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

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SUMMARY A detailed cephalometric analysis was conducted on a sample of 31 adult males who underwent correction of mandibular prognathism by mandibular setback osteotomy (BSRO) with rigid fixation to evaluate the changes in uvuloglossopharyngeal morphology, hyoid bone position and head posture. Lateral cephalograms were obtained 1–3 days prior to the operation and at standardized 6 months and 3 years post-operative follow-up. Statistical evaluation was performed by paired Student's *t*-test and Pearson product moment correlation analysis.

Inferior position of the hyoid bone (AH⊥FH, AH⊥ML, AH⊥S) and valeculla (V⊥FH) was recorded at the 6-month follow-up, a transient finding as at 3 years almost complete recovery to their pre-surgical position was noted. No posterior displacement of the above structures (AH–C3 Hor, V–C3) was recorded. Soft palate length (pm–U) was increased and maintained at the long-term follow-up while its posture (NL/pm–U) became less upright. The tongue showed increased length (V–T) and sagittal area (TA) and a more upright posture (VT/FH) at the late follow-up. Increased contact length between tongue and the soft palate (CL) and less residual oropharyngeal area [area not occupied by soft tissues, (TA+SPA)/OPA] was found at the long-term follow-up. Craniocervical agulation (NSL/OPT, NSL/CVT) was increased indicating cervical hyperflexion at the 3-year follow-up. Reduction of the sagittal dimension of the oropharyngeal airway space (U–MPW) appeared at the first follow-up and was sustained at the longest follow-up which, in conjunction with the decrease in residual oropharyngeal area, could raise questions regarding airway patency after mandibular setback osteotomy.

Introduction

Orthognathic surgical procedures are designed to correct congenital or acquired dentofacial deformities, achieve cosmetic improvement of the face and dentition, and normalize stomatognathic function (Athanasiou *et al*., 1989). Several studies have shown that a mandibular setback osteotomy influences the position of the hyoid bone and, consequently, the tongue position as these structures are intimately related (Takagi *et al*., 1967; Fromm and Lundberg, 1970; Wickwire *et al*., 1972; Athanasiou *et al*., 1991; Lew, 1993; Enacar *et al*., 1994), the pharyngeal airway space (Guilleminault *et al*., 1985; Riley *et al*., 1987; Wenzel *et al*., 1989a,b; Greco *et al*., 1990; Athanasiou *et al*., 1991; Katakura *et al*., 1993; Enacar *et al*., 1994; Hochban *et al*., 1996) and head posture (Wenzel *et al*., 1989a,b).

Adequate airway space is one of the most important features to maintain vital functions in the human body. Even head posture has been found to be deviated to obtain airway adequacy (Solow and Kreiborg, 1977; Holmberg and Linder-Aronson, 1979; Solow *et al*., 1984). Narrowing of the upper airway space due to anatomical aberrances is responsible for development of the potentially life threatening disorder obstructive sleep apnoea (OSA). Other predisposing or aetiological factors such as craniofacial deformity, muscular hypotrophy, sleep posture, fatty depositions in upper airway soft tissues, gender and age have been reported (Miles *et al*., 1995). 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 in uvuloglosso-pharyngeal morphology. Crumley *et al*. (1987), using flexible endoscopy, demonstrated that the base of the tongue and the soft palate particularly contribute to the airway obstruction process seen in these subjects.

The position and 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). As the hyoid bone is regarded as representative of the postural behaviour of the tongue, changes in tongue position can be assessed by analyzing the alterations in hyoid bone position. Surgical correction of mandibular prognathism was reported in early studies to alter the position of the hyoid bone by downward repositioning carrying the root of the tongue downwards (Takagi *et al*., 1967; Fromm and Lundberg, 1970). Wickwire *et al*. (1972) later demonstrated a postero-inferior repositioning of the hyoid bone immediately post-operatively, but followed with a tendency to return to its original position, a finding supported by recent studies (Athanasiou *et al*., 1991; Lew, 1993; Enacar *et al*., 1994). 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 hyo-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.

In previous reports (Guilleminaut *et al*., 1985; Riley *et al*., 1987; Hochban *et al*., 1996) it was shown that following surgical setback of the mandible changes in the pharyngeal airway space, inducing breathing problems, could occur. Cephalometric studies of patients subjected to mandibular setback have shown either a decrease in the anteroposterior dimension of the upper pharyngeal airway space (Wenzel *et al*., 1989a,b; Greco *et al*., 1990; Katakura *et al*., 1993; Enacar *et al*., 1994; Hochban *et al*., 1996) or maintenance of its pre-surgical dimension (Athanasiou *et al*., 1991).

