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Surgical mandibular advancement and changes in uvuloglossopharyngeal morphology and head posture: a short- and long-term cephalometric study in males

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SUMMARY The aim of the present study was to investigate, by means of an extensive cephalometric examination, the alterations which took place in hyoid bone position, head posture, position and morphology of the soft palate, and tongue and sagittal dimensions of the pharyngeal airway after mandibular advancement osteotomy for the correction of mandibular retrognathism. The sample consisted only of adult males who underwent mandibular advancement by bilateral sagittal ramus split osteotomy (BSRO) with rigid fixation. Profile cephalograms were obtained 1–3 days before surgery (20 subjects), and 6 months (20 subjects) and 3 years (19 subjects) after the surgery. Statistical evaluation was performed by paired Student's *t*-test and Pearson product moment correlation analysis.

At the short-term follow-up, hyoid bone and vallecula assumed a more superior (AH⊥FH, AH⊥ML, AH⊥S, V⊥FH) and anterior position (AH–C3 Hor, V–C3), which was maintained at the long-term follow-up. The soft palate (NL/PM–U) became more upright at the short-term follow-up. The tongue demonstrated a transient increase in height (H⊥VT) and a less upright position (VT/FH) at the long-term observation. In addition, a more upright cervical spine (OPT/HOR, CVT/HOR) was recorded at the long-term follow-up. The pharyngeal airway space at the level of the oropharynx (U–MPW) and the retroglossal space at the base of the tongue (PASmin) showed an increase in the sagittal dimension at the short-term follow-up. Significant widening at the PASmin level was sustained at the long-term follow-up, indicating that mandibular advancement osteotomy could increase airway patency and be a treatment approach for sleep apnoea in selected patients.

Introduction

Orthognathic surgical procedures designed to correct dentofacial anomalies and deformities affect the size and position of surrounding soft tissues by altering the pre-existing soft/hard tissue relationship (Greco *et al*., 1990). Mandibular advancement osteotomy has been reported to influence the position of the hyoid bone (Schendel *et al*., 1978; LaBanc and Epker, 1984; Hayes *et al*., 1994), and consequently tongue position, pharyngeal airway morphology (Farole, 1990; Yu *et al*., 1994), and head flexion (Schendel *et al*., 1978; Valk *et al*., 1992).

Obstructive sleep apnoea (OSA) is a potentially life-threatening disorder caused by repetitive narrowing and occlusion of the upper airway during sleep, and has been associated with loud snoring, excessive daytime sleepiness, intellectual deterioration, hypertension, right heart failure, and cardiac arrhythmias. A narrow upper airway and other predisposing or aetiological factors, such as craniofacial deformity, mandibular retrognathia or micrognathia, muscular hypotony, sleep posture, fatty depositions in the soft tissue of the upper airway, gender, and age, have been reported (Valero and Alroy, 1965; Tammeling *et al*., 1972; Coccagna *et al.*, 1978; Guilleminault *et al.*, 1984; Cote, 1988; Fujita, 1993; Miles *et al.*, 1996). This occurs with an incidence of 1–3 per cent among people of modern civilized countries (Gislason *et al.*, 1988).

Computerized tomography (Haponik *et al.*, 1983; Lowe *et al.*, 1986; Lowe and Fleetham, 1991), magnetic resonance (MR) scans (Horner *et al.*, 1989), but above all cephalometric radiography (Riley *et al.*, 1983; Djupesland *et al.*, 1987; Lyberg *et al.*, 1989b; Tangugsorn *et al.*, 1995) have been widely utilized for documentation of aberrations related to uvuloglossopharyngeal morphology connected with OSA. Crumley *et al.* (1987), using rapid cine-computed tomography scans, demonstrated that the base of the tongue and soft palate commonly contributed to the airway obstruction associated with this disorder.

Recent studies have shown that during episodes of OSA the site of airway narrowing is located either in the oropharyngeal (Riley *et al.*, 1985; Solow *et al.*, 1996) or the hypopharyngeal region (Surrat *et al.*, 1983; Shepard and Thawley, 1985; Morrison *et al.*, 1993).

Different treatment approaches have been used for OSA patients including mandibular advancement (Kuo *et al.*, 1979; Bear and Priest, 1980; Riley *et al.*, 1984, 1989), maxillomandibular advancement (Waite *et al.*, 1989; Riley *et al.*, 1990; Hochban *et al.*, 1994) or mandibular repositioning appliances (George, 1987; Bonham *et al.*, 1988; Athanasiou *et al.*, 1994).

Mandibular advancement leads to advancement of the suprahyoid and tongue muscles as the hyoid bone is attached to the mandible via the geniohyoid, anterior digastric, and mylohyoid muscles (Wickwire *et al.*, 1972). Consequently, the position of the base of the tongue is dictated by the position of the mandible and hyoid bone. The changes in the position of the hyoid bone are determined by the conjoint action of the supra- and infra-hyoid muscles, and the resistance provided by the elastic membranes of the larynx and trachea (Fromm and Lundberg, 1970; Bibby and Preston, 1981).

