Cephalometric and demographic characteristics of obstructive sleep apnea: An evaluation with partial least squares analysis

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Obstructive sleep apnea (OSA) is defined by a combination of many clinical complaints, signs and symptoms that result from repeated partial (hypopnea), and/or complete (apnea) obstructions of the upper airway during sleep. Although OSA can be induced by external factors, such as alcohol ingestion, it is accepted to be an "intrinsic sleep disorder," which implies that its primary etiology is abnormalities in physiological or pathological processes and/or anatomical structures.[1-5]

Several methods using advanced technologies (e.g., CT, MRI, and videoendoscopy) have been used to evaluate the anatomical characteristics of the upper airway and craniofacial structures that may predict OSA, and/or to determine the site(s) of obstruction.[6-18] However, the traditional cephalometric method has been the most practical.[11-13,16,18-27] Although the method has disadvantages in that it is two dimensional, static, and patients are awake during the exposures, these studies have nevertheless been useful, as they have shown that significant differences exist between asymptomatic controls and patients with OSA in a large number of cephalometric measurements.

The purpose of this study was to test the relative contributions of specific demographic and cephalometric measurements to OSA severity. Partial least squares (PLS) analysis, which provides a simple summary of associations among multiple measures in two or more blocks (pre-

Abstract

Obstructive sleep apnea (OSA) is caused by repeated obstruction of the upper airway during sleep. The purpose of this study was to test the relative contributions of specific demographic and cephalometric measurements to OSA severity. Demographic, cephalometric, and overnight polysomnographic records of 291 male OSA patients and 49 male nonapneic snorers were evaluated. A partial least squares (PLS) analysis was used for statistical evaluation. The results revealed that the predictive powers of obesity and neck size variables for OSA severity were higher than the cephalometric variables used in this study. Compared with other cephalometric characteristics, an extended and forward natural head posture, lower hyoid bone position, increased soft palate and tongue dimensions, and decreased nasopharyngeal and velopharyngeal airway dimensions had relatively higher associations with OSA severity. The respiratory disturbance index (RDI) was the OSA outcome variable that was best explained by the demographic and cephalometric predictor variables. We conclude that the PLS analysis can successfully summarize the correlations between a large number of variables, and that obesity, neck size, and certain cephalometric measurements may be used together to evaluate OSA severity.

Key Words

Obstructive sleep apnea • Cephalometrics • Obesity • Partial least squares analysis.

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Figure 1
Measurements for vertical craniofacial skeletal pattern block. Angular measurements: sella-nasion line (SN) to palatal plane (PP), SNPP; mandibular plane (MP) to PP, MPPP; Frankfort plane to MP, FPPP; SN to MP, SNMP; gonial angle, GoA. Linear measurements: upper facial height, UFH; lower facial height, LFH; total facial height, TFH; posterior facial height, PFH; ramal height, RH; sella-nasion length, S-N.

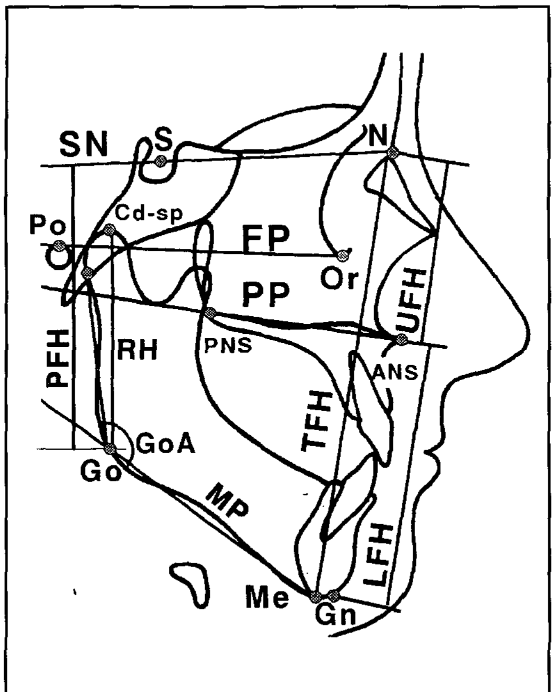

Figure 1

Table 1
PLS for vertical craniofacial skeletal structure and OSA severity blocks

Vertical pattern block	s
SNPP	0.50
FPMP	0.46
SNMP	0.36
LFH/S-N	0.33
RH	0.27
TFH	0.25
GoA	0.22
LFH	0.20
UFH	0.20
PFH/LFH	-0.18
MPPP	0.11
PFH	-0.02
UFH/LFH	-0.02
r=0.248	
OSA Block	s
$MinSaO_2$%	-0.69
AI	0.67
#Des<90%	-0.22
RDI	0.16
HI	-0.03

dictor and outcome blocks), was used for the statistical evaluation.[12,28-31]

