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The role of lateral cephalometric radiography and fluoroscopy in assessing mandibular advancement in sleep-related disorders

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SUMMARY Mandibular advancement splints are successful in managing obstructive sleep apnoea (OSA) in selected subjects. For these to be effective, some improvement in the dimensions of the oropharyngeal airway must occur.

Twenty subjects with proven obstructive sleep apnoea were examined using lateral cephalometric radiography and a fluoroscopic technique. Cephalograms were analysed, and assessed for both skeletal and soft tissue abnormalities known to be present in OSA subjects. On the basis of these, a prediction was made as to whether the subject's oropharyngeal airway would increase during mandibular protrusion. From the fluoroscopic sequences, the narrowest antero-posterior dimensions of the post-palatal and post-lingual airways were recorded as the mandible moved from the intercuspal position into maximal protrusion. The changes in airway size were noted and these were compared with the predictions made from the static films.

In nine subjects, fluoroscopy indicated that the airway opened well during mandibular protrusion, seven did not improve and in four the changes were minimal. Post-palatally the mean airway increase was 2.6 mm, whilst behind the tongue a mean improvement of 3.1 mm was seen. In all but two instances, the cephalometric prediction agreed exactly with the outcome demonstrated by fluoroscopy. All subjects whose airways clearly increased were correctly identified by the cephalogram alone. Cephalometric features associated with a good airway response to protrusion were a reduced lower facial height, low maxillo-mandibular planes angle and a high hyoid position, accompanied by a normal antero-posterior relationship of the jaws, relatively normal mandibular body length and soft palate area. The more abnormal the skeletal and soft tissue dimensions, the poorer the prognosis.

Thus, whilst a single radiograph could indicate whether a positive mandibular response to protrusion could be expected, where doubt existed, a fluoroscopic analysis could provide a useful adjunct to diagnosis.

Introduction

Imaging of the upper airway and associated dentofacial structures has traditionally employed lateral cephalometric radiography and such techniques have also been applied to the investigation of craniofacial morphology in subjects with obstructive sleep apnoea (Jamieson *et al.*, 1986; Lowe *et al.*, 1986; Bacon *et al.*, 1988; de Berry-Borowiecki *et al.*, 1988). Characteristic differences have been described in skeletal, oral and pharyngeal dimensions between OSA subjects and their normal peers (Jamieson *et al.*, 1986; de Berry-Borowiecki *et al.*, 1988; Partinen *et al.*, 1988; Lyberg *et al.*, 1989). Such studies, whilst informative, possess the limitations of any two-dimensional radiographic procedure: changes which occur in the transverse dimension cannot be seen. However, cephalometry is readily available and associated with a relatively low dosage of radiation. Because subjects with sleep related disorders may have skeletal as well as pharyngeal abnormalities, it has been proposed that cephalometry may help to identify the patient in whom the structural anomalies contribute to airway obstruction (Ferguson *et al.*, 1995; Lowe *et al.*, 1995; Mayer and Meier-Ewert, 1995; Tangugsorn *et al.*, 1995).

A strong linear relationship between two-dimensional cephalometric and three-dimensional computer tomographic reconstructions of the tongue, soft palate, and naso-pharynx has been described, although such agreement is not apparent in the oro- and hypo-pharyngeal regions (Lowe, 1993). However, three-dimensional reconstructions cannot be justified routinely: they are expensive, of limited access and require relatively high doses of radiation.

Mandibular advancement splints are increasingly being considered as a possible therapeutic option for sufferers of mild to moderate obstructive sleep apnoea (Schmidt-Nowara *et al.*, 1995). The effectiveness of such devices is dependent upon forward movement of the tongue and soft palate, thus increasing the airway at these levels (Clark *et al.*, 1993; Lowe, 1993). Reported success rates vary, as do the authors' criteria for its achievement. If a reduction in the number of apnoeic events of 50 per cent or greater is adequate, then success rates as high as 87 per cent have been described (Clark *et al.*, 1993). Where fewer than 10 such occurrences per hour are equated with success, outcome rates vary from 46 to 71 per cent (Schmidt-Nowara *et al.*, 1995).

There is great diversity in appliance design and no precise criteria for deciding upon either the optimal degree of mandibular protrusion or the associated vertical opening (Bonham *et al.*, 1988; Schmidt-Nowara *et al.*, 1991; Clark *et al.*, 1993; O'Sullivan *et al.*, 1995). More importantly, there are no clear guidelines as to which subjects may be expected to benefit from mandibular advancement devices, reducing prescription to an *ad hoc* basis. This absence of prognostic information may explain the wide variations in success rates and underlines the need to identify why some individuals respond favourably and others do not (Lowe, 1993).

The position of the hyoid has been considered a prognostic indicator (Eveloff *et al.*, 1994; Yoshida, 1994), whilst cephalometric studies have also described predictors for the successful application of the Esmarch device (Yoshida, 1994; Mayer and Meier-Ewert, 1995). As there are no indications as to the precise design of this appliance (apart from considerable vertical opening), these theoretically derived data may not be universally applicable.

