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Collapsibility of the relaxed pharynx and risk of sleep apnoea.

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Abstract

In this study we measured hypotonic pharyngeal collapsibility in subjects not known to have obstructive sleep apnoea (OSA), and assessed variables that affect collapsibility and its relationship to OSA.

The critical closing pressure of the pharynx (Pcrit) was measured under the hypotonic condition of anesthesia in 227 subjects that underwent elective surgery. The risk of OSA in this population was estimated using the Berlin questionnaire.

The mean Pcrit for all subjects was positive (above-atmospheric), ranging from 0.69 (CI -7.39 to 8.77) to 4.0 (CI -4.82 to 12.82) cmH_2O for subjects with low and high prevalence of OSA, respectively. Pcrit ≤-5 cmH_2O was found only in 3.1% of our subjects. In this general population, Pcrit was similar in men and women, and correlated positively with increasing age, while a correlation with neck circumference was found only in men. Pcrit accounted only for 12.25% of the variability in OSA risk score.

We conclude that subjects with high Pcrit are at increased risk to develop OSA. However, the human pharynx is prone to collapse, and occludes in most people in the absence of neuromuscular support. Therefore, the level of neuromuscular activity may ultimately determine, in most subjects, the occurrence of sleep apnea.

Introduction.

The obstructive sleep apnoea (OSA) syndrome is characterized by repetitive collapse and closing of the pharynx during sleep. Many anatomic variations and abnormalities of the upper airway and surrounding structures were implicated in the pathogenesis of OSA. Regardless of the type of local anatomic or structural factor(s) that increase susceptibility to collapse, the pharynx may be considered to function mechanically as a self-supporting, soft walled collapsible tube (1, 2), conceptually characterized by the Starling resistor model. The collapsibility of such tubes depends on the stability of their walls and the magnitude of surrounding pressure, and can be defined by the intraluminal pressure under which the tube collapses and occludes, known as the critical pressure (Pcrit). Applied to the upper airway, the pharynx of a patient with positive (above atmospheric) Pcrit will be occluded, unless active forces prevent passive collapse. As the collapsibility of the pharynx is determined both by passive mechanical, anatomical properties and by active neuromuscular control mechanisms that affect wall stiffness and surrounding pressure, investigators developed a methodology to study pharyngeal biomechanics during periods of almost absent neuromuscular activity during sleep (3). This "passive Pcrit" (4,5) was believed to closely represent the anatomic property of the pharynx, determined to a large degree by factors like weight, neck circumference, age, pharyngeal length and other craniopharyngeal properties. It was found to be negative in healthy subjects, and positive in patients with OSA (4, 5). Apparently even more convincing was the similar finding obtained under anesthesia and muscle paralysis (6). Based on these results, several investigators interpreted their findings according to the concept that hypotonic Pcrit measured during sleep represents anatomic collapsibility (7, 8). Accepting this concept would indicate that the healthy pharynx is protected against collapse by its inherent anatomic properties, and it remains patent even in the absence of neural drive.

This concept seems to contradict the well established observations that the upper airway of most human is occluded during anesthesia, and that restoration of upper airway patency is the first step in the resuscitation of the unconscious patient (9). We hypothesized that positive Pcrit values will be found in most healthy subjects under conditions that lower muscle tone more than sleep. In the present work we assessed, therefore, flow-mechanics and Pcrit in subjects not known to have OSA, under the hypotonic conditions of general anesthesia. This Pcrit, considered to represent more closely passive anatomic conditions, was used to assess the relationships between relaxed pharyngeal collapsibility and OSA risk and anthropometric parameters.

Methods.

Subjects. Consecutive patients older than 18 years, admitted for elective surgery in the general surgery, orthopedic and urology departments of Bnai Zion Medical Center, Technion School of Medicine, Haifa, Israel, were recruited to this study. All patients underwent pre-surgical evaluation by two anesthesiologists. Inclusion criteria were clearance for general anesthesia, and understanding and signing the informed consent. Patients with cardio-respiratory instability, significant heart or respiratory failure, or debilitating conditions were excluded. The study was approved by the institutional Human Investigations Review Board.