Lowe et al.[12] used PLS to assess the interrelations between OSA outcome variables and computer tomographic, cephalometric, and demographic predictor blocks. In the present study, instead of using the "type" of measurement (e.g., CT volumes) as a criterion to form the predictor blocks, we created blocks using measurements that represent the same characteristics (e.g., demographic block), anatomic areas (e.g., upper airway block), or skeletal pattern (e.g., sagittal skeletal pattern block), to evaluate the associations between these different blocks and OSA severity, to determine which variables best account for the increases in OSA severity and to find out which OSA variables are better explained by a particular block.

Materials and methods

Demographic, cephalometric (upright and supine), and overnight polysomnographic records for 340 male subjects (mean age 45.9±11.9, ranging from 17 to 73) were used. Details of the overnight polysomnography have been explained elsewhere.[10,13,24] The cephalometric films were taken using the same cephalostat (Counterbalanced Cephalometer Model W-105, Wehmer Co). The distance from the x-ray source to the median plane of the head was 165 cm and the median plane to film distance was 14 cm. Natural head posture (NHP)[32] was used while taking the upright cephalometric films, and the lower border of the cephalometric film determined the "true horizontal" reference line. For the supine cephalometric films, subjects were asked to lie face up on a stretcher, to choose a pillow similar in height to what they normally use, and to maintain the lower jaw in the rest position. To enhance the outlines of the upper airway tissues, subjects swallowed a spoonful of radiopaque barium sulphate oesophageal cream (65%W/W) to coat the dorsum of the tongue and the upper airway. Of the 340 subjects, 291 had a respiratory disturbance index (RDI) greater than 10 or an apnea index (AI) greater than 5. The remaining 49 subjects had no objective symptoms of OSA as determined by overnight studies.

Determination of OSA severity (OSA severity "outcome" block)

Severity of OSA was assessed by five variables. Measurements were obtained from the overnight polysomnographic records:

Apnea index (AI). Apnea is defined as the cessation of breathing during sleep for 10 seconds or more. AI is the average number of apneas per hour.

Hypopnea index (HI). Hypopnea is defined as a greater than 50% decrease in airflow for 10 seconds or more. HI is the average number of hypopneas per hour.

Respiratory disturbance index (RDI). Average number of apneas plus hypopneas per hour during sleep.

Percentage of minimum oxygen desaturation ($MinSaO_2$%) during sleep.

Table 2
PLS for sagittal craniofacial skeletal structure and OSA severity blocks

Sagittal pattern block	s
MdUL	-0.53
SNPg	-0.50
ULD	-0.38
SNB	-0.38
ANB	0.30
MxUL	-0.26
SNA	-0.17
r=0.145	
OSA Block	s
RDI	0.57
MinSaO$_2$%	-0.47
AI	0.44
#Des<90%	0.40
HI	0.33

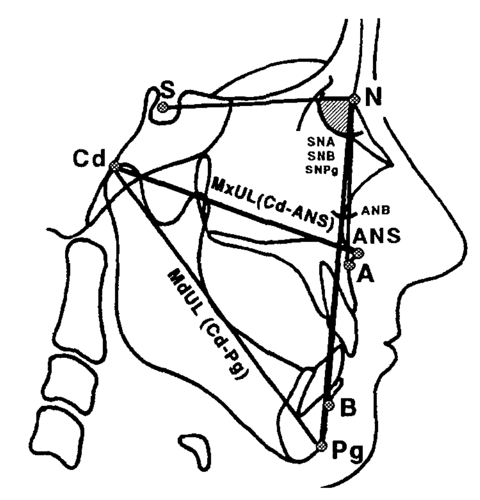

Figure 2

Figure 2
Measurements for sagittal craniofacial skeletal pattern block. Angular measurements: SNA, SNB, SNPg, ANB. Linear measurements: maxillary unit length, MxUL; mandibular unit length, MdUL; unit length discrepancy, ULD (MdUL-MxUL).

Number of desaturations less than 90% (#Des<90%) during sleep.