It may be assumed that since the mandible is surgically posteriorly repositioned relative to the other craniofacial structures the tongue and hyoid bone are literally carried back and a reduction of the lumen of the oropharynx could occur as these structures encroach upon the vital oro- and hypo-pharyngeal airway space (Timms, 1990). Consequently, as demonstrated by Wenzel *et al*. (1989a) cervical hyperflexion could be a compensatory mechanism to maintain airway adequacy.

The aim of this investigation was to conduct a detailed cephalometric evaluation of the alterations taking place in the pharyngeal airway space and morphology, hyoid bone and tongue position and head posture after mandibular setback osteotomy for the correction of mandibular prognathism. Both short- and long-term differences were analysed to determine whether the short-term alterations were stable.

Subjects and methods

The subjects consisted of 31 adult males with mandibular prognathism subjected to bilateral sagittal ramus osteotomy (BSRO) for mandibular setback with rigid fixation. All were selected from the files of patients at the Department of Orthodontics at the University of Oslo and the Department of Maxillofacial Surgery, Ullevaal

Table 1 Age distribution of the subjects ($n = 31$).

Age	Mean	SD	Range
Initial (T0)	24.92	6.29	18.00–39.83
1st follow-up (T1)	25.45	6.28	18.50–40.41
2nd follow-up (T2)	28.06	6.19	21.08–42.75

University Hospital, Oslo. They had all undergone pre- and post-operative orthodontic treatment to correct the dentoalveolar compensation due to basal discrepancy and to establish a stable 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 the operation. Mean age at the time when the profile radiographs were taken is shown 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 the 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 the analysis have been reported elsewhere (Achilleos *et al*., 2000). The definitions have been described in previous papers (Solow and Greve, 1979; Lyberg *et al*., 1989a,b). For definition of some unfamiliar landmarks, planes and measurements, see Achilleos *et al*. (2000).

Reliability

All the lateral cephalograms were traced twice by hand on acetate tracing paper and digitized twice to 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 using the Minitab computer program (Minitab Inc., State College, PA, USA). The comparison of the means was obtained with the level of significance by using a two-tailed paired Student's *t*-test. The relationships among variables were assessed by means of Pearson product-moment correlation analysis.

Results

Craniofacial and cervical morphology

Craniofacial morphology (Table 2A and B). Variables describing craniofacial morphology before surgery (T0), and at the short- and long-term follow-up (T1 and T2, respectively) are shown in Table 2A and B. The differences were as expected after surgical correction of mandibular prognathism, i.e. reduction of mandibular prognathism (s–n–sm) resulting in an increase in relative prognathism (ss–n–sm). There was a slight but significant relapse between T1 and T2. The anterior face height (AFH) was significantly reduced with apparently stable results. The difference in overjet and overbite from T1 to T2 showed no significant changes.

Hyoid bone position (Table 3A and B). Significant changes showing a more inferior position of the hyoid bone (AH⊥FH, AH–S Ver, AH⊥ML; $P < 0.001$, $P < 0.001$, $P < 0.05$, respectively) were recorded at T1. At T2 there was a significant elevation of the hyoid almost to its pre-surgical level with no significant

Table 2 (A) Cephalometric variables of craniofacial morphology for T0, T1 and T2. Values are given in degrees (°) and mm ($n = 31$).

Variable	T0		T1		T2	
	Mean	SD	Mean	SD	Mean	SD
nsba (°)	130.82	5.37	131.06	5.45	131.06	5.67
snss (°)	83.20	4.21	83.30	4.12	83.25	4.15
snsm (°)	87.49	4.11	83.78	3.49	84.20	3.58
ssnsm (°)	–4.28	3.13	–0.48	2.57	–0.95	2.51
ML/NSL (mm)	31.32	5.33	31.90	7.87	30.00	5.97
AFH (mm)	130.12	6.66	128.70	6.35	128.60	6.21
PFH (mm)	84.52	6.53	85.04	6.57	85.21	6.82
pm–ba (mm)	49.63	4.50	49.71	4.61	49.82	4.39
pm–aa (mm)	35.35	4.17	35.71	4.51	35.76	4.05
Overbite (mm)	–1	1.67	1.56	1.34	1.30	1.46
Overjet (mm)	–5.84	2.38	2.2	1.18	2.03	1.95

Table 2 (B) Mean differences and *t*-values between T0, T1 and T2 for craniofacial morphology ($n = 31$).

