Relationship between cephalometric parameters and the apnoea-hypopnoea index in OSA patients: a retrospective cohort study

Published Version:
Stipa, C., Cameli, M., Sorrenti, G., Ippolito, D.R., Pelligra, I., Alessandri Bonetti, G. (2020). Relationship between cephalometric parameters and the apnoea-hypopnoea index in OSA patients: a retrospective cohort study. THE EUROPEAN JOURNAL OF ORTHODONTICS, 42(1), 101-106 [10.1093/ejo/cjz038].

Availability:
This version is available at: https://hdl.handle.net/11585/724244 since: 2020-02-12

Published:
DOI: http://doi.org/10.1093/ejo/cjz038

Relationship between cephalometric parameters and the apnea-hypopnea index in OSA patients: a retrospective cohort study

SUMMARY

Objective: The purpose of this study was to assess the relationship between cephalometric parameters and apnea-hypopnea index (AHI) controlling for the effect of gender, age and body mass index (BMI) on a large sample of patients with obstructive sleep apnea (OSA).

Methods: This retrospective cohort study was conducted on the lateral cephalograms of 253 Caucasian adult OSA patients. Cephalometric analyses were performed using 14 parameters for skeletal and soft tissue morphology, including antero-posterior and vertical jaw relationships, hyoid bone position, soft palate length and thickness, airway space, tongue length and height. A hierarchical regression was run to examine the amount of variability in AHI that cephalometric variables explained after controlling for patients' general characteristics (gender, age and BMI).

Results: After controlling for gender, age and BMI, the increase in AHI variance accounted for by cephalometric parameters was equal to 0.103. Among the cephalometric variables, only MP-H and PNS-P were statistically significant ($p<0.05$).

Limitations: Given the retrospective nature of the study, it is difficult to assess whether other confounding variables not considered in the present study could have influenced the relationship between cephalometric parameters and AHI.

Conclusions: This study revealed the existence of a relationship between OSA severity and some cephalometric parameters. Indeed soft palate length and vertical position of the hyoid bone were significant predictors of AHI in adult Caucasian OSA patients.

Keywords: Obstructive sleep apnea; Cephalometry; Apnea/hypopnea index; Body mass

index.

Introduction

Obstructive sleep apnea (OSA) is characterized by repetitive episodes of complete or partial closure of the upper airways during sleep that lead to sleep fragmentation and oxygen desaturation (1).

The pathogenesis of OSA is multifactorial, with both anatomic (compromised or collapsible upper airways) and non-anatomic (high loop gain, low arousal threshold and inadequate responsiveness of the upper airway dilator muscles) traits playing an important role (2, 3). It has been reported that various factors related to the morphology of either skeletal (such as mandibular deficiency, maxillary hypoplasia and inferior position of hyoid bone) or pharyngeal soft tissues (such as the elongation of the soft palate and tonsillar hypertrophy) could predispose to upper airway obstruction during sleep, by determining an imbalance between upper airway soft tissue volume and bony enclosure size (4, 5).

Although many advanced imaging techniques have been proposed to assess the anatomic configuration of orofacial structures in OSA patients (including computed tomography, magnetic resonance imaging, somnofluoroscopy and acoustic reflection), cephalometry is still suitable as a screening procedure to evaluate skeletal and soft tissue characteristics since it is low-cost, easy to perform and widely available (6, 7).

Several studies have attempted to correlate specific cephalometric parameters (concerning both hard and soft tissues) to the presence of OSA (8, 9). However few studies have explored the relationship between these variables and OSA severity, evaluated through the apneahypopnea index (AHI) (10-14). Moreover, even less studies have investigated the relationship

between cephalometric parameters and AHI taking into consideration the effect of potential confounders like gender, age and body mass index (BMI) (15-17).