Explanation of partial least squares (PLS)[12,28-31]

The PLS method provides a simple summary of associations among multiple measures in two or more blocks by providing the best reduction of the structure of a covariance matrix as merely one-dimensional, expressing just one latent variable score (LV) per block. Blocks are not arbitrary, but correspond to a priori lists of related variables. From the current literature and clinical experience, we know that certain demographic and cephalometric measures increase the risk of a higher level of OSA severity. With the use of a PLS analysis, we wish to scale the measurements within each predictor block to best explain the cross-block correlations, and to determine which OSA "outcome" variables are better explained by the predictor blocks. PLS does not "test" hypotheses about the relations of predictors and outcomes. Instead, it quantifies the relationships among alternate predictors or alternate outcomes, within a cause-effect context that is not in itself in doubt. Like other regression and correlation analyses, PLS does not prove causal ordering.

Two-block analyses yield three basic statistics used to make decisions concerning the final model: (1) Singular values and their associated vectors (saliences) describe the patterns of correlation between the indicators of either block with the LV score of the other block. In other words, these saliences express the contribution of each variable to the association between the two blocks. (2) The ratio of the first two singular values (rsv) of the cross-correlation matrix estimates how effectively a single pair of patterns exhausts the correlation matrix. An arbitrary cutoff at a 2:1 ratio between the first and second singular values is used, which represents a 4:1 ratio of the explained summed squared correlations as a threshold for "meaning" of the first LV pair. That the rsv is less than 2.0 implies that the first and second pairs of singular vectors are not sufficiently distinguished and that a one-dimensional representation of the cross-correlation matrix might be seriously misleading. (3) The two-block correlation coefficient between LV scores is r, which is the ordinary Pearsonian correlation between the two linear combinations of the indicators, block by block, as weighted by their saliances. Before accepting r as the correlation between the predictor and outcome blocks, it is essential to determine whether this particular pair of LVs summarizes a sufficient fraction of the available correlation information by looking at the rsv value.

In this study, PLS analyses have been applied to these questions: What cephalometric and demographic measurements best account for overall OSA severity as determined by the five different overnight polysomnogram variables? Which of these five outcome variables are best explained by which particular predictor block?

A total of eight predictor blocks were initially formed as described below. The PLS procedure

Figure 3
Upper airway, soft palate, and tongue measurements. Cross-sectional area measurements: soft palate, SP-Area (1); tongue, Tng-Area (2); nasopharynx, Naso-Area (3); oropharynx, Oro-Area (4); hypopharynx, Hypo-Area (5). Linear measurements: maximum palatal thickness, MPT (6); soft palate length, PNS-P (7); tongue length, TGL (8); tongue height, TGH (9); superior posterior airway space, SPAS (10); middle airway space, MAS (11); inferior airway space, IAS (12).

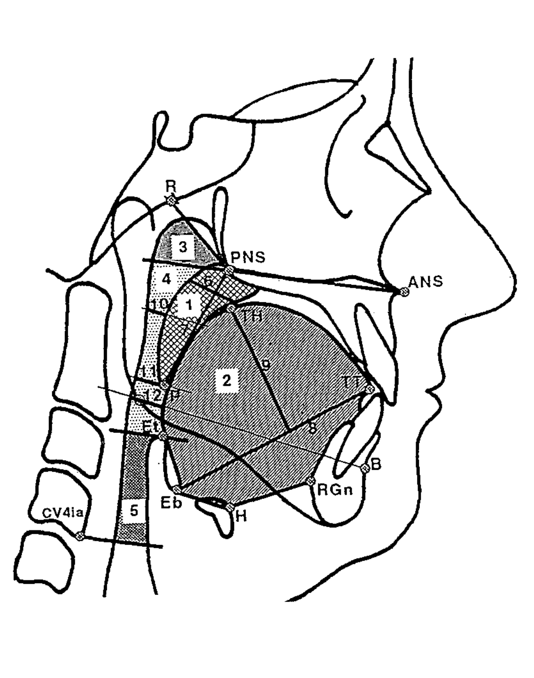

Figure 3

Table 3
PLS for upper airway (upright) and OSA severity blocks.

Airway block (upright)	s
SP-Area	0.46
SPAS	-0.38
Naso-Area	-0.36
MPT	0.35
TGL	0.32
TGL/TGH	0.30
Tng-Area	0.27
PNS-P/MPT	-0.24
PNS-P	0.21
TGH	-0.09
Oro-Area	-0.09
MAS	-0.09
IAS	-0.06
Hypo-Area	0.04
r=0.326	
OSA block	s
RDI	0.64
AI	0.46
HI	0.40
MinSaO$_2$%	-0.34
#Des<90%	0.31

was applied to the complete list of all 68 predictor measurements (final predictor block) to determine the best predictors of an overall increase in OSA severity and to find the OSA outcome variable best explained by the demographic and cephalometric data.