Variable	T0–T1		T1–T2		T0–T2	
	Mean diff.	*t*-values	Mean diff.	*t*-values	Mean diff.	*t*-values
nsba	–0.2	–1.64	–0.04	–0.23	–0.2	–1.34
snss	–0.1	–0.83	–0.05	–0.38	–0.04	–0.03
snsm	3.70	12.16***	–0.42	–2.77**	3.28	10.85***
ssnsm	–3.79	–12.78***	0.47	–3.23**	–3.32	–11.52***
ML/NSL	–0.58	–0.50	1.90	1.91	1.32	2.40*
AFH	1.41	3.76***	0.10	0.42	1.51	4.08***
PFH	–0.51	–1.18	–0.17	0.41	–0.69	–1.59
pm–ba	–0.08	–0.36	–0.11	0.78	–0.19	0.72
pm–aa	–0.36	–0.97	–0.05	–0.185	–0.41	–1.24
Overbite	–2.56	–8.08***	0.25	1.17	–2.31	–7.57***
Overjet	–8.04	–16.27***	0.16	0.68	–7.88	–17.64***

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

differences between T0 and T2. The vertical position relative to the cervical spine (AH–C3 Ver) showed a small and non-significant increase from T0 to T1. From T1 to T2 there was a significant decrease ($P < 0.01$), resulting in a higher position than at T0. This difference was, however, not significant. The horizontal position (AH–C3 Hor) showed only small and non-significant differences.

Head posture (Table 3A and B). A statistically significant increase ($P < 0.01$) was found for the variables describing craniocervical angulation (NSL/OPT, NSL/CVT) at the late follow-up (T2) indicating a greater cervical flexion.

Uvuloglossopharyngeal morphology

Soft palate and tongue (Tables 4A and B, and 5A and B). The soft palate showed increased length (pm–U; $P < 0.001$) at T1 which was maintained at T2. The thickness decreased (SPT; $P < 0.05$) at T1, but there was no significant difference between T0 and T2. In addition, its posture

Table 3 (A) Cephalometric variables for hyoid bone position and head posture. Values given in degrees (°) and mm ($n = 31$).

Variable	T0		T1		T2	
	Mean	SD	Mean	SD	Mean	SD
Hyoid bone position						
AH–S Ver (mm)	117.98	7.60	120.55	9.12	118.55	8.63
AH⊥FH (mm)	94.53	7.26	98.20	8.07	96.18	7.76
AH⊥ML (mm)	14.38	5.26	16.15	4.65	15.59	4.75
AH–C3 Hor (mm)	43.00	4.54	42.08	4.71	42.99	4.52
AH–C3 Ver (mm)	15.39	6.47	17.04	7.43	14.11	7.31
Head posture						
NSL/VER (°)	86.38	9.78	88.03	6.25	87.14	8.68
NSL/OPT (°)	90.78	9.33	93.10	11.36	94.27	8.35
NSL/CVT (°)	95.48	8.06	97.16	8.08	98.68	6.92
CVT/HOR (°)	85.31	8.51	84.43	11.04	84.97	7.02
CVT/OPT (°)	4.69	3.56	4.05	4.70	4.40	3.23

Table 3 (B) Mean differences and *t*-values between T0, T1 and T2 for hyoid bone position and head posture ($n = 31$).

Variable	T0–T1		T1–T2		T0–T2	
	Mean diff.	*t*-values	Mean diff.	*t*-values	Mean diff.	*t*-values
Hyoid bone position						
AH–s Ver	–2.57	–3.21***	2.00	3.46**	–0.56	0.74
AH⊥FH	–3.66	–4.08***	2.01	2.95**	–1.64	–1.84
AH⊥ML	–1.76	–2.08*	0.56	0.8	–1.2	–1.66
AH–C3 Hor	0.92	1.91	–0.91	–1.83	0.01	0.02
AH–C3 Ver	–1.65	–1.42	2.92	3.51**	1.27	1.27
Head posture						
NSL/VER	–1.65	–0.82	0.89	0.62	–0.75	–0.35
NSL/OPT	–2.34	–1.53	–1.15	–0.91	–3.49	–3.37**
NSL/CVT	–1.68	–1.33	–1.51	–1.44	–3.2	–3.20**
CVT/HOR	0.88	0.53	–0.54	0.35	0.33	0.24
CVT/OPT	0.64	1.12	–0.36	–0.72	0.29	1.32

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

became less upright as the angle to NL increased significantly (NL/pm–U; $P < 0.01$) between T0–T1, but decreased slightly resulting in a difference between T0 and T2 significant at the 5 per cent level.