Anesthesia. Induction of anesthesia in the operating room, before starting halotan anesthesia for the planned surgical procedure, was performed in 192 patients with propofol by the same anesthesiologists that recruited the patients. A loading dose of 2.5 mg/kg, followed by bolus doses of 25 mg if required, were administered. To ensure that our findings are not drug-specific, anesthesia induction was performed also with thiopental (2-7 mg/kg) in an additional group of 35 patients. Using CPAP levels that enabled breathing without flow limitation, we aimed to assess the pressure:flow relationships of the patients over a period of 2-3 minutes of stable breathing, 2-3 minutes after injection of an adequate dose of the anesthetic drug. Anesthesia was considered to be adequate for the purpose of this study when reaction to pain was completely abolished, and adequate ventilation, as monitored by the pneumotachometer and pulse oxymetry, was stable for about a minute.

Instrumentation and recording procedures. Subjects were studied in the supine position, with the head on the operation table without a pillow. They breathed through a full-face mask, fitted tightly to prevent air leaks. A pneumotachometer was mounted on the mask, and connected to a Validyne ± 2 cmH_2O pressure transducer for airflow measurement. The pneumotachometer was connected to a digitized variable pressure-source at the inflow port, enabling variation of nasal pressure (Pn) between 20 to –10 cm H_2O. Pn was monitored with a catheter connected to a side port of the mask. Flow and Pn were recorded on a Graphtec WR 7700 writer.

Pressure-flow relationships. The passive upper airway pressure:flow relationships during anesthesia was delineated as previously described for sleeping patients (3). Pn was maintained at a level sufficient to prevent flow limitation (holding pressure). During stable ventilation, Pn was lowered for 4-5 breaths randomly to several levels, encompassing 4-5 levels associated with clear inspiratory flow limitation and a level at which airflow ceased (i.e., the upper airway occluded completely). Flow limitation was recognized by the decrease in flow rate associated with the typical flattening of the inspiratory flow curve. After each pressure drop, Pn was raised back to the holding pressure for 5-10 breaths. Only studies in which mean flow rate and breathing frequency at the beginning and the end of the pressure-flow evaluation remained nearly unchanged while on holding pressure (variation <20%) were used. Inspiratory flow was measured at the mid-portion of inspiration, at each level of Pn that was associated with flow limitation. The pressure:flow relationships was determined with least square linear regression. This relationship was used to calculate Pcrit as the level of Pn below which airflow became zero, as well as upstream resistance (Rus), defined as the slope of Pn:flow.

Assessment of risk for sleep apnea syndrome. To estimate the prevalence of sleep apnea in our patients, we used the "Berlin questionnaire" (10). This rather short and well-validated questionnaire estimates the risk of having OSA based on questions about snoring, day-time sleepiness, BMI and hypertension, with a score of 0-3. Subjects with an OSA risk-score (OSA-RS) of ≥2 are considered to be at increased OSA risk. Two experienced anesthesiologists, that performed the pre-surgical evaluation, also filled the questionnaire. In addition, neck circumference was measured in all patients.

Statistical analysis: SPSS version 7.5 was used for all calculations. Data are presented as mean±SD. Pcrit data are presented as mean and confidence interval (CI). ANOVA

was used for the comparison of results of propofol and thiopenthal, males and females and snoring and non-snoring subjects. Correlations were assessed by the Pearson's correlation method. A linear regression model was used to establish the determinants of Pcrit (dependent variable). The independent variables were age, BMI, and neck circumference. $P<0.05$ was considered as statistically significant.

Results.

Two hundred twenty seven subjects were studied. Additional eight subjects that needed a holding pressure >15 cmH_2O were excluded, due to difficulties with mask-fitting, that hindered prevention of air leaks. Typical flow tracings at different CPAP levels, used to construct the pressure:flow relationships and derive Pcrit and Rus, are shown in figure 1. The mean Pcrit for all subjects was 1.78 cmH_2O (CI -7.06 to 10.92). Pcrit <0 (passive occlusion below atmospheric pressure) was found in 68 subjects (30.0%), and only 7 (3.1%) had a Pcrit ≤-5 cmH_2O.

Anesthetics: Comparison of the anthropometric parameters and findings of our subjects, divided according to the anesthetics used, is presented in table 1. Although not randomized, the two groups of patients were similar in all parameters. Thiopental-anesthetized subjects tended to have slightly higher Pcrit and OSA-RS, but this differences were not significant ($p=0.15$ and 0.23, respectively). Therefore, further results are presented for all subjects together.