Indeed, marked differences in the severity of OSA, indexed by AHI, are reported in the literature as a function of age and gender. The severity of OSA seems to increase with age in both men and women, but men have consistently higher AHI for each age group, regardless of ethnic origins (18). Moreover obesity is an important risk factor for sleep related breathing disorders (19, 20). Peppard et al. in a longitudinal study with 4-years follow-up on over 600 participants, observed that a weight gain of 10% was correlated with a 32% increase in AHI, while weight loss of 10% resulted in a 26% reduction of AHI (21).

Therefore the aim of this study was to evaluate the relationship between AHI and cephalometric parameters, controlling for the effect of gender, age and BMI, on a large sample of adult Caucasian OSA patients.

Subjects and methods

Study design and sample

The study was designed as a retrospective cohort study. The study population included OSA patients referred to the ENT Unit of Sant'Orsola-Malpighi University Hospital in Bologna between March 2013 and December 2017. Inclusion criteria were: white ancestry, age over 18 years, a diagnosis of OSA carried out on the basis of polysomnography (i.e. AHI ≥ 5 with symptoms/sequelae or AHI ≥ 15 regardless of associated symptoms) (22), availability of a digital lateral cephalogram taken with the same cephalostat (Planmeca ProMax 2D S2; Planmeca, Helsinki, Finland), with the patient in upright position, natural head posture and centric occlusion, at the end of tidal breathing (23). Exclusion criteria were: history of reconstructive/orthognathic surgery to the head and neck, pharyngeal surgery, craniofacial syndromes, teleradiographs lacking distinctness of structures in the image. Based on the inclusion/exclusion criteria described above, of the 304 patients considered for inclusion 46 patients were excluded because of lack of structures distinctness and/or blurred cephalometric landmarks in the image and 5 patients were excluded because they were missing data regarding BMI. Therefore the final sample consisted of 253 OSA patients. The main patient characteristics are presented in Table 1.

All data were obtained from medical record review. The study was approved by the Ethic Committee of S.Orsola-Malpighi University Hospital, Bologna (number of approval: 3885/2017) and subjects gave voluntary informed consent to participate in research.

Cephalometric Analysis

A single, blinded, duly calibrated examiner performed cephalometric analyses. The digital cephalograms were imported to the Deltadent software (Deltadent 1.4, Outside Format, Spino D'Adda (CR), Italy). The images were calibrated by digitizing 2 points on the ruler. Fourteen variables for skeletal and soft tissue morphology, including antero-posterior and vertical jaw relationships, hyoid bone position, soft palate length and thickness, airway space, tongue length and height, were selected from previous studies using cephalometric analysis in subjects with OSA (24-28). Cephalometric landmarks and reference lines are shown in Figure 1; cephalometric variables are defined in Table 2 and shown in Figure 1.

Statistical analysis

Method error and reliability

The random error was determined using Dahlberg's formula and it ranged between 0.772 mm and 1.620 mm for linear measurements and between 0.610° and 0.967° for angular measurements. No systematic error was detected by the paired t-test for any measurements ($p>0.05$). Intra-observer reliability was tested using the intraclass correlation coefficient (ICC) by repeating the cephalometric measurements on 20 randomly selected teleradiographs twice 3 weeks apart. ICC values were excellent, ranging from 0.837 to 0.987. A second blinded, duly calibrated operator analyzed the same 20 cephalograms to evaluate the inter-observer reliability by using the ICC. Satisfactory values were found, with the ICC ranging between 0.715 and 0.958. Hierarchical regression A hierarchical regression was run to examine the amount of variability in AHI that cephalometric variables explained after controlling for patients' general characteristics (gender, age and BMI). Therefore in the first step of the hierarchical regression procedure, patients' general characteristics (gender, age and BMI) were block entered providing the variance accounted for by this group of independent variables. In the second step cephalometric variables were entered into the step 1 model, providing the unique contribution of cephalometric variables to AHI. All statistical analyses were conducted using the Statistical Package for Social Sciences Software (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY) at the 0.05 level of significance.