Fluoroscopy has been employed in investigations of upper airway obstruction (Suratt *et al.*, 1983) and to study adaptive patterns of behaviour in the oropharyngeal complex (Vig and Cohen, 1974). The dynamic effect of mandibular advancement on the adaptive patterns of behaviour of tongue, soft palate and airway have been described in a pilot study using high resolution fluoroscopy in the conscious, supine, OSA subject (L'Estrange *et al.*, 1996). This indicated a wide range of individual variation in the dimensional changes of the post-palatal and post-lingual airways in response to mandibular protrusion. Benefit was not apparent in all subjects, even at maximal protrusion and in such individuals, it was possible to identify a morphological basis for this. Where good airway responses were seen, it seemed reasonable to suggest that the subjects would benefit from the provision of a mandibular advancement splint. Whilst lack of antero-posterior improvement did not preclude some increase in the transverse plane, subjects who demonstrated no measurable enlargement in the airway were considered unlikely candidates for a dental device.

The morphological features of all subjects were examined in more detail by analysis of their lateral cephalometric radiographs. By comparing these measurements with those of normal adult males (Battagel and L'Estrange, 1996) it was possible to quantify the skeletal and soft tissue abnormalities in each subject. When the cephalograms were examined, the patients whose airways responded favourably to mandibular advancement seemed to possess different craniofacial morphologies from those who did not. Lowe (1993) suggested that it did not appear to be possible to predict sufficiently accurately, the success of a dental appliance based on anatomical considerations alone. In view of this, it seemed appropriate to investigate the matter further. The present study was therefore undertaken with the following aims:

(1) To examine the changes in oropharyngeal dimensions in the post-palatal and post-lingual regions in response to mandibular protrusion in subjects with known OSA, using a fluoroscopic technique.
(2) On the basis of these fluoroscopic findings, to decide whether the subject would be likely to benefit from a mandibular advancement splint.
(3) Without prior knowledge of the fluoroscopic results, to analyse the craniofacial and soft tissue parameters of the lateral cephalogram, and to forecast whether or not a splint could be used to advantage.
(4) To compare the results of these two approaches in order to assess the predictive possibilities of a single cephalometric film.

Materials and methods

Subjects

Twenty subjects with proven OSA, but who were unable to tolerate nasal continuous positive airway pressure (the standard treatment for this disorder) formed the basis for this study. All were adult white male Caucasians, referred from the Department of Thoracic Medicine for assessment with regard to their suitability for treatment with mandibular advancement splints. All individuals had undergone ENT assessment with nasopharyngoscopy and any necessary nasal corrective procedures had been completed.

Informed consent was obtained from all individuals and the study was carried out with the approval of the ethics committee of The Prince Charles Hospital, Brisbane, Australia.

Methods

Lateral cephalometric radiography. Lateral cephalometric radiographs were taken with the teeth in occlusion and following a standardized procedure. The subject was positioned in the cephalostat and the midline of the tongue painted with a thin layer of barium sulphate contrast medium to assist the identification of its contour. In order to fix the hyoid in a consistent position, the patient was requested to breathe in slowly and then exhale, holding the latter position whilst the film was exposed.

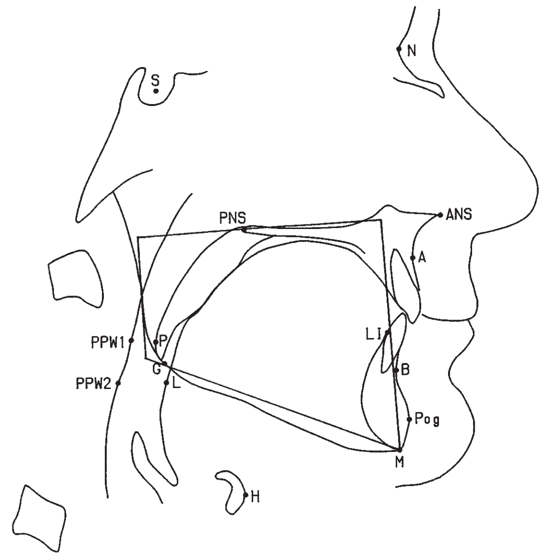

Figure 1 The cephalometric points recorded. Except where listed below, points, lines, and planes conformed to British Standard definitions (British Standard Institution, 1983). Hard tissue: A, point 'A'; ANS, anterior nasal spine; B, point 'B'; G, gonion (the point where the bisector of the angle between the posterior and lower mandibular border tangents meets the mandibular angle); H, the most anterior point on the hyoid bone; L, point on the posterior aspect of the tongue where the post-lingual airway is at its narrowest; LI, lingual gingival margin of the lower incisor; M, menton (the point of intersection of the lower mandibular border and the symphysial outline); N, nasion; P, point on the posterior aspect of the soft palate where the post-palatal airway is at its narrowest; PNS, posterior nasal spine; PPW1, point on the posterior pharyngeal wall where the post-palatal airway is at its narrowest; PPW2, point on the posterior pharyngeal wall where the post-lingual airway is at its narrowest; Pog, pogonion; S, sella. The trapezium outlined represents the intermaxillary space. This is bounded by the maxillary and mandibular planes, the posterior pharyngeal wall at the level of the occlusal plane and a perpendicular from the maxillary plane to menton.