Several studies and reports have shown that following mandibular advancement surgery the hyoid bone initially responded with a forward movement with a subsequent return to the pre-operative position (Schendel *et al.*, 1978; LaBanc and Epker, 1984). Other studies, such as Hayes *et al.* (1994), described a superior movement of the hyoid with only a slight anterior component resulting in a more stable position. In addition, flexion of the head was recorded, however, with a tendency to return to the pre-operative position in the follow-up, but without fully reaching the starting point (Schendel and Epker, 1980; Valk *et al.*, 1992). Head posture (Gustavsson *et al.*, 1972; Winnberg *et al.*, 1988) and changes in the inclination of the mandible (Graber, 1978; Tallgren and Solow, 1987) have been found to influence the position of the hyoid bone. In addition, it has been shown that the hyoid cervical distance exhibits less variability than the hyoid relationship to the skull and mandible (Fromm and Lundberg, 1970; Bibby and Preston, 1981; Tallgren *et al.*, 1983), and according to Tallgren and Solow (1987) the hyoid position is co-ordinated both with facial morphology, and head and cervical posture.

As reported previously, surgical advancement of the mandible can be a treatment modality for OSA patients (Bear and Priest, 1980; Kuo *et al.*, 1979; Riley *et al.*, 1984, 1990). Cephalometric studies of patients subjected to mandibular advancement have shown an increase in the anteroposterior dimension of the pharyngeal airway space, but in an unpredictable way (Farole, 1990; Yu *et al.*, 1994).

Planning successful treatment for the correction of anatomic abnormalities of the upper airway by surgical advancement of the mandible depends on extensive knowledge of pharyngeal airway space, and morphology, hyoid bone, and tongue position changes induced by the advancement surgery. However, there is limited scientific evidence concerning the above-mentioned changes after mandibular advancement (Farole, 1990; Yu *et al.*, 1994; Schendel *et al.*, 1978; LaBanc and Epker, 1984).

The aim of this investigation was to conduct an extensive cephalometric evaluation of the alterations that take place in the pharyngeal airway space and morphology, hyoid bone and tongue position, and head posture after mandibular advancement surgery for the correction of mandibular retrognathism.

Subjects and methods

The subjects comprised 20 adult male patients with mandibular retrognathism treated by bilateral sagittal ramus osteotomy (BSRO) with rigid fixation for mandibular advancement. The subjects were selected from the files of patients at the Orthodontic Department, University of Oslo and the Department of Maxillofacial Surgery, Ullevaal University Hospital, Oslo. They had all undergone pre- and post-operative orthodontic treatment to eliminate the dento-alveolar compensation due to basal discrepancy, and to co-ordinate the dental arches in order to establish maximum inter-cuspation in the post-operative occlusion.

Lateral cephalometric radiographs were taken 1–3 days prior to the operation (T0), and approximately 6 months (T1) and 3 years (T2) after surgery. At the long-term follow-up (T2) only 19 radiographs were available. The mean age at time when profile radiographs were taken is given in Table 1.

Cephalometric analysis

All lateral cephalograms were taken using a Lumex B (Siemens Norge A/S, Oslo, Norway) cephalostat with intensifying screen and motorized adjustable grid. The KVP (peak kV) was adjusted to optimize the contrast of both hard and soft tissues. The distance from the focus to the median plane was 180 cm and the median plane to film distance was 10 cm. The enlargement was 5.6 per cent, which was not corrected. The subject was seated with the median plane parallel to the film with maximal inter-cuspation of the teeth and lips in light contact, and in the natural head position (Moorrees and Kean, 1958). A possible lateral head tilt or rotation was prevented by means of a cross-light beam projected onto the face, and finally bilateral ear rods were gently inserted into the external part of the auditory canal to stabilize the head posture during exposure. The reference points and lines used in this analysis are given in Figures 1–5.

The definitions have been described in previous papers (Solow and Greve, 1979; Lyberg *et al.*, 1989a,b). Some unfamiliar landmarks and measurements are described below.

Table 1 Age distribution of the subjects.

		Mean	SD	Range
T0	Initial (n = 20)	26.27	7.68	17.33–43.58
T1	1st follow-up (n = 20)	26.79	7.67	17.91–44.16
T2	2nd follow-up (n = 19)	29.43	8.03	20.41–46.16

1. Landmarks (Figures 1 and 4)

aa: anterior atlas, representing the most anterior point of atlas.

AH: anterior hyoid, representing the most antero-superior point on the body of the hyoid bone.

C2, C3: cervical vertebrae 2 and 3, representing the most antero-inferior point of the cervical vertebral bodies.

p: palate, representing the most cranial point of the palatal vault relative to the occlusal line (OL).

GE: the genial tubercle, representing the most posterior point of the mandibular symphysis and the antero-inferior part of the tongue.

H: the most superior point of the tongue in relation to the line from V to T.

LPW: lower pharyngeal wall, intersection of a perpendicular line from V with the posterior pharyngeal wall.

MPW: middle pharyngeal wall, intersection of a perpendicular line from U with the posterior pharyngeal wall.

T: the tip of the tongue.

UPW: upper pharyngeal wall, intersection of the pm–ba line and the posterior pharyngeal wall.

V: vallecula, the intersection of epiglottis and the base of the tongue.

U: tip of the uvula, the most postero-inferior point of the uvula.