Snoring: Table 2 presents comparison between subjects that reported persistent loud snoring (as defined in the Berlin questionnaire) and all other subjects. The percentage of men and women was similar in the two groups, but snorers were older and more obese than non-snorers. Accordingly, snorers had a significantly higher Pcrit (3.47, CI -5.11 to 12.05 cmH_2O, as compared to 0.49, CI -7.7 to 8.68 cmH_2O in non-snorers, $p<0.0001$). This difference persisted also after adjusting for BMI, neck circumference, gender and age ($p<0.025$), indicating that other variables participate in the higher collapsibility of the pharynx of snorers.

Gender: Table 3 presents comparison between men and women. Men and women in our group were of similar BMI, but the women were older, and had a smaller neck circumference. Their Pcrit and OSA-RS were similar to those of men, and remained similar also after adjusting for differences in age, weight and neck circumference.

Anthropometric parameters: In our subjects, Pcrit correlated best with age ($R=0.36$, $p<0.0001$), but the correlation with BMI ($R=0.18$) was also highly significant ($p<0.006$). As seen in figure 2, subjects with high Pcrit tended to be older and most of them snored. The effect of age on Pcrit was similar in snorer and non snorer: in the mean, every 10 years were associated with an increase in Pcrit of 0.66 and 0.68 cmH_2O, respectively. Only one out of the 13 older obese subjects (age>60 and BMI≥30) had Pcrit<0 (mean age, BMI and Pcrit for this group were 72.1±7.8 years, 32.7±2.4 kg/m^2 and 5.7±5.8 cmH_2O, respectively), as compared to 6 out of the 9 young and lean subjects (<30 years and BMI ≤20. Mean age, BMI and Pcrit for this group 22.3±4.3 years, 19.0±1.1 kg/m^2 and -1.9±2.4 cmH_2O, respectively, $p<0.002$ for comparison of Pcrit of the two groups). The relatively low correlation between pharyngeal collapsibility and BMI was due, in part, to the difference between men and women, shown in table 4. While the correlation between Pcrit and age was similar

in both genders, a significant correlation between Pcrit and BMI and neck circumference was found for men only. In a model that adjusts stepwise for these parameters, Pcrit correlated significantly in men only with age and neck circumference, both together producing a correlation of R=0.421. In women, a significant adjusted correlation was found with age only (R=0.40).

OSA risk: Figure 3 depicts the relationships between Pcrit and the OSA-RS. Increasing Pcrit was associated with increased OSA-RS. The mean Pcrit of subjects at high risk for OSA (OSA-RS≥2, n=71) was 4.0 (CI -4.82 to12.82cmH_2O), as compared to 0.69 (CI -7.39 to 8.77 cmH_2O) for the subjects with a score <2 ($p<0.001$). However, the correlation between Pcrit and OSA-RS for all subjects was rather modest (R=0.35), similar for both genders (table 4), indicating that only slightly more than 12% of the individual variance in OSA-RS was explained by their passive hypotonic pharyngeal collapsibility.

Discussion.

The results of this study confirmed our hypothesis that the normal fully relaxed human Pcrit is close to or even above atmospheric, indicating that the anatomic properties of most healthy human promote pharyngeal occlusion during profound relaxation, and muscle tone is mandatory in most people to maintain pharyngeal patency during sleep. In addition, we found that age, weight and neck circumference accounted for a relatively small percentage of the variability in the relaxed Pcrit, and Pcrit explained only a small percentage of the individual variability in OSA-RS.