Cephalometric analysis. Radiographs were traced, orientated with the maxillary plane horizontal and skeletal and soft tissue points identified (Figure 1). Definitions of the landmarks are

Table 1 Ages and occlusal and skeletal base relationships of the subjects.

Subject	Age (years)	Occlusion	SNA	SNB	ANB	Maxillo-mandibular planes angle	Lower face height (%)
1	35.5	Cl. I	78.1	78.9	–0.8	16.8	54.1
2	55.4	Cl. I	85.6	81.0	2.8	23.2	56.3
3	26.0	Cl. II div 1	79.4	71.8	7.6	36.9	55.5
4	45.0	Cl. I	83.4	81.3	2.1	20.7	56.3
5	65.5	Cl. I	87.1	81.8	3.1	23.0	55.1
6	51.0	Cl. I	79.0	85.3	–6.3	15.1	56.5
7	55.0	Cl. I	78.5	79.0	–0.5	19.2	53.6
8	37.3	Cl. III	82.4	84.2	–1.8	17.7	54.7
9	64.8	Cl. II div 1	80.8	75.6	5.2	23.6	54.5
10	42.7	Cl. II div 1	79.9	75.4	4.6	37.8	58.7
11	49.0	Cl. II div 1	80.0	72.8	7.2	41.8	61.7
12	62.4	Cl. II div 1	81.0	75.2	5.8	26.4	57.3
13	36.2	Cl. II div 1	78.9	73.5	5.5	32.9	58.5
14	54.6	Cl. I	78.8	78.5	0.3	20.5	51.7
15	39.2	Cl. II div 1	88.1	76.6	7.6	34.8	57.7
16	48.9	Cl. II div 1	82.4	76.9	5.5	36.5	56.4
17	61.5	Cl. II div 1	91.0	87.9	–0.4	24.3	59.5
18	50.2	Cl. II div 1	81.5	74.0	7.4	33.6	56.6
19	43.7	Cl. I	82.7	81.4	1.3	27.2	55.9
20	50.4	Cl. I	74.7	70.7	6.0	32.8	56.6

given in the accompanying legend. Points were digitized twice in a predetermined sequence to a tolerance of 0.2 mm and the mean value taken. The soft tissue outlines of the tongue and soft palate were registered. The following measurements were made: position of the maxilla (SNA); position of the mandible (SNB); mandibular body length (gonion to menton); maxillo-mandibular planes angle; lower anterior face height expressed as a percentage of total face height; vertical distance of hyoid to mandibular plane; the narrowest dimensions of the oropharyngeal airway behind the soft palate and tongue; the area of the soft palate as viewed in sagittal section; tongue proportion (the area of the tongue viewed in sagittal section as a percentage of the intermaxillary space). Intermaxillary space is delineated as described by Vig and Cohen (1974), that is by the trapezium drawn through the maxillary and mandibular planes, the posterior pharyngeal wall at the level of the occlusal plane and a perpendicular from the maxillary plane to menton, as shown in Figure 1. All measurements were converted to life size. The ages, occlusal and skeletal relationships of the subjects are shown in Table 1.

From a pilot fluoroscopic investigation, certain morphological features were considered to have particular prognostic significance. Subjects showing a reduced lower facial height, low maxillo-mandibular plane angle and high hyoid position appeared to have facial morphologies associated with a good increase in pharyngeal dimensions. Where splints were constructed for such subjects, the response had been favourable. Conversely, those individuals with an increased lower face height, high maxillo-mandibular planes angle, short mandibular body and a low hyoid were thought unlikely to benefit from splint construction. Where both soft tissue and skeletal measurements were outside the normal ranges, the prognosis for airway improvement in response to mandibular protrusion was poor. Favourable and unfavourable combinations of the parameters examined are given in Table 2.

Fluoroscopy. Fluoroscopy of the upper airway was performed using a 'Philips' H3000 digital cardiac imaging system with an MRC tube (Philips Medical Systems, Best, The Netherlands). The patient was placed in a supine position on the angiographic table with the head supported

Table 2 Basis for prediction from lateral cephalometric radiograph.

