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ORIGINAL ARTICLE

Anatomical characteristics of catathrenia (nocturnal groaning) in upper airway and orofacial structures

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Abstract
Background Catathrenia is a rare sleep disorder characterized by repeated groaning in a protracted expiration preceded by a deep inspiration. This study aimed to explore whether anatomy is one of pathophysiology of catathrenia by investigating the anatomical features associated with catathrenia in the upper airway, craniofacial structures, and dental patterns.
Material and methods Twenty-two patients with catathrenia (7 males, 15 females; age 22 to 69 years) were recruited as well as 66 patients matched by age and gender (matching proportion 1:3) with obstructive sleep apnea syndrome (OSAS). Both groups underwent cephalograms and dental casting, and cephalometric measurements and the Peer Assessment Rating (PAR) index was applied. Differences between the two groups were evaluated and cephalometric measurements in catathrenia group were compared with control values of Chinese patients from previous studies.
Results As for airway-related measurements, increased PNS-R, PNS-UPW, and H-FH and decreased SPT and TGL were found in catathrenia group compared to normal values. Such trends were found even more evident when compared with the OSAS Group. As for craniofacial parameters, values of U1/NA and U1/SN were found increased in the catathrenia group compared with normal values and values of MP/FH and Y decreased. The differences were more distinct from the OSAS Group. Increased arch lengths and upper inter-first molar widths, and decreased overbite and PAR index, were found in catathrenia group compared with the OSAS Group.
Conclusion Catathrenia patients present with a broad upper airway, yet protrusive upper incisors and flat mandibular angles. Anatomical characteristics of catathrenia are different from those associated with OSAS, namely a wide airway, large skeleton, and good occlusion.

Keywords Catathrenia · Craniofacial · Upper airway · Occlusion · OSAS · Cephalometrics

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Introduction

Catathrenia, also known as nocturnal groaning, is a rare disorder with an unknown prevalence and incidence and is characterized by repeated groaning during protracted expiration preceded by a deep inspiration predominantly during REM sleep and sometimes during NREM sleep [1–3]. Patient's generally present complaining of social issues resulting from the nocturnal groaning. Sounds of groaning usually last from 2 to 49 s according to the

2nd edition of International Classification of Sleep Disorders (ICSD-2) [4], yet sounds less than 2 s were also observed with a different respiration pattern [3]. The groaning sounds usually do not persist for the entire night and respirations switch from normal to bradypnea. Despite this, no long-term consequences have been identified.

Catathrenia was formerly classified as a parasominia by the ICSD-2, but has since been reclassified as an isolated symptoms and normal variants under sleep-related breathing disorder [4, 5]. Catathrenia is considered to be similar to central sleep apnea as they share the symptom of recurrent bradypneic episodes, yet no oxygen desaturation presents in catathrenia, and groaning sounds are present. Some evidence from previous studies has suggested that catathrenia is a sleep-related breathing disorder, including the observation of obstructive sleep apnea syndrome (OSAS) manifestation: a deficient mandible, retrusive maxilla and mandible, and small chin implying inadequate bony space in the upper airway in catathrenia patients [1]; endoesophageal pressure during groaning slightly increased at the initial phase of expiration suggesting mild obstruction in the upper airway during expiration [6, 7]; and partially effectiveness of continuous positive airway pressure (CPAP), surgical intervention, and oral appliances in the treatment of catathrenia [1, 8, 9].

As is known, anatomical deficiencies contribute to OSAS in a certain degree. Whether anatomical features contribute to groaning remain to be a mystery. As previous studies of catathrenia have been somewhat limited, the present study seeks to establish the anatomical characteristics of the upper airway, craniofacial structures, and dental patterns associated with catathrenia. Furthermore, the relationships between OSAS and catathrenia were evaluated by assessing the similarity of upper airway size and orofacial features.

Materials and methods

The study protocol was approved by ethic committee of PKUSSIRB (No. IRB-201412010).

