($P < 0·01$) from a mean value of 7·8–9·9 mm. The soft palate depth and length measurements both decreased (Table 5). The oropharynx area increased significantly, but the tongue thickness and area did not change subsequent to surgery. However the tongue proportion, which is the tongue area expressed as a percentage of the intermaxillary space area (Figure 3), decreased by a mean of 6·9 per cent. The minimum lingual airway width increased significantly ($P < 0·01$) after mandibular advancement, and was associated with an increase in intermaxillary space length and area.

Oropharyngeal changes: Class III group. The surgical changes in oropharyngeal anatomy for the Class III bimaxillary osteotomy group are displayed in Table 6. All 13 cases underwent a mandibular set back procedure, which was associated with a significant reduction in the minimum lingual airway width ($P < 0·01$) from 11·1 to 6·8 mm. A representative example of the change in this variable is shown by the pre- and post-operative cephalometric tracings for a Class III case (Figure 4). The mean tongue proportion increased by 8·4 per cent ($P < 0·01$), whereas the other tongue variables showed no significant changes. Both the intermaxillary area and length decreased significantly ($P < 0·01$).

TABLE 5 *Oropharyngeal dimensions before and after surgery.* ***Class II group***: *Mandibular advancement (*n = *12)*

Variable	Pre–surgery Mean ± SD	Range	Post–surgery Mean ± SD	Range	Diff of mean	Stat sign.
Soft palate depth (mm)	22·9 (3·2)	17·1–28·4	18·4 (4·9)	9·4–25·8	–4·5	**
Soft palate thickness (mm)	8·4 (1·2)	6·4–10·1	8·7 (1·4)	5·8–11·0	0·4	NS
Soft palate length (mm)	33·8 (3·1)	30·1–39·2	31·8 (2·8)	27·1–35·9	–1·9	*
Palatal angle (°)	131·6 (4·3)	123·5–137·8	126·3 (9·4)	109·6–137·9	–5·3	NS
Soft palate area (cm^2)	2·9 (0·6)	1·8–4·1	2·9 (0·6)	1·9–3·7	–0·1	NS
Oropharynx area (cm^2)	5·9 (1·1)	4·6–8·1	6·9 (1·9)	3·2–9·5	1·1	*
Min. palatal airway (mm)	7·8 (2·7)	4·4–11·9	9·9 (3·9)	3·0–15·2	2·1	**
Min. lingual airway (mm)	7·7 (2·4)	5·1–13·5	11·6 (5·2)	3·6–22·1	3·9	**
Tongue thickness (mm)	30·9 (3·9)	23·9–37·8	32·3 (3·2)	26·1–36·4	1·4	NS
Tongue area (cm^2)	30·5 (4·3)	25·4–39·4	30·8 (3·6)	27·1–38·8	0·3	NS
Tongue proportion (%)	96·4 (16·7)	74·1–135·4	89·5 (15·1)	72·4–120·2	–6·9	*
IMS length (mm)	70·8 (6·4)	60·6–81·4	76·4 (8·3)	62·5–90·7	5·6	**
IMS area (cm^2)	32·1 (5·5)	24·2–45·6	35·0 (5·8)	26·2–47·1	2·9	**

Statistical significance: *$P < 0·05$; **$P < 0·01$; ***$P < 0·001$; NS, not significant.
For explanation of measurements see Figures 2 and 3.