Favourable	Unfavourable
Low maxillo-mandibular planes angle	High maxillo-mandibular planes angle
Low lower face height (%)	Increased lower face height (%)
High position of hyoid	Low, posterior hyoid position
Normal position of maxilla	Posteriorly positioned maxilla
Normal position of mandible	Retrusive mandible
Normal mandibular body length	Short mandibular body
Normal soft palate area	Long, thick soft palate
Normal tongue proportion	Large tongue proportion
Relatively normal post-palatal airway at its narrowest dimension	Reduced post-palatal airway at its narrowest dimension
Relatively normal post-lingual airway	Reduced post-lingual airway

on a pillow. The head orientation was adjusted so that a lateral projection was achieved in which bilateral structures were accurately superimposed.

Recordings were commenced with the teeth in the intercuspal position. The patient was instructed to slide the mandible forwards, keeping the teeth together, until maximal protrusion was reached. The sequence was performed at mid-inhalation and subjects were requested not to swallow during the procedure. All fluoroscopic sequences were undertaken by the radiographer in charge of the angiography unit (B.H) after careful instruction in the technique. Both he and one of the authors (P.L'E) were present at, and jointly responsible for, each fluoroscopic procedure. Recording was performed at 4 frames per second, permitting registration of all adaptive movements, whilst minimizing the radiation dosage. This was set at 0.075 mSv/frame. All patients wore a protective lead apron and lead glasses to safeguard their eyes. Whilst it would have been ideal to record duplicate fluoroscopic sequences, it was considered more important to minimize the dosage of ionizing radiation; thus, only a single run was obtained. At the end of each fluoroscopic sequence, a calibration bar marked in one centimetre steps was placed in the mid-sagittal plane and a single frame recorded. This allowed calculation of the magnification associated with the procedure (this differed slightly between subjects) and permitted all measurements to be converted to life size.

Fluoroscopic analysis

Data for airway dimensions at each distinct position of the mandible were recorded for each subject to the nearest 0.5 mm. As measurements were performed on a high resolution viewing screen, a transparent, flexible ruler was considered appropriate. This afforded close adaptation of the ruler to the slight curvature of the monitor, facilitating the measuring process. All calculations were rounded to one significant figure. Graphs were plotted of both retro-palatal and post-lingual oropharyngeal airway dimensions against forward mandibular movement. Initial and final dimensions of the airway were recorded for both sites and the amount of enlargement associated with protrusion was calculated (Tables 3 and 4). Finally, bar charts were drawn, illustrating the changes in both post-palatal and post-lingual dimensions for each subject (Figure 2).

Where a 2-mm or more increase in airway dimensions was seen at both post-palatal and post-lingual sites, and the airways in protrusion measured at least 5 and 10 mm, respectively, it was considered that the response was favourable and that a mandibular advancement splint would be of therapeutic benefit. Where less than a 1-mm improvement was noted, whether this was at one site or both, the subject was considered unsuitable for splint therapy. These criteria were agreed by two clinicians with experience in the cephalometry of sleep disorders and in the provision of mandibular advancement splints.

Table 3 Post-palatal airway dimensions as determined by fluoroscopy.

Subject	Airway at start (mm)	Airway in maximum mandibular protrusion (mm)	Difference (mm)
1	5.0	8.8	3.8
2	5.3	8.8	3.5
3	1.3	6.6	5.3
4	2.2	6.3	4.1
5	0.0	0.0	0.0
6	1.2	7.9	6.7
7	3.9	7.1	3.2
8	5.0	8.4	3.4
9	5.0	7.9	2.9
10	2.1	4.2	2.1
11	1.5	1.5	0.0
12	0.7	1.0	0.3
13	2.9	8.1	5.9
14	2.2	8.1	5.9
15	5.0	3.4	–1.6
16	4.5	3.9	–0.7
17	0.7	0.0	–0.7
18	2.9	7.9	5.0
19	1.3	3.1	1.9
20	1.2	2.4	1.2
Mean	2.9	5.5	2.6

Table 4 Post-lingual airway dimensions as determined by fluoroscopy.

Subject	Airway at start (mm)	Airway in maximum mandibular protrusion (mm)	Difference (mm)
1	8.8	15.3	6.5
2	9.7	14.4	4.7
3	2.0	2.7	0.7
4	8.8	11.8	3.0
5	5.6	8.1	2.5
6	6.1	11.8	5.7
7	9.6	14.6	5.0
8	13.1	14.7	1.6
9	7.5	12.9	5.4
10	7.1	10.0	2.9
11	8.1	9.6	1.5
12	8.0	9.3	1.3
13	7.1	13.6	6.5
14	11.1	17.0	5.9
15	10.6	9.4	–0.3
16	4.5	3.9	–0.7
17	5.2	7.7	1.6
18	3.8	6.5	2.7
19	5.6	6.9	1.3
20	4.2	9.1	4.9
Mean	7.4	10.5	3.1

Comparison of fluoroscopic and cephalometric analyses

Predictions from the cephalometry and the results of the fluoroscopy were compared (Table 5). The agreement between the two techniques is given in the last column.