Cephalometric predictor blocks (Tables 1-7)

Tracings of the cephalometric films were prepared and traditional contours and points were digitized.[24] A total of 63 cephalometric measurements were completed (Tables 1 to 7 and Figures 1 to 5). Reliability of cephalometric landmark identification and digitizing was assessed using intraclass correlation coefficients. Duplicate tracings and digitization of 24 headfilms revealed that the values for intra-examiner reliability ranged from 0.83 to 0.99 for vertical skeletal pattern measurements, 0.84 to 0.98 for sagittal skeletal measurements, 0.80 to 0.97 for upper airway block measurements, 0.97 to 0.99 for hyoid bone position measurements, and 0.94 to 0.99 for NHP measurements. The predictability of these measurements for OSA severity was evaluated in the following cephalometric predictor blocks (see figure legends for the definitions of cephalometric measurements):

Vertical skeletal pattern block (upright) (Table 1)
Sagittal skeletal pattern block (upright) (Table 2)
Upper airway block (upright) (Table 3)
Upper airway block (supine) (Table 4)
Hyoid bone position block (upright) (Table 5)
Hyoid bone position block (supine) (Table 6)
Natural head posture block (upright) (Table 7)

Table 4
PLS for upper airway (supine) and OSA severity blocks.

Airway block (supine)	s
SP-Area$_{SP}$	0.50
Tng-Area$_{SP}$	0.38
Naso-Area$_{SP}$	-0.37
TGL$_{SP}$	0.34
TGL/TGH$_{SP}$	0.31
PNS-P$_{SP}$	0.30
SPAS$_{SP}$	-0.30
MPT$_{SP}$	0.23
MAS$_{SP}$	-0.12
TGH$_{SP}$	-0.09
PNS-P/MPT$_{SP}$	-0.06
Hypo-Area$_{SP}$	-0.06
IAS$_{SP}$	0.03
Oro-Area$_{SP}$	0.02
r=0.326	
OSA block	s
RDI	0.55
HI	0.51
MinSaO$_2$%	-0.49
AI	0.33
#Des<90%	0.31

Demographic predictor block (Table 8)

Five variables were used to form this block: age; weight (kg); body mass index (BMI), calculated by dividing the weight (kg) by the height squared (m^2) (BMI=kg/m^2); neck size, measured as the neck circumference at the level of the cricothyroid membrane; and predicted neck size (PPNC), calculated with the formula established by Davies and Stradling[19] and providing a compensation for increases in neck circumference by height.

Table 5
PLS for upright hyoid bone position and OSA severity blocks

Hyoid block (upright)	s
H-MP	0.62
H-H1	0.52
H-CV3	0.50
H-RGn	0.31
H-CV3/H-RGn	0.05
r=0.28	
OSA block	s
RDI	0.61
#Des<90%	0.45
AI	0.41
$MinSaO_2$%	-0.41
HI	0.31

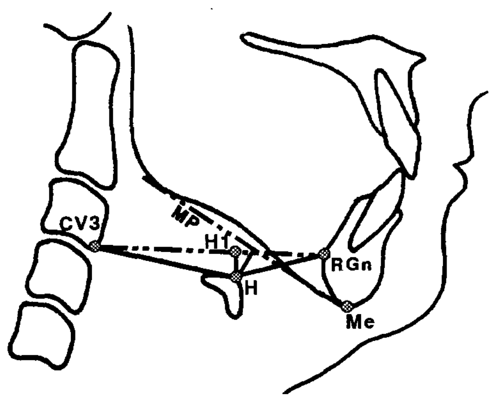

Figure 4

Figure 4
Measurements for hyoid bone position. Distances of hyoid bone to mandibular plane, H-MP; to RGn-CV3 line, H-H1; to the cervical column, H-CV3 and to mandibular symphisis, H-RGn.

