An Anatomically Based Analysis of Objectively Measured Pediatric Snoring: A Pilot Study

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Abstract

Objective. To assess pediatric habitual snoring (PS) using home sleep test (HST) technology and attempt to correlate the objective components of PS to specific upper airway anatomy. In addition, the effects of adenotonsillectomy (± turbinoplasty) on objective measures of PS were evaluated.

Study Design. Prospective cohort study.

Setting. Tertiary medical center.

Subjects and Methods. Pediatric patients with a chief complaint of snoring and probable obstructive sleep apnea underwent an HST (SNAP Diagnostics, Wheeling, Illinois) with a detailed acoustical snoring analysis prior to adenotonsillectomy (± turbinoplasty). During surgery, detailed anatomical measurements were performed and correlated to snoring analysis results. After surgery, patients were offered another HST with snoring analysis. Data analysis was performed using descriptive statistics and statistical correlation with attention to the multiple-comparisons paradox.

Results. Twenty-two patients (45% male; mean age, 5.4 years [range, 2.4-8.4 years]) completed the preoperative HST and operative measurements. Unlike typical adult snoring, only a minority of PS was from palatal flutter (mean palatal component, 24%; median, 10%). The resistance occurrence percentage (ROP; percentage of breathing events with snoring noise) was associated with body mass index (BMI; Spearman ρ = 0.55; P = .017), subjective turbinate size (0.54; P = .032), palatal obstruction (0.63; P = .008), and mean oxygen saturation (−0.729; P = .0003) but not adenotonsillar hypertrophy. Twelve patients (54%) completed a postoperative HST. The ROP was significantly reduced (median, 20.5% vs 6.5%; P = .006, sign rank test) postoperatively. The magnitude of the ROP reduction was proportional to the volume of the removed tonsils (0.74; P = .022).

Conclusion. Pediatric snoring has different acoustical characteristics than adult snoring. Objective PS is associated with BMI, turbinate size, and palatal obstruction. Adenotonsillectomy (± turbinoplasty) may significantly reduce objective PS.

Keywords

snoring, tonsillectomy, adenoidectomy, home sleep study, turbinates

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the objective components of PS to specific components of upper airway anatomy, including tonsil, adenoid, and turbi-
nate size, as well as other pharyngeal measures. Furthermore, the effects of adenotonsillectomy (± turbino-
plasty) on objective measures of PS will be formally assessed using this same HST technology.

Methods

This study was first approved by the Walter Reed National Military Medical Center Institutional Review Board before patient enrollment was initiated. Financial support was received from the Diachii Technology CORE grant from the American Society of Pediatric Otolaryngology (ASPO). SNAP Diagnostics (Wheeling, Illinois) provided unrestricted use of home sleep test technology (the SNAP test) with blinded sleep apnea and acoustical snoring analysis.

Subjects between 2 and 12 years of age who presented to the Walter Reed National Military Medical Center (WRNNMC) Otolaryngology clinic with a chief complaint of nightly snoring and probable OSAHS were recruited for study participation. Exclusion criteria consisted of (1) severe obesity (body mass index [BMI] >25), (2) craniofa-
cial syndromes (Trisomy 21, cleft palate, etc), (3) neuro-
muscular disorders (cerebral palsy, etc), or (4) history of previous tonsil or adenoid surgery. Although recurrent phar-
yngitis was not designated a priori as an exclusion criterion for study participation, none of the recruited subjects had a history of recurrent pharyngitis. Subjects who met the inclu-
sion criteria and consented to be in the study were asked to undergo a home sleep test using the SNAP test prior to scheduled adenotonsillectomy (± turbinoplasty). The decision to perform turbinoplasty was based on the patient having concurrent daytime nasal obstruction symptoms such as mouth breathing and relative turbinate hypertrophy on physical examination.