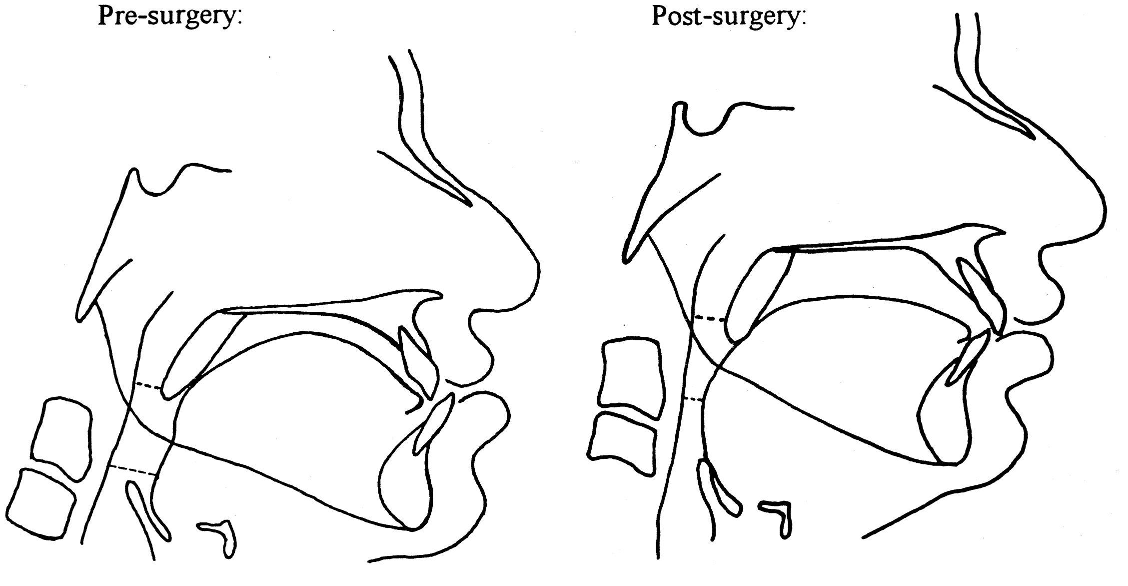

FIG. 4 Cephalometric tracings before and after mandibular setback surgery illustrating typical reduction in retrolingual airway dimension. (Dotted lines indicates minimum lingual and palatal airway dimensions)

In the upper airway space, soft palate depth, length, and palatal angle increased significantly. In contrast, the minimum palatal airway width and oropharynx area demonstrated a mildly significant decrease ($P < 0{\cdot}05$), even though the maxilla was surgically advanced. A Class III subgroup consisting of only single jaw maxillary advancement surgery was also assessed ($n = 7$), and again revealed no significant change in the post-palatal airway dimension.

The total Class III group of all 18 maxillary surgery cases (Table 7) produced clear changes in the upper airway variables after surgery, apart from the minimum palatal airway width which, as in the previous groups, did not alter.

Mini-sleep Study

The overnight sleep study was carried out on nine subjects, all of whom underwent mandibular surgery (three advancements, six setbacks). Sleep quality was assessed by analysis of the overnight sleep tracings, and changes in oximetry and respiratory noise (Table 8).

A Class II case, who was a self-reported snorer, illustrated an abnormally loud pre-operative respiratory noise pattern (case 1) with a very high L5 value and a high number of oxygen desaturations during sleep. These oxygen dips were scored as significant when dropping by ≥ 4 per cent below the mean overnight saturation level. After mandibular advancement surgery the noise levels and oxygen dips reduced to a level similar to the other subjects (Figure 5). This individual exhibited a moderate degree of pre-operative sleep apnoea, which is clearly illustrated by the sleep tracing in Figure 6. This is a representative 10-minute segment of sleep, and shows a very close association between the loud sound spikes and frequent oxygen desaturations, which drop to as low as 81 per cent and last approximately 20–30 seconds. In the intervals between the sound spikes, the saturation remains steady at around 97 per cent, a pattern indicative of sleep apnoea. The subsequent improvement in sleep profile after mandibular advancement surgery is clearly demonstrated in the post-operative sleep tracing (Figure 7).

The sound and oximetry profiles for the Class III mandibular setback cases were statistically assessed as a separate group (Table 8). Prior to operation they demonstrated normal sound and oximetry profiles, and analysis using the Wilcoxon sign ranks test revealed no significant changes

TABLE 6 *Oropharyngeal dimensions before and after bimaxillary surgery.* ***Class III group****: mandibular setback (13)/maxillary advance (11)*

Variable	Pre–surgery Mean ± SD	Range	Post–surgery Mean ± SD	Range	Diff of mean	Stat sign.
Soft palate depth (mm)	17·0 (3·9)	11·6–24·0	21·4 (5·1)	14·1–34·9	4·4	**
Soft palate thickness (mm)	9·1 (1·5)	6·6–12·1	9·1 (1·3)	7·2–12·5	–0·1	NS
Soft palate length (mm)	31·4 (3·7)	27·3–40·1	33·7 (5·3)	26·4–46·8	2·3	*
Palatal angle (°)	120·6 (7·9)	105·9–136·1	126·1 (6·7)	114·4–136·1	5·5	*
Soft palate area (cm^2)	2·9 (0·6)	2·1–4·1	3·2 (0·9)	2·2–5·5	0·3	NS
Oropharynx area (cm^2)	7·4 (1·8)	5·2–10·8	6·2 (2·3)	3·5–11·9	–1·2	*
Min. palatal airway (mm)	8·9 (1·9)	6·1–12·8	6·9 (3·3)	2·6–12·7	–1·9	*
Min. lingual airway (mm)	11·1 (2·4)	7·4–16·1	6·8 (2·7)	3·7–11·4	–4·3	**
Tongue thickness (mm)	34·1 (3·4)	25·0–38·1	35·0 (3·4)	31·4–42·3	0·9	NS
Tongue area (cm^2)	33·9 (5·7)	26·2–46·5	33·9 (6·5)	27·3–52·8	0·1	NS
Tongue proportion (%)	84·8 (9·8)	69·7–99·6	92·8 (12·1)	74·0–106·8	8·4	**
IMS length (mm)	81·6 (4·5)	75·1–89·3	75·1 (4·7)	68·1–84·4	–6·1	**
IMS area (cm^2)	39·5 (5·7)	33·5–53·9	36·7 (5·6)	27·6–49·9	–2·6	**

Statistical significance: *$P < 0{\cdot}05$; **$P < 0{\cdot}01$; ***$P < 0{\cdot}001$; NS, not significant.
For explanation of measurements see Figures 2 and 3.