2. Linear measurements (Figures 2 and 4)

AH–C3 Hor: the horizontal distance measured parallel to the Frankfort horizontal plane (FH) from the hyoid bone

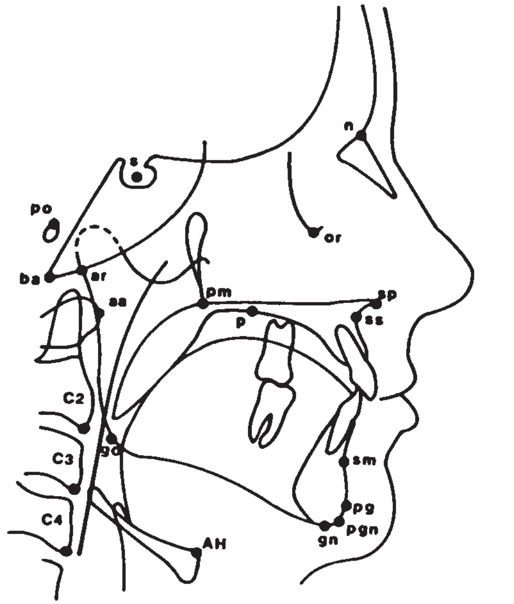

Figure 1 Cervico-craniofacial skeletal reference points used in this study. aa: anterior atlas; ar: articulare; ba: basion; C2, C3, C4: cervical vertebrae 2, 3, and 4; gn: gnathion; go: gonion; n: nasion; or: orbitale; p: palate; pg: pogonion; pgn: prognathion; pm: pterygomaxillare; po: porion; s: sella; sm: supramentale; sp: spinale; ss: subspinale; AH: anterior hyoid (Lyberg *et al*., 1989a).

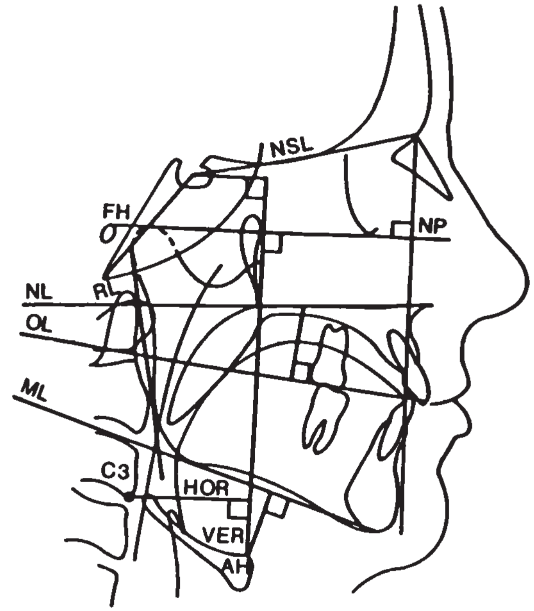

Figure 2 Reference lines used in this study. FH: Frankfort horizontal line; ML: mandibular line; NL: nasal line; NP: nasion perpendicular; OL: occlusal line; NSL: nasion–sella line; RL: ramus line; AH–C3 Hor: horizontal position of hyoid bone related to the third cervical vertebra; AH–Cr Ver: vertical position of hyoid bone related to the third cervical vertebra (Lyberg *et al*., 1989a).

(AH) to the third cervical vertebra (C3).

AH–C3 Ver: the vertical distance measured perpendicular to the Frankfort horizontal plane (FH) from the hyoid bone (AH) to the third cervical vertebra (C3).

AH⊥FH: the vertical distance measured perpendicular to the Frankfort horizontal plane (FH) from the hyoid bone (AH) to the Frankfort horizontal plane (FH).

AH⊥ML: the perpendicular distance from the hyoid bone (AH) to the mandibular line (ML).

AH–s Ver: the vertical distance measured perpendicular to the Frankfort horizontal plane (FH) from the hyoid bone (AH) to sella (s).

p⊥OL: the perpendicular distance from the occlusal line to the most cranial point of the palatal vault (p), the height of the hard palate.

pm–aa: the length of the lower bony nasopharynx.

pm–ba: The length of the upper bony nasopharynx.

V–T: the distance from V to T, representing the tongue length, and also the long axis of the tongue.

H ⊥ VT: the perpendicular distance from H to the line connecting V and T, representing the tongue height.

pm–UPW: the distance from pm to UPW, representing the nasopharyngeal airway space.

U–MPW: the distance from U to MPW, representing the oropharyngeal airway space.

V–LPW: the distance from V to LPW, representing the hypopharyngeal airway space.

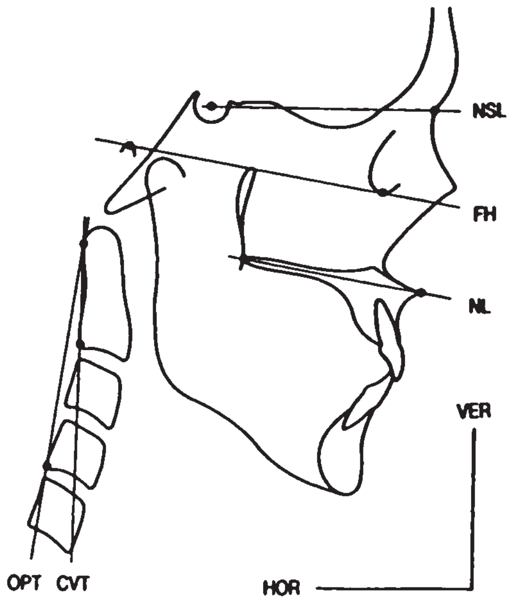

Figure 3 Reference points and lines used to study head posture. NSL: nasion–sella line; FH: Frankfort horizontal line; NL: nasal line; OPT: odontoid process tangent; CVT: cervical vertebra tangent; VER: true vertical; HOR: true horizontal (Solow and Greve, 1979).