Results

The results of the hierarchical regression predicting AHI from cephalometric variables after controlling for patients' general characteristics (gender, age and BMI) are reported in Table 3. The results of step one indicated that the variance accounted for (R2) by the patients' general characteristics equaled 0.075, which was significantly different from zero ($F(3, 249) = 6.705$, $p<0.001$). Among the patients' general characteristics, only BMI was statistically significant ($p<0.001$). Next, cephalometric variables were entered into the regression equation. The change in variance accounted for (ΔR2) was equal to 0.103. The increase in variance accounted for over the step one model was statistically significant ($\Delta F(14,235) = 2.093$, $p=0.013$). Among the cephalometric variables, only MP-H and PNS-P were statistically significant ($p<0.05$).

Discussion

Craniofacial and pharyngeal soft tissue characteristics are acknowledged to contribute to the occurrence of apnea episodes by influencing upper airway patency; however their significance in the pathogenesis of OSA remains controversial (13). Several studies analyzed the relationship between cephalometric measurements and the presence of OSA (5). According to recent systematic reviews, reduced pharyngeal airway space and inferiorly placed hyoid bone are the cephalometric parameters that show the most consistent and strong association with OSA (5, 6). So far, few clinical studies have evaluated the relationship between severity of OSA (expressed as AHI) and cephalometric measures taking into account the effect of potential confounders like gender, age and BMI (15-17). To our knowledge, this is the first study to investigate the relationship between AHI and several cephalometric parameters related to either skeletal morphology or soft tissue characteristics, controlling for the effect of gender, age and BMI, on a large sample of Caucasian adult OSA patients. In the present study among the patients' general characteristics only BMI was a significant predictor of AHI. The relationship between AHI and obesity is well documented (21, 29, 30). Increased fat deposition around the soft tissues of the neck and the tongue contributes to a raise in extra-luminal pressures in the pharynx that elevates the pharingeal critical pressure, thereby enhancing the chances of airway collapse (19, 20). An abrupt fall in upper airway dilator muscle activity following sleep onset and a reduced lung volume are also likely to contribute to poor upper airway function in obese OSA patients (19, 20). The correlation between AHI and both age and gender has been widely described in the literature. Indeed, the severity of OSA seems to increase with age in both men and women, but men have consistently higher AHI for each age group (18, 31, 32). However gender and age did not prove to be significant predictors of AHI in our sample of OSA patients. A plausible explanation for this finding could be that in our sample male/female ratio is unbalanced, with male subjects accounting for 90.9 % of the total sample, and age variation is rather large (standard deviation: 10.1 years). Therefore, given the widely accepted influence of gender and age on AHI and the unbalanced distribution of these variables in our sample, we deemed it appropriate to include them in the final model, regardless of their statistical significance, through a hierarchical regression model. Among the cephalometric variables MP-H and PNS-P were significant determinants in the model for AHI. The alteration of MP-H in OSA patients is widely described in the literature: several studies described a lower position of the hyoid bone in OSA patients than in non-OSA patients (7, 8, 33). Moreover its relationship with desease severity has already been reported: a study conducted by Silva et al. (13) showed that patients with moderate and severe OSA had significantly higher values of MP-H than snorers and mild OSA patients. Kitamura et al. (15) found that the distance from the mandibular plane to the hyoid bone correlated significantly with AHI ($p<0.001$). Silva et al. (13) showed that patients with moderate and severe OSA had longer palates than snorers and mild OSA patients; however this difference was not statistically significant. Although a long soft palate could result in a crowded pharynx and contribute to more severe sleep apnea, such abnormalities may also be the result of greater traumatic soft tissue edema induced by recurrent apneic episodes in severe OSA (34). Our study design could not further clarify this relationship. Although MP-H and PNS-P significantly predicted AHI, the percentage of variance in AHI they accounted for was rather low. The difficulty of directly associating cephalometric variables with AHI may reasonably be attributed to several factors. First, cephalometry is performed in an awake state and in an upright position whereas the pathology of OSA arises during sleep, with the patient lying down. This is particularly important considering that the significant relationships found in this study concerned anatomical structures (hyoid bone and soft palate) which, unlike skeletal structures, could be affected by patient’s position and state of consciousness. Indeed Yildirim et al. (35) suggested that posture has an important effect on upper airway morphology, reporting that in the supine position uvular width was increased, retroglossal hypopharynx was widened, there was anterior movement of the hyoid and neck flexion.