TABLE 7 *Oropharyngeal dimensions before and after surgery.* ***Class III group****: Maxillary surgery (18) with mandibular setbacks (11)*

Variable	Pre–surgery Mean ± SD	Range	Post–surgery Mean ± SD	Range	Diff of mean	Stat sign.
Soft palate depth (mm)	17·8 (4·3)	11·6–25·8	22·3 (4·5)	16·2–34·9	4·5	**
Soft palate thickness(mm)	9·2 (1·4)	6·6–12·1	9·5 (1·5)	7·2–12·7	0·3	NS
Soft palate length (mm)	32·1 (4·0)	27·3–41·1	34·1 (5·0)	26·4–46·8	1·9	*
Palatal angle (°)	122·2 (9·4)	105·9–141·7	128·6 (8·3)	114·9–145·2	6·5	**
Soft palate area (cm^2)	3·1 (0·7)	2·1–4·6	3·3 (0·8)	2·2–5·5	0·2	*
Oropharynx area (cm^2)	7·1 (1·8)	4·5–10·8	6·6 (2·1)	3·5–11·9	–0·5	NS
Min. palatal airway (mm)	8·5 (2·2)	4·2–12·8	7·6 (3·2)	2·6–12·7	–0·8	NS
Min. lingual airway (mm)	10·5 (3·4)	3·1–16·1	8·9 (3·4)	3·7–14·7	–1·6	NS
Tongue thickness (mm)	34·7 (3·4)	25·0–40·5	34·5 (2·9)	30·1–42·2	–0·1	NS
Tongue area (cm^2)	33·9 (5·2)	26·2–46·7	34·0 (5·8)	27·3–52·8	0·1	NS
Tongue proportion (%)	87·0 (10·6)	69·7–110·9	90·9 (10·8)	74·0–110·3	3·9	NS
IMS length (mm)	80·1 (5·1)	71·2–89·3	76·7 (4·2)	68·1–84·4	–3·4	*
IMS area (cm^2)	38·8 (5·4)	32·9–53·9	37·6 (5·1)	27·6–49·9	–1·2	*

Statistical significance: *$P < 0{\cdot}05$; **$P < 0{\cdot}01$; ***$P < 0{\cdot}001$; NS, not significant.
For explanation of measurements see Figures 2 and 3.

TABLE 8 *Sound and oximetry results for mandibular setback surgery group (*n = 6*)*

Variable (cases 4–9)	Pre–surgery Mean ± SD	Range	Post–surgery Mean ± SD	Range	Diff of mean	Stat sign.
Mean % oxygen	97 (1·0)	96–97	96 (1·0)	95–97	–1	NS
Minimum % oxygen	93 (1·3)	91–95	92 (1·7)	90–95	–1	NS
Oxygen dips/hour	2·1 (0·7)	1·1–2·9	2·5 (1·1)	0·8–3·8	0·4	NS
L5 (mV)	4·5 (2·5)	2·0–7·0	3·5 (2·5)	2·0–9·0	–1·0	NS
L95 (mV)	2·3 (0·7)	2·0–4·0	1·6 (0·7)	0·0–2·0	–0·7	NS

See text for details of variables; oxygen dips represent ≥4 per cent drop in saturation below mean level; ns, not statistically significant, $P > 0·05$.