Subjects

Twenty-six patients diagnosed with catathrenia were evaluated and underwent audio polysomnography at the Sleep Disorder Center of Peking University People's Hospital. Twenty-two of these cases met the diagnostic criteria for catathrenia [4], while 4 patients were diagnosed as catathrenia combined with OSAS and were excluded. All patients presented with complaints of nocturnal groaning observed by bed partners, roommates, and/or family members.

A second group of 66 patients with OSAS were recruited from a database of 1148 patients diagnosed using polysomnography [10] at the Stomatology Hospital of Peking University. Three OSAS patients were selected for evaluation for every one catathrenia patient and were non-randomly selected in order to closely match age and gender.

Polysomnography

All patients in catathrenia group underwent overnight audio polysomnography using the Alice 5 Polysomnography System (Respironics, Inc., USA) at the Sleep Disorder Center of Peking University People's Hospital. Polysomnography was performed using a three-channel electroencephalogram (central and occipital), a two-channel electrooculogram, a two-channel electromyogram (submental and anterior tibialis muscles), an electrocardiogram with surface electrodes, and a sound recording channel. Nasal air pressure monitors, pulse oximeters, piezoelectric bands, and body position/respirator sensors were also used. Apneas and hypopneas were scored to determine apnea-hypopnea index (AHI). Groaning events were scored separately but not in clusters under the guideline of ICSD-2 in order to determine the groaning index. All the sleep records were scored manually by a certified sleep disorder technician and verified by a researcher. The technician/researcher who scored the PSG did not participate in data measurement.

Cephalometric analysis

Cephalograms of both the catathrenia and OSAS groups were routinely taken. Standing still by the machine, patients' Frankfort planes were adjusted parallel to the horizontal plane with the use of orbital pointers and mechanical earplugs. Patients were asked to close their lips naturally, bite down, and breathe smoothly without swallowing. The cephalograms were taken by an OC-100 (Instrumentarium Imaging Company, Finland) with an uncorrected 11 % linear magnification. Measurements of craniofacial structures, the upper airway, and