Passive pharyngeal collapsibility: The fact that the pharynx is occluded in most people under conditions of profound hypotony, like anesthesia or deep coma, is common knowledge and based on old studies. Safar et al. found complete or partial pharyngeal occlusion in 90% of their anesthetized subjects (9). In children studied after death, Reed et al. found a mean closing pressure of about zero cmH_2O (range -2 to 5 cmH_2O) (11). Closure of the upper airway was reported to happen in most thin, normal adults during REM sleep (12), as well as during central apneas in non-REM sleep (13). Eastwood et al. reported that Pcrit of healthy subjects increases with increasing concentrations of propofol anesthesia, starting at mean of -0.3 and reaching 1.4 cmH_2O (14). Propofol does not affect muscle tension directly (15), and the same finding was reported also with isuflorane anesthesia (16), indicating that, as in our study, the positive Pcrit is not related to a specific anesthetic. All these findings indicate that the negative values of hypotonic Pcrit obtained during sleep in healthy subjects are likely to represent, in addition to anatomic properties, also substantial maintained muscle tone. The negative Pcrit value measured in almost all anesthetized, paralyzed, healthy subject by Isono et al. (6) is probably due to the specific methodology that had to be used to assess the pharyngeal closing pressure during paralysis. In contrast, Safar et al. reported that ventilation of anesthetized, curarized subjects through a face mask failed due to pharyngeal obstruction (17). It should be noted that, based of the mean slope of the hypotonic pharyngeal pressure:flow relationships observed during sleep (3, 4, 18), Pcrit needs to be below -4 cmH_2O to prevent substantial (>50%) decrease in flow (hypopnea) at atmospheric pressure.

Comparison to collapsibility during sleep: Earlier studies that evaluated Pcrit during sleep in health and disease did not use the methodology of hypotonic Pcrit measurement (19, 20). However, the presence of genioglossus EMG activity, both tonic and phasic, has been documented also during measurements of hypotonic Pcrit during sleep (3). Similarly, Pcrit measured during the expiratory period in sleeping tracheotomized OSA patients was, in the mean, 5 cmH_2O higher than during inspiration, indicating the presence of substantial neuromuscular activity that modulates collapsibility during sleep (21). Interestingly, this value compares closely to the difference (4.9 cmH_2O) between the Pcrit reported in healthy subjects during sleep (5), and that of our non-snoring subjects during anesthesia. Accordingly, a positive (above atmospheric) Pcrit measured during sleep could be due to either disadvantageous anatomical properties, or decreased residual neuromuscular tone maintained during sleep (figure 4, B and C, respectively), or both. However, Patil et al. (5) found a difference of 4.45 cmH_2O between the Pcrit of healthy subjects and that of patients with OSA during sleep, a magnitude almost identical to the difference in Pcrit found in the present study between subjects with OSA-RS of 0 and 3 (4.35 cmH_2O). This comparison suggests that the mean magnitude of the neuromuscular tone included in and affecting collapsibility during sleep is similar in healthy subjects and OSA patients (A and B in figure 3), and, therefore, that the increased collapsibility of the pharynx of OSA subjects during sleep is due primarily to anatomic factors (B in figure 3). This conclusion is supported also by the finding that anaesthetised patients who needed positive pressure to maintain airway patency had more severe sleep-disordered breathing (particularly during REM sleep) than did those whose airways remained patent at or below atmospheric pressure (22). Obviously, these mean data do not contradict the possibility that individual subjects with high "passive" pharyngeal collapsibility may maintain "active" neuromuscular compensation that prevents obstruction (5). On the other hand, the finding that the relaxed Pcrit of most human is positive, explains why most healthy subjects develop occasional apneas and or hypopneas (per definition up to 5 per hour), as well as snoring or plain OSA when normal dilator drive is reduced by drugs or alcohol.

Effects of anesthesia: The relevance of findings observed under anesthesia to sleep and OSA has been previously documented (22). Propofol anesthesia is even sometimes referred-to as "drug-induced sleep" (23). In order to recruit a large cohort of subjects from the community, we had to abbreviate the study protocol to a minimum. Therefore, we did not attempt to establish a prolonged steady state of anesthesia during the pressure:flow measurements, and did not measure or aim to reach a pre-defined level of anesthesia. The potential effect of possible minor anesthesia dissipation during the few minutes required to assess Pcrit was neutralized by randomizing the order of pressure drops performed to measure pressure:flow relationships. In addition, the anesthesiologists used the same protocol to administer the anesthetics, and the same clinical criteria to ascertain adequate and stable anesthesia in all subjects. With the relatively large number of subjects studied, we believe that differences in mean Pcrit between groups are unlikely to be due to differences in response to propofol. However, the lack of objective measurements of the depth of anesthesia, both in our and in previous studies that measured Pcrit under anesthesia, limits comparison of results between studies. On the other hand, the lack of a more standardized mode of anesthesia does not affect the main finding of this study, namely that Pcrit is above-atmospheric in most healthy subjects while anesthetized. Actually, deeper anesthesia would be expected to increase the mean

Pcrit and the number of subjects with positive Pcrit (14, 16), and it is possible that in some subjects, a negative Pcrit was found due to more superficial anesthesia.

