Insights into the Diagnosis and Management of SDB Utilizing Upper Airway Imaging

Richard J. Schwab, M.D.
Professor of Medicine
Division of Sleep Medicine
Pulmonary, Allergy and Critical Care Division
University of Pennsylvania Medical Center
Philadelphia, Pennsylvania

Insights into the Management of SDB Utilizing Upper Airway Imaging

- Physical examination/anatomic risk factors for OSA
- Upper airway imaging modalities
  - MRI
  - Drug induced endoscopy
- Treatment of sleep apnea
  - CPAP
  - Weight loss
  - Oral appliances
  - Upper airway surgery

Modified Mallampati Classification

- Class 1
- Class 2
- Class 3
- Class 4

Tsai et al. AJRCCM 167:1427-1432, 2003

Insights into the Diagnosis and Management of SDB Utilizing Upper Airway Imaging - Disclosures

- NIH grants - RO1/PPG (Obesity and OSA)
- Consultant:
  - Apnicure
  - Foramis Medical Group
Modified Mallampati Classification

What is this patient’s Modified Mallampati score?

Anatomic Risk Factors for Sleep Apnea

- Obesity and its effects on the upper airway tissues
- Increased neck circumference
- Nasal airway restriction: septal deviation, allergic rhinitis, nasal polyps
- Macroglossia/tongue ridging
- Adeno-tonsillar hypertrophy (palatine/lingual tonsils)
- Lateral peritonsillar narrowing
- Enlargement/elongation of the soft palate
- Recessed mandible (retrognathia)/maxilla
- Narrowed hard palate - overbite/overjet
- A combination of soft tissue and/or craniofacial risk factors is likely most important

Morphometric Measurements

(Schellenberg AJRCCM 162:740-748, 2000)

- Macroglossia: tongue being above level of mandibular occlusal plane
- Uvula enlargement: > 1.5 cm in length or > 1.0 cm in width
- Enlargement of lateral walls: > 25% impingement pharyngeal space by peritonsillar tissues
- Tonsillar enlargement: > 50% lateral impingement of posterior pharyngeal airspace

Normal Upper Airway

(Schellenberg et al, AJRCCM 162:740-748, 2000)
Physical Examination and Sleep Apnea
(Schellenberg et al, AJRCCM 162;740-748, 2000)

Macroglossia

Tongue ridging

Normal Upper Airway
(Schellenberg et al, AJRCCM 162;740-748, 2000)

Physical Examination and Sleep Apnea
(Schellenberg et al, AJRCCM 162;740-748, 2000)

Enlarged Uvula

Lateral Narrowing

Lateral Narrowing
Lateral Pharyngeal Grading System

- Class I = palatopharyngeal arch intersects at the edge of the tongue
- Class II = palatopharyngeal arch intersects at 25% or more of the tongue diameter
- Class III = palatopharyngeal arch intersects at 50% or more of the tongue diameter
- Class IV = palatopharyngeal arch intersects at 75% or more of the tongue diameter


Physical Examination and Sleep Apnea
(Schellenberg et al, AJRCCM 162;740-748, 2000)

### Adjusted Odds Ratio (OR) for Sleep Apnea

<table>
<thead>
<tr>
<th>Physical Finding</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Narrowing</td>
<td>2.6*</td>
<td>1.7 - 4.1</td>
</tr>
<tr>
<td>Tonsillar hypertrophy</td>
<td>2.1*</td>
<td>1.1 - 4.2</td>
</tr>
<tr>
<td>Macroglossia</td>
<td>2.0</td>
<td>1.1 - 3.6</td>
</tr>
<tr>
<td>Enlarged soft palate</td>
<td>1.9</td>
<td>1.2 - 2.9</td>
</tr>
<tr>
<td>Retrognathia</td>
<td>1.3</td>
<td>0.8 - 2.1</td>
</tr>
</tbody>
</table>

*Maintained significance after adjusting for BMI/neck size
Digital Morphometrics with Laser Ruler