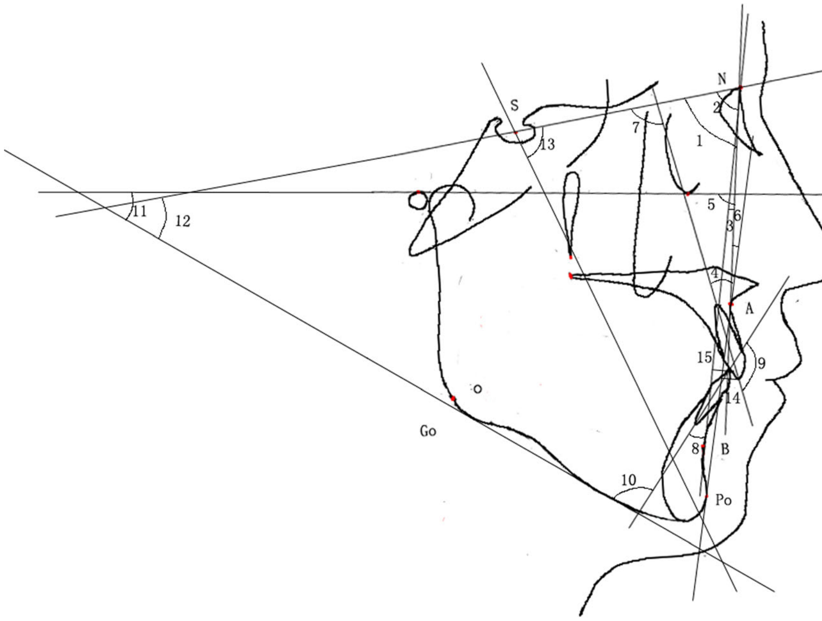

Fig. 1 Cephalometric measurements. *S* Sella, the geometric center of the pituitary fossa. *N* Nasion, the intersection of the internasal and frontonasal sutures. *A* Subspinale, the deepest point in the bony concavity in the midline below the anterior nasal spine. *B* Supramental, the deepest point in the profile curvature of the mandible. *Po* Pogonion, the most anterior point of the contour of the chin. *Go* Gonion, the most posterioinferior point on the outline of the angle of the mandible. FH plane: a horizontal plane, the line through the superior point of the auditory canal and the inferior point of the optic fossa. SN plane: anterior cranial base plane, the line through S and N. MP plane: madibular plane, tangent line of lower edge of mandible. *1* SNA; *2* SNB; *3* ANB; *4* U1/NA; *5* FH/NP; *6* NA/PA; *7* U1/SN; *8* L1/NB; *9* U1/L1; *10* L1/MP; *11* MP/FH; *12* MP/SN; *13* Y; *14* U1-NA; *15* L1-NB

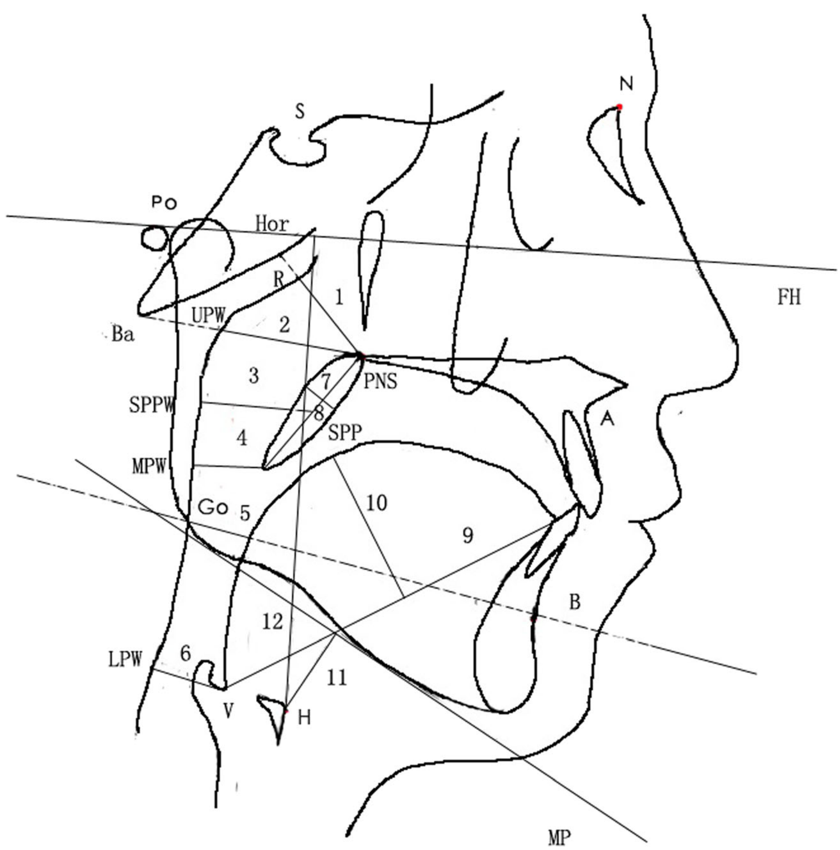

Fig. 2 Upper airway and surrounding structures measurements. *Hor* point located at the intersection between the greater wing and the body of the sphenoid bone. *R* point located at the intersection between posterior pharyngeal wall and PNS-Hor line. *UPW* point located at the intersection between posterior pharyngeal wall and PNS-Ba line. *U* tip of soft palate. *MPW* foot point at the posterior pharyngeal wall of perpendicular line from point U. *V* base of the epiglottis. *LPW* foot point at the posterior pharyngeal wall of perpendicular line from point V. *H* the most superior and anterior point on the body of hyoid bone. *1* PNS-R; *2* PNS-UPW; *3* SPP-SPPW; *4* U-MPW; *5* PAS; *6* V-LPW; *7* soft palate length (*SPL*); *8* soft palate thickness (*SPT*); *9* tongue length (*TGL*); *10* tongue height (*TGH*); *11* H-MP; *12* H-FH

