Insights into the Management of SDB Utilizing Upper Airway Imaging

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

- NIH grants - RO1/PPG (Obesity and OSA)
- Consultant:
  - Apnicure
  - Apnex
Insights into the Management of SDB Utilizing Upper Airway Imaging

- Upper airway imaging modalities
- Phenotyping the pharynx
  - Anatomic risk factors/three dimensional MRI
- Treatment of sleep apnea
  - CPAP
  - Weight loss
  - Oral appliances
  - Upper airway surgery
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)
Physical Examination and Sleep Apnea
(Schellenberg AJRCCM 162;740-748, 2000)

<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
What is the Best Upper Airway Imaging Modality?

- Morphometric examination/digital photography
- Cephalometrics
- Nasopharyngoscopy/sleep endoscopy
- Acoustic Reflectance
- Optical Coherence Tomography
- Computed Tomography
- Magnetic Resonance Imaging
Traditional Cephalometry
Müller Maneuver - Retropalatal Region

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

Normal

Sitting - Baseline

Sitting - Maximum Effort

Studied 18 normal subjects with Müller maneuver during NPL
Müller Maneuver - Retropalatal Region
(Ritter et al, Laryngoscope 109:954-963, 1999)

Normal

Baseline (Quiet Respiration)

- 10 cm H₂O
- 20 cm H₂O
- 30 cm H₂O
- 40 cm H₂O
Acoustic Reflectance
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
Cone Beam CT

- Their small size makes installation within a dental clinic feasible, but image interpretation requires training and expertise.

- Similar to conventional CT scanners but 3 major differences:
  - It uses a low-energy fixed anode tube.
  - Scanner rotates around the patient only once, capturing the data using a cone-shaped x-ray beam (approximately 20% of the regular radiation).
  - Patient is in the sitting position, although some machines have the ability to perform scanning supine position.

- Studies need to be performed with the cone beam CT scanners to determine if they have value in the diagnostic and treatment planning in patients with OSA.

- May have utility in examining UA changes with OA.
Normal Subject (Mid-Sagittal View)  
Normal Subject (Axial View)
MR Cephalometry

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

Angles:
SNA (maxilla)
SNB (mandible)
NSH (hyoid)
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)
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
Craniofacial Changes in Normals and Apneics
(Chi et al, European Respiratory Journal 38: 348-58, 2011)
Sagittal Upper Airway MR Images
Axial Upper Airway MR Images

Normal Subject

Apneic Patient
Patient with Sleep Apnea

Normal Subject

Parapharyngeal Fat Pads

Soft Palate

Pharyngeal Walls

Airway

Parapharyngeal Fat Pads

Soft Palate

Pharyngeal Walls

Airway

Tongue

Mandible

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

Adjusted§ Odds Ratio (OR) for Sleep Apnea:

<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
- Primary muscle disorder/injury
- Vibration/snoring/surface tension
- Weight gain/obesity
- Gender
- 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.
Tongue Fat in Normals and Apneics

Tongue Fat can be measured with spectroscopy and Dixon imaging
Icelandic Sleep Apnea Cohort (ISAC)

- 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
Effect of BMI on the Upper Airway - ISAC

• 679 subjects (551 male*, 128 female) with MRI’s that could be analyzed

<table>
<thead>
<tr>
<th>*N=551 (men)</th>
<th>BMI &lt; 30 N=189</th>
<th>BMI 30-35 N=207</th>
<th>BMI &gt; 35 N=155</th>
<th>ANOVA P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>55.2 ± 9.8</td>
<td>54.3 ± 10.8</td>
<td>51.2 ± 11.3</td>
<td>0.0089</td>
</tr>
<tr>
<td>AHI**</td>
<td>38.0 ± 15.6</td>
<td>46.5 ± 20.6</td>
<td>50.7 ± 23.3</td>
<td>0.0012</td>
</tr>
<tr>
<td>ODI**</td>
<td>26.6 ± 12.5</td>
<td>37.0 ± 19.3</td>
<td>43.7 ± 23.4</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

1 log transformed for normality

• Hypothesis:
  • Size of soft tissue structures surrounding the upper airway will increase with body mass index (BMI)
Effect of BMI on the Upper Airway - ISAC

- Cross-sectional airway size decreases laterally at the minimum cross-section of the retropalatal airway

BMI: 29  
AHI: 42; AGE: 53  
RP Width = 28.5

BMI: 33  
AHI: 42; AGE: 46  
RP Width = 13.6 mm

BMI: 39  
AHI: 46; AGE: 52  
RP Width = 12.0

- Axial MRI slices, mid-soft palate

= Airway  = Lateral Walls  = Fat Pads
Effect of BMI on the Upper Airway - ISAC

• Total soft tissue (TST) volume increases with BMI

BMI: 29
AHI: 42; AGE: 53
TST = 154417.2 mm³

BMI: 33
AHI: 42; AGE: 46
TST = 184403.9 mm³

BMI: 39
AHI: 46; AGE: 52
TST = 213167.6 mm³

= Mandible/Hyoid Bone
= Tongue
= Other Tongue Muscles
= Soft Palate
= Lateral Walls
= Airway
= Fat Pads
= Pterygoid Muscles
= Epiglottis
Effect of BMI on the Upper Airway - ISAC