Quantify Anatomic Risk Factors for OSA with Digital Morphometrics/Laser Ruler

Upper Airway Soft Tissue and Craniofacial Measurements

Different Imaging Modalities to Phenotype the Upper Airway

- Morphometric examination/digital photography
- Cephalometrics - craniofacial skeleton
- Nasopharyngoscopy - awake and sleep induced (Propofol)
- Acoustic Reflectance - airway
- Optical Coherence Tomography - airway lumen
- Computed Tomography
- Magnetic Resonance Imaging
**Traditional Cephalometry**

Examination of craniofacial skeleton - but a two dimensional analysis of a three dimensional structure

---

**Müller Maneuver - Retropalatal Region**

(Ritter et al, Laryngoscope 109:954-963, 1999)

Studied 18 normal subjects with Müller maneuver during NPL; quantification of airway caliber; changes in airway dimensions

---

**Utility of CBCT in OSA**

- The literature lacks strong evidence for using CBCT to assess treatment outcomes in the OSA population
- However the available studies provide some evidence of utilizing CBCT to measure anatomic airway changes with surgical and dental appliance treatment for OSA
- Three studies using oral appliances and CBCT:
- CBCT may emerge as an objective tool to anatomically and functionally assess OSA treatment outcomes
- High-quality evidence studies, with statistically appropriate sample sizes and clinical cross validation are needed to determine the role of CBCT to assess treatment outcome in OSA patients

**Drug Induced Sleep Endoscopy**

Borek et al. (2012) Laryngoscope; 122:2592-9

<table>
<thead>
<tr>
<th>Region</th>
<th>Measurement</th>
<th>% Change</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP (n = 24)</td>
<td>Area</td>
<td>$-84.1 \pm 18.7$</td>
<td>.0001</td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>$-71.7 \pm 30.5$</td>
<td>.0001</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>$-66.9 \pm 35.5$</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>RG (n = 27)</td>
<td>Area</td>
<td>$-39.3 \pm 37.5$</td>
<td>.0009</td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>$-23.8 \pm 39.7$</td>
<td>.0057</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>$-29.9 \pm 33.2$</td>
<td>.0006</td>
</tr>
<tr>
<td>RE (n = 29)</td>
<td>Area</td>
<td>$-44.6 \pm 42.8$</td>
<td>.0007</td>
</tr>
<tr>
<td></td>
<td>AP</td>
<td>$-37.1 \pm 41.8$</td>
<td>.0004</td>
</tr>
<tr>
<td></td>
<td>Lateral</td>
<td>$-31.6 \pm 35.1$</td>
<td>.0003</td>
</tr>
</tbody>
</table>

*P value for paired t test.
RP = retropalatal; AP = anterior-posterior; RG = retroglossal; RE = retroepiglottic.
Normal Subject (Mid-Sagittal View)  

- Soft Palate
- Tongue
- Airway
- Mandible
- Subcutaneous Fat

Normal Subject (Axial View)  

- Airway
- Pharyngeal Wall
- Mandible
- Parapharyngeal Fat Pad
- Parotid
- Pharyngeal Wall
- Subcutaneous Fat
- Spinal Cord

MR Cephalometry

Landmarks:
S: sella  
N: nasion  
A: subspinale  
B: supramentale  
Gn: gnathion  
H: hyoid

Angles:
SNA (maxilla)  
SNB (mandible)  
NSH (hyoid)

Novel MR Cephalometry: Mandible

Linear distances computed mathematically from Cartesian coordinates (z-axis determined by slice number and thickness)
Craniofacial Changes in Normals and Apneics
(Chi et al, European Respiratory Journal 38: 348-58, 2011)

- We found that a 1-SD increase in mandibular length and depth were associated with decreased risk of sleep apnea in men but not in the women.
- The hyoid was more inferior and posteriorly positioned in apneics.
- The difference between apneics and controls for hyoid position was lost after controlling for tongue volume. Thus, increased tongue size mediates the inferior position of the hyoid.