Table 1 Demographic data of catathrenia group and OSAS group (mean±SD)

	Catathrenia group (*n*=22)	OSAS group (*n*=66)	*P*
Age (years)	34.86±12.23	34.88±12.08	0.995
Male/female	7/15	21/45	–
BMI (kg/m^2)	22.06±2.90	22.82±3.19	0.326
AHI	1.76±1.34	22.53±16.66	0.000*
Groaning index	7.93±7.33	–	–

*$P<0.001$

surrounding structures are summarized in Appendix Table 5 and Figs. 1 and 2.

There were 88 cephalograms collected in total including 22 with catathrenia and 66 with OSAS. The staff who collected, mixed, and rearranged the sequence of cephalograms did not participate in data measurement. One researcher compared craniofacial cephalometry values from the catathrenia group to published normal values for ethnic Chinese patients [11, 12]. The baseline values published by Liu [12] in 1996 included 100 non-snoring ethnic Chinese patients (50 male, 50 female; age range 18–25 years).

Model analysis

Dental models from the catathrenia and OSAS groups were obtained during their first visit to the Department of Orthodontics at the Stomatology Hospital of Peking University. The model measurements are summarized in Appendix Table 6 [13]. There were 88 dental models collected in total including 22 with catathrenia and 66 with OSAS. The staff who collected, mixed, and rearranged the sequence of dental models did not participate in data measurement. All linear measurements were measured using calipers by one researcher. The PAR index score was used to evaluate how far a dental model deviated from baseline values [14].

Statistic analysis

All measurements were done by one researcher. And they were repeated 2 weeks later by the same researcher.

Table 2 Craniofacial features of catathrenia group, compared with normal value and OSAS group, respectively (mean±SD)

Item	Chinese normal value [11]	Catathrenia group (*n*=22)	P_N	OSAS group (*n*=66)	Catathrenia group (*n*=22)	P_O
SNA (°)	82.8±4.0	81.4±3.7	0.125	79.57±3.87	81.4±3.7	0.009**
SNB (°)	80.1±3.9	78.8±3.8	0.146	74.58±3.78	78.8±3.8	0.000***
ANB (°)	2.7±2.0	3.2±2.8	0.304	4.81±2.36	3.2±2.8	0.004**
FH/NP (°)	85.4±3.7	86.9±4.1	0.083	81.69±8.33	86.9±4.1	0.003**
NA/PA (°)	6.0±4.4	5.5±7.0	0.651	8.98±5.50	5.5±7.0	0.007**
U1-NA (mm)	5.1±2.4	6.1±2.9	0.079	6.17±2.92	6.1±2.9	0.963
U1/NA (°)	22.8±5.7	27.5±7.9	0.001**	24.86±7.40	27.5±7.9	0.064
L1-NB (mm)	6.7±2.1	6.9±2.7	0.690	8.53±2.71	6.9±2.7	0.016*
L1/NB (°)	30.3±5.8	28.4±5.8	0.154	31.74±6.90	28.4±5.8	0.049*
U1/L1 (°)	125.4±7.9	120.9±10.4	0.019*	118.59±10.75	120.9±10.4	0.545
U1/SN (°)	105.7±6.3	108.9±7.9	0.034*	104.43±7.55	108.9±7.9	0.011*
MP/SN (°)	32.5±5.2	35.9±5.3	0.005**	40.11±6.81	35.9±5.3	0.001**
MP/FH (°)	31.1±5.6	27.9±5.7	0.014*	32.92±7.39	27.9±5.7	0.000***
L1/MP (°)	92.6±7.0	94.4±6.8	0.261	96.87±7.51	94.4±6.8	0.167
Y (°)	66.3±7.1	63.2±4.2	0.048*	67.54±5.38	63.2±4.2	0.001**