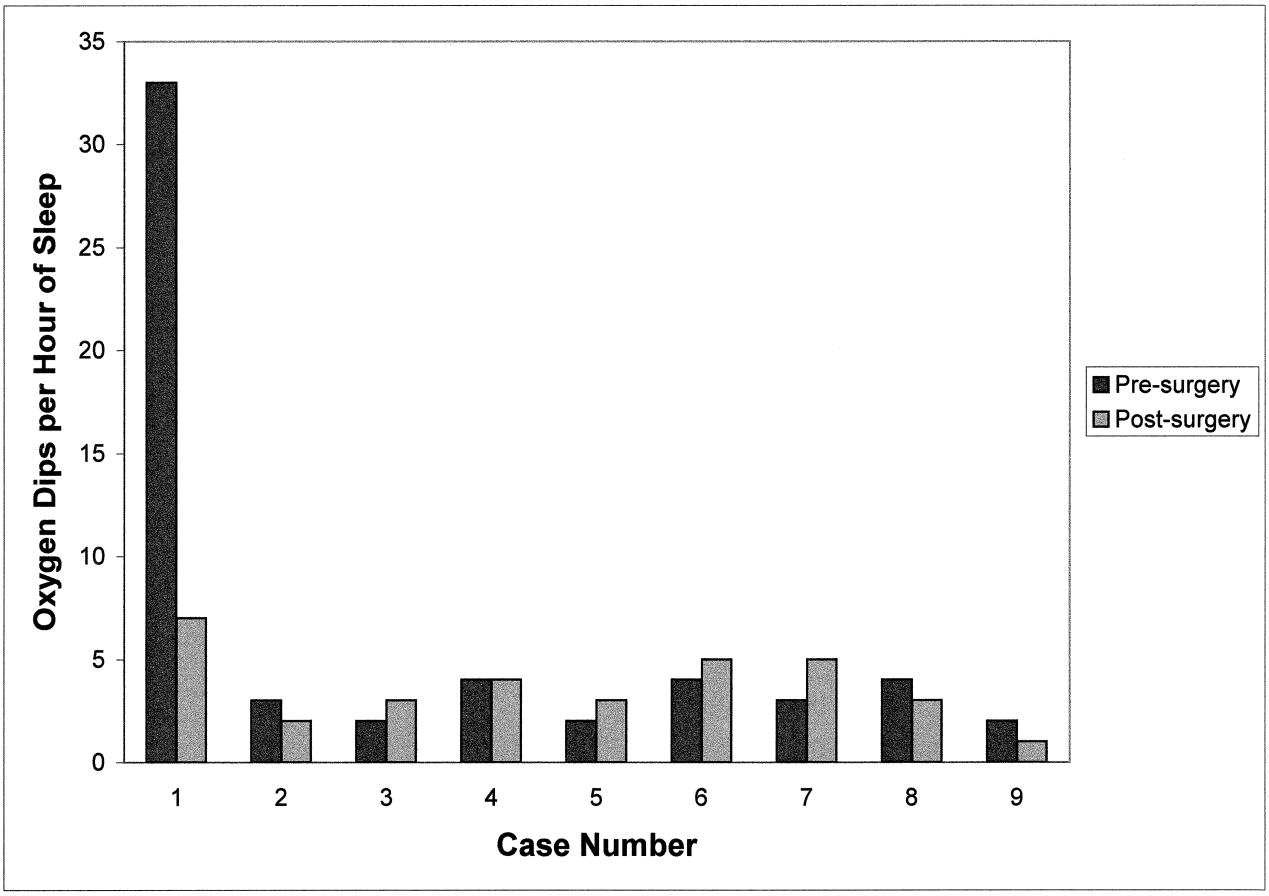

FIG. 5 Number of oxygen desaturations per hour of sleep time for nine cases before and after mandibular surgery. Cases 1–3, mandibular advancement surgery; cases 4–9, mandibular setback surgery. Oxygen desaturations (dips) ≥4 per cent below the mean overnight level were recorded. Case 1 illustrates more than 30 dips per hour of sleep pre-operatively, which reduced markedly after mandibular advancement surgery. Oxygen desaturations in the remaining cases are within the normal range (3–4 dips/hour) for a healthy sleep pattern, and did not change significantly after either mandibular advancement or setback surgery.

after mandibular setback surgery. This was confirmed by the sleep recordings for the Class III cases that did not change following surgery and were very similar to the healthy sleep tracing shown in Figure 7.

Discussion

Based on the questionnaire findings, neither the pre-operative skeletal pattern nor the type of surgery performed had a significant effect on snoring incidence. The Epworth sleepiness scale (ESS) is thought to be less subjective than most simple questionnaires and able to distinguish simple snoring from sleep apnoea (Johns, 1993), and has been shown to have a high test-retest reliability in normal subjects (Johns, 1992). In the present study, the mean pre-operative ESS score for both the Class II and Class III patients was approximately 5, and is within the range of clinically normal scores. Following surgery ESS changed very little, indicating that the sleep pattern was minimally affected.