Sagittal Upper Airway MR Images

Axial Upper Airway MR Images
**Volumetric Anatomic Risk Factors for Sleep Apnea (Cases/Controls: N = 96)**
(Schwab et al, AJRCCM 168; 522-530, 2003)

<table>
<thead>
<tr>
<th>Soft Tissue Volume</th>
<th>OR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat pads</td>
<td>1.64</td>
<td>1.00 - 2.81</td>
</tr>
<tr>
<td>Lateral Walls</td>
<td>6.01*</td>
<td>2.62 - 17.14</td>
</tr>
<tr>
<td>Soft Palate</td>
<td>1.66</td>
<td>0.99 - 3.18</td>
</tr>
<tr>
<td>Tongue</td>
<td>6.55*</td>
<td>2.81 - 19.42</td>
</tr>
<tr>
<td>Total Soft Tissue</td>
<td>6.95*</td>
<td>3.08 - 19.11</td>
</tr>
</tbody>
</table>

§ Adjusted for gender, ethnicity, age, craniofacial size and visceral neck fat

* = Significant

---

**Why are Upper Airway Soft Tissue Structures Enlarged in Apneics?**

- Edema from negative pressure
- Changes in blood flow
- Muscle disorder/function/exercise
- Vibration/snoring/surface tension
- Weight gain/obesity
- Gender
- Genetic factors

---

**Does Exercising the Upper Airway Muscles Improve Sleep Apnea?**

- Playing the didgeridoo improves sleep apnea
  – Puhan et al, BMJ 332; 266 - 270, 2006

- Performing oropharyngeal exercises improves sleep apnea
  – Guimaraes et al, AJRCCM 179; 962 - 966, 2009
  – What does exercise do to the upper airway - tongue fat?
Does Playing the Didgeridoo Train the Muscles of the Upper Airway?

14 subjects in the didgeridoo group and 11 controls with AHI between 15-30 events per hour. They played the didgeridoo for 25 minutes 6 days a week for 4 months.

Effects of Didgeridoo Playing on Mild to Moderate Sleep Apnea
(Puhan et al, BMJ 332:266, 2006)

Changes in AHI after 4 months
- Didgeridoo group: - 10.7 (7.7) episodes/hour (initial AHI 22.3 events/hour)
- Control group: - 4.5 (6.9) episodes/hour (initial AHI 19.9 events/hour)
- Difference between groups (mean 95% CI): - 6.2 (- 12.3 to - 0.1) p < 0.05

Guimaraes et al, AJRCCM 179; 962 - 966, 2009

15 patients with moderate OSA randomized to sham Rx; 16 patients to 30 minutes/day of oropharyngeal exercises (AHI reduced from 22.4 ± 4.8 to 13.7 ± 8.5)

Study Objectives
Kim et al: Metabolic Activity of the Genioglossus in Obstructive Sleep Apnea Patients - A Novel Application of FDG-PET Imaging (conditionally accepted AJRCCM)

- The metabolic activity of the tongue in apneics is unknown
- The genioglossus in patients with sleep apnea has both been shown to have an increased percentage of type II muscle fibers and intramuscular fat, both of which have been shown to lower glucose uptake
**Study Objectives**

*Kim et al: Metabolic Activity of the Genioglossus in Obstructive Sleep Apnea Patients - A Novel Application of FDG-PET Imaging (Conditionally Accepted AJRCCM)*

- To investigate the metabolic activity of the genioglossus in obese apneics compared to obese controls
- Examined a priori hypotheses:
  - Glucose metabolism would be decreased in the genioglossus of apneics in comparison to obese controls
  - There would be no differences in glucose uptake in the control muscles (masseter and pterygoid) and subcutaneous fat deposits (neck and submental) of the upper airway between apneics and controls

**Comparison of Soft Tissue SUVs in Case and Control Subjects**

*Kim et al: (Conditionally Accepted AJRCCM)*

<table>
<thead>
<tr>
<th>Tissue Type</th>
<th>Case Mean (SD)</th>
<th>Control Mean (SD)</th>
<th>p*</th>
<th>p‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genioglossus (Middle slot only)</td>
<td>1.23 ± 0.21</td>
<td>1.67 ± 0.16</td>
<td>0.0045</td>
<td>0.0409</td>
</tr>
<tr>
<td>Neck/Thorax</td>
<td>1.38 ± 0.20</td>
<td>1.41 ± 0.25</td>
<td>0.0457</td>
<td>0.0206</td>
</tr>
<tr>
<td>Control Muscle SUVs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masseter</td>
<td>1.07 ± 0.16</td>
<td>0.92 ± 0.24</td>
<td>0.0775</td>
<td>0.3821</td>
</tr>
<tr>
<td>Pterygoid</td>
<td>1.14 ± 0.23</td>
<td>1.16 ± 0.23</td>
<td>0.7921</td>
<td>0.6992</td>
</tr>
<tr>
<td>Subcutaneous &amp; Deep Fat SUVs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck Fat</td>
<td>0.40 ± 0.19</td>
<td>0.40 ± 0.19</td>
<td>0.4861</td>
<td>0.4861</td>
</tr>
<tr>
<td>Submental Fat</td>
<td>0.57 ± 0.20</td>
<td>0.50 ± 0.25</td>
<td>0.8047</td>
<td>0.8570</td>
</tr>
</tbody>
</table>