P_N represents comparisons between catathrenia group and normal value

P_O represents comparisons between catathrenia group and OSAS group

*$P<0.05$; **$P<0.01$; ***$P<0.001$

Intra-reliability was tested by intra-class correlation coefficient with results between 0.81 and 1.00 (>0.75). All measurements were expressed as the mean±the standard deviation (Tables 2, 3, and 4). Comparisons were performed using Stata 12.0 (VC90, Microsoft Inc., USA). Independent *t* tests were applied to compare both groups, as well as to compare the catathrenia group to reference values. Statistical significance was considered when $P<0.05$.

Results

Subjects characteristics

The 22 catathrenia cases included 7 males and 15 females with a mean age of 35 years (range 22–69 years) and a body mass index (BMI) range of 18.6–28.1 kg/m^2. The mean apnea-hypopnea index (AHI) was 1.76 (range 0–4.41). The groaning index (groaning duration per hour of sleep, GI) ranged from 0.87 to 22.76 with a mean value of 7.93.

Most patients had an unremarkable past medical history, and the only cases with histories of note included a 33-year-old male who had stopped taking antidepressant medication in 2011, a 69-year-old male who occasionally took hypnotics for insomnia, two female patients who suffered from thyroid nodules, and a 23-year-old female with a family history of catathrenia. Otolaryngological examinations were unremarkable except in one patient that had allergic rhinitis. No patients complained of daytime drowsiness.

The mean BMI of the OSAS group was 22.82±3.19 kg/m^2 (range 16.3–29.8 kg/m^2) and mean AHI was 22.53±16.66 (range 5.2–76.1). Demographic data for both groups is summarized in Table 1.

Measurements of craniofacial, upper airway, and dental items

Craniofacial structures of the catathrenia group were compared with normal values and the OSAS group (Table 2). Increased U1/NA, MP/SN ($P<0.01$), U1/SN ($P<0.05$), and decreased MP/FH, U1/L1, and Y ($P<0.05$) were found in the catathrenia group compared

Table 3 Features of upper airway in catathrenia group, compared with reference values and OSAS group, respectively (mean±SD)

Items	Reference value [12] (*n*=100)	Catathrenia group (*n*=22)	P_N	OSAS group (*n*=66)	Catathrenia group (*n*=22)	P_O
Upper airway measurements						
PNS-R (mm)	23.1±3.1	24.6±3.2	0.043*	22.3±3.1	24.6±3.2	0.004**
PNS-UPW (mm)	28.6±3.1	30.1±2.9	0.040*	26.3±3.6	30.1±2.9	0.000***
SPP-SPPW (mm)	13.6±2.8	14.4±3.6	0.253	9.7±4.1	14.4±3.6	0.000***
U-MPW (mm)	12.4±3.2	12.4±4.8	1.000	7.7±2.8	12.4±4.8	0.000***
PAS (mm)	13.7±3.6	14.2±5.1	0.588	10.3±3.7	14.2±5.1	0.000***
V-LPW (mm)	20.1±4.5	20.6±3.9	0.630	18.6±3.8	20.6±3.9	0.033*
Soft palate measurements						
SPL (mm)	36.6±3.6	37.6±5.2	0.282	40.6±4.6	37.6±5.2	0.014*
SPT (mm)	10.2±1.8	8.9±2.1	0.004**	9.5±1.9	8.9±2.1	0.174
Tongue measurements						
TGL (mm)	79.0±7.0	73.6±7.7	0.004**	77.8±8.1	73.6±7.7	0.036*
TGH (mm)	37.1±3.7	37.2±2.7	0.905	37.5±5.1	37.2±2.7	0.824
Hyoid bone position						
H-MP (mm)	12.6±5.0	11.0±6.3	0.198	17.8±6.2	11.0±6.3	0.000***
H-FH (mm)	94.5±9.7	83.3±9.2	0.000***	89.1±8.8	83.3±9.2	0.013*