Second, cephalogram is a 2-dimensional projection of a 3-dimensional structure; therefore no information is provided on the laterolateral pharyngeal dimensions (7). These limitations have already been highlighted in other fields related to anatomic aspects of OSA patients, such as the prediction of treatment outcome and the evaluation of dentoskeletal side effects with mandibular advancement devices in adult patients with OSA (36, 37). Therefore imaging techniques which are able to provide a 3-dimensional representation of upper airways and which are done in conditions which approach the sleep as closely as possible should also be considered for the assessment of the anatomic configuration of orofacial structures in OSA patients. However, even with 3-dimensional imaging, particular attention should be paid to the association between head posture and upper airways because changing jaw position significantly affects their dimensions (38). In the present study cephalometry carried out with a standardized patient position was used since it provides a simple and low-cost insight into craniofacial characteristics with less radiation exposure than computed tomography, and these advantages may offset the disadvantages of being a 2- dimensional exam that is performed in an awake state and in an upright position. Finally, although there may be an anatomic predisposition in the pathogenesis of OSA, nonanatomic factors, such as the ability of the upper airway dilator muscles to respond to respiratory challenge during sleep, the propensity to wake from increased respiratory drive during sleep (arousal threshold) and the stability of the respiratory control system (loop gain) must be taken into account (3, 4). In this study skeletal structures evaluated on cephalograms were poor predictors of AHI, unlike some soft tissues parameters whose relationship with AHI deserves further attention in future studies.

Limitations of the study

Given the retrospective nature of the study, it is difficult to assess whether other confounding variables not considered in the present study (lifestyle factors like dietary habits, alcohol consumption, cigarettes and physical activity) could have influenced the relationship between cephalometric parameters and AHI.

Conclusions

This study aimed to assess the relationship between cephalometric parameters and AHI controlling for the effect of gender, age and BMI in patients diagnosed with OSA. In this study soft palate length and vertical position of the hyoid bone were significant predictors of AHI in adult Caucasian OSA patients.

Conflict of Interest

None to declare

Acknowledgements

We thank Professor Furio Camillo for assistance with statistical analysis. A warm thanks also to Outside Format for providing the software for cephalometric analysis.

Funding

No funding was received for this research.

References

1. Epstein, L.J., et al. (2009) Clinical guideline for the evaluation, management and longterm care of obstructive sleep apnea in adults. Journal of Clinical Sleep Medicine, 5, 263-276.

2. Owens, R.L., Edwards, B.A., Eckert, D.J., Jordan, A.S., Sands, S.A., Malhotra, A., White, D.P., Loring, S.H., Butler, J.P. and Wellman, A. (2015) An Integrative Model of Physiological Traits Can be Used to Predict Obstructive Sleep Apnea and Response to Non Positive Airway Pressure Therapy. Sleep, 38, 961-970.

3. Bosi, M., et al. (2018) Phenotyping the pathophysiology of obstructive sleep apnea using polygraphy/polysomnography: a review of the literature. Sleep & Breathing, 22, 579-592.

4. Eckert, D.J. and Malhotra, A. (2008) Pathophysiology of Adult Obstructive Sleep Apnea. Proceedings of the American Thoracic Society, 5, 144-153.