Significant differences (p < 0.05) are presented in bold 'p'-value from T-test; ‡ p-value from linear regression model adjusted for age, BMI, gender and race
Main Findings - Kim et al: (Conditionally Accepted AJRCCM)

• After adjusting for age, BMI, gender and race, we found that FDG uptake is reduced in the genioglossus of apneics compared to controls
• These results remained after adjusting for tongue fat
• There were no differences in FDG uptake in the masseter and pterygoid muscles and in the fat deposits in the neck between apneics and controls
• Our results support the concept that the increased compound tongue EMG activity in apneics is the result of denervation/reinervation injury and not the neuromuscular compensation hypothesis

Why are Upper Airway Soft Tissue Structures Enlarged in Apneics?

• Edema from negative pressure
• Changes in blood flow/redistribution leg edema
• Muscle disorder/function/exercise
• Vibration/snoring/surface tension
• Weight gain/obesity
• Gender
• Ethnicity
• Genetic factors

We Still Do Not Understand the Effect of Obesity on Upper Airway Tissues

• Increased volume of adipose tissue (several studies have demonstrated this)
  – In parapharyngeal fat pads – increased tissue pressure?
  – ? Within tongue – does this size and function?
  – Fat under mandible and subcutaneous
• Increased muscular tissue with weight gain
  – ? Increase in size of lateral walls, tongue, soft palate
Images from the Nashi autopsy study [Laryngoscope 117; 1467-1473, 2007]. Left panel (A) shows a sagittal image of the tongue demonstrating a significant amount of fat in the posterior third of the tongue and in the sublingual region below the intrinsic tongue muscles; bottom (B) is a schematic demonstrating the percent of tongue fat in the anterior, posterior and sublingual regions in 121 tongue autopsy specimens. The right panel demonstrates another autopsy specimen with a significant amount of tongue fat.

Histomicrographs of psoas muscle (A: top) and tongue (B: bottom) in an obese subject. Note there is greater fat in the tongue than the psoas muscle. Nashi Laryngoscope 117; 1467-1473, 2007

Study Objectives
(Kim et al, Conditionally Accepted to Sleep)

- The primary goal of this study was to identify alterations in fat deposition within the tongue of obese apneics in comparison to obese subjects without sleep apnea using the three-point Dixon method (a method for fat/water discrimination)
- Compared tongue fat to fat in the masseter muscles
- Examined tongue topography for fat
- Compared men and women

Nashi et al, Laryngoscope 2007; 117:1467-73
Comparison of Muscle Volumes and Intramuscular Fat in Case and Control Subjects (Kim et al, Conditionally Accepted to Sleep)

<table>
<thead>
<tr>
<th>Soft Tissue Volume</th>
<th>Apneics (n=90)</th>
<th>Controls (n=31)</th>
<th>t Test (p value)</th>
<th>²p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongue, mm³</td>
<td>101,193 ± 17,651</td>
<td>85,542 ± 13,813</td>
<td>&lt; 0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Tongue fat, mm³</td>
<td>32,791 ± 9,175</td>
<td>23,390 ± 5,511</td>
<td>&lt; 0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Tongue fat, %</td>
<td>32.6 ± 7.9</td>
<td>27.7 ± 6.7</td>
<td>0.002</td>
<td>0.089</td>
</tr>
<tr>
<td>Left masseter, mm³</td>
<td>16,204 ± 6,633</td>
<td>14,517 ± 6,342</td>
<td>0.214</td>
<td>0.794</td>
</tr>
<tr>
<td>Left masseter fat, mm³</td>
<td>786 ± 859</td>
<td>599 ± 766</td>
<td>0.262</td>
<td>0.118</td>
</tr>
<tr>
<td>Left masseter fat, %</td>
<td>5.15 ± 5.85</td>
<td>4.82 ± 6.05</td>
<td>0.794</td>
<td>0.384</td>
</tr>
</tbody>
</table>

Significant differences (p < 0.05) are presented in bold. ²p indicates after adjustment for age, BMI, gender, and race.