OSA-RS: To estimate the prevalence of OSA in our subjects we used a well-standardized and validated OSA risk scoring (10, 24). Although polysomnography would have provided a more accurate estimate of the individual apnea-hypopnea index of our subjects, the Berlin questionnaire is a well accepted tool to estimate the prevalence of OSA, that was validated in primary care settings. This instrument is used to classify subjects who are at high- and low risk for OSA by identifying snoring behavior, daytime sleepiness, obesity, and hypertension, and has a positive predictive value of 0.89. In the validation study, 37.5% of 744 primary care patients were identified as being at high risk for OSA (29-44% in different clinics). In a later study of 8,000 primary care patients (24) and 1,506 adults from the general population (25), 32% and 26%, respectively, had a high probability for OSA, based on the Berlin questionnaire. As our subjects arrived to the hospital for simple elective surgery, not related to OSA or OSA risk factors, they can be considered, for our purpose, as a random population similar to primary care patients, and the prevalence of high risk in our study (31.3%) is within this range. In the Berlin questionnaire validation study, Netzer et al (10) reported a mean AHI of 21.1 and 4.7 in the high- and low-risk groups, respectively. Despite the low prevalence of OSA expected in our low-risk group, not only did the majority of the subjects have a positive Pcrit, but even when considering the subset of non-snorer with low OSA-RS, 57% and 95% of them had a Pcrit >0 and >-5, respectively.

Anthropometric parameters and Pcrit: Although our study did not measure the "true anatomic" Pcrit, the difference between anesthesia-induced hypotony and complete muscle relaxation is probably small, as we found only minor increase in Pcrit in anesthetized dogs after dissection of the hypoglossus nerves (26). Therefore, the Pcrit measured during anesthesia is likely to enable an accurate assessment of the relationship between anatomic collapsibility and anthropometric parameters. In addition, different from previous studies that compared similar parameters to measures of collapsibility in OSA patients (7, 20), we could assess this relationship in a mixed general population, the majority of whom had no OSA. We found that pharyngeal collapsibility explained only 12.25% of the variance of individual OSA-RS in the general population, a substantially lower estimate than that reported for the severity of OSA in OSA patients (7). The prevalence of OSA is known to increase with age (7, 25, 27-30). In the present study we found the highest correlation between Pcrit and age, similar in men and women, confirming previous studies (7, 30). On the other hand, the correlation between OSA-RS and age remained significant after adjusting for Pcrit, indicating that the increased prevalence of OSA with age is not due to anatomic collapsibility only. OSA is also more common in men (20, 25, 28, 29, 31). Nevertheless, we did not find a gender difference in Pcrit after adjusting for age and BMI, similar to previous studies that assessed collapsibility during sleep (7, 32), and Younes related the higher prevalence of OSA in men to their higher flow demand (7). In addition, the association between BMI and the prevalence of OSA is well documented (7, 25, 28, 29), and an association between pharyngeal collapsibility and BMI was reported in OSA patients (almost all male), both during sleep (7, 33) and paralyzis (34). However, this correlation, as well as the correlation between Pcrit and neck circumference, was statistically significant in the present study only for men, confirming previous assumptions that differences in weight distribution between men

and women affect pharyngeal collapsibility more than overweight. When a stepwise regression analysis was performed for variables that correlate with collapsibility, with Pcrit as the dependent and age, BMI and neck circumference as independent variables, the variables included in the model accounted for only 16.8% of the variability in Pcrit. This finding suggests that in the general population, other factors play a more important role in determining collapsibility, probably individual cephalometric characteristics, independently of age and weight.

In conclusion, our findings indicate that 1. The human pharynx is almost always fully or substantially occluded in the absence of neuromuscular support. 2. The anatomic collapsibility is higher in snorers and in patients with high OSA-RS. 3. Anatomy seems to explain only a small part of the variance in OSA prevalence in the general population. 4. Hypotonic Pcrit of the general population is similar in men and women after adjusting to confounders. It increases with increasing age, but is affected by neck circumference in men only. 5. Factors other than age, weight and neck circumference determine most of the variance of pharyngeal collapsibility. 6. Comparing the Pcrit found in the present study with that reported during sleep suggests that substantial residual neuromuscular tone is maintained during sleep both in healthy subjects and in OSA patients.