The tongue showed increased length (V–T) between T1 and T2, and T0 and T2 ($P < 0.01$ and $P < 0.001$, respectively). Vallecula moved downwards between T0–T1 (V⊥FH; $P < 0.05$), but during T1–T2 it moved upwards again ending at a position not significantly different from T0. According to this the tongue became more upright at T1 (VT/FH; $P < 0.001$), this movement was reversed between T1 and T2, but still there was a significant difference ($P < 0.05$) between T0 and T2. The contact length between the tongue and the soft palate (CL) showed a tendency to increase from T0 to T2 ($P < 0.05$).

Table 4 (A) Cephalometric variables of soft palate and tongue. Values are given in degrees (°) and mm ($n = 31$).

Variable	T0		T1		T2	
	Mean	SD	Mean	SD	Mean	SD
Soft palate						
pm–U (mm)	33.99	4.29	36.34	4.07	35.90	4.41
SPT (mm)	11.77	1.62	10.95	1.94	11.26	1.72
CL (mm)	4.4	5.37	6.56	6.95	7.67	6.52
NL/pm–U (°)	116.31	12.96	121.56	6.60	120.88	6.40
Tongue						
V–T (mm)	75.77	5.92	76.46	5.31	78.83	4.05
H⊥VT (mm)	42.49	4.14	40.25	8.99	42.35	4.37
V⊥FH (mm)	96.60	7.18	98.49	6.58	97.14	6.85
V–C3 (mm)	26.06	4.06	25.11	4.20	25.48	3.61
VT/FH (°)	30.68	4.46	35.48	7.05	32.55	5.60

Table 4 (B) Mean differences and *t*-values of soft palate and tongue between T0, T1 and T2 ($n = 31$).

Variable	T0–T1		T1–T2		T0–T2	
	Mean diff.	*t*-values	Mean diff.	*t*-values	Mean diff.	*t*-values
Soft palate						
pm–U	–2.35	–4.06***	0.4	0.71	–1.91	–3.85***
SPT	0.82	2.57*	–0.34	–1.35	0.48	1.93
CL	–2.16	–1.55	–1.10	–0.9	–3.27	–2.47*
NL/pm–U	–5.24	–3.09**	0.67	0.88	–4.56	–2.40*
Tongue						
V–T	–0.69	–0.70	–2.36	–2.81**	–3.05	–3.88***
H⊥VT	2.23	1.25	–2.10	–1.18	0.13	0.23
V⊥FH	–1.89	–2.73*	1.35	2.38*	–0.54	–0.79
V–C3	0.93	1.39	–0.36	–0.52	0.56	0.89
VT/FH	–4.80	–4.84***	2.93	3.21**	–1.86	2.66*

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

The tongue area (TA) increased between T1 and T2, and T0 and T2 ($P < 0.01$ and $P < 0.001$, respectively). This alteration resulted in significant larger area ratios (TA/OA, TA + SPA/OPA and SPA/OPA–OA; $P < 0.01$, $P < 0.01$, and $P < 0.05$, respectively).

Pharynx (Table 5A and B). A statistically significant reduction in the pharyngeal airway space (U–MPW; $P < 0.001$) was recorded between T0 and T1. A slight increase from T1 to T2 resulted in a difference between T0 and T2 significant at the 1 per cent level. A slight reduction in the hypopharyngeal and minimal posterior airway space (V–LPW, PASmin) did not reach a significant level at any stage.

Correlation analysis (Table 6). There was a significant covariation between the amount of setback (Pg⊥NP) and changes especially in the vertical position of the hyoid bone (AH–C3 Ver; $P < 0.001$) and the craniocervical angulation

Table 5 (A) Cephalometric variables of pharynx and area measurements. Values are given in mm and cm^2 (n = 31).