Apneic Subject
- BMI: 34.2 kg/m²
- AHI: 59.1 events/hour
- Tongue Volume: 95,492 mm³
- Tongue Fat Volume: 41,686 mm³
- Tongue Fat Percentage: 42%

Normal Subject
- BMI: 35.0 kg/m²
- AHI: 9.6 events/hour
- Tongue Volume: 65,674 mm³
- Tongue Fat Volume: 16,056 mm³
- Tongue Fat Percentage: 24%
Main Findings (Kim et al, Conditionally Accepted to Sleep)

- Obese apneics have enlarged tongue volumes and increased fat within the tongue in comparison to obese normal subjects after adjustment for differences in age, BMI, gender, and race
- There is a heterogeneous distribution of fat within the tongue
- Tongue fat distribution in apneics is increased in specific locations of the tongue (greater in the retroglossal region)
- Tongue size and tongue fat are correlated with AHI
- No difference in tongue fat between apneic men and women

Ramifications of Tongue Fat (Kim et al, Conditionally Accepted to Sleep)

- We believe that increased tongue fat increases AHI by not only increasing the size of the tongue, which affects airway size and collapsibility, but may also adversely affect muscle function
- The increased presence of intramuscular fat may affect the tongue’s ability to properly perform as a pharyngeal dilator muscle by potentially altering its shape thereby reducing its contractile force
- The presence of increased intramuscular fat may additionally directly contribute to alterations in contractile performance

Icelandic Sleep Apnea Cohort (ISAC) (Schwab et al, in preparation)

- All patients diagnosed with OSA in Iceland and referred for CPAP treatment at the Landspitali University Hospital in Reykjavik, Iceland, from September 2005 - August 2009
  - 713 subjects had MRI (upper airway, neck and abdomen) and PSG (Embletta)
- All apneics with wide range of severity - AHI/ODI
- Three BMI categories < 30, 30-35, > 35 kg/m²
- Men and women but mostly men

Intra-Mandibular Volume (IMV): the Amount of Tissue within “the Box” (Schwab et al, in preparation)
Severity of AHI: Based on Craniofacial and Soft Tissue Interactions in Men in ISAC (Schwab et al, in preparation)

<table>
<thead>
<tr>
<th>AHI 15 - 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHI 30 - 50</td>
</tr>
<tr>
<td>AHI ≥ 50</td>
</tr>
<tr>
<td>n = 137</td>
</tr>
<tr>
<td>n = 211</td>
</tr>
<tr>
<td>n = 201</td>
</tr>
<tr>
<td>Unadjusted p</td>
</tr>
<tr>
<td>Total Soft Tissue (mm³)</td>
</tr>
<tr>
<td>IMV (mm³)</td>
</tr>
<tr>
<td>TST/IMV Ratio</td>
</tr>
</tbody>
</table>

The ratio of the total soft tissue (TST) to intra-mandibular volume (IMV) was significantly greater in the patients with the most severe apnea.

Weight Loss and Sleep Apnea

- How much weight loss results in clinical improvement?
  - Weight loss of 5 - 10% may be effective
- Does size of parapharyngeal fat pads decrease with weight loss?
- Does size of lateral pharyngeal walls, soft palate and tongue decrease with weight loss?
  - Weight loss is associated with reductions in both fat (75%) and fat-free mass (25%)
Airway

Pre-weight loss - normal

Post-weight loss - normal

Welch et al, Sleep 25; 532-542, 2002

Effect of CPAP on Upper Airway Geometry?

- Airway size increases with application of CPAP in both normals and apneics
  - CT: Kuna et al. ARRD 1988; 138:969-975
  - MRI: Abbey et al. ARRD 1989; 140:717-723
- CPAP originally thought to push tongue and soft palate forward
  - AP or lateral airway changes?