The SNAP test home sleep test is a Food and Drug Administration (FDA)–approved (initial 510K premarket clearance for adults and children ages 1 year and older received in 1995) portable sleep monitor device. The SNAP test uses sound (measured via an oronasal cannula), airflow, pulse oximetry, and a respiratory effort channel to detect and document snoring and sleep apnea. The SNAP test has been validated versus a traditional polysomnogram in adults.8,9 It has also been used extensively in unselected pediatric patients to screen for clinically significant OSAHS.10 In addition to an apnea-hypopnea index, the SNAP test also provides a detailed acoustical analysis of snoring. Snoring is objectively quantified by the snoring index (snoring events per hour), the resistance occurrence percentage (percentage of breathing events with a snoring type noise), the average snoring loudness above the baseline noise (measured in decibels), the maximal snoring loudness above the baseline (decibels), and the average snoring fre-
quency (Hertz). Based on the frequency of the snoring sound, the SNAP test can also determine whether it is predom-
inantly palatal or nonpalatal in origin. The SNAP test has been used to study adult snoring with a key finding that adult snoring that is responsive to surgical therapy is predo-
nantly due to palatal flutter (70%-100%).11 Each sub-
ject’s SNAP test was scored using proprietary software with technician oversight in a blinded manner, producing a report with an estimated apnea-hypopnea index (AHI), acoustical snoring measurements as described above, and complete overnight pulse oximetry data.

After completion of the SNAP test, subjects then under-
went planned adenotonsillectomy (± turbinoplasty) with inclusion of several anatomic measurements. Immediately prior to general anesthesia, each subject’s tonsil size (Brodsky 0-4+ scale),12 Mallampati score (1-4),13 Friedman palate position score (1-4),14 and turbinate size (1 = small, 2 = medium, and 3 = large) were assessed by 2 blinded observ-
ers. The procedure was completed under general anesthesia. Tonsillectomy was performed using electrocautery dissection, and adenoidectomy was completed using suction electrosurgical fulguration. Bilateral inferior turbinohe was com-
pleted using Coblation (ArthroCare, Andover, Massachusetts) with the pediatric turbinohe reduction wand. After decon-
gestion with topical oxymetazoline and injection with 2% lidocaine with 1:100,000 epinephrine, 2 passes with 15 sec-
onds per mark (30 seconds total) of radiofrequency energy delivery were made per turbinate on a maximum setting of “6.” Inferior turbinate outfracture was also performed in each case.

Detailed anatomic measurements were collected for each subject while under anesthesia. These measurements included adenoid size (nearest 10% obstruction of the choana based on mirror indirect nasopharyngoscopy), distance between the tonsils prior to removal (mm), distance between the posterior pillars (mm), distance between ante-
rior pillars (mm), midline hard palate length (mm), hard palate width (distance between genial tubercles in mm), midline soft palate length (mm), uvular length (mm), uvular width at the base (mm), intramolar distance (mandible, mm), and the nasopharyngeal inlet (space between the edge of the soft palate and the posterior pharyngeal wall while in the supine position in mm). After tonsil removal, the weight (grams) and volume (cc, based on volumetric displacement of room temperature saline) of each tonsil were measured and recorded.

After completion of adenotonsillectomy (± turbino-
plasty), each patient was requested to undergo a second SNAP test a minimum of 6 weeks after surgery. Patients who had residual OSAHS on the postoperative SNAP test were offered an in-laboratory formal polysomnogram for further evaluation.

Statistical analysis was performed with computer statisti-
cal software (STATA version 8.2; StataCorp LP, College Station, Texas). Most of the acoustical snoring data were not normally distributed. Therefore, nonparametric testing using the Spearman rank correlation coefficient test and sign rank test were used extensively. As this study was intended to explore hypotheses versus provide definitive data, multiple statistical tests were performed to explore potential relationships between snoring measurements and
patient anatomical features, introducing the possibility of a multiple-comparisons paradox. Given the small but broad data set, a Bonferroni-adjusted approach was not feasible as possible associations could be missed due to this stringent standard. Therefore, significant relationships were identified and reported based on physiologic plausibility, a correlation coefficient of 0.40 or greater, a significant P value for the correlation coefficient of less than 0.05, and a favorable visual assessment of the relationship on scatter plot. Multivariate analysis was performed using stepwise (forward and backward) multivariate linear regression with attention to possible interaction between terms. A P value of less than .05 was considered significant.

Results

Thirty patients attempted the initial HST (Figure 1). However, only 22 (73%) subjects successfully completed the SNAP test with complete snoring data. Technical difficulties completing the study were common, including patient resistance, errors due to not properly following device usage instructions, and missing data from displaced probes. All 22 patients who completed the preoperative HST underwent adenotonsillectomy. Fourteen of these patients (64%) underwent concurrent turbinoplasty. Only 12 patients (54%) completed the postoperative HST a mean 114 days (median, 115 days; range, 84-167 days) after surgery. Eight of these 12 patients (75%) had undergone turbinoplasty with adenotonsillectomy. Many parents were unwilling to have their child complete the postoperative HST due to the difficulties of the first preoperative test and/or they were very satisfied by the result of the surgery and did not want to be bothered, despite the financial incentives ($25 gift card for preoperative HST and $50 gift card for postoperative HST) that were offered to the child to complete the second HST as part of the study.