Table 6
PLS for supine hyoid position and OSA severity blocks

Hyoid block (supine)	s
$H\text{-}MP_{SP}$	0.60
$H\text{-}H1_{SP}$	0.52
$H\text{-}RGn_{SP}$	0.48
$H\text{-}CV3_{SP}$	0.36
$H\text{-}CV3/H\text{-}RGn_{SP}$	-0.11
r=0.334	
OSA block	s
RDI	0.58
HI	0.43
$MinSaO_2$%	-0.42
AI	0.40
#Des<90%	0.37

Results

Cephalometric and demographic blocks (Tables 1-8)

The rsvs and Pearson correlations between the LVs of these predictor blocks and the OSA severity block suggested that a one-dimensional representation of the cross-correlation matrix was appropriate for all our predictor blocks (rsv>2.0). The Pearson's correlation coefficients (r) between the predictor block LVs and the weighted average of the OSA variables ranged between 0.145 to 0.407. These values are significant according to the conventional multiple regression analysis at the 1% level of significance. The demographic block had the highest correlation (r=0.407), followed by upper airway, hyoid bone position, and natural head posture blocks (r=0.281 to 0.334). The pairs of LVs explained 73% to 99% of the predictability between the blocks. The best predicted OSA variables were $MinSaO_2$% and AI for the vertical skeletal pattern block, (Table 1); RDI for the sagittal skeletal pattern, upper airway morphology in the upright position and upright and supine hyoid bone position blocks (Tables 2, 3, 5, and 6); RDI and HI for the upper airway morphology in the supine position block (Table 4); RDI and AI for the NHP block (Table 7); and $MinSaO_2$% and RDI for the demographic block (Table 8).

Final block (Table 9)

In the final block, the r-value for the Pearson's correlation coefficient between the two blocks was 0.485, which suggests that the information obtained from our final predictor block explains approximately 25% of the variability in overall OSA severity defined by the five OPG variables.

Obesity measurements (BMI, PPNC, neck size and weight) had higher saliances when compared with the cephalometric measurements used in this report (Table 9). For the upright cephalometric films, the measurements with highest predictive values for OSA severity were generally those concerning the natural head pos-

Figure 5
Natural head posture (NHP) measurements. Craniocervical posture: NSL.OPT (1), NSL.CVT (2); cervical posture: OPT.HOR (3), CVT.HOR (4); cervical curvature: OPT.CVT(5).

Figure 6
A typical male patient to diagrammatically portray the most likely demographic and cephalometric characteristics observed in severe OSA.