Schwab et al, AJRCCM 154:1106-1116, 1996

CPAP - Airway 3D Volumes

CPAP - 0 cm H₂O

CPAP - 15 cm H₂O

Schwab et al, AJRCCM 154:1106-1116, 1996
**Oral Appliances**

- Mandibular repositioning devices are an effective alternative to CPAP in patients with mild to moderate OSA
- Mandibular repositioning devices clasp on upper and lower teeth pulling mandible forward and downward
- To determine most effective oral appliance we need to understand each appliance’s mechanism of action

**How do Oral Appliances Change Upper Airway Geometry?**

- Do oral appliances simply pull mandible and tongue forward?
- How important is vertical bite opening?
- Studies indicate airway caliber increases in lateral dimension with oral appliances
- Structures lateral to airway may be important in understanding how oral devices maintain upper airway patency
Custom-Made Two-Piece Mandibular Advancement Splint (MAS) (a Modification of the Somnodent MAS)

Representative Axial Images From a Responder and Non-Responder

Volumetric Reconstructions of the Upper Airway in a Responder Showing the Increase in Caliber of the Upper Airway With Mandibular Advancement

Chan et al. Thorax 2010;65:726-732
<table>
<thead>
<tr>
<th></th>
<th>Without MAS</th>
<th>With MAS</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total airway volume (cm³)</td>
<td>16.5±0.7</td>
<td>18.1±0.8</td>
<td>0.001</td>
</tr>
<tr>
<td>Minimum cross-sectional area (cm²)</td>
<td>0.49±0.04</td>
<td>0.57±0.03</td>
<td>0.031</td>
</tr>
<tr>
<td>Airway length (cm)</td>
<td>9.4±0.1</td>
<td>9.2±0.1</td>
<td>0.15</td>
</tr>
<tr>
<td>Velopharynx</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (cm³)</td>
<td>5.7±0.3</td>
<td>6.5±0.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Antero-posterior dimensions (cm)</td>
<td>1.13±0.04</td>
<td>1.17±0.04</td>
<td>0.22</td>
</tr>
<tr>
<td>Lateral dimensions (cm)</td>
<td>1.67±0.07</td>
<td>1.91±0.07</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Oropharynx</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (cm³)</td>
<td>3.7±0.2</td>
<td>3.9±0.2</td>
<td>0.24</td>
</tr>
<tr>
<td>Antero-posterior dimensions (cm)</td>
<td>1.22±0.04</td>
<td>1.27±0.04</td>
<td>0.13</td>
</tr>
<tr>
<td>Lateral dimensions (cm)</td>
<td>2.23±0.09</td>
<td>2.34±0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>Hypopharynx</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume (cm³)</td>
<td>7.1±0.4</td>
<td>7.7±0.4</td>
<td>0.017</td>
</tr>
<tr>
<td>Antero-posterior dimensions (cm)</td>
<td>1.37±0.05</td>
<td>1.47±0.05</td>
<td>0.023</td>
</tr>
<tr>
<td>Lateral dimensions (cm)</td>
<td>2.50±0.08</td>
<td>2.52±0.08</td>
<td>0.74</td>
</tr>
</tbody>
</table>

*Without MAS compared with with MAS.
**Is Upper Airway Surgery Effective?**

- Why is uvulopalatopharyngoplasty (UPPP) only effective in 50% of patients?
- Patients with retropalatal obstruction have a better surgical outcome than patients who have retroglossal obstruction
- Should upper airway surgery be more directed at the lateral pharyngeal walls or tongue than the soft palate?

---

**Upper Airway Surgery and Lateral Pharyngeal Walls**

- UA surgery that affects lateral pharyngeal walls directly or indirectly (hyoid bone repositioning) has been shown to be effective:
  - Hyoid advancement/rotation
  - Lateral pharyngoplasty
    - Cahali et al, Sleep 27; 942-950, 2004
    - Lateral pharyngoplasty (15 cases; AHI 42 pre, 16 post;) was shown to be more effective than UUPPP (12 cases; AHI 35 pre, 30 post)
  - Tonsillectomy
Why is UPPP Surgery Not More Effective?