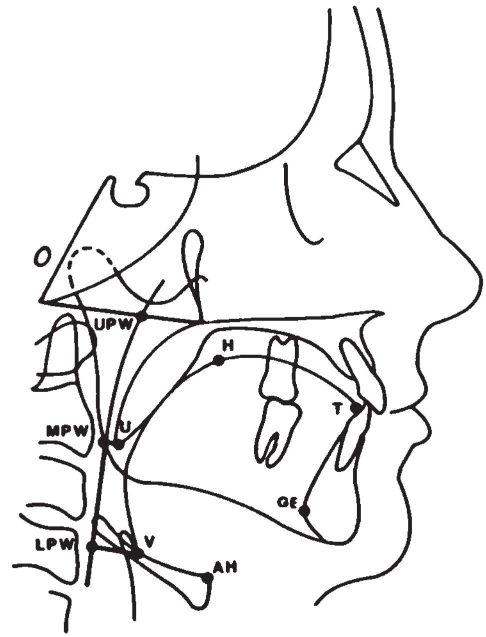

Figure 4 Uvuloglossopharyngeal reference points used in this study. AH: anterior hyoid; GE: genial tubercle; H: highest dorsal point of the tongue; LPW: lower pharyngeal wall; MPW: middle pharyngeal wall; T: tip of the tongue; U: tip of the uvula; UPW: upper pharyngeal wall; V: vallecula (Lyberg *et al*., 1989b).

PASmin: the minimal distance between the base of the tongue and the posterior pharyngeal wall, representing the minimal pharyngeal airway space.

pm–U: the distance from pm to U, representing the length of the soft palate, and also the long axis of the soft palate.

SPT: the maximal thickness of the soft palate measured perpendicular to the pm–U line.

CL: contact length between the dorsal contour of the tongue and the soft palate.

V⊥FH: the perpendicular distance from V to FH, representing the vertical position of vallecula.

V–C3: the distance from V to the third cervical vertebra (C3), measured parallel to FH, representing the horizontal position of vallecula.

3. Angular measurements (Figures 3 and 5)

NL/pm–U (NL): the inclination of the long axis of the soft palate relative to the nasal line.

V–T/FH: the inclination of the long axis of the tongue relative to the Frankfort horizontal.

NSL/VER: head position in relation to the true vertical.

NSL/OPT: head position in relation to the cervical spine.

NSL/CVT: head position in relation to cervical vertebrae.

CVT/HOR: inclination of the cervical column.

CVT/OPT: cervical curvature.

4. Area measurements (Figure 5)

TA: tongue area, the upper outline was defined by the dorsal contour of the

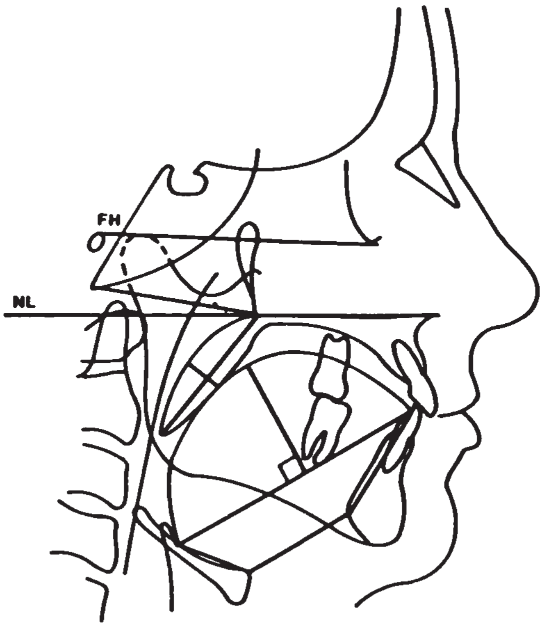

Figure 5 Reference lines used in this study. FH: Frankfort horizontal line; NL: nasal line (Lyberg *et al*., 1989b).

tongue from V through H to T. The lower outline was reduced to a geometric polygon of which the boundary was defined by line segments connecting the following points V, AH, GE, and T.

SPA: soft palate area, the outline was defined along the anterior and posterior contour of the soft palate, the superior border was a line through pterygomaxillare (pm) perpendicular to the pm–U line.

OA: oral area, included tongue area (TA) and extended superiorly to the outline of the soft and hard palate.

OPA: oropharyngeal area, included oral area (OA), soft palate area (SPA), and the area defined by the points pm, UPW, LPW, and V along the posterior pharyngeal wall, and the dorsal outline of the tongue.

5. Ratios

TA/OA: the relationship between the tongue area (TA) and the oral area (OA).

(TA+SPA)/OPA: a relationship between the tongue area (TA) and the soft palate area (SPA) and the oropharyngeal area (OPA).

SPA/(OPA–OA): a relationship between the soft palate area (SPA) and the residual pharyngeal area.

Reliability

All the lateral cephalograms were traced twice by hand onto acetate tracing paper and digitized twice with the Dentofacial Planner computer program (Dentofacial Software Inc., Toronto, Canada) on an IBM 286/AT desktop computer. If the difference exceeded 1 mm or 1 degree, a third measurement was taken and the middle value of the two nearest measurements was used (Slagsvold, 1969).

Statistics

All the statistical procedures were performed by using the Minitab computer program (Minitab Inc., State College, PA, U.S.A.). The comparison of the means was obtained by using a two-tailed paired Student's *t*-test. In comparing T1–T2 and T0–T2, only 19 subjects were used. The relationships among variables were assessed by means of Pearson's product-moment correlation analysis.