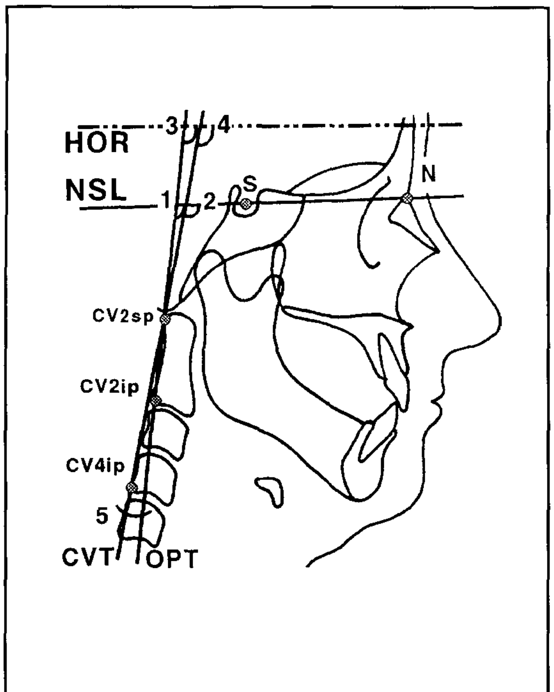

Figure 5

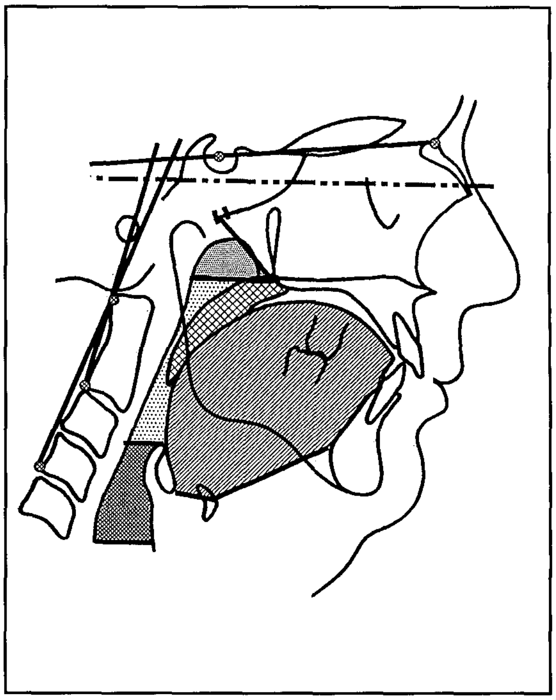

Figure 6

Table 7
PLS for natural head and neck posture and OSA severity blocks

Natural head posture block	s
NSL.CVT	0.53
NSL.OPT	0.53
OPT.HOR	0.48
CVT.HOR	0.46
OPT.CVT	-0.08
r=0.281	
OSA block	s
RDI	0.58
AI	0.57
$MinSaO_2$%	-0.42
HI	0.30
#Des<90%	0.29

Table 8
PLS for demographic and OSA severity blocks

Demographic block	s
BMI	0.51
P-neck size	0.50
Weight	0.49
Neck size	0.49
Age	0.11
r=0.407	
OSA block	s
$MinSaO_2$%	-0.53
RDI	0.52
HI	0.43
#Des<90%	0.41
AI	0.30

ture (NSL.CVT, NSL.OPT, OPT.HOR, CVT.HOR), hyoid bone position (H-MP, H-H1, H-CV3), soft palate size (SP-Area, MPT), nasopharyngeal airway cross-sectional area (Naso-Area), and the superior posterior airway size (SPAS). These were followed by tongue size and shape measurements (TGL, TGL/TGH and Tng-Area), and some skeletal variables, such as the inclination of the palatal plane (SNPP), mandibular size (MdUL) and mandibular position (SNPg). Measurements regarding oropharyngeal and hypopharyngeal airway dimensions had relatively lower predictive values. For the supine cephalometric films, again the hyoid bone position measurements ($H\text{-}MP_{SP}$, $H\text{-}H1_{SP}$, $H\text{-}RGN_{SP}$), soft palate cross-sectional area ($SP\text{-}Area_{SP}$) and nasopharyngeal airway cross-sectional area ($Naso\text{-}Area_{SP}$) had relatively higher saliances. These were followed by tongue size and shape measurements ($Tng\text{-}Area_{SP}$, TGL_{SP}, TGL/TGH_{SP}).

The oropharyngeal and hypopharyngeal airway dimensions had relatively lower predictive values. RDI (respiratory disturbance index) was the best explained OSA outcome variable by the final predictor block.

Table 9
Final PLS with all predictor variables

All predictor		SNPP	0.12	TFH	0.03
variables	s	TGL/TGH	0.12	Oro-Area	-0.03
BMI	0.28	Tng-Area	0.11	PNS-P/MPT$_{SP}$	-0.03
PPNC	0.28	MDUL	-0.10	UFH/LFH	0.03
Neck Size	0.27	SPAS$_{SP}$	-0.10	OPT.CVT	-0.02
WT	0.27	SNPg	-0.10	Hypo-Area	0.02
H-MP$_{SP}$	0.22	PNS-P$_{SP}$	0.09	Hypo-Area$_{SP}$	-0.02
NSL.CVT	0.19	H-RGN	0.09	IAS	-0.02
H-H1$_{SP}$	0.19	PNS-P/MPT	-0.09	Oro-Area$_{SP}$	0.02
NSL.OPT	0.19	PNS-P	0.08	H-CV3/H-RGn	0.02
H-MP	0.18	FPMP	0.08	PFH/LFH	-0.01
H-RGn$_{SP}$	0.18	MPT$_{SP}$	0.08	MPPP	0.01
SP-Area	0.18	SNB	-0.07	RH	-0.01
SP-Area$_{SP}$	0.17	SNMP	0.07	IAS$_{SP}$	0.01
OPT.HOR	0.17	ULD	-0.07	PFH	-0.01
CVT.HOR	0.16	AGE	0.06	LFH	0.01
H-H1	0.15	ANB	0.06	r=0.484	
H-CV3	0.15	MXUL	-0.05		
Naso-Area	-0.14	GoA	0.05		
Naso-Area$_{SP}$	-0.14	UFH	0.04		
SPAS	-0.14	LFH/S-N	0.04	OSA block	
Tng-Area$_{SP}$	0.14	TGH	-0.04		
H-CV3$_{SP}$	0.14	H-CV3/H-RGn$_{SP}$	-0.04	RDI	0.57
MPT	0.13	TGH$_{SP}$	-0.04	MinSaO$_2$%	-0.47
TGL$_{SP}$	0.13	MAS$_{SP}$	-0.04	AI	0.42
TGL	0.12	SNA	-0.03	HI	0.39
TGL/TGH$_{SP}$	0.12	MAS	-0.03	#Des<90%	0.35