- Soft palate a strut for lateral pharyngeal walls?
  - Palatopharyngeus muscles arise from soft palate and make up a portion of lateral walls
- Proximal (nonresected) soft palate may be a problem
- Surgery primarily directed at AP tissues
- No effect on tongue
- Scarring from UPPP may result in traction and stiffing of lateral walls
  - Over time scarring may “soften” and apnea could return? (UPPP outcomes worsen with time)
**Matched Axial Slices**

<table>
<thead>
<tr>
<th></th>
<th>Non-resected RP</th>
<th>Resected RP</th>
<th>Retroglossal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre UPPP</strong></td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td><strong>Post UPPP</strong></td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
</tbody>
</table>

**Imaging of the Upper Airway - "Take Home Messages"**

- Increased volume of upper airway soft tissue structures is an important risk factor for sleep apnea
- Reduction in mandibular size is also an important risk factor for OSA
- Metabolic activity of the tongue is reduced in apneics
- Tongue fat may explain the relationship between obesity and sleep apnea
- We need to better understand the changes in upper airway anatomy that occur with oral appliances, weight loss and upper airway surgery

**Thank you for your attention!**

Any Questions?

rschwab@mail.med.upenn.edu
Pre & Post UPPP
Axial Scans: Non-Resected RP Region

Pre UPPP
Post UPPP

Pre & Post UPPP
Axial Scans: Resected RP Region

Pre UPPP
Post UPPP

Craniofacial Changes in Normals and Apneics
(Chi et al, European Respiratory Journal 38: 348-58, 2011)

Representative CT, PET, and fused PET/CT images of the entire body. Color bars below PET and fused PET/CT image indicating high uptake (black, red) and low/no uptake (white/blue). Note: Heart (orange arrow) has relatively high SUV whereas liver (red arrow) and resting quadriceps muscle (yellow arrow) have significantly lower SUV.
Comparison of Soft Tissue SUVs in Case and Control Subjects
Kim et al: (Conditionally Accepted AJRCCM)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Apneics (n=90)</th>
<th>Controls (n=30)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>49.6 ± 9.9</td>
<td>41.6 ± 13.2</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>39.1 ± 8.3</td>
<td>34.1 ± 4.8</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>AHI, events/hour</td>
<td>43.2 ± 27.3</td>
<td>4.1 ± 2.7</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Gender, M:F</td>
<td>42:48</td>
<td>10:21</td>
<td>0.162</td>
</tr>
<tr>
<td>Race, C:AA</td>
<td>39:51</td>
<td>18:13</td>
<td>0.281</td>
</tr>
</tbody>
</table>

Demographics of Case and Control Subjects
(Kim et al, Conditionally Accepted to Sleep)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Apneics (n=90)</th>
<th>Controls (n=31)</th>
<th>t test (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>49.6 ± 9.9</td>
<td>41.6 ± 13.2</td>
<td>0.004</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>39.1 ± 8.3</td>
<td>34.1 ± 4.8</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>AHI, events/hour</td>
<td>43.2 ± 27.3</td>
<td>4.1 ± 2.7</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Gender, M:F</td>
<td>42:48</td>
<td>10:21</td>
<td>0.162</td>
</tr>
<tr>
<td>Race, C:AA</td>
<td>39:51</td>
<td>18:13</td>
<td>0.281</td>
</tr>
</tbody>
</table>

Definition of abbreviations: AHI=apnea/hypopnea index; BMI=body mass index; C=Caucasian; AA=African American
Effect of Weight Loss on UA Structures (Welch et al, Sleep 25; 532-542, 2002)

- MRI in 12 normal women (AHI <1) before and after 17% weight loss - volumetric analysis
- Upper airway volume significantly increased with weight loss
- Volume of parapharyngeal fat pads and lateral pharyngeal walls decreased significantly with weight loss - why?
- Tongue and soft palate volume did not decrease significantly with weight loss - why?

Acoustic Reflectance

Using sound waves to indirectly measure nasal/airway lumen

Optical Coherence Tomography


Endoscopic optical technique that allows macroscopic images of the airway in order to accurately determine shape and size of the upper airway; can be performed during sleep.
Schwab et al, ARRD 148:1385-1400, 1993