Upper Airway Anatomy and Physiology

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Lecture Outline

- Comparative anatomy and phylogeny
- Physiologic Function and Control
- Pathophysiology
- Patient Evaluation and clinical anatomy
- Surgical Treatment options
  - Nasal
  - Oral cavity/Oral pharynx
  - Tongue base
  - Skeletal
  - Novel Surgical approaches
Comparative Anatomy and Phylogeny

- With the exception of the English Bulldog and the Elephant Seal, Obstructive Sleep Apnea is a distinctly human condition.
- Understanding why this is so is important toward understanding and treating the disease.
Anatomy

- In all mammals