Method error

All cephalograms were retraced and random method error assessed as described by Dahlberg (1940). Systematic error was determined as suggested by Houston (1983). Errors ranged from 0.4 cm^2 for the area of the soft palate seen in sagittal section, to 1.7 mm for the antero-posterior width of the post-lingual airway. No systematic errors were detected.

The fluoroscopic sequences were also remeasured and where recordings differed by more than 0.5 mm, the procedure was repeated until two satisfactory readings had been obtained. A mean

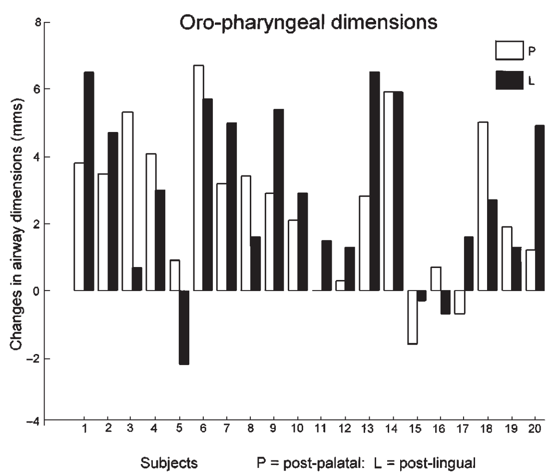

Figure 2 Bar charts showing the alterations in post-palatal and post-lingual airways in response to mandibular protrusion for all 20 subjects. Post-palatal changes are given on the left and post-lingual alterations are shown on the right of each pair of bars. A wide range of individual variation is apparent.

Table 5 Comparison of the suggested airway response from lateral cephalometric radiographs with the reaction seen using fluoroscopy. Where there was complete agreement between the cephalometric prediction and the fluoroscopic response, 'Yes' was entered in the final column.

Subject	Cephalometric prediction			Results of fluoroscopy			Agreement
	Likely	Doubtful	Unlikely	Likely	Doubtful	Unlikely	
1	*			*			Yes
2	*			*			Yes
3			*			*	Yes
4	*			*			Yes
5			*			*	Yes
6	*			*			Yes
7	*			*			Yes
8	*			*			Yes
9	*			*			Yes
10		*			*		Yes
11			*			*	Yes
12			*			*	Yes
13	*			*			Yes
14	*			*			Yes
15			*			*	Yes
16			*			*	Yes
17		*				*	Partial
18		*			*		Yes
19		*			*		Yes
20			*		*		Partial

of the two measurements was used in the calculations.

Results

Cephalometry (Tables 1 and 5, columns 1–3)

From the criteria listed in Table 2, each subject's likely response to mandibular advancement was assessed. Subjects were categorized as likely, doubtful or unlikely to benefit from mandibular advancement, and the results are presented in columns 1–3 of Table 5. Nine individuals were thought to have favourable skeletal anatomies and soft tissues which would be likely to respond sufficiently to mandibular advancement to enlarge the oropharyngeal airways. In four subjects the response was considered to be doubtful and for the remaining seven it was considered that no helpful response would be elicited.

Fluoroscopy (Tables 3 and 4, Table 5, columns 4–6, Figure 2)

The dimensions of the post-palatal airway in the intercuspal position (column 1) and maximally protruded positions (column 2) are given in Table 3. Column 4 indicates the difference between the two positions, i.e. the increase in airway dimensions achieved. The data for the post-lingual region are presented in Table 4. The changes in airway dimensions brought about by maximal protrusion are illustrated graphically in Figure 2.

The minimum post-palatal airway, with the teeth in the intercuspal position, varied between 0.7 and 5.0 mm (mean 2.9 mm), with a range at maximal protrusion of 0.0 to 8.8 mm (mean 5.5 mm). Individual responses varied from 1.6 mm of reduction to 5.9 mm increase in airway dimensions (mean 2.6 mm). Subjects with the greatest mandibular protrusion did not necessarily demonstrate the best airway responses because of the varying sizes of the soft palates. In the subjects where no post-palatal response was seen, the soft palates were excessively thick, and extensible with their tips capable of simultaneous contact with both the posterior pharyngeal wall and the postero-superior surface of the tongue.

Table 4 shows the data for the post-lingual airway. The range here was greater, with the largest values being within normal limits: figures ranged from 2.0 to 13.1 mm with a mean of 7.4 mm. The degree of airway improvement in response to mandibular protrusion was similar to that seen in the post-palatal region. This varied from –0.7 to 6.5 mm with a mean of 3.1 mm. Airways with the lower jaw held as far forwards as possible ranged from 2.7 to 17.0 mm (mean 10.5 mm). Again, there was no relationship between the initial airway dimension and the response to protrusion. Subject 8, whose post-lingual dimensions were initially within normal limits, showed little further improvement.