Cephalometry

Although cephalometry provides only a two-dimensional image of the pharyngeal airway, it is still used extensively in

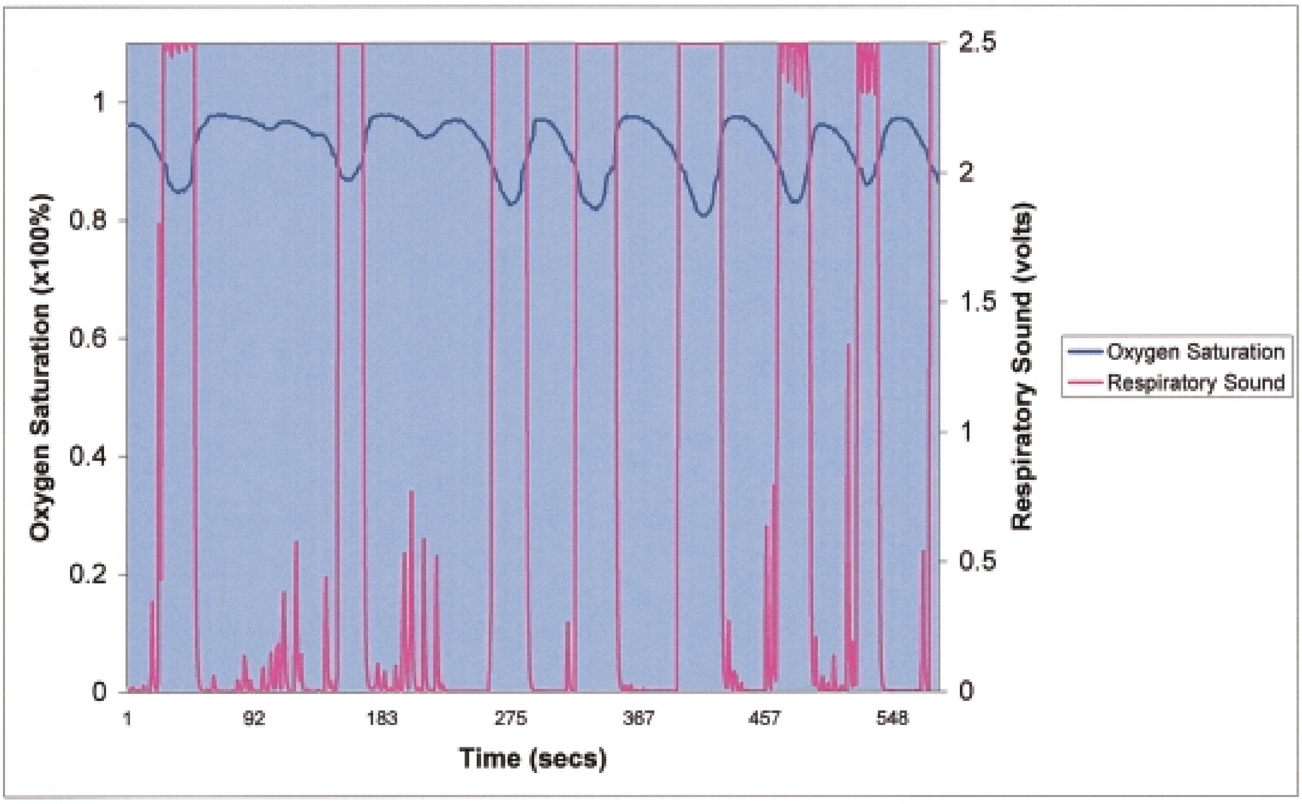

FIG. 6 Illustration of sleep recording (pre-operative Class II case). This 10-minute sleep tracing illustrates a moderate degree of sleep apnoea for this subject prior to surgery. There is close co-ordination of the respiratory sound spikes (lower trace) with the multiple oxygen desaturations (upper trace). This regular and characteristic pattern is indicative of sleep apnoea. The sound level frequently extends off the scale as the oxygen saturation drops from 0·97 (97 per cent) down to 0·81 (81 per cent).

the assessment of sleep apnoea and craniofacial form (Pae *et al*., 1997; Battagel *et al*., 1998; Ozbek *et al*., 1998). The advantages of cephalometry include its wide availability, simplicity, low expense, and ease of comparison with extensive normative data and other studies (Miles *et al*., 1995). A criticism of cephalometry is that it does not assess airway dimensions during natural sleep conditions. However, studies on sleep apnoea subjects, using cephalometry, computerized tomography (CT), and magnetic resonance imaging, have shown clear differences in craniofacial and pharyngeal morphology between awake OSA patients and healthy controls. This implies that at least some of the physiological and anatomical factors which cause the nocturnal respiratory symptoms will persist when the patient is awake and during cephalometric examination (Ozbek *et al*., 1998). Good correlation between cephalometric and CT measurements for many pharyngeal structures were reported by Riley *et al*. (1986). This work was confirmed by Lowe *et al*. (1995) for tongue, soft palate, and nasopharynx variables comparing cephalometry with 3-D CT scans.