Variable	T0		T1		T2	
	Mean	SD	Mean	SD	Mean	SD
Pharynx						
pm–UPW (mm)	27.27	3.25	27.00	3.23	26.91	3.13
U–MPW (mm)	15.37	4.16	13.27	4.10	13.86	4.80
V–LPW (mm)	22.32	6.77	22.77	5.98	21.22	6.47
PASmin (mm)	14.41	3.89	13.04	3.97	13.63	3.71
Area measurements						
TA (cm^2)	34.01	4.10	34.88	3.58	36.00	3.99
SPA (cm^2)	2.91	0.48	2.93	0.56	3.01	0.62
OA (cm^2)	39.03	3.87	38.99	3.71	39.11	3.35
OPA (cm^2)	54.74	5.71	54.10	5.15	54.24	4.62
Ratios						
TA/OA	0.87	0.06	0.89	0.07	0.91	0.05
(TA+SPA)/OPA	0.67	0.05	0.70	0.05	0.71	0.05
SPA/(OPA–OA)	0.18	0.03	0.19	0.04	0.20	0.04

Table 5 (B) Mean differences and *t*-values of pharynx and area measurements between T0, T1 and T2 (n = 31).

Variable	T0–T1		T1–T2		T0–T2	
	Mean diff.	*t*-values	Mean diff.	*t*-values	Mean diff.	*t*-values
Pharynx						
pm–UPW	0.26	0.60	0.08	0.18	0.35	0.79
U–MPW	2.10	4.30***	–0.59	–1.11	1.51	2.92**
V–LPW	–0.45	–0.56	1.55	1.89	1.10	1.34
PASmin	1.36	1.7	–0.58	–0.94	0.78	1.03
Area Measurements						
TA	–0.86	–1.43	–1.11	–2.7**	–1.98	–3.75***
SPA	–0.01	–0.26	–0.08	–1.45	–0.10	–1.39
OA	0.03	0.10	–0.12	–0.39	–0.08	–0.27
OPA	0.63	0.99	–0.13	–0.28	0.49	1.03
Ratios						
TA/OA	–0.024	–1.43	–0.023	–1.94	–0.047	–3.9***
(TA+SPA)/OPA	–0.024	–1.67	–0.018	–1.82	–0.043	–3.78***
SPA/(OPA–OA)	–0.009	–1.22	–0.005	–0.78	–0.014	–2.05*

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

(NSL/OPT; P < 0.05, NSL/CTV; P < 0.01) at T1. These covariations seemed to be slightly weaker at T2.

Discussion

Tongue, pharyngeal airway and hyoid bone are three-dimensional structures evaluated by a two-dimensional lateral cephalogram, and a question concerning validity could be raised. Computerized tomography (CT) might be a better method. However, Riley and Powell (1990) evaluating the reliability of CT scans and cephalograms in determining the posterior airway space reported a very high, statistically significant correlation (r = 0.92) between

Table 6 Correlation coefficients between changes in craniofacial morphology, pharyngeal depth, hyoid bone position and head posture after mandibular setback (n=31).

Variable	T0–T1				T0–T2			
	Pg⊥NP	*OJ*	V–LPW	PASmin	Pg⊥NP	*OJ*	V–LPW	PASmin
U–MPW	0.30	0.11	0.54**	0.63***	0.24	0.20	0.56**	0.70***
V–LPW	0.33	0.19		0.34*	0.26	0.20		0.55***
PASmin	0.30	0.10	0.34*		0.30	0.23	0.55**	
AH⊥FH	0.15	0.15	0.51**	0.35*	0.15	0.06	0.48*	0.37*
AH⊥ML	0.43*	0.20	0.62***	0.57***	0.38*	0.20	0.55**	0.41*
AH–C3 Hor	0.39*	0.19	0.33	0.53**	0.44*	0.04	0.19	0.36*
AH–C3 Ver	–0.59***	–0.28	–0.32	–0.39*	–0.54**	–0.17	–0.31	–0.37*
NSL/OPT	0.44*	0.34	0.30	0.35*	0.39*	0.29	0.32	0.44*
NSL/CVT	0.49**	0.33	0.42*	0.55**	0.44*	0.32	0.41*	0.57***
OPT/CVT	–0.02	0.03	–0.26	–0.11	–0.09	0.05	–0.17	–0.02

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

posterior airway space and the volume of the pharyngeal airway. Besides, cephalometry combines significant advantages of low cost, convenience and minimal radiation.