P_N represents comparisons between catathrenia group and reference values

P_O represents comparisons between catathrenia group and OSAS group

*$P<0.05$; **$P<0.01$; ***$P<0.001$

Table 4 Dental features of catathrenia group, compared with OSAS group (mean±SD)

Items	Catathrenia group (n=22)	OSAS group (n=66)	t	P
Upper arch crowding (mm)	1.05±1.39	1.35±1.75	−0.737	0.463
Lower arch crowding (mm)	1.93±1.69	2.15±1.91	−0.481	0.632
Overbite (mm)	1.75±1.08	2.54±1.69	−2.002	0.048*
Overjet (mm)	3.78±2.12	4.45±1.95	−1.277	0.211
Upper arch length (mm)	44.90±2.75	43.45±2.59	2.207	0.030*
Lower arch length (mm)	41.10±2.83	39.24±3.31	2.346	0.021*
Upper arch intercuspid width (mm)	35.60±2.12	34.51±2.65	1.137	0.086
Upper arch inter-first premolar width (mm)	43.12±2.67	42.47±3.17	0.869	0.387
Upper arch inter-first-molar width (mm)	53.43±4.11	51.39±4.02	2.014	0.047*
Lower arch intercuspid width (mm)	26.97±2.48	25.96±2.10	1.857	0.067
Lower arch inter-first premolar width (mm)	35.16±2.51	34.60±2.67	0.870	0.387
Lower arch inter-first molar width (mm)	46.18±2.57	44.59±4.12	1.694	0.094
PAR index	10.18±8.06	14.64±9.33	−2.002	0.048*

*P<0.05

to normal values. SNA, SNB, FH/NP (P<0.01), and U1/SN (P<0.05) were found to be increased and ANB, NA/PA, MP/SN, MP/FH, Y (P<0.01), L1-NB, and L1/NB (P<0.05) to be decreased in the catathrenia group compared to the OSAS group.

Measurements of the upper airway are shown in Table 3. Compared with reference values, increased PNS-R and PNS-UPW (P<0.05) as well as decreased H-FH, SPT, and TGL (P<0.01) were noted in the catathrenia group. Compared to the OSAS Group, the catathrenia group had increased PNS-R, PNS-UPW, SPP-SPPW, U-MPW, PAS (P<0.01), and V-LPW (P<0.05) with decreased SPL, TGL, H-FH (P<0.05), and H-MP (P<0.01).

Analysis of dental models is shown in Table 4. Normal occlusion in the catathrenia group was found in five patients with one patient excluded due to previous orthodontic treatment and in six patients within the OSAS group. As for teeth alignment, upper and lower arch length and upper arch inter-first-molar width (P<0.05) were found to be increased, while overbite and PAR index (P<0.05) were found to be decreased in the catathrenia group compared to the OSAS group.

Discussion

In the present study, we found that catathrenia presented with almost normal craniofacial structures, except for protrusive upper incisors (increased U1/NA, U1/SN) and a flat mandibular angle (decreased MP/FH, Y). Furthermore, the nasopharynx in catathrenia patients appeared larger than normal people (increased PNS-R, PNS-UPW). They also have wide oropharynx benefiting from thin soft palate, short tongue length, and superiorly positioned hyoid bone (decreased H-FH, SPT, and TGL). Narrowing and obstruction of upper airways is common in sleep disorder breathing (SDB). As shown herein, the anatomical characteristics in patients with catathrenia were remarkably different from those with OSAS. Patients with catathrenia had wider upper airway at every level (increased PNS-R, PNS-UPW, SPP-SPPW, U-MPW, PAS, and V-LPW) and a larger skeleton (increased SNA, SNB) than patients with OSAS, as well as smaller airway-related soft tissues (decreased SPL, TGL, H-FH, H-MP). Moreover, a larger dental arch—in length and width—and better occlusion were found in patients with catathrenia when compared to patients with OSAS.