The cephalometric assessment used to identify oropharyngeal changes after surgery was based on 13 measurements (Tables 5–7). Airway width was assessed by two measures; the minimal width posterior to the soft palate and posterior to the base of tongue. This is in contrast to other studies which have used a single anatomically defined measure called Posterior Airway Space (PAS), which does not necessarily represent the site of greatest narrowing (Jamieson *et al*., 1986; Riley *et al*., 1987; Waite *et al*., 1989). However, as the aim is to identify sites of pharyngeal narrowing subsequent to jaw movements then the most valid measure is the narrowest dimension within the pharynx. In addition, the two sites which are most often reported to be narrowed/obstructed in sleep apnoea prone individuals are the tongue base and retropalatal airway (Bohlman *et al*., 1983; Haponik *et al*., 1983; Lowe *et al*., 1986; Riley *et al*., 1993; Battagel and L'Estrange, 1996). Therefore, measurement of these two variables at their narrowest dimension should most accurately reveal the effects of the surgery on the oropharynx. Of the 13 oropharyngeal measurements used in this study, approximately half demonstrated consistent statistically significant changes following orthognathic surgery.

Class II Group

All patients underwent mandibular advancement osteotomies, which produced a statistically significant increase (mean 3·9 mm, $P < 0{\cdot}01$) in the minimum lingual airway dimension. This is in agreement with a case report by Powell *et al*. (1983) and a multiple case study by Riley *et al*. (1990), which reported a mean increase in the posterior airway space (PAS) of 5·6 mm after maxillo-mandibular advancement surgery in a group of sleep apnoea subjects. Evidence

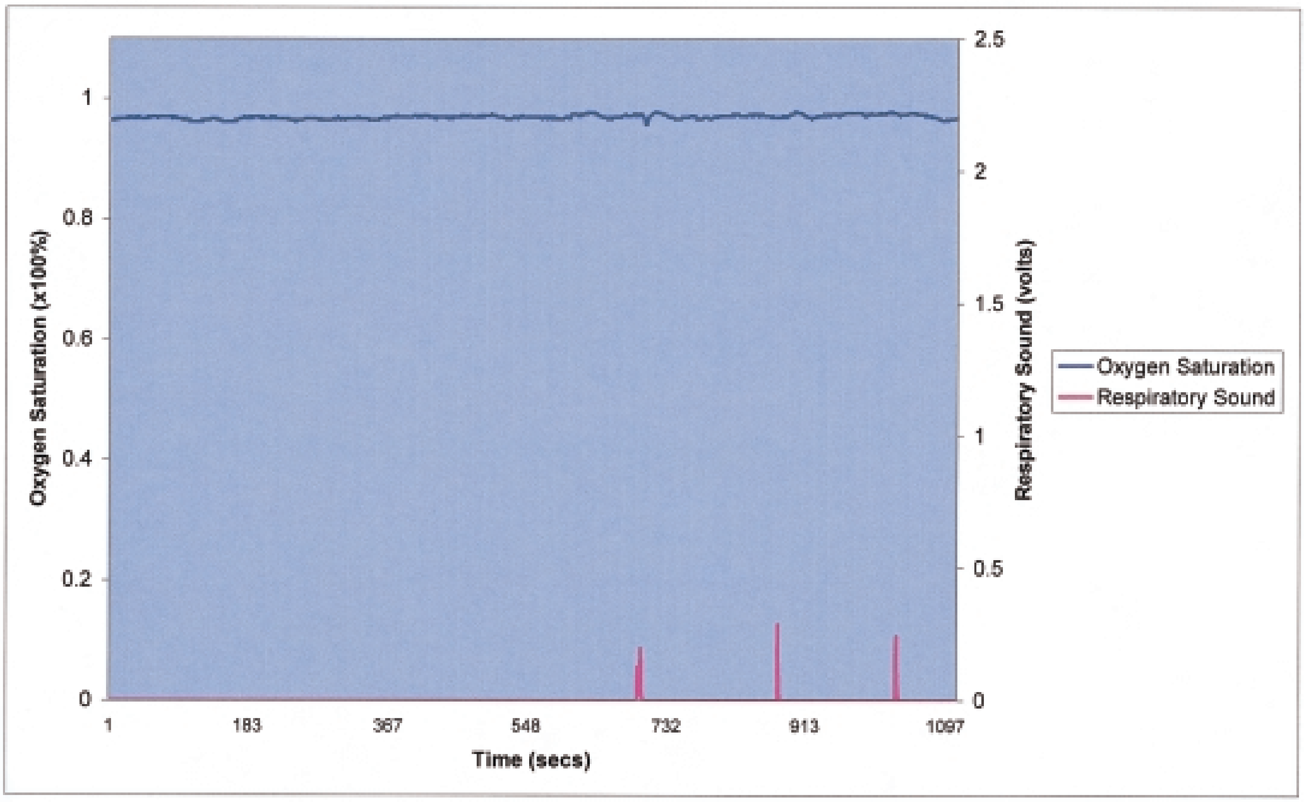

FIG. 7 Illustration of healthy sleep recording. The post-surgery sleep tracing for a typical 15-minute segment of sleep is displayed for the same subject shown in Figure 6. The sleep profile is significantly improved, with the oxygen saturation (upper trace) remaining flat and steady at the 0·97 (97 per cent) level. The respiratory noise (lower trace) is markedly reduced and close to zero volts. The Class 3 mandibular setback surgery cases demonstrated this healthy sleep pattern both before and after surgery.