Comparisons between cephalometry and fluoroscopy (Table 5)

In 18 out of the 20 cases, complete agreement was achieved: all nine subjects who had been considered suitable from their cephalometry responded well during fluoroscopy. Three subjects were grouped as doubtful responders by both techniques (subjects 10, 18, 19). Of the seven subjects whose fluoroscopic results suggested that they would not respond to advancement splints, six were similarly classified cephalometrically (subjects 3, 5, 11, 12, 15, 16). It was considered that the remaining two individuals (17 and 20) would not respond but whether this was unlikely or only doubtful was indeterminate.

Figures 3 and 4 illustrate the concordance between the two techniques. The radiograph in Figure 3a shows the typical skeletal proportions of a subject expected to respond well, and in whom there were no grossly abnormal soft tissue factors. This was subject 6, the patient with the best overall airway response to mandibular advancement. The film demonstrates a low lower face height, a low maxillo-mandibular planes angle, and a Class I skeletal relationship of the upper and lower jaws. Hyoid position is high. The mandibular body is not unduly short and neither the soft palate nor the tongue is excessively large. Despite this, the initial post-palatal and post-lingual airways were below the mean recorded (Figure 3b, top). The improvement in the airways at full protrusion is shown in the lower portion of Figure 3b.

By contrast, Figure 4 depicts the fluoroscopic response of subject 11 where the airway improvements were negligible: zero post-palatally and 1.5 mm in the post-lingual region. The lower facial height is grossly increased and the maxillo-mandibular planes angle is high with the mandible being both short and markedly retrusive. The hyoid is exceptionally low. The soft palate is large and long and the tongue extends vertically over a considerable area to reach its attachments to the hyoid bone.

Discussion

The response of the airway to mandibular protrusion, recorded by fluoroscopy

In theory, mandibular protrusion will bring both the tongue and attached hyoid further forwards. Because a posterior oral seal is normally present between the soft palate and tongue, lingual advancement is accompanied by synchronous forward movement of the soft palate, the soft tissues acting as a single entity. Protrusion cannot be achieved without some concomitant opening and it is important that appliances do not rotate the mandible downwards and back (Lowe, 1994). If this occurs in the presence of hypopharyngeal narrowing, the sleep apnoea will worsen and it is possible that this has contributed to the appliance failures reported in some studies. Whilst fluoroscopy permits an assessment of the changes in airway dimensions in the conscious subject, it does not identify the exact site of the obstruction during sleep.

Only nine out of the 20 subjects in this study showed obvious improvement in both post-palatal and post-lingual airways. This proportion could be criticized in that the airway was examined at maximum mandibular protrusion and this might not be a tolerable position in which to construct a splint in the first instance (Eveloff