Results

Craniofacial and cervical morphology (Table 2A, B)

Variables describing craniofacial morphology before surgery (T0) and at the short- and long-term follow-up T1 and T2, respectively, are shown in Tables 2 and 3. As expected after surgical correction of mandibular retrognathism, there was an increase in mandibular prognathism (s–n–sm; $P < 0.001$) and a decrease in relative prognathism (ss–n–sm; $P < 0.001$). Between T1 and T2 there were no significant differences with regard to skeletal relationships. Although there was a slight significant relapse in overbite ($P < 0.01$) between T1 and T2, overjet showed no significant change during the same period.

Table 2 (A) Cephalometric variables of facial morphology. Values are given in degrees (°) and mm.

Variable	T0 (n = 20)		T1 (n = 20)		T2 (n = 19)	
	Mean	SD	Mean	SD	Mean	SD
nsba (°)	131.61	5.30	131.59	5.15	131.87	5.17
snss (°)	82.89	4.11	82.92	4.29	83.20	3.83
snsm (°)	77.19	3.53	80.05	3.77	79.68	3.25
ssnsm (°)	5.70	2.72	2.87	2.95	3.52	2.58
ML/NSL (mm)	27.81	9.56	31.25	8.30	30.03	6.86
AFH (mm)	123.77	9.61	126.04	9.08	125.88	7.95
PFH (mm)	84.99	6.96	83.48	6.43	82.61	6.22
pm–ba (mm)	50.72	4.59	50.96	4.71	50.72	4.59
pm–aa (mm)	36.35	4.63	36.63	4.23	35.79	3.73
Overbite (mm)	5.47	3.13	2.91	0.99	3.01	1.49
Overjet (mm)	7.76	2.16	2.26	1.10	3.71	1.49

Table 2 (B) Mean differences and t-values between T0, T1 and T2.

Variable	T0–T1 (n = 20)		T1–T2 (n = 19)		T0–T2 (n = 19)	
	Mean diff.	t-values	Mean diff.	t-values	Mean diff.	t-values
nsba	0.02	0.12	0.08	0.39	0.15	0.82
snss	–0.02	–0.28	0.10	0.98	0.06	0.15
snsm	–2.86	–10.46***	0.73	1.82	–2.16	–8.03***
ssnsm	2.84	10.18***	–0.17	–0.58	2.23	7.15***
ML/NSL	–3.44	–3.29**	0.62	1.27	–3.01	–3.22**
AFH	–2.26	–3.21**	–0.75	–1.45	–3.03	–4.96***
PFH	1.50	2.80*	0.83	1.90	2.33	5.16**
pm–ba	–0.24	–0.73	0.75	1.07	0.27	0.35
pm–aa	–0.27	–0.70	1.21	1.36	0.85	0.91
Overbite	3.21	5.23***	–0.72	–2.33*	2.67	4.24***
Overjet	4.85	11.83***	–0.84	–1.92	3.92	7.15***

Level of significance: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Hyoid bone position (Table 3A,B). The hyoid bone assumed a significantly more superior position at the first follow-up (T1) (AH–s Ver, AH⊥FH, AH⊥ML; $P < 0.05$, $P < 0.05$, $P < 0.05$) a finding which was recorded also at the longest follow-up (T2).

Concerning the horizontal position of the hyoid bone in relation to the cervical vertebrae, statistically significant anterior repositioning was observed immediately post-surgically. This change remained stable at the longest follow-up T2 (AH–C3 Hor; $P < 0.05$). On the other hand, a gradual elevation in relation to the vertebra was recorded between T0, T1, and T2 ending at a significantly higher level (AH–C3 Ver; $P < 0.01$) at the longest follow-up.

Head posture (Table 3A,B). Statistically significant alterations were recorded for the variables describing the cervico-horizontal angulation (OPT/HOR, CVR/HOR; $P < 0.01$) between T1 and T2. This change was highly significant ($P < 0.001$) during the overall period T0 to T2 indicating a gradual increase.

Furthermore, a significant decrease ($P < 0.05$) was recorded for the cervical curvature (OPT/

Table 3 (A) Cephalometric variables for hyoid bone position and head posture. Values given in degrees (°) and mm.

Variable	T0 (n = 20)		T1 (n = 20)		T2 (n = 19)	
	Mean	SD	Mean	SD	Mean	SD
Hyoid bone position						
AH–s Ver (mm)	116.95	10.01	113.98	8.09	113.26	8.80
AH⊥FH (mm)	96.68	9.36	94.31	8.30	93.22	8.45
AH⊥ML (mm)	18.15	7.95	16.04	7.08	14.98	4.91
AH–C3 Hor (mm)	39.37	5.05	40.40	4.80	41.17	3.46
AH–C3 Ver (mm)	13.28	6.72	11.58	5.18	9.38	6.44
Head posture						
NSL/VER (°)	86.51	6.65	84.51	7.41	82.71	5.79
NSL/OPT (°)	97.33	9.23	95.97	8.65	96.27	8.73
NSL/CVT (°)	102.4	9.44	100.59	8.52	101.05	8.93
OPT/HOR (°)	84.62	11.15	83.86	13.58	91.22	8.09
CVT/HOR (°)	79.78	10.78	79.12	13.27	86.42	8.10
OPT/CVT (°)	5.26	2.66	4.49	2.69	4.78	2.79

Table 3 (B) Mean differences and t-values between T0, T1 and T2.