for the effects of orthognathic surgery on healthy non-apnoeic patients is provided by Farole *et al.* (1990). They reported an increase in PAS after mandibular advancement in 19 of 25 patients treated for severe mandibular hypoplasia. However, they noted that the increases were varied and unpredictable. This was also found by Yu *et al.* (1994) in 16 non-OSA mandibular advancement cases.

In addition to the lingual airway changes, the minimum palatal airway dimension increased significantly (2·1 mm, $P < 0{\cdot}01$), as did the soft palate depth and length, indicating an anterior repositioning of the soft palate to maintain an oral seal as the mandible and attached genial muscles advanced forward. This is in agreement with Yu *et al.* (1994). Further evidence for this is derived from studies using intra-oral mandibular advancement splints. Battagel *et al.* (1998) found that forward posturing of the mandible with intra-oral appliances produced a mean increase of the retropalatal airway dimension of 2·9 mm, which is similar to the value found in the present study after surgical advancement of the mandible.

Intermaxillary space (IMS) was described by Vig and Cohen (1974) and has not been used as an assessment measure in other surgical studies (see Figure 3). However, it provides a very good measure of oropharyngeal size and relative tongue changes. A reduction in tongue proportion from 96 to 89 per cent was found after mandibular advancement. This is to be expected as the size of the oral cavity (and IMS) increases. As the tongue area did not change after surgery, this indicates an increase in functional space for the tongue, which appears to adopt a more anterior position in the oral cavity. Battagel and L'Estrange (1996) in a study comparing sleep apnoeic subjects with matched healthy controls found that the tongue proportion was significantly larger in OSA patients, causing impingement of the tongue base into the lingual airway space. An incidental finding in the present study was the difference in tongue proportion values prior to surgery in the Class II (96 per cent) and the Class III (88 per cent) groups, the latter group enjoying a greater functional tongue space. After surgery, the tongue proportion values converged to 90 and 89 per cent, respectively, possibly indicating that the various osteotomies had produced a more standardized oropharyngeal morphology.

In summary, mandibular advancement surgery causes a significant increase in lingual airway dimension, and also produces a mild increase in the retropalatal airway and change in soft palate shape. This latter effect is probably due to postural change of the soft palate in order to maintain the normal relationship with the dorsum of the tongue as this structure moves forward with the mandible. The inter-maxillary space increases and tongue proportion decreases, so that the tongue has more space to function resulting in a more forward position and consequent widening of the retrolingual airway.

Class III Group

The main finding from the Class III surgical group is the significant ($P < 0{\cdot}01$) decrease in retrolingual airway subsequent to mandibular setback. This occurred in all of the subjects. Proffit *et al.* (1990) noted that modern trends in orthognathic surgery result in the majority of mandibular setback osteotomies being carried out with concurrent maxillary advancements, which produces heterogeneous bimaxillary surgical groups for analysis. This was the case in the present study and, therefore, the effects of these two forms of surgery on the pharyngeal airway could not be assessed in isolation. This increase in bimaxillary surgery is partly due to refinements of the Le-Fort 1 down fracture technique (Epker and Wolford, 1975), but also as a result of an increased diagnostic awareness of maxillary hypoplasia as an important component in Class III dysgnathia (Ellis and McNamara, 1984).

Associated with the decrease in lingual airway was a significant decrease in intermaxillary space (area and length) and an increase in tongue proportion. Therefore, it is reasonable to assume that as the mandible is surgically retruded, the size of the oral cavity reduces, and the relative tongue proportion increases. The tongue may then be displaced superiorly and posteriorly, so reducing the lingual airway dimension.

Previous work in this area is limited to two case reports (Guilleminault *et al.*, 1985; Riley *et al.*, 1987) and a retrospective multiple case study (Greco *et al.*, 1990). The case reports highlighted the development of sleep apnoea in two previously healthy non-obese females following cosmetic mandibular retrusion surgery. However, only one of the cases was investigated cephalometrically and although this showed a reduction in the post-operative lingual airway, it was not quantified. The study by Greco *et al.* (1990) also reported a reduction in lingual airway space in 11 patients shortly after mandibular setback surgery. This work cannot be directly compared with the present study, as an area measurement of the posterior pharyngeal space was used, for which the hard tissue reference lines were arbitrary, difficult to determine and would certainly alter with the surgery. Also, their work was retrospective which ensured that there was no control over the cephalometric technique and phase of respiration, which may modify tongue position significantly. Notwithstanding the differences in methodology, Greco *et al.* (1990) did demonstrate a reduction in the retrolingual area of 7·1 per cent after surgery. However, a further comparative problem is that their sample contained only single jaw mandibular procedures, whereas in this study the majority were bimaxillary cases.