In the present study every effort was taken to obtain high quality and reliable radiographs including optimally adjusted KVP (peak kV) and high quality intensifying screen and grid. Furthermore, every caution was taken to ensure an unstrained, reproducible position of the head as well of the cervical column during exposure of the cephalometric radiography according to Moorrees and Kean (1958).

Craniofacial morphology was as expected after surgical correction of mandibular prognathism, i.e. reduction of mandibular prognathism (s–n–sm) resulting in an increase in relative prognathism (ss–n–sm). There was a slightly significant relapse between T1 and T2, a finding which is in agreement with previous studies (Franko *et al*., 1989; Phillips *et al*., 1986). In spite of this, there was no significant difference in overjet and overbite from T1 to T2, indicating stability of the occlusion.

The hyoid bone was significantly inferiorly positioned at the short-term follow-up (AH⊥FH, AH⊥ML, AH⊥S, AH–C3Ver), a transient finding as the long-term follow-up showed a significant elevation of the hyoid almost to its pre-surgical level. This is a common finding in patients after osteotomy for the correction of mandibular prognathism (Takagi *et al*., 1967; Wickwire *et al*., 1972; Athanasiou *et al*., 1991; Lew, 1993; Enacar *et al*., 1994). Insignificant changes in the anteroposterior relationship of the hyoid bone to the cervical vertebrae (AH–C3Hor) are also in accordance with previous studies where minimal changes in the anteroposterior relationship of the hyoid bone to the cervical vertebrae were recorded after mandibular setback (Takagi *et al*., 1967; Fromm and Lundberg, 1970; Wickwire *et al*., 1972; Athanasiou *et al*., 1991). Significant alterations of craniocervical angulation (NSL/OPT, NSL/CVT) at the late post-surgical follow-up indicated that cervical hyperflexion had taken place after correction of mandibular prognathism, a finding supported by the studies of Fromm and Lundberg (1970) and Wenzel *et al*. (1989a,b). Gustavsson *et al*. (1972) and Winnberg *et al*. (1988) found that changes in head posture influenced the position of the hyoid bone. It could thus be suggested that the positional changes of the hyoid bone could be attributed to alteration of head posture. However, as the craniocervical angle increased significantly at T2 in the present study, the hyoid bone moved upwards towards its original position. This finding could indicate a long-term adaptation to maintain airway patency.

Significant morphological and positional changes of the soft palate (pm–U, NL/pm–U) were recorded at T1, changes that remained significant at the late follow-up ($P < 0.001$, $P < 0.05$). The significant alteration in the inclination of the soft palate both at T1 and T2 reflects the changes in the oropharyngeal airway space (U–MPW) which remained significantly smaller at T2 ($P < 0.01$). Furthermore, the contact length between the soft palate and the tongue (CL) seemed to increase slightly at T2 ($P < 0.05$). Continuous upper airway pressure recordings have confirmed the soft palate region to be an obstruction site of central importance in OSA (Skatvedt, 1993). The present findings accordingly raise questions regarding oropharyngeal airway patency after mandibular setback osteotomies.

There was a tendency for the base of the tongue (V⊥FH) to move downwards at the short-term follow-up, but like the hyoid bone, vallecula moved upwards again ending in a position not significantly different from the initial position. This is consistent with findings in previous studies (Takagi *et al.*, 1967; Wickwire *et al.*, 1972).

The tongue further assumed a more upright position at T1. This angle decreased somewhat at T2, but was still significantly larger than at T0. Since the tip of the tongue presumably remained at the same position at T1 and T2, the altered inclinations at the long-term follow-up could be explained partly by elevation of vallecula and partly by the increased craniocervical angle (NSL/OPT, NSL/CVT).

The increased length of the tongue (V–T) and the soft palate (pm–U) resulted in an increased soft tissue area which occupied more of the oropharyngeal space (TA + SPA/OPA), presumably leaving less space for airway patency.

Although several cephalometric studies (Wenzel *et al.*, 1989a; Greco *et al.*, 1990; Athanasiou *et al.*, 1991; Katakura *et al.*, 1993; Enacar *et al.*, 1994; Hochban *et al.*, 1996) investigated the alterations in the pharyngeal airway after mandibular setback osteotomy none performed detailed investigations at all possible sites of obstruction at the different levels of the upper airway. Furthermore, these studies varied considerably in the methodology used and the characteristics of the patient material.