Variable	T0–T1 (n = 20)		T1–T2 (n = 19)		T0–T2 (n = 19)	
	Mean diff.	t-values	Mean diff.	t-values	Mean diff.	t-values
Hyoid bone position						
AH–s Ver	2.97	2.20*	–0.17	–0.17	2.92	2.58*
AH⊥FH	2.37	2.15*	–0.31	0.43	2.75	2.42*
AH⊥ML	2.10	2.01*	0.57	0.53	2.88	2.09*
AH–C3 Hor	–1.02	–2.42*	–0.70	–1.27	–1.63	–2.29*
AH–C3 Ver	2.25	1.90	2.08	2.60**	3.79	2.86**
Head posture						
NSL/VER	2.00	0.89	1.77	0.77	4.06	1.75
NSL/OPT	1.36	1.01	–0.65	–0.44	0.69	0.50
NSL/CVT	1.81	1.21	–0.87	–0.57	1.02	0.68
OPT/HOR	0.76	0.28	–6.70	–2.68**	–6.75	–3.88***
CVT/HOR	0.65	0.25	–6.55	–2.70**	–6.83	–3.76***
OPT/CVT	0.77	2.10*	–0.24	–0.85	0.30	1.23

Level of significance: *P < 0.05; **P < 0.01; ***P < 0.001.

CVT) at the short-term follow-up, but this change was transient becoming insignificant at the long-term follow-up.

Uvuloglossopharyngeal morphology

Soft palate and tongue (Table 4A,B). As expected, there were no changes in soft palate size. However, soft palate posture became more upright at T1 (NL/pm–U; P < 0.05) a transient finding as no significant difference was recorded at the longest follow-up.

The tongue showed an increase in height at T1 (H⊥VT; P < 0.5), but this change was not significant at T2.

Vallecula moved upwards and forwards between T0 and T1 (V⊥FH, V–C3; P < 0.05), a positional change that was maintained at T2

Table 4 (A) Cephalometric variables of soft palate and tongue. Values are given in degrees (°) and mm.

Variable	T0 (n = 20)		T1 (n = 20)		T2 (n = 19)	
	Mean	SD	Mean	SD	Mean	SD
Soft palate						
pm–U (mm)	35.22	4.55	34.15	4.29	33.08	5.17
SPT (mm)	11.05	1.55	11.47	1.74	11.49	1.52
CL (mm)	5.44	5.88	4.92	5.36	3.73	4.69
NL/pm–U (°)	130.25	8.04	127.29	7.65	128.22	6.70
Tongue						
V–T (mm)	78.31	6.51	77.55	5.07	76.53	6.44
H⊥VT (mm)	36.28	4.68	38.15	3.78	36.69	3.96
V⊥FH (mm)	97.80	8.74	95.51	8.62	94.13	7.39
V–C3 (mm)	22.76	3.73	24.20	4.60	24.15	2.60
VT/FH (°)	35.89	5.49	33.22	3.54	32.98	4.21

Table 4 (B) Mean differences and t-values between T0, T1 and T2.

Variable	T0–T1 (n = 20)		T1–T2 (n = 19)		T0–T2 (n = 19)	
	Mean diff.	t-values	Mean diff.	t-values	Mean diff.	t-values
Soft palate						
pm–U	1.07	1.08	1.19	1.08	2.22	1.45
SPT	–0.42	–1.34	–0.03	–0.13	–0.37	–1.20
CL	0.52	0.33	1.44	1.46	1.98	1.32
NL/pm–U	2.96	2.17*	–0.72	–0.61	2.19	1.79
Tongue						
V–T	0.75	0.79	0.85	0.61	1.75	1.16
H⊥VT	–1.87	–2.35*	1.25	1.70	–0.66	–0.78
V⊥FH	2.29	2.26*	0.41	0.59	2.97	3.07**
V–C3	–1.43	–2.09*	–0.06	–0.08	–1.36	–2.04*
VT/FH	2.67	2.73**	–0.08	–0.15	2.85	2.97**

Level of significance: *$P < 0.05$; **$P < 0.01$.

(V⊥FH, V–C3; $P < 0.01$, $P < 0.05$, respectively). Corresponding to the superior anterior movement of the hyoid bone and vallecula, the tongue assumed a less upright position, a finding which also persisted at T2 (VT/FH; $P < 0.01$).

Pharynx (Table 5A,B). Larger sagittal dimensions of the pharyngeal airway were observed at the first post-surgical follow-up, both at the oropharynx and at the base of the tongue level (U–MPW, PASmin; $P < 0.05$, $P < 0.01$, respectively). The minimal dimension of pharyngeal airway at the base of the tongue level was also found to be significantly wider at the longest follow-up T2 (PASmin; $P < 0.05$). The increased dimension at the oropharyngeal space at T1 corresponded with the alteration in soft palate posture.

Furthermore, a statistically significant decrease in the ratio indicating the relationship between the soft palate (SPA) and the residual pharyngeal area (SPA/(OPA-OA); $P < 0.01$) was recorded at T1.

Table 5 (A) Cephalometric variables of pharynx and area measurements. Values are given in mm and cm^2.

Variable	T0 (n = 20)		T1 (n = 20)		T2 (n = 19)	
	Mean	SD	Mean	SD	Mean	SD
Pharynx						
pm–UPW (mm)	27.44	4.55	28.18	4.61	27.78	2.38
U–MPW (mm)	12.53	3.67	13.75	4.44	13.59	4.27
V–LPW (mm)	19.9	7.69	20.20	7.16	18.26	4.95
PASmin (mm)	10.3	4.48	12.88	3.83	12.75	3.63
Area measurements						
TA (cm^2)	32.61	3.68	33.17	3.23	33.09	3.52
SPA (cm^2)	3.05	0.57	2.91	0.52	2.89	0.81
OA (cm^2)	37.05	4.42	37.08	4.59	36.65	4.13
OPA (cm^2)	49.86	5.40	50.55	5.24	50.19	5.11
Ratios						
TA/OA	0.88	0.07	0.89	0.06	0.90	0.04
(TA+SPA)/OPA	0.71	0.07	0.71	0.05	0.71	0.04
SPA/(OPA–OA)	0.24	0.04	0.22	0.04	0.21	0.06

Table 5 (B) Mean differences and t-values between T0, T1 and T2.