The demographic data for the subjects who completed the preoperative HST are shown in Table 1. The cohort was 52% female, and all subjects had an AHI of greater than 1.0 and therefore met the formal diagnostic criteria for OSAHS. As expected from previous reports, the AHI was significantly associated with objective measured combined tonsil volume (Spearman r = 0.574, P = .0128) but not with subjective (0-4 scale) tonsil size. None of the acoustical measurements of PS correlated to the AHI. In stark contrast to similar snoring acoustical data for adult patients,11 palatal flutter comprised only a small minority (mean, 24%; median, 10%) of the measured snoring noise.

Extensive univariate analysis of patient-specific anatomical measurements and snoring acoustical measurements was performed. There was no association between subject age and any SNAP test measurement. The preoperative snoring index (events per hour) was associated with patient BMI (Spearman ρ = 0.574, P = .0128) but not with subjective (0-4+ scale) tonsil size. None of the acoustical measurements of PS correlated to the AHI. In stark contrast to similar snoring acoustical data for adult patients,11 palatal flutter comprised only a small minority (mean, 24%; median, 10%) of the measured snoring noise.

Table 1. Demographic and Baseline Preoperative Home Sleep Test Snoring Measurements.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean (Median)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>5.4 (4.8)</td>
<td>2.4-8.4</td>
</tr>
<tr>
<td>Body mass index</td>
<td>16.3 (16.1)</td>
<td>12.9-19.9</td>
</tr>
<tr>
<td>Brodsky tonsil size (0-4+)</td>
<td>3.2 (3)</td>
<td>2-4</td>
</tr>
<tr>
<td>Mallampati score (0-4)</td>
<td>1.5 (2)</td>
<td>1-3</td>
</tr>
<tr>
<td>Friedman palate position score</td>
<td>1.6 (1.5)</td>
<td>1-3</td>
</tr>
<tr>
<td>Apnea hypopnea index, events/h</td>
<td>12.0 (4.7)</td>
<td>1-126</td>
</tr>
<tr>
<td>Turbinate size (1-3+)</td>
<td>2.4 (2)</td>
<td>1-3</td>
</tr>
<tr>
<td>Snoring index (snorers per hour)</td>
<td>229 (188)</td>
<td>4-527</td>
</tr>
<tr>
<td>Maximum relative snoring loudness, dB</td>
<td>14.8 (13.5)</td>
<td>8-26</td>
</tr>
<tr>
<td>Average relative snoring loudness, dB</td>
<td>8.8 (9.0)</td>
<td>0-16</td>
</tr>
<tr>
<td>Palatal snoring, %</td>
<td>24 (10)</td>
<td>0-100</td>
</tr>
<tr>
<td>Palatal flutter frequency, Hz</td>
<td>78.1 (95)</td>
<td>0-151</td>
</tr>
<tr>
<td>Resistance occurrence percentage, %a</td>
<td>28.4 (20.5)</td>
<td>1-63</td>
</tr>
<tr>
<td>Lowest pulse oximetry saturation level, %</td>
<td>86 (89)</td>
<td>42-96</td>
</tr>
<tr>
<td>Mean pulse oximetry saturation level, %</td>
<td>95 (97)</td>
<td>74-98</td>
</tr>
</tbody>
</table>

*aPercentage of breathing events associated with a snoring noise.
specific patient measurements and pulse oximetry data. The snoring maximal loudness, average loudness, palatal flutter percentage, and palatal flutter frequency were not significantly associated with any specific anatomic measurements.