Katakura *et al.* (1993), Hochban *et al.* (1996), and Wenzel *et al.* (1989a) all showed a significant decrease of the pharyngeal sagittal dimensions. The first two groups used measurements around the region of the minimal and hypopharyngeal airway space, and the third at the nasopharyngeal level with population samples which varied greatly with regard to follow-up observation time. That of Wenzel *et al.* (1989b) and Hochban *et al.* (1996) was 1.2 and 1 year, respectively, while Katakura *et al.* (1993) compared the immediate post-operative with the pre-operative (2–14 days) situation. Greco *et al.* (1990) investigated long-term changes in a sample ranging from 2–6 (mean 4) years observation time. Enacar *et al.* (1994) used area measurements for the hypopharyngeal airway space and showed significant reduction 1.5 years post-operatively. In contrast, Athanasiou *et al.* (1991) demonstrated that the pharyngeal depth at the level of the second and fourth vertebrae maintained its pre-surgical dimensions 1 year after surgery.

The present study showed a statistically significant reduction of the oropharyngeal airway space (U-MPW) between T0 and T1, a change which was maintained at T2, and which corresponded with the post-surgical changes in the inclination of the soft palate and the positional and morphological adaptations of the tongue. Furthermore, the ratio SPA/(OPA–OA) at T2 indicated that the soft palate occupied more of the pharyngeal airway than before surgery.

The hypopharyngeal and minimal pharyngeal airway space (V–LPW, PASmin), although showing a tendency for reduction, never reached statistically significant levels. Another important finding was the reduction of the residual oropharyngeal airway space (TA+SPA/OPA) at the longest follow-up compared with the pre-surgical condition.

As the site of airway obstruction during apnoeic episodes in OSA is usually located in the oropharyngeal region, involving the soft palate, the dorsum of the tongue, and the posterior pharyngeal wall, the results of the present study suggest that this knowledge should be adequately taken into consideration in decision making prior to orthognathic surgery, as narrowing of the oropharyngeal airway space is likely to occur after mandibular setback.

On the other hand, no significant long-term reduction of the minimal pharyngeal and hypopharyngeal sagittal airway dimensions was recorded. This could be explained on the basis of compensatory functional readjustments of the hyoid, lingual, and cervical musculature to maintain airway patency in the surgically altered environment. Furthermore, the statistically significant altered craniocervical angulation (NSL/OPT, NSL/CVT) at the late post-surgical follow-up (T2) indicated that cervical hyperflexion had taken place as a compensatory mechanism supported also by significant correlations between changes in craniocervical angulation and in pharyngeal airway dimensions (PASmin, V–LPW). Previous experimental studies demonstrated associations between craniocervical angulations and pharyngeal diameters in normal subjects, with the head positioned at different degrees of extension and flexion (Davies and Stradling, 1990; Hellsing, 1989).

Solow *et al*. (1996) clearly demonstrated this postural compensatory mechanism which takes place to maintain airway patency in awake OSA patients. According to their interpretation, the extended craniocervical relationship serves to lift away the base of the tongue and the soft palate from the posterior pharyngeal wall. This mechanism operates efficiently and opens the airway at the most caudal part of the pharynx, i.e. at the level of the base of the tongue and the epiglottis. At the most cranial level, such as the soft palate the effect is limited and requires a large increase in craniocervical angulation to produce increase in the airway dimensions.

Conclusions

Soft tissue alterations took place as a result of the mandibular setback surgery. They comprised positional changes of the hyoid bone, increased length and inclination of the soft palate, more upright tongue, and reduction of the oropharyngeal airway space. The minimal and hypopharyngeal airway space seemed not to be altered on a long-term basis, probably because of a compensatory increase in craniocervical angulation. These changes are of such a nature that they should be taken into consideration when planning mandibular setback osteotomies. Thus, all patients undergoing correction for mandibular prognathism by setback operations should be carefully evaluated prior to surgery to identify those potentially at risk for development of OSA.

Furthermore, a multi-centre study with standardized cephalometric measurements (alternatively CT or MRI examinations using standardized sections), in conjunction with laboratory tests and polysomnography pre- and post-operatively, and probably on a long-term longitudinal basis with follow-ups over decades, is needed to detect whether the correction of mandibular prognathism provokes sleep apnoea as the subject's age increases.

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