Neelapu, B.C., Kharbanda, O.P., Sardana, H.K., Balachandran, R., Sardana, V., Kapoor, P., Gupta, A. and Vasamsetti, S. (2017) Craniofacial and upper airway morphology in adult obstructive sleep apnea patients: A systematic review and metaanalysis of cephalometric studies. Sleep Medicine Reviews, 31, 79-90.

6. Armalaite, J. and Lopatiene, K. (2016) Lateral teleradiography of the head as a diagnostic tool used to predict obstructive sleep apnea. Dento Maxillo Facial Radiology, 45, 20150085.

7. Faber, C.E. and Grymer, L. (2003) Available techniques for objective assessment of upper airway narrowing in snoring and sleep apnea. Sleep & Breathing, 7, 77-86.

8. Sforza, E., Bacon, W., Weiss, T., Thibault, A., Petiau, C. and Krieger, J. (2000) Upper Airway Collapsibility and Cephalometric Variables in Patients with Obstructive Sleep Apnea. American Journal of Respiratory and Critical Care Medicine, 161, 347-352.

9. Riha, R.L., Brander, P., Vennelle, M. and Douglas, N.J. (2005) A Cephalometric Comparison of Patients with the Sleep Apnea/Hypopnea Syndrome and Their Siblings. Sleep, 28, 315-320.
10. Bates, C.J. and McDonald, J.P. (2005) The relationship between severity of obstructive sleep apnoea/hypopnoea syndrome (OSAHS) and lateral cephalometric radiograph values: a clinical diagnostic tool. Surgeon, 3, 338-346.
11. Gulati, A., Chate, R. and Howes, T.Q. (2010) Can a Single Cephalometric Measurement Predict Obstructive Sleep Apnea Severity? Journal of Clinical Sleep Medicine, 6, 64-68.
12. Banhiran, W., Wanichakorntrakul, P., Metheetrairut, C., Chiewvit, P. and Planuphap, W. (2013) Lateral cephalometric analysis and the risks of moderate to severe obstructive sleep-disordered breathing in Thai patients. Sleep & Breathing, 17, 1249-1255.
13. Silva, V.G., Pinheiro, L.A., Silveira, P.L., Duarte, A.S., Faria, A.C., Carvalho, E.G., Zancanella, E. and Crespo, A.N. (2014) Correlation between cephalometric data and severity of sleep apnea. Brazilian Journal of Otorhinolaryngology, 80, 191-195.
14. Bilici, S., Yigit, O., Celebi, O.O., Yasak, A.G. and Yardimci, A.H. (2018) Relations between hyoid-related cephalometric measurements and severity of obstructive sleep apnea. The Journal of Craniofacial Surgery, 29, 1276-1281.
15. Kitamura, T., Sakabe, A., Ueda, N., Shiomori, T., Udaka, T., Ohbuchi, T. and Suzuki, H. (2008) Usefulness of cephalometry and pharyngeal findings in the primary diagnosis of obstructive sleep apnea syndrome. Nihon Jibiinkoka Gakkai Kaiho, 111, 695-700.
16. Hou, H.M., Hägg, U., Sam, K., Rabie, A.B., Wong, R.W., Lam, B. and Ip, M.S. (2006) Dentofacial characteristics of Chinese obstructive sleep apnea patients in