Surgical advancement of the maxilla either alone or in combination with mandibular setback did not produce an increase in retropalatal airway diameter. In contrast, in the bimaxillary group of 13 mandibular setbacks, there was a statistically significant decrease in post-palatal airway dimension, probably due to the mandibular setback component causing a posterior repositioning of the soft palate as a result of contact with the dorsum of the tongue as this structure moved back.

In agreement with previous work (Schendel *et al.*, 1979; Epker and Schendel 1980), soft palate shape, and position was found to alter with the surgery; a significant increase in palatal angle, depth, and length occurred ($P < 0{\cdot}01$) in both groups. This probably represents adaptive postural changes of the soft palate in order to maintain adequate palatal function and an oropharyngeal seal. Schendel *et al.* (1979) quantified the changes in palatal morphology after Le-Fort 1 maxillary advancement surgery and reported a one degree increase in palatal angle and a 0·5-mm increase in soft palate length per mm of maxillary advancement. This is similar to the present study, in which the mean surgical maxillary advancement was 5·5 mm and the change in palatal angle was 6·5 degrees.

The significance of these soft palate changes relates to velopharyngeal competence. It was noted by Epker and Wolford (1975) that, in terms of speech, patients who exhibit no velopharyngeal incompetence prior to surgery generally remain unchanged after maxillary advancement. It is likely that the lack of an increase in retropalatal airway dimension observed in the present study is due to adaptive changes in soft palate shape. The palatal angle increased, as did the soft palate length and depth, so allowing the soft palate to maintain contact with the posterior pharyngeal wall during speech and swallowing, even after surgical advancement of the maxilla.

It is possible that the reduction in retrolingual airway and intermaxillary space found after surgery in the Class III group may predispose to sleep apnoea in some individuals. Evidence for this is provided by studies comparing oropharyngeal morphology in sleep apnoea subjects with healthy controls. Reduced airway dimensions have been reported in sleep disorders by many workers (Bohlman *et al.*, 1983; Bacon *et al.*, 1988; Horner *et al.*, 1989; Pae *et al.*, 1997), and a reduction in IMS and an increase in tongue proportion, as in the present work, has also been described (Pracharktam *et al.*, 1994; Battagel and L'Estrange, 1996). In the present study some of these features were produced after surgery, indicating a change in oropharyngeal morphology to a pattern more closely resembling that seen in sleep apnoea subjects.

Mini-sleep Study

The mini-sleep study provided an objective assessment of nocturnal respiratory noise and oxygen saturation in nine subjects before and after orthognathic surgery. Pre-operatively, this identified normal sleep profiles for all subjects apart from one previously undiagnosed case of sleep apnoea.

Post-operatively, the sleep apnoea patient illustrated an 80 per cent reduction in the number of oxygen desaturations during sleep. The Class III mandibular setback cases demonstrated normal sleep profiles pre-operatively and were unchanged following surgery. None of these individuals became snorers or developed a sleep-related disorder, even though the cephalometry identified significant reductions in retrolingual airway dimension in this group after surgery.

Conclusions

1. Cephalometry revealed a significant reduction in retrolingual airway dimension after mandibular setback surgery in all Class III cases. This was associated with

posterior repositioning of the tongue and impingement on lingual airway space.
2. Mandibular advancement osteotomies in the Class II cases produced an increase in both the retrolingual and post-palatal airway dimensions and a postural change of the soft palate.
3. In contrast, Class III setback surgery caused a decrease in retropalatal airway width, even when combined with a maxillary advancement procedure.
4. The mini-sleep study revealed no change in sleep quality after mandibular setback surgery. A reduction in snoring/sleep apnoea was recorded after mandibular advancement.
5. In the short term orthognathic surgery causes pharyngeal dimensional changes, but in the majority of young and healthy subjects this has little effect on sleep quality.

In summary, the cephalometry indicates that the changes produced by the Class III bimaxillary surgery produces a shift in oropharyngeal characteristics to a morphology commonly associated with sleep apnoea. In the longer term, this may confer a predisposition to sleep disordered breathing, especially when these patients reach middle age and are more likely to exhibit other risk factors for sleep apnoea.

Further Work

A larger sample size will allow analysis of larger and more homogenous surgical groups, and further development and simplification of the sleep monitoring equipment is desirable in order to increase patient compliance. Longer term cephalometric assessment of the subjects will determine whether, in time, the original pharyngeal airway size and morphology is re-established after surgery.

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