Multivariate analysis was also performed using stepwise (forward and backward) multiple linear regression. All snoring measurements and all anatomic measurements were assessed, but the ROP was again the most useful acoustical measure. Modeling of the preoperative ROP demonstrated that BMI (coefficient = 4.09; 95% confidence interval [CI], 0.258 to 7.91; \(P = .038\)) and nasopharyngeal inlet (\(-2.4.01; 2.7.30 to 2.0.708; P = .021\)) were the only significant covariates (\(r^2 = 0.540\)). Interestingly, turbinate size and nasopharyngeal inlet were significantly inversely associated (Spearman \(p = -0.815, P < .001\)) and therefore were determined to interact within the regression model (interaction term coefficient = \(-8.06; -15.9 to -0.220; P = .045\)). Upon revised modeling, turbinate size was thereby also found to be a significant covariate (14.7; 95% CI, 0.687-28.2; \(P = .041\)) of the preoperative ROP model along with BMI.

Limited analysis of the change in snoring measurements after adenotonsillectomy was performed. The small sample size precluded extensive analysis to include assessing the specific effects of turbinoplasty. The snoring index and ROP both were significantly reduced postoperatively but not the snoring maximal relative loudness, average relative loudness, palatal flutter, or flutter frequency (see Table 3).

Also of note, the decrease in ROP after surgery was significantly associated with the volume of the removed tonsils (Spearman \(p = 0.739, P = .023\)) (see Figure 3).

Discussion

The key finding of this study demonstrates that PS is fundamentally different from typical adult snoring. Adult snoring arises predominantly from soft palatal flutter, whereas PS appears to be associated with increasing BMI (in nonobese children), tonsil hypertrophy, soft palate obstruction (by

<table>
<thead>
<tr>
<th>Measurement 1</th>
<th>Measurement 2</th>
<th>Spearman Correlation Coefficient</th>
<th>(P) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass index</td>
<td>Snoring index (events/h)</td>
<td>0.515</td>
<td>.0345</td>
</tr>
<tr>
<td>Body mass index</td>
<td>Resistance occurrence %(^a)</td>
<td>0.555</td>
<td>.0169</td>
</tr>
<tr>
<td>Nasopharyngeal inlet, mm</td>
<td>Resistance occurrence %</td>
<td>-0.626</td>
<td>.0079</td>
</tr>
<tr>
<td>Turbinate size (1-3+)</td>
<td>Resistance occurrence %</td>
<td>0.538</td>
<td>.0318</td>
</tr>
<tr>
<td>Mean oximetry %</td>
<td>Resistance occurrence %</td>
<td>-0.729</td>
<td>.0003</td>
</tr>
<tr>
<td>Lowest oximetry %</td>
<td>Resistance occurrence %</td>
<td>-0.446</td>
<td>.0434</td>
</tr>
</tbody>
</table>

\(^a\)Percentage of breathing events associated with a snoring noise.

Figure 2. Scatterplots of objective snoring measurements and patient-specific measurements. (A) Body mass index (BMI) versus snoring index, (B) BMI versus resistance occurrence percentage (ROP), (C) nasopharyngeal inlet versus ROP, (D) subjective turbinate size (1-3+) and ROP, (E) lowest pulse oximetry saturation measurement (%) versus ROP, and (F) mean pulse oximetry saturation measurement (%) versus ROP.

Table 2. Key Associations between Patient Anatomical Measurements and Snoring Acoustical Measurements.
way of a decreased nasopharyngeal inlet), and possibly inferior turbinate hypertrophy. Increased measures of objective snoring were also significantly correlated to decreased nadir and mean pulse oximetry levels. Last, the current study showed that adenotonsillectomy significantly reduced multiple objective measures of pediatric snoring in a small sample of patients.

With use of a single inclusive common term of snoring, it is implied that all snoring is similar in composition and arises from a similar anatomic and physiologic source. It was demonstrated in a previous adult study using the SNAP test that most adult snoring arises from flutter of the soft palate. Subsequently, procedures directed at changing the flutter dynamics of the soft palate (ie, palatal stiffening procedures) are very effective for adult snoring patients. In this same study, it was determined that patients with approximately a 70% or greater composition of palatal snoring had an increased rate of treatment success with a palatal stiffening procedure. However, in this current pediatric study, only 2 of 20 patients (9%) had over 70% palatal snoring, and the mean and median were far below that, clearly indicating a completely different pathophysiologic mechanism for the production of snoring in most pediatric patients.