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Legend to figures

Figure 1. Flow tracings of one of the subjects, at different CPAP levels (upper panel), used to construct the pressure : flow relationships (lower panel). Only flow tracings with flow limitation (recognizable by the typical flat inspiratory flow pattern) are used. The pressure : flow relationships is linear, with high correlation (corr). Pcrit is the x-intercept (pressure at which occlusion = 0 flow occurs). The reciprocal of the slope is defined as upstream resistance (Rus).

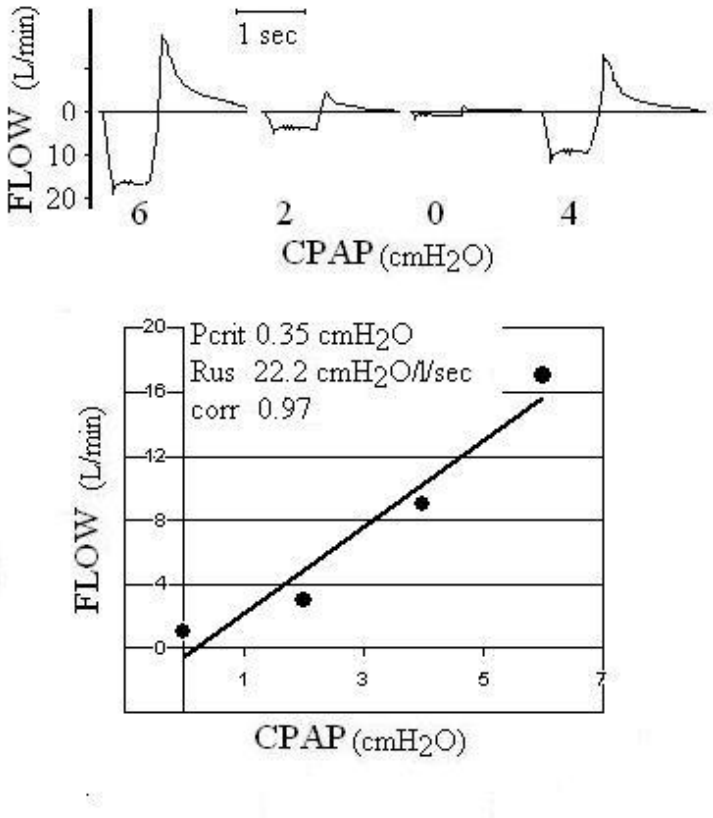

Figure 2. Relationships between Pcrit and age.
n=227. Open squares – non-snorers. Closed squares – snorers. Shaded area – "safe" Pcrit that prevents hypopneas.