Variable	T0–T1 (n = 20)		T1–T2 (n = 19)		T0–T2 (n = 19)	
	Mean diff.	t–values	Mean diff.	t–values	Mean diff.	t–values
Pharynx						
pm–UPW	–0.74	–1.30	0.85	1.06	–0.02	–0.03
U–MPW	–1.22	–2.36*	0.26	0.31	–0.87	–1.20
V–LPW	–0.30	–0.29	1.15	1.11	1.15	0.79
PASmin	–2.58	–3.77**	0.13	0.23	–2.44	2.30*
Area measurements						
TA	–0.55	–1.30	–0.11	–0.40	–0.57	–1.31
SPA	0.13	1.88	0.04	0.25	0.18	1.15
OA	–0.03	0.08	0.08	0.22	0.16	0.31
OPA	–0.69	–1.14	–0.08	–0.15	–0.47	–0.58
Ratios						
TA/OA	–0.014	–0.75	–0.002	–0.26	–0.017	–1.22
(TA+SPA)/OPA	0.002	0.19	–0.001	–0.15	–0.001	0.12
SPA/(OPA–OA)	0.022	3.53**	0.001	0.13	0.025	1.53

Level of significance: $*P < 0.05$; $**P < 0.01$.

Correlation analysis

The correlation among variables is described in Table 6.

Significant correlations were found between the vertical position of the hyoid bone (AH⊥FH, AH⊥ML, AH–C3 Ver), and the differences in sagittal airway dimensions at the levels of the hypopharynx and the base of the tongue (V–LPW, PASmin) for both T0–T1 and T0–T2 comparisons ($P < 0.05$ except for AH⊥ML and V–LPW; $P < 0.01$)

In addition, a significant negative correlation between cervico-horizontal inclination of the cervical spine (OPT/HOR, CVT HOR), and the sagittal airway dimension at the base of the

Table 6 Correlation coefficients between changes in pharyngeal depth, hyoid bone position and head posture after mandibular advancement.

Variable	T0–T1 (*n* = 20)				T0–T2 (*n* = 19)			
	Pg⊥NP	Overjet	V–LPW	PASmin	Pg⊥NP	Overjet	V–LPW	PASmin
U–MPW	0.30	0.18	0.27	0.27	0.22	0.22	0.35	0.43
V–LPW	0.18	0.17		0.31	0.17	0.16		0.23
PASmin	0.26	0.18	0.31		0.19	0.27	0.23	
AH⊥FH	0.17	0.27	0.44*	0.47*	0.16	0.15	0.45*	0.50*
AH⊥ML	0.21	0.42	0.57**	0.48*	0.35	0.43	0.45*	0.45*
AH–C3 Hor	–0.24	–0.24	0.19	0.35	–0.25	–0.14	0.23	0.31
AH–C3 Ver	–0.15	0.25	0.45*	0.39	–0.19	0.15	0.55*	0.37
NSL/OPT	–0.15	0.14	–0.25	–0.13	–0.10	0.09	0.03	0.37
NSL/CVT	–0.13	0.23	–0.25	–0.17	–0.06	0.10	0.07	0.38
OPT/HOR	0.21	0.26	0.14	–0.45*	0.21	–0.18	–0.28	–0.59**
CVT/HOR	0.21	0.20	0.16	–0.44*	0.19	–0.20	0.30	–0.61**
OPT/CVT	0.03	0.14	–0.12	–0.18	0.15	0.13	–0.19	–0.21

Level of significance: $^*P < 0.05$; $^{**}P < 0.01$.

tongue (PASmin) was observed for both T0–T1 and T0–T2 comparisons.

Discussion

Cephalometric radiography has been extensively used as a diagnostic and follow-up technique in the study of craniofacial morphology and the surgical management of craniofacial anomalies. Computerized tomography (CT) could offer a unique potential for three-dimensional reconstruction of the structures and provide more precise measurements of the changes, compared with cephalometry, which is a two-dimensional method for evaluating three-dimensional structures. However, a study by Riley and Powell (1990) evaluating the reliability of CT-scans and cephalograms in determining the posterior airway space reported a statistically significant correlation (R = 0.92) between posterior airway space and the volume of the pharyngeal airway. Furthermore, in a recent study Miles *et al*. (1995) reported conclusively that the majority of the commonly used landmarks of the airway structures could reliably be identified, irrespective of the quality of the radiograph, so lateral cephalometric radiography must be considered a valuable tool in describing the pharyngeal airway.

Shen *et al*. (1994) reported that statistically significant differences exist between the sexes in uvuloglossopharyngeal morphology and hyoid bone position. The sample chosen for this study, even though the number decreased by one individual at the longest post-surgical follow-up, consisted of only adult males. They were radiographically registered according to Moorrees and Kean (1958), and the operations were performed under identical conditions, thus providing a homogeneous and representative sample. Due to its importance in studies dealing with pharyngeal airway space and hyoid bone position, every caution was taken to ensure an unstrained, reproducible position of the head, as well as of the cervical column during the cephalometric radiography.