Discussion

PLS is designed specifically for those investigations that attempt to pursue "downwards" into the "normal range" a cause-and-effect relationship that is known to lead a syndrome.[31] In this regard, PLS is aimed at the combination of a normal population and a group of cases having a "clearly defined syndromology." With both controls and patients included, a graduated range of subjects with different levels of disease severity can be evaluated from the absence of disease through mild-moderate and severe levels. Therefore, we combined the OSA patients with the nonapneic snorers. The ability to use more than one OPG variable to evaluate OSA severity enabled us to find out which of these variables were better explained by a particular block by looking at their saliences. At this point, readers should be reminded that, like other regression and correlation analyses, PLS does not prove causal ordering, and the terms "prediction" or "predictor" which have been used throughout this text and previous PLS studies do not imply a causation. They are used as statistical terms equivalent to "independent variable" or "covariate variable" in regression and correlation analysis.[33]

Many previous studies have proposed obesity as one of the primary causes of OSA.[14,16,34-38] Our final block also demonstrates the predictive power of obesity for OSA severity (Table 9). Both weight and neck size variables had higher saliances than the cephalometric measurements used in this study. However, the nature of the associations between obesity and OSA remains controversial. MRI studies have found larger fat deposits around the retropalatal airspace and in the palatopharyngeal region in obese OSA patients when compared with weight-matched controls.[8,36] However, the association between the degree of obesity and the size of fat deposits did not reach the level of statistical significance. More recently, Schwab et al.[15] demonstrated that, although the total volume of parapharyngeal fat was larger in OSA patients (who were also more obese) than in controls, the predominant factor causing the airway narrowing in apneic patients at the minimum airway space level was the increased thickness of the lateral pharyngeal walls, not the enlargement of the parapharyngeal fat pads.

Mass loading on the airway can produce changes of airway configuration and function.[34] Cervical fat can produce a gravitational load effect on the airway, especially when patients are in the supine position. Therefore, obesity may also produce its effect due to excess adipose tissue in the neck. Davies and Stradling[19] and Katz et al.[39] demonstrated the predictive power of neck size on the Apnea-Hypopnea Index and on dips in arterial oxygen saturation during sleep. In addition, obesity is one of the most commonly seen causes of lung restriction.[40] Accumulation of adipose tissue in and around the ribs, abdomen, and diaphragm may cause reduced compliance in the thoracic cage, and increased weight may be applied to the lungs.[41] Swings in SaO_2 may be present without apnea in obese patients, and these swings may be related to periodic changes in ventilation or to incomplete upper airway occlusion (hypopnea).[40] Quear-

Salva et al.[42] demonstrated a significant relationship between BMI and nocturnal SaO_2 drops. In a sample of obese patients, Suratt et al.[37] found a significant increase in oxygenation during both sleep and wakefulness after a mean weight loss of 20.6 kg. Parallel to these results, the decrease in the minimum oxygen desaturation during sleep ($MinSaO_2\%$) and the increase in RDI (mainly related to increases in hypopneas) in this report, were the best predicted OSA variables with our demographic block, which comprised the obesity and neck size measurements (Table 8).

The craniocervical (NSL.OPT, NSL.CVT) and cervical (OPT.HOR, CVT.HOR) posture variables were among the best predictors of OSA severity in our final block (Table 9). The best explained OSA variables by the posture block were RDI and AI (Table 7). A more forward and extended head posture was related to increases in RDI and AI, and decreases in $MinSaO_2\%$. Solow et al.[43] and Tangugsorn et al.[44] also found that the average craniocervical angle in the OSA sample was significantly larger than that observed in controls, which was mediated by the forward inclination of the cervical column. These results are not unexpected considering the relationship between the upper airway characteristics and OSA syndrome,[7,10-13,17,18,20,22-24,26,45] and considering the studies of the relationship between the natural head and/or neck posture and upper airway.[46-51]