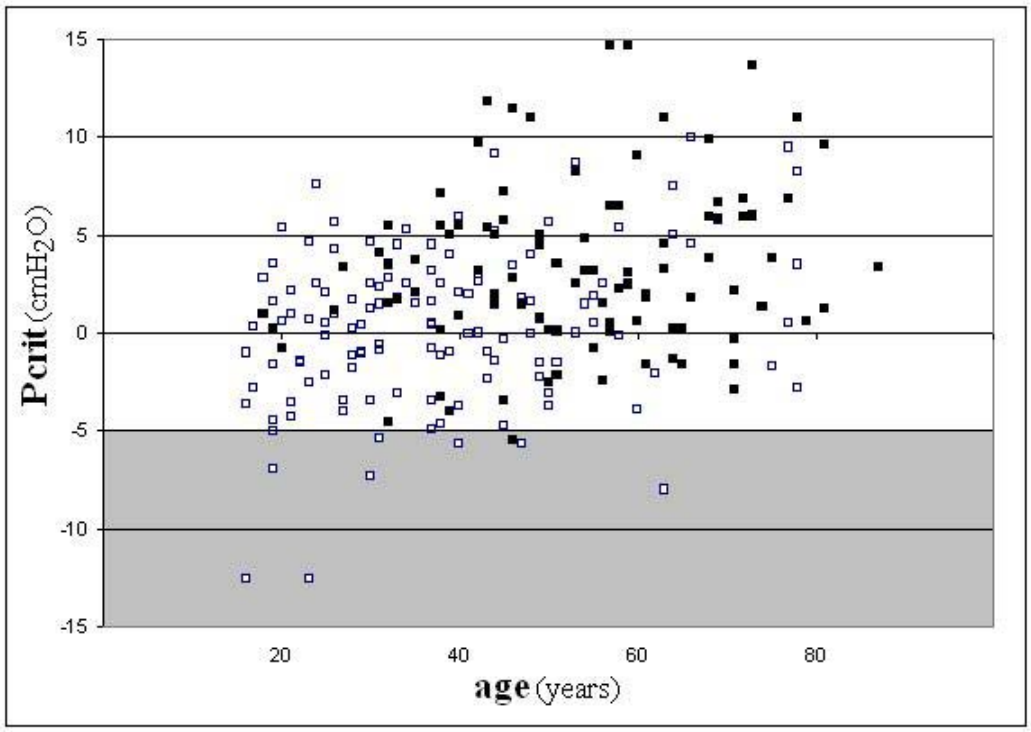

Figure 3. Relationships between Pcrit and the OSA risk score (OSA-RS). Pcrit is presented as mean ± SEM for each level of OSA-RS.

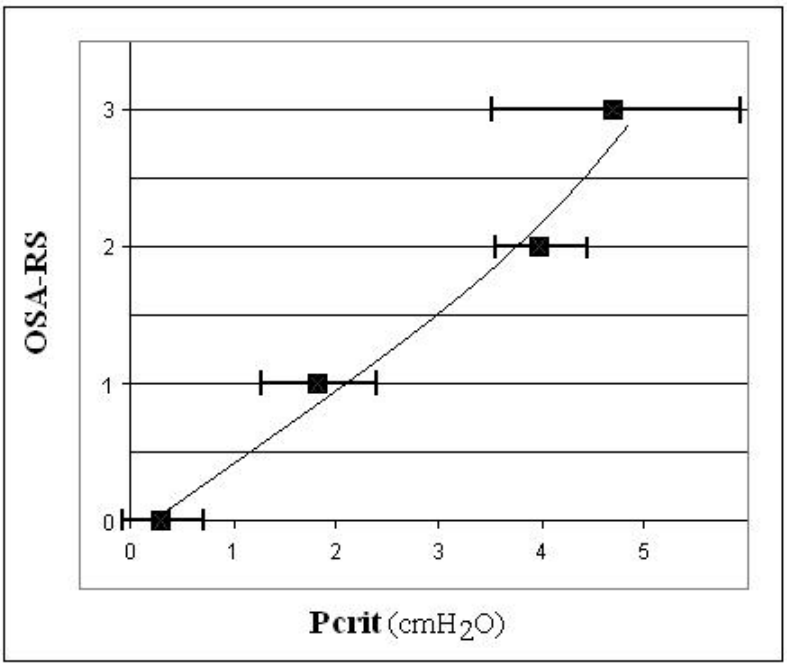

Figure 4. Schematic presentation of possible relationships between anatomic, completely relaxed Pcrit (squares), Pcrit under anesthesia (triangles, assumed to be very close to the anatomic Pcrit), and hypotonic Pcrit observed in previous studies during sleep (diamonds). "A" (open symbols) represents the healthy population, whose anatomic Pcrit is positive, but retained neuromuscular tone maintains a negative hypotonic Pcrit during sleep. "B" (shaded symbols) represents a population with increased anatomic collapsibility. Despite neuromuscular tone equal to healthy subjects, Pcrit of this group will be positive during sleep, promoting OSA. "C" (closed symbols) represents patients with normal anatomy, but due to reduced neuromuscular tone during sleep, the resultant hypotonic Pcrit during sleep is as in B. Individual subjects can have any combination of the above, as well as increased neuromuscular tone during sleep, that may compensate for unfavorable anatomy.