This study confirms with objective data that the quantity of PS decreases after adenotonsillectomy. The next logical assumption then becomes that PS should be caused anatomically at least in part from enlargement of the tonsils and adenoids. This study failed to show a clear association between subjective tonsil size (using the Brodsky 0–4+ scale) and objective measures of snoring. This should not be considered that surprising as subjective tonsil size also has a very weak (at best) association with objective OSAS severity. Furthermore, the current study also showed that objective measures of tonsil size (weight and volume) were not directly correlated to objective snoring measures. However, it should be noted that the validity of this assessment may be limited in that all patients included in the study had some level of tonsil hypertrophy, with the majority (15 of 22 [68%]) having 3+ or 4+ tonsils and none having 1+ tonsils. The current study did show that the improvement in snoring measures postoperatively was significantly correlated to the volume of the removed tonsil tissue indirectly, suggesting that tonsil hypertrophy did indeed influence the objective snoring. A larger study with a more diverse sample of patients with different tonsil size is needed to elucidate the exact relationship.

Curiously, adenoid size was not correlated to any objective snoring measures. This goes against the commonly encountered supposition that “tonsils produce the apneas and adenoids produce the snoring.” Adenoid size was inversely correlated to age (Spearman ρ = −0.496, P = 0.0221), going along with the common observation that adenoid hypertrophy decreases in many children as they grow. Unquestionably, adenoid hypertrophy is associated with nasal obstruction. However, nasal obstruction may not be the only origin of PS. Interestingly, objective snoring was directly correlated to increasing turbinate size and increasing palatal obstruction (by way of the decreasing nasopharyngeal inlet—the measured distance from the edge of the midline soft palate and posterior pharyngeal wall in the supine position), indicating nasal and nasopharyngeal dimensions and airflow and their anatomic relationships may be at least partially implicated in the origins of PS. More specific studies are needed to investigate this association.

Several limitations of this study should be recognized. First and foremost, the sample size is modest. Multiple

Table 3. Change in Acoustical Snoring Measurements after Adenotonsillectomy.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Preoperative Value, Median a</th>
<th>Postoperative Value, Median a</th>
<th>P Value b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snoring index (events/h)</td>
<td>187.5</td>
<td>57.8</td>
<td>.041</td>
</tr>
<tr>
<td>Resistance occurrence %</td>
<td>20.5</td>
<td>6.5</td>
<td>.006</td>
</tr>
<tr>
<td>Maximum relative loudness, dB</td>
<td>13.5</td>
<td>13.0</td>
<td>.306</td>
</tr>
<tr>
<td>Average relative loudness, dB</td>
<td>9.0</td>
<td>6.5</td>
<td>.447</td>
</tr>
<tr>
<td>Palatal flutter %</td>
<td>10</td>
<td>0</td>
<td>.755</td>
</tr>
<tr>
<td>Palatal flutter frequency, Hz</td>
<td>95</td>
<td>20</td>
<td>.195</td>
</tr>
</tbody>
</table>

*Median used as most measures were not normally distributed.

*Sign rank test (nonparametric statistical test).
logistical obstacles (eg, closure of the Walter Reed Army Medical Center where the study was initiated) during the study, as well difficulties in getting subjects to complete the postoperative SNAP test, limited the sample. In addition, home sleep test technology was used to collect all the snoring data. Although the convenience and economic advantages of HSTs are unquestionable, they are performed in an unmonitored home setting, and therefore the quality of the data cannot be ensured. Also, the pharyngeal measurements were collected (by necessity) in the anesthetized pediatric patient, which may not reflect the true measurements that matter in the sleeping, snoring child. Last, all the patients included in this study met the criteria for OSAS on their HST. Pediatric snoring in the context of OSAHS may be distinctly different from PS without concurrent OSAS, and the observations from this study therefore may not be generalizable to all snoring children.

Conclusion

Pediatric habitual snoring appears to arise from an anatomic and physiologic source that is distinct from adult palatal flutter–based snoring. Objective measures of PS are associated with increasing BMI, palatal obstruction, and possibly turbinate size. Adenotonsillectomy (± turbinoplasty) may significantly reduce objective measures of PS.

Author Contributions

Scott E. Brietzke, study concept, design, data collection, data interpretation, manuscript preparation and review; Max D. Pusz, study concept, design, manuscript preparation and review.

Disclosures

Competing interests: None.

Sponsorships: SNAP Diagnostics provided unrestricted, unlimited, and blinded use of home sleep test technology with snoring analysis. SNAP had no input on study design, data analysis or interpretation, or manuscript preparation or review.

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References