Craniofacial morphology was, as expected after surgical correction of mandibular retrognathism, indicated by the significant increase in mandibular prognathism (s–n–sm) and a decrease in relative prognathism (ss–n–sm). In contrast to previous studies (Schendel *et al*., 1978; Schendel and Epker, 1980) these findings indicate stability of the surgical mandibular advancement which can probably be attributed to the rigid fixation.

Post-surgically at the short-term observation, the hyoid bone occupied a significant superior (AH⊥FH, AH⊥ML, AH⊥S) and anterior

(AH–C3 Hor) position, which corresponds with the findings of Valk *et al*. (1992). Schendel *et al*. (1978), and LaBanc and Epker (1984) reported short-term anterior movement of the hyoid bone after mandibular advancement with a long-term re-adaptation towards its original position. Our findings are in accordance with the short-term results of the above mentioned authors, but at the long-term follow-up the hyoid bone was located significantly anterior to its pre-surgical position (AH–C3 Hor). This finding can be explained by the fact that no suprahyoid myotomy had been performed and by the insignificant extent of skeletal relapse. Furthermore, the long-term vertical position of the hyoid bone in relation to the cranial structures (AH⊥FH, AH⊥S) appeared to be significantly more superior than pre-surgically, a finding which is in accordance with the pattern described by Hayes *et al*. (1994).

In addition to the above findings, the vertical position of the hyoid bone in relation to the third cervical vertebra (AH–C3 Ver) showed significant elevation at the long-term follow-up. This difference can be explained by the significant more upright cervical spine (OPT/HOR, CVT/HOR) acquired during the T1–T2 period since head posture (Gustavsson *et al*., 1972; Winnberg *et al*., 1988) and changes in the inclination of the mandible (Graber, 1978; Tallgren and Solow, 1987) have been found to influence the position of the hyoid bone.

Schendel and Epker (1980) described a forward movement of the cervical spine leading to increased cervical lordosis and flexion of the head after mandibular advancement. At long-term follow-up, they demonstrated a return towards the pre-operative state without reaching it. Our study showed that flexion of the head did not occur at a significant level, but a significantly upright cervical spine (OPT/HOR, CVT/HOR) was recorded, especially between T1 and T2.

Soft palate posture became significantly more upright at T1 (NL/PM–U), a finding indicating an increased patency of the oropharyngeal airway. Larger sagittal dimensions of the pharyngeal airway were observed at the first post-surgical follow-up, both at the oropharynx and retro-glossal space at the base of the tongue (U–MPW, PASmin) with a tendency to a reduced size over the T1–T2 period, a finding consistent with previous studies (Farole, 1990; Yu *et al*., 1994). At long-term follow-up the retroglossal pharyngeal space at the base of the tongue (PASmin) maintained a statistically significant wider dimension, a finding which is in agreement with that of the above-mentioned authors.

The mechanism of action in mandibular advancement is a forward displacement of the base of the tongue and increase in longitudinal tension of the palatoglossal arch. Isono *et al*. (1995), in a study on anaesthetized OSA patients, where the glossopharyngeal muscles were paralysed, demonstrated that forward displacement of the mandible widens velo- and oro-pharyngeal airway primary obstruction sites, and reduces the collapsibility of the oropharynx.

The pattern of vertical movement of vallecula in relation to cranial structures (V⊥FH) showed a significant superior positioning at T1 which was maintained at long-term follow-up T2. LaBanc and Epker (1984) also reported a trend towards significant superior positioning at the longest follow-up 30 ± 4 months.

In agreement with the study of LaBanc and Epker (1984) no changes in any of the measured areas were noted. It is obvious that the new position of the mandible affected the position and shape of the tongue mass. This is indicated by findings such as increased tongue height (H⊥VT) at T1, less upright tongue position (VT/FH) and a more superior and forward positioning of vallecula both at T1 and T2 (V⊥FH, V–C3). This corresponded with the superior anterior movement of the hyoid bone (AH⊥FH, AH–C3 Hor), the indirect indicator of the position of the base of the tongue.

Interesting findings are also the statistically significant correlation found between the vertical position of the hyoid bone (AH⊥FH, AH⊥ML, AH–C3 Ver), and the sagittal airway dimensions at the levels of the hypopharynx and the base of the tongue (V–LPW, PASmin) for both T0–T1 and T0–T2 periods. Also during the period T0–T1 and T1–T2, a significant correlation between cervico-horizontal inclination of the cervical spine and the sagittal airway dimension at the base of the tongue (PASmin) was observed. This finding indicates that flexion and extension of the head could influence the dimensions of the pharyngeal airway (Hellsing, 1989; Rubinstein *et al.*, 1987; Fitzpatric *et al.*, 1990).

Conclusions

Alterations such as long-term superior and anterior positioning of hyoid bone and vallecula, less upright tongue, more upright soft palate posture, and, not least, a long-term widening of the minimal pharyngeal airway space, could provide conditions for increased airway patency after stable mandibular advancement surgery. Thus, the above findings should be taken into due consideration when evaluating the various options available for treatment of OSA patients.

In order to predict more exactly the efficacy of mandibular advancement as a treatment modality for OSA patients, further studies are clearly needed which correlate cephalometric variables to polysomnographic recordings and continuous pharyngeal pressure measurements. Such studies should be performed both in OSA patients and in those undergoing mandibular advancement for gnathofunctional or aesthetic reasons.

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