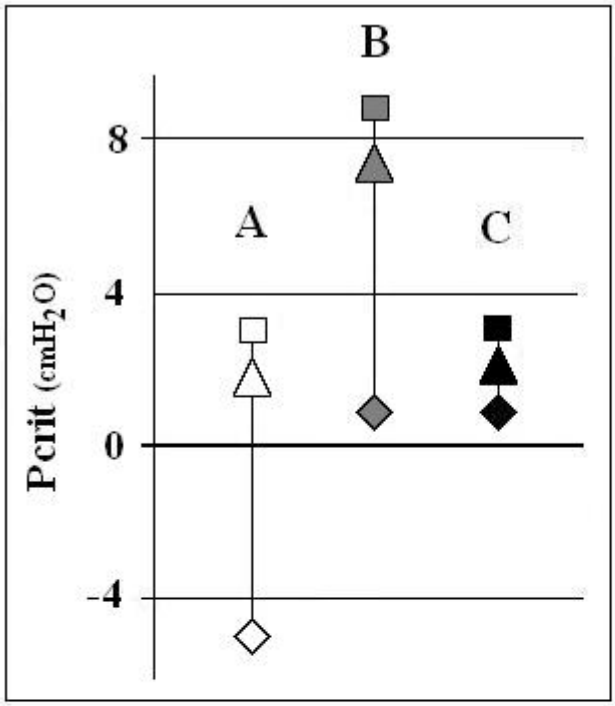
B
8
A
C
4
Pcrit (cmH2O)
0
-4

Table 1. Characteristics of the population.

	age years	gender %male	BMI kg/m^2	neck cm	OSA-RS 0-3	snoring %	Pcrit cmH_2O	Rus $cmH_2O/l/s$
propofol n=192	45.6 ±17.1	51	26.2 ±4.4	39.7 ±4.6	0.92 ±0.95	42	1.60 ±4.36	23.3 ±15.5
penthotal n=35	43.5 ±16.9	60	27.4 ±4.7	41.2 ±3.6	1.14 ±1.19	46	2.81 ±5.29	25.9 ±15.0
all n=227	45.2 ±17.1	52	26.5 ± 4.5	40.0 ± 4.5	0.96 ±0.99	43	1.78 ± 4.51	23.7 ±15.0

Neck – neck circumference. OSA-RS – OSA risk score (Berlin questionnaire). Pcrit – critical (closing) pressure. Rus – upstream resistance. None of the differences between groups is significant.

Table 2. Characteristics of male and female. The female in this study were older than men, and had a smaller neck circumference. Gender differences in OSA risk score (OSA-RS) and Pcrit (both unadjusted and adjusted for the difference in age and neck size) were not significant.

	age (years)	BMI (kg/m^2)	neck (cm)	OSA-RS (0-3)	snoring %	Pcrit cmH_2O	Rus $cmH_2O/l/s$
Male (n=119)	42.7 ±16.5	26.3 ±4.0	42.0 ±3.9	0.94 ±1.07	48	2.05 ±5.01	24.9 ±18.3
Female (n=108)	47.9 * ±17.2	26.7 ±5.0	37.8 ** ±3.9	0.98 ±0.91	39	1.43 ±3.94	22.6 ±10.2

* = $p<0.05$, ** = $p<0.001$ for comparison between male and female

Table 3. Comparison of non-snorers and snorers (defined according to the Berlin questionnaire). Non-snorers were significantly younger and leaner than snorers, and had a smaller neck circumference and higher OSA risk score (OSA-RS) and Pcrit. The difference in Pcrit and OSA-RS between non-snorers and snorers remained highly significant also after adjusting for the anthropometric differences.

	age (years)	BMI (kg/m^2)	neck (cm)	gender (%male)	OSA-RS (0-3)	Pcrit cmH_2O	Rus $cmH_2O/l/s$
non-snorers (n=129)	38.5 ±15.6	25.0 ±4.2	38.4 ±4.1	48	0.38 ±0.59	0.39 ±4.01	23.2 ±11.8
snorers (n=98)	53.6 * ±15.3	28.3* ±4.0	42.0 * ±4.3	58	1.76* ±0.87	3.40* ±4.27	24.5 ±18.5

* $p<0.001$ for comparison between non-snorers and snorers.

Table 4: Unadjusted Pearson correlation between age, BMI, neck circumference, OSA risk score (OSA-RS) and Pcrit for men (left, n=119) and women (right, n=108).

men					women
	age	0.32***	0.12	0.57***	0.40***
0.34***	**BMI**	0.64***	0.47***	0.10	
0.32***	0.71***	**neck**	0.28*	0.09	
0.55***	0.54***	0.53***	**OSA-RS**	0.37***	
0.37***	0.27**	0.31***	0.34***	**Pcrit**	

* - $p<0.002$, **- $p<0.001$ ***- $p<0.0001$