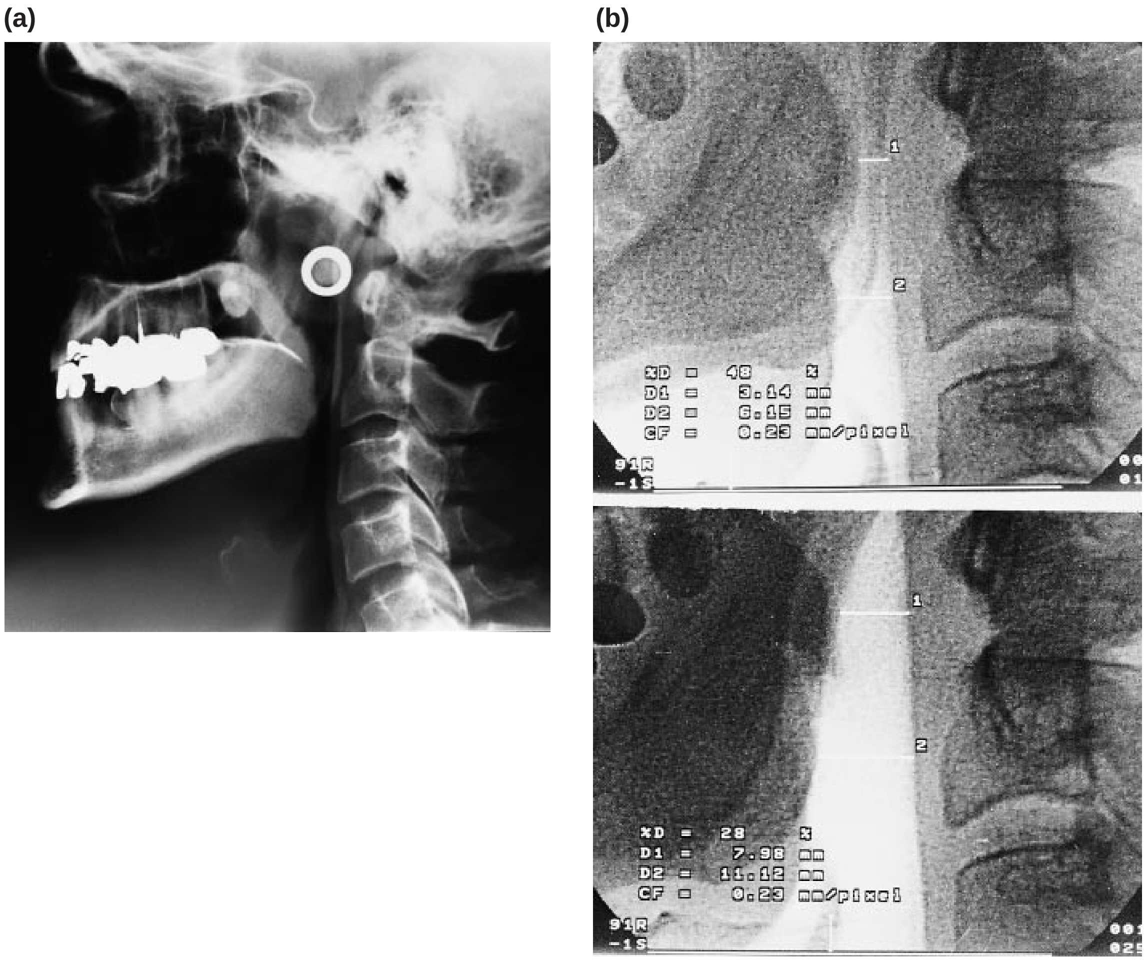

Figure 3 (a) Lateral cephalometric radiograph of subject 6, whose airway response to mandibular protrusion shown by fluoroscopy, was very favourable (see Figure 2). The radiograph shows a low lower facial height and maxillo-mandibular planes angle, and a lower jaw which is at least as protrusive as the upper. The hyoid position is high. The mandibular body is not unduly short, and neither the soft palate nor the tongue is excessively large. (b) Freeze frames from the fluoroscopic sequence. Above: in the intercuspal position both post-palatal and post-lingual airways are reduced. Below: the airway dimensions have almost doubled in full mandibular protrusion.

et al., 1994). Seventy-five per cent of maximum protrusion is normally recommended (Clark *et al.*, 1994; O'Sullivan *et al.*, 1995). However since work by Lowe *et al.* (1995) has indicated that progressive advancement allows eventual positioning of the jaw in advance of its original maximal protrusion, the fluoroscopic assessment may well be realistic. Indeed, subjects who fail to demonstrate adequate airway enhancement because they have very limited initial protrusion, may respond where progressive advancement is undertaken.

The response rate: comparisons with other studies

The success of mandibular advancement splints to control OSA varies widely between studies. Using the most stringent criterion, 10 or less apnoeic events per hour, success rates vary between 46 and 71 per cent (Schmidt-Nowara *et al.*, 1995). The 45 per cent response of the airway to mandibular advancement found in this study equates with the lower end of this range. If fluoroscopy were an indicator of appliance success, it might be expected that the proportion of

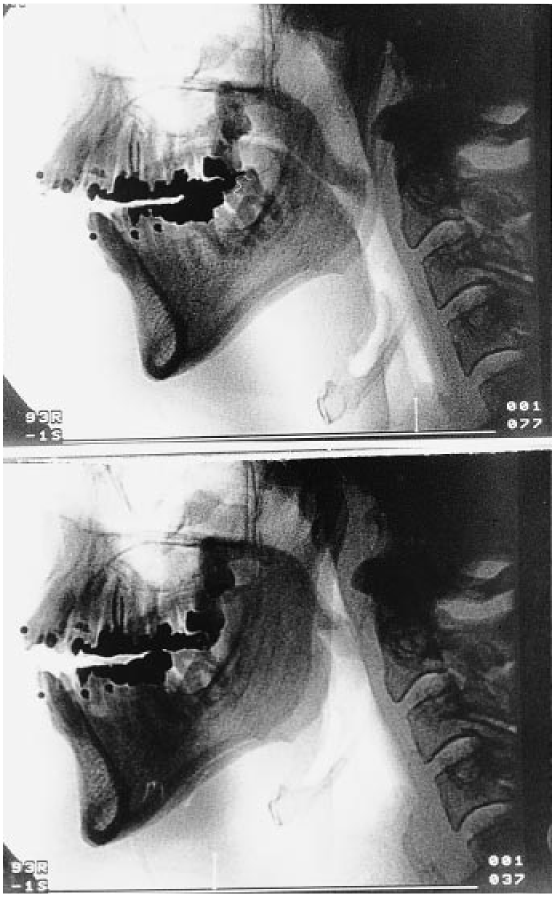

Figure 4 Frames from the fluoroscopic sequence of subject 11, whose airway response to mandibular protrusion was virtually nil. Above: the airway with the mandible in the intercuspal position and below: the airway in full mandibular protrusion. The tip of the soft palate remains in contact with the posterior pharyngeal wall in both positions. The films show a grossly increased lower facial height and maxillo-mandibular planes angle. The mandibular body is extremely short and the lower jaw markedly retrusive. The hyoid is extremely low. The soft palate is large and long and the tongue extends vertically for a considerable distance.

subjects responding would equal the number of individuals in trials with no preselection criteria, who benefited from an advancement splint. In a larger investigation, in which subjects had been randomly allocated, this would probably be true. However, the individuals reported here, were not an unbiased sample: all had failed to cope with nasal continuous positive airway pressure, and some had also refused, failed to respond to, or were considered poor risks for, various surgical procedures. Thus, a splint was being considered as a last resort.