relation to obesity and severity. The Angle Orthodontist, 76, 962-969.
17. Cillo, J.E. Jr, Thayer, S., Dasheiff, R.M. and Finn, R. (2012) Relations between obstructive sleep apnea syndrome and specific cephalometric measurements, body mass index, and apnea-hypopnea index. Journal of Oral and Maxillofacial Surgery, 70, e278-e283.
18. Subramanian, S., Hesselbacher, S., Mattewal, A. and Surani, S. (2013) Gender and age influence the effects of slow-wave sleep on respiration in patients with obstructive sleep apnea. Sleep & Breathing, 17, 51-56.
19. Zammit, C., Liddicoat, H., Moonsie, I. and Makker, H. (2010) Obesity and respiratory diseases. International Journal of General Medicine, 3, 335-343.
20. Stadler, D.L., McEvoy, R.D., Bradley, J., Paul, D. and Catcheside, P.G. (2010) Changes in lung volume and diaphragm muscle activity at sleep onset in obese obstructive sleep apnea patients vs. healthy-weight controls. Journal of Applied Physiology, 109, 1027-1036.
21. Peppard, P.E., Young, T., Palta, M., Dempsey, J. and Skatrud, J. (2000) Longitudinal study of moderate weight change and sleep-disordered breathing. Journal of the American Medical Association, 284, 3015-3021.
22. Sateia, M.J. (2014) International classification of sleep disorders-third edition: highlights and modifications. Chest, 146:1387-1394.
23. Pae, E.K., Lowe, A.A., Sasaki, K., Price, C., Tsuchiya, M. and Fleetham, J.A. (1994) A cephalometric and electromyographic study of upper airway structures in the upright and supine positions. American Journal of Orthodontics and Dentofacial Orthopedics, 106, 52-59.
24. Fransson, A.M., Tegelberg, A., Svenson B.A., Lennartsson, B. and Isacsson, G. (2002) Influence of mandibular protruding device on airway passages and dentofacial

characteristics in obstructive sleep apnea and snoring. American Journal of Orthodontics and Dentofacial Orthopedics, 122, 371-379.

25. Hammond, R.J., Gotsopoulos, H., Shen, G., Petocz, P., Cistulli, P.A. and Darendeliler, M.A. (2007) A follow-up study of dental and skeletal changes associated with mandibular advancement splint use in obstructive sleep apnea. American Journal of Orthodontics and Dentofacial Orthopedics, 132, 806-814.

26. Arya, D., Tripathi, A., Singh, S.V., Tripathi, S., Nagar, A. and Mishra, A. (2010) A pilot study to evaluate posttreatment cephalometric changes in subjects with OSA. The Journal of Prosthetic Dentistry, 103, 170-177.

27. Fritsch, K.M., Iseli, A., Russi, E.W. and Bloch, K.E. (2001) Side effects of mandibular advancement devices for sleep apnea treatment. American Journal of Respiratory and Critical Care Medicine, 164, 813-818.

Bayat, M., Shariati, M., Rakhshan, V., Abbasi, M., Fateh, A., Sobouti, F. and Davoudmanesh, Z. (2017) Cephalometric risk factors of obstructive sleep apnea. Cranio, 35, 321-326.

29. Battagel, J.M. and Johal, A. (2000) A cephalometric comparison of normal weight and obese subjects with obstructive sleep apnoea. Radiography, 6, 283-292.

30. Watanabe, T., Isono, S., Tanaka, A., Tanzawa, H. and Nishino, T. (2002) Contribution of body habitus and craniofacial characteristics to segmental closing pressures of the passive pharynx in patients with sleep-disordered breathing. American Journal of Respiratory and Critical Care Medicine, 165, 260-265.

31. Gabbay, IE. and Lavie, P. (2012) Age- and gender-related characteristics of obstructive sleep apnea. Sleep & Breathing, 16, 453-460.

32. Deng, X., Gu, W., Li, Y., Liu, M., Li, Y. and Gao, X. (2014) Age-group-specific associations between the severity of obstructive sleep apnea and relevant risk factors

in male and female patients. PLoS One, 9, e107380.

33. Partinen, M., Guilleminault, C., Quera-Salva, M.A. and Jamieson, A. (1988) Obstructive Sleep Apnea and cephalometric roentgenograms. The role of anatomic upper airway abnormalities in the definition of abnormal breathing during sleep. Chest, 93, 1199-1205.

34. Lam, B., Ooi, C.G., Peh, W.C., Lauder, I., Tsang, K.W., Lam, W.K. and Ip, M.S. (2004) Computed tomographic evaluation of the role of craniofacial and upper airway morphology in obstructive sleep apnea in Chinese. Respiratory Medicine, 98, 301-307.