In contrast to the current study, Guilleminault et al. reported mandibular or maxillo-mandibular deficiency in six of seven catathrenia patients using physical examination and frontal/lateral photos with anthropometric analysis [1]. Ott et al. observed a subtotal closure of the glottis during expiration using laryngoscopy under deep sedation without stenosis of the upper airway in one female with catathrenia [15]. Vetrugno

Fig. 3 Typical cephalograms of a catathrenia patient (*left*) and matched OSAS (*right*) with the same gender and age. Catathrenia is featured in wider upper airway, larger jaws, flatter mandibular plane, more superiorly positioned hyoid bone and more protrusive upper incisors

et al. took advantage of the positive pressure swings by endoesophageal examination to discover possible mild airway obstruction [6]. Overland et al. observed one of four catathrenia patients experienced slightly increased positive pressure at the start of expiration, suggesting an obstruction at the level of the vocal cords [7]. De Roeck and Van Hoof found that the possible pathogenic mechanism of catathrenia was occlusion of the vocal cords in addition to a narrow airway during expiration [16]. Different views may be derived from various methods and subjects differences.

However, catathrenia was reclassified in ICSD-3 [5] as normal variants and isolated symptoms under the section of sleep-related breathing disorders, and this change reflects the current lack of pathophysiological understanding. As is known, OSAS is a disorder involving anatomic problems, so anatomical deficiency is not only a clinical manifestation but also one of several pathophysiologies of OSAS. From this study, there remains an evident gap in anatomical features between catathrenia and OSA, as demonstrated in Fig. 3. That catathrenia is significantly different from OSA with seldom anatomic problem supported that anatomy might rarely play a role in pathophysiology of catathrenia. However, we still cannot draw any conclusion on what on earth contributes to the pathophysiology of catathrenia.

In this study, quantitative measurements of the craniofacial structures and sagittal diameter of the upper airway were obtained using cephalogram. However, there are some limitations on this technique. As the upper airway is a three-dimensional structure, a wide sagittal length does not exactly equal to a wide three-dimensional volume or transverse area. In addition, sleep breathing is a dynamic process and sleep groaning involves airway changes during inspiration and expiration. Wide airway in late expiration does not exactly equal to a wide airway in whole respiration period during sleep. However, further researches with a larger sample size and with other techniques are necessary to determine the true pathogenesis of catathrenia.

Conclusion

Patients with catathrenia were found to have a broad and spacious upper airway when compared to normal value. Their craniofacial structures appeared rather large and patients presented with protrusive upper incisors and flat mandibular angles. Compared to patients with OSAS, the differences were more remarkable, and patients with catathrenia exhibited a wider airway, larger skeleton, and better occlusion.

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Conflict interest We declare that there is no commercial or associative interest that presents conflict with the work submitted.

Appendix

Measurements of craniofacial structures are summarized in Appendix Table 5.