Along with NHP variables, measurements concerning the position of the hyoid bone, especially those showing its vertical location both in upright and supine positions ($H\text{-}MP_{SP}$, H-MP, $H\text{-}H1_{SP}$ and H-H1), also had relatively higher saliances in our final PLS block. A lower hyoid bone position was found to be related to a higher OSA severity. RDI was the best explained OSA outcome variable by our upright and supine hyoid blocks (Tables 5 and 6). The hyoid bone plays an important part in maintaining the upper airway dimensions and an upright natural head posture.[52,53] Thurow[54] proposed that the constantly active geniohyoid muscle functions to adjust the anteroposterior position of the hyoid bone and to maintain airway patency throughout the various movements of the craniomandibular complex. A hyoid bone positioned level with the genial tubercle will increase the efficiency of the geniohyoid muscle in pulling the tongue forward. A lower hyoid bone with a lower tongue posture places the geniohyoid muscle at a mechanical disadvantage by its angulation. This may not only increase the mandibular load because of the need to elevate the tongue, it may also cause a stronger opening force on the mandible.[54] These factors may aggravate an apnea by facilitating the open mouth posture during sleep that is often observed in OSA patients.[55]

A number of previous studies found increases in soft palate and/or tongue size in OSA patients.[8,10,13,15,19,20,22,23,26,27,56] Similar results with the PLS method were obtained in this report. Soft palate cross-sectional area was among the best predictors of OSA severity both in the upright and supine positions (Tables 3, 4 and 9). This was followed by nasopharyngeal airway cross-sectional area, superior posterior airway size, tongue size and shape, and other soft palate measurements. The predictive power of the lower levels of the upper airway for OSA severity was much weaker when compared with nasopharyngeal and velopharyngeal levels. This is in agreement with many studies that evaluated awake and/or sleeping patients using more sophisticated techniques (such as CT, MRI and videoendoscopy) and proposed the velopharyngeal level as the major site of complete obstruction.[7-9,14,17,18,45]

With respect to the skeletal craniofacial measurements, increased angulation of the maxilla and the mandible in relation to the skull (SNPP, FPMP, SNMP), decreased mandibular size with a posterior position (MdUL, SNPg, SNB) and a tendency to a sagittal skeletal Class II discrepancy (ULD and ANB) were related to an overall increase in OSA severity (Table 9). It should be noted that the predictive powers (saliances) of these measurements were higher than those associated with oropharyngeal and hypopharyngeal airway sizes. These results suggest that certain craniofacial skeletal characteristics, combined with an increase in soft palate and tongue size, a small nasopharyngeal cross-sectional area, an increased craniocervical angulation in the natural head posture, and a lower hyoid bone position may significantly contribute to OSA severity.

Advanced technologies such as CT, MRI and videoendoscopy may be too time-consuming and expensive for routine clinical use. The general consistency of our results with previous studies that used the above technologies implies that cephalometric films can be used to evaluate the craniofacial soft and hard tissue structures. In recent years, there has been an increasing demand for oral appliances for the treatment of snoring and/or OSA, because they are simple, reversible, quiet and cost-effective.[57-59] The use of cephalometric evaluation and oral appliances for the diagnosis and treatment of OSA has resulted in a professional relationship between the sleep physician and the orthodontist. The recommendations developed by the Standards of Practice Committee and approved by the Board of Directors of the American Sleep Disorders Association describe the appropriate use of oral appliances for the treatment of OSA in adults.[60]

A question remains whether it is better to use upright or supine cephalometric films to assess the upper airway and related structures that may be associated with OSA severity. Based on our results, we can speculate that taking both may not be necessary as a routine clinical procedure. Supine cephalometric films would seem to be advantageous as they most closely resemble the sleeping posture. However, several factors need to be considered before a clinician can decide which films are required for a particular patient: The posture and/or tonicity of the related soft and hard tissue structures may differ in awake and sleep states; patients may sleep in different positions during the night; the reproducibility of head posture in the supine position is questionable, whereas the reproducibility of upright cephalometric films obtained in the natural head and neck posture has been widely demonstrated[30,61-63] (we obtained similar information from the upright and supine measurements).

Conclusions

The PLS method used in this report successfully summarized the intercorrelations among a large number of variables into a remarkably simple form. Based on our results, the following demographic and cephalometric characteristics are most likely to be expected in patients with severe OSA (Figure 6): Increased obesity and neck size, a forward and extended head posture, increased soft palate and tongue dimensions, a small nasopharyngeal cross-sectional area, decreased sagittal upper-airway dimensions especially at the velopharyngeal level, a lower hyoid position, a smaller and retrognathic mandible together with an overall reduction in sagittal craniofacial dimensions. RDI was the best explained OSA outcome variable by the final predictor block, which contained all the cephalometric and demographic measurements used in this study.

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