35. Yildirim, N., Fitzpatrick, M.F., Whyte, K.F., Jalleh, R., Wightman, A.J. and Douglas, N.J. (1991) The effect of posture on upper airway dimensions in normal subjects and in patients with the sleep apnea/hypopnea syndrome. The American Review of Respiratory Disease, 144, 845-847.

Alessandri-Bonetti, G., Ippolito, D.R., Bartolucci, M.L., D’Antò, V and IncertiParenti, S. (2015) Cephalometric predictors of treatment outcome with mandibular advancement devices in adult patients with obstructive sleep apnea: a systematic review. Korean Journal of Orthodontics, 45, 308-21.

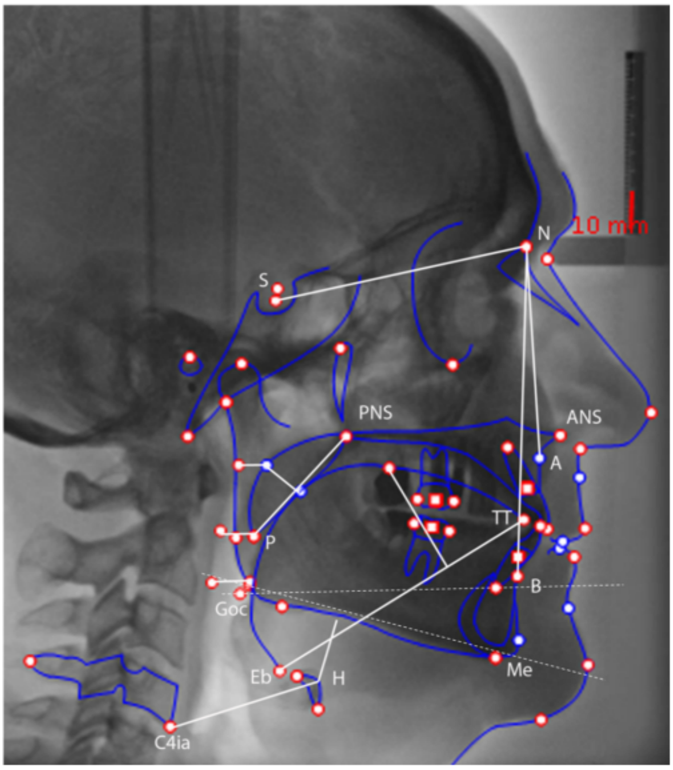
37. Alessandri-Bonetti, G., D'Antò, V., Stipa, C., Rongo, R., Incerti-Parenti, S. and Michelotti, A. (2017) Dentoskeletal effects of oral appliance wear in obstructive sleep apnoea and snoring patients. European Journal of Orthodontics, 39, 482-488.

38. Glupker, L., Kula, K., Parks, E., Babler, W., Stewart, K. and Ghoneima, A. (2015) Three-dimensional computed tomography analysis of airway volume changes between open and closed jaw positions. American Journal of Orthodontics and Dentofacial Orthopedics, 147, 426-434.

Figure legends

Figure 1. Graphical representation of landmarks, reference lines and cephalometric parameters.

Landmarks: A, subspinale; B, supramentale; C4ia, C4 vertebra inferoanterior, most inferior anterior point of fourth cervical vertebrae; Eb, epiglottis base; Goc, gonion; H, hyoidale, most superior and anterior point on body of hyoid bone; Me, menton, most inferior point on bony chin; N, nasion; P, soft-palate tip; PNS, posterior nasal spine; S, sella, center of sella turcica; TT, tongue tip. Reference lines: Go-B, plane between Gonion and B point; MP, mandibular plane; SN, S-N line. See Table 2 for cephalometric parameters description. Dotted lines indicate construction lines.