Table 5 Craniofacial and upper airway measurements

Item	Definition	Chinese normal value
Craniofacial measurements		
SNA (°)	The inferoposterior angle formed by the intersection of the line S-N and N-A, which represents the anteroposterior position of maxilla in relation to the cranial base	82.8±4.0
SNB (°)	The inferoposterior angle formed by the intersection of the line S-N and N-B, which represents the anteroposterior position of mandible in relation to the cranial base	80.1±3.9
ANB (°)	The angle formed by the intersection of the line N-A and N-B, which represents the relationship or discrepancy of maxilla and mandible in relation to the cranium. When SNA>SNB, ANB>0; otherwise ANB<0	2.7±2.0
U1-NA (mm)	Perpendicular distance from the tip of upper central incisor to line NA	5.1±2.4
FH/NP (°)	The inferoposterior angle between the line N-P and FH plane, which represents the degree of mandible protrusion	85.4±3.7
NA/PA (°)	The angle between line N-A and line P-A, which represents the degree of maxilla protrusion	6.0±4.4
U1/NA (°)	The angle between the long axis of upper central incisor and line NA	22.8±5.7
U1/SN (°)	The inferoposterior angle between the long axis of upper central incisor and SN plane. U1-NA, U1/NA and U1/SN altogether represent the inclination and protrusion of upper incisors	105.7±6.3
L1-NB (mm)	Perpendicular distance from the tip of lower central incisor to line NB	6.7±2.1
L1/NB (°)	The angle between the long axis of lower central incisor and line NB	30.3±5.8
U1/L1 (°)	The angle between the long axis of upper central incisor and lower central incisor	125.4±7.9
L1/MP (°)	The posterosuperior angle between the long axis of lower central incisor and MP plane. L1-NB, L1/NB and L1/MP altogether represent the inclination and protrusion of lower incisors	92.6±7.0
MP/SN (°)	The angle formed by the intersection of the SN plane and MP plane, which represents mandibular inclination	32.5±5.2
MP/FH (°)	The angle formed by the intersection of the FH plane and MP plane, which also represents mandibular inclination	31.1±5.6
Y (°)	Y axis is the line through S and gnathion (the middle of pogonion and menton, Gn). Y is the anteroinferior angle between Y axis and FH plane, which represents protrusion of mental region, as well as the growth direction	66.3±7.1
Upper airway measurements		Reference value [12]
PNS-R (mm)	Distance between PNS and R	23.1±3.1
PNS-UPW (mm)	Distance between PNS and UPW	28.6±3.1
SPP-SPPW (mm)	Width of the airway space along the perpendicular line to posterior pharyngeal wall from the center of soft palate	13.6±2.8
U-MPW (mm)	Distance between U and MPW	12.4±3.2
PAS (mm)	Width of the airway space along the Go-B line	13.7±3.6
V-LPW (mm)	Distance between V and LPW	20.1±4.5
Soft palate measurements		
SPL (mm)	Soft palate length, distance between posterior nasal spine and tip of soft palate	36.6±3.6
SPT (mm)	Soft palate thickness, maximum thickness of soft palate measured on line perpendicular to soft palate length line	10.2±1.8
Tongue measurements		
TGL (mm)	Tongue length, distance between base of epiglottis and tongue tip	79.0±7.0
TGH (mm)	Tongue height, maximum height of tongue along perpendicular line of tongue length line to tongue dorsum	37.1±3.7
Hyoid bone position		
H-MP (mm)	Perpendicular distance from H to mandibular plane	12.6±5.0
H-FH (mm)	Perpendicular distance from H to Frankfort plane	94.5±9.7

Measurements of the upper airway, and surrounding structures are summarized in Appendix Table 6.

Table 6 Measurements of dental models

Item	Definition
Dental crowding (mm)	The difference between the sum of the crown width and the length of the existing arc of dental arch
Overbite (mm)	Distance of vertical (superior-inferior) overlap of the maxillary central incisors over the mandibular central incisors
Overjet (mm)	Maximum distance of horizontal (anterior-posterior) overlap of the maxillary central incisors over the mandibular central incisors
Dental arch length (mm)	Perpendicular distance from central incisor mesial contact point to the line through bilateral second molar distal contacts
Dental arch width (mm)	Including intercuspid width (distance between bilateral cusps of canines), inter-first premolar width (distance between bilateral buccal cusps of premolars) and inter-first molar width (distance between bilateral mesial buccal cusps of first molars)
PAR index [14]	The score, which is a summary of several scores including crowding, occlusion, overbite, open bite, overjet, crossbite, and midline, presents a degree of how far a case deviates from normal alignment and occlusion

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