It should be noted that a favourable airway response indicated by fluoroscopy merely suggests that a splint is likely to be effective. However, there is no unanimity amongst authors as to whether an increase in either the post-palatal or post-lingual airway spaces occurs when a splint is being worn for a therapeutic effect. An improvement in posterior airway space (equivalent to the post-lingual dimension in this study) was recorded by Schmidt-Nowara *et al.* (1991), but not seen in studies by Bonham *et al.* (1988) or Eveloff *et al.* (1994). Superior (post-palatal) airway space also increased (Bonham *et al.*, 1988). Despite the inconclusive contribution of posterior airway space, this dimension was included in predictive regression equations for appliance success by both Eveloff *et al.* (1994), and Mayer and Meier-Ewert (1995). This suggests that the mechanism of treatment may be more complex than a simple cause and effect relationship between the mandible, soft palate, and tongue. It lends support to the contention that different subjects will react differently, depending on their overall facial anatomy, that the position of the hyoid could be influential, and that the effects of any splint will be also dependent upon its design. Where the measurements quoted are part of a regression equation, this relates to a single, selected group. That these results have not been easily replicated, underlines the complexity, and uncertainty of theoretical predictions on relatively small groups of patients.

Features of the subjects who failed to respond

Six subjects failed to show an appreciable response of the airway to mandibular protrusion (Figure 2). Most showed small airway dimensions which did not improve or altered only a little. In some the minimum dimension reduced due to alterations in shape of either the soft palate or tongue. Despite these variations, it was apparent from the fluoroscopy that these individuals possessed certain features in common.

Skeletal disharmonies were accompanied by excessively long, thick and flexible soft palates. These seemed capable of altering their shape considerably, whilst still maintaining contact with the tongue. Thus, whilst the main body of the soft palate remained in contact with the advancing tongue, the lower portion did not alter its relationship with the posterior pharyngeal wall. This finding would appear to support observations that a short soft palate was an indicator of splint success (Yoshida, 1994; Mayer and Meier-Ewert, 1995).

Associated skeletal anomalies were increased lower facial height, high maxillo-mandibular planes angle, and an abnormally low position of the hyoid. These were accompanied by a short, retrusive mandible. This vertical facial disproportion cannot respond to mandibular protrusion. Protrusion gives a positive response where the primary movement required is in the antero-posterior direction, but when there is a vertical problem, the tongue is unable to move both vertically and forward. Although the hyoid did move antero-superiorly during mandibular protrusion, it started from such an inferior position that even maximal elevation was insufficient to bring the base of the tongue away from the pharyngeal wall.

Whilst a low position of the hyoid has been recognized as a characteristic of OSA subjects in numerous cephalometric studies (Jamieson *et al.*, 1986; de Berry-Borowiecki *et al.*, 1988; Partinen *et al.*, 1988), the diagnostic and prognostic features of this phenomenon have received less attention (Eveloff *et al.*, 1994). The observations in this study support the data suggesting that an inferiorly positioned hyoid is associated with a poor response to splint therapy (Eveloff *et al.*, 1994; Yoshida, 1994). The importance of a low hyoid position in the management of OSA has been recognized by Riley *et al.* (1989, 1990); in their surgical approach to treatment, the bone may be repositioned anteriorly.

The agreement between the two approaches

The morphological features associated both with the best and poorest responses on the fluoroscopic traces were best identified on the cephalometric films. It would appear therefore, that useful prognostic information is available from a single cephalometric radiograph, despite the fact that this was recorded in the upright rather than in the supine position. The subjects at both ends of the response spectrum were clearly identified from the cephalogram alone. The relationship between form and function becomes apparent: the results of this study offer support for the existence of an association between form, function, and a predictive response. Further work on the spatial relationship of the hyoid and its dynamic functional movements, both in normal and OSA subjects, may be informative.

Further work

Studies are under way to test the validity of this diagnostic approach, constructing splints for all subjects, regardless of the predictions. Their results will be the subject of a future communication.

Conclusions

1. High resolution fluoroscopy offers a means of studying the response of the oropharynx to mandibular advancement.
2. From this limited appraisal of the face, certain features were identified in subjects who demonstrated a favourable response. Equally, where these characteristics were reversed, little or no response was observed.
3. These features could be identified rather better from a single lateral cephalometric radiograph of the same subject even though this had been taken in the upright position.
4. Although all good responders were easy to identify from the cephalogram, those towards the other end of the spectrum were not as readily distinguished. For these subjects, fluoroscopy is recommended: for the majority of individuals this expensive investigation should be unnecessary.

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