Graphical representation of landmarks, reference lines and cephalometric parameters.

81x92mm (300 x 300 DPI)

Table 1. Patients' demographic and clinical characteristics (n = 253)

Males	230 (90.9%)
Age (years)*	49.9±10.1
BMI (kg/m^2)*	28.4±3.5
Normal weight (BMI< 25)	37 (14.6%)
Overweight (25≤BMI<30)	136 (53.7%)
Class I obesity (30≤BMI<35)	70 (27.7%)
Class II obesity (35≤BMI<40)	10 (4.0%)
AHI (events/hour)*	33.9±19.8
Mild OSA (5≤AHI<15)	48 (19.0%)
Moderate OSA (15≤AHI<30)	76 (30.0%)
Severe OSA (AHI≥30)	129 (51.0%)

Data are expressed as number of participants (percentages), unless otherwise specified; *data are expressed as mean±standard deviation. BMI: Body mass index; AHI: apnea-hypopnea index.

Table 2. Cephalometric parameters

Angular measurements (°)		
	SNA	Antero-posterior position of the maxilla relative to the anterior cranial base
	SNB	Antero-posterior position of the mandible relative to the anterior cranial base
	ANB	Antero-posterior relation of the maxilla and the mandible
	SN/GoMe	Inclination of the mandibular plane in relation to the anterior base of the cranium
Linear measurements (mm)		
	Goc-Me	Mandibular corpus length
	H-C4ia	Distance from hyoid bone to C4ia (antero-posterior position of hyoid bone)
	MP-H	Perpendicular distance from hyoid bone to mandibular plane (vertical position of hyoid bone)
	PNS-P	Soft palate lenght from PNS to P
	SPT	Soft palate thickness; maximal diameter of soft palate perpendicular to PNS-P
	SPAS	Superior posterior airway space: width at the level of soft palate (along parallel line to Go-B line)
	MAS	Middle airway space along parallel line to Go-B line through P
	PAS	Posterior airway space (distance between posterior pharyngeal wall and the dorsal base of tongue surface, measured on a line intersecting Goc and B Point)
	TGL	Tongue length as the distance between the base of the epiglottis and tongue tip (TT-Eb)
	TGH	Maximum tongue height perpendicular to TT-Eb (the maximum height of tongue along perpendicular line between the base of the epiglottis and tongue tip to tongue dorsum)

Table 3. Hierarchical regression analysis evaluating predictors of AHI

	B	Std. Error	Beta	t
Step 1				
Intercept	-4.581	12.747		-0.359
Age	0.038	0.121	0.020	0.315
Gender (M=1; W=2)	-4.381	4.270	-0.064	-1.026
BMI	1.456	0.344	0.260	4.234*
Step 2				
Intercept	-42.866	38.373		-1.117
Age	-0.082	0.125	-0.042	-0.656
Gender (M=1; W=2)	0.621	4.966	0.009	0.125
BMI	1.277	0.352	0.228	3.628*
SNA	-23.343	23.156	-4.795	-1.008
SNB	23.588	23.172	4.992	1.018
ANB	24.142	23.127	3.206	1.044
SN/GoMe	-0.120	0.229	-0.039	-0.525
SPAS	-0.437	0.515	-0.061	-0.848
MAS	0.090	0.541	0.014	0.167
PAS	-0.572	0.320	-0.131	-1.787
H-C4ia	0.230	0.283	0.067	0.816
MP-H	0.635	0.248	0.194	2.565*
SPT	0.180	0.614	0.020	0.292
PNS-P	0.661	0.281	0.185	2.351*
TGH	-0.431	0.339	-0.097	-1.273
TGL	-0.049	0.273	-0.021	-0.181
Goc-Me	0.001	0.243	0.000	0.004

Std. Error: standard error; t: t value; M: men; W: women; BMI: body mass index; * statistically significant ($p<0.05$). See Table 2 for cephalometric variables definition.