- Tongue volume increases with BMI

BMI: 29
AHI: 42; AGE: 53
Tongue = 84511.3 mm³

BMI: 33
AHI: 42; AGE: 46
Tongue = 101422.6 mm³

BMI: 39
AHI: 46; AGE: 52
Tongue = 119200.4 mm³

= Mandible/Hyoid Bone
= Tongue
= Other Tongue Muscles
= Soft Palate
= Lateral Walls
= Airway
= Fat Pads
= Pterygoid Muscles
= Epiglottis
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%)
Pharyngeal Wall
Parapharyngeal Fat Pad
Subcutaneous Fat

Pre-weight loss
Post-weight loss
Pre-weight loss - normal

Post-weight loss - normal

Welch et al, *Sleep* 25; 532-542, 2002
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?
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?
CPAP - Airway 3D Volumes

(Schwab et al, AJRCCM 154:1106-1116, 1996)
CPAP - 0 cm H$_2$O

CPAP - 15 cm H$_2$O

(Schwab et al, AJRCCM 154:1106-1116, 1996)
(Schwab et al, AJRCCM 154:1106-1116, 1996)
Mid-sagittal MRI with and without CPAP in a Normal Subject

(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)

Chan et al. Thorax 2010;65:726-732
Representative Axial Images From a Responder and Non-Responder

Chan et al. Thorax 2010;65:726-732
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 2  Airway parameters without mandibular advancement splint (MAS) and with MAS (all patients; n=69)

<table>
<thead>
<tr>
<th>Parameter</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>0.0001</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.
### Table 3  Cephalometric measurements without mandibular advancement splint (MAS) and with MAS (all patients; n=69)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Without MAS</th>
<th>With MAS</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNA angle (°)‡</td>
<td>82.5±0.7</td>
<td>81.9±1.1</td>
<td>0.48</td>
</tr>
<tr>
<td>SNB angle (°)‡</td>
<td>79.7±0.7</td>
<td>80.1±1.4</td>
<td>0.78</td>
</tr>
<tr>
<td>ANB angle (°)‡</td>
<td>2.8±0.5</td>
<td>1.8±1.0</td>
<td>0.26</td>
</tr>
<tr>
<td>ANS—Gn distance (cm)</td>
<td>6.8±0.1</td>
<td>7.5±0.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>H—C3 distance (cm)</td>
<td>3.7±0.1</td>
<td>3.8±0.1</td>
<td>0.048</td>
</tr>
<tr>
<td>H—PNS distance (cm)</td>
<td>7.4±0.1</td>
<td>7.2±0.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>H—Gn distance (cm)</td>
<td>4.7±0.1</td>
<td>4.8±0.1</td>
<td>0.061</td>
</tr>
</tbody>
</table>

*Without MAS compared with with MAS.
‡n=57 for SNA angle, SNB angle and ANB angle as imaging did not include the nasion in all patients.

ANB, A point—nasion—B point; ANS, anterior nasal spine; Gn, gnathion; H, hyoid; PNS, posterior nasal spine; SNA, sella—nasion—A point; SNB, sella—nasion—B point.
Movement of Centroids of Soft Tissue Structures With Mandibular Advancement

Chan et al. Thorax 2010;65:726-732
Custom-Made Two-Piece Mandibular Advancement Splint (MAS) (a Modification of the Somnodent MAS)

Sutherland et al. Sleep 34: 469-477, 2011
Tongue Retaining Device

Sutherland et al. Sleep 34: 469-477, 2011
Sutherland et al. Sleep 34: 469-477, 2011
Sutherland et al. Sleep 34: 469-477, 2011

A) Velopharynx

B) Diagram showing changes in lumen dimensions with MAS and TSD.

C) Oropharynx

D) Hypopharynx

Legend:
- ○ Lateral (L)
- ● Anteroposterior (A-P)
- ▲ A-P:L ratio
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 UPPP (12 cases; AHI 35 pre, 30 post)
  - Tonsillectomy
Upper Airway Structures - Lateral View

- Genioglossus m.
- Mandible
- Geniohyoid m.
- Hyoglossus m.
- Stylohyoid m.
- Thyroid cartilage
- Thyrohyoid m.
- Trachea
- Palatoglossus m.
- Palatine tonsil
- Styloglossus m.
- Palatine tonsil
- Stylohyoid ligament
- Stylopharyngeus m.
- Styloid process
- Stylohyoid m.
- Sup pharyngeal constrictor m.
- Mid pharyngeal constrictor m.
- Hyoid bone
- Inf pharyngeal constrictor m.
- Esophagus
Cahali MB. Laryngoscope 113; 1961-1968, 2003

SPC = superior pharyngeal constrictor muscle
Cahali MB. Laryngoscope 113; 1961-1968, 2003
SPC = superior pharyngeal constrictor muscle
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)
Pre & Post Mid-Sagittal Scans
Matched Axial Slices

Non-resected RP

Resected RP

Retroglossal

Pre UPPP

Post UPPP
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
Pre Sliding Genioplasty

Post Sliding Genioplasty
Imaging of the Upper Airway - "Take Home Message"

- 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.
- Obesity increases the size of the upper airway soft tissue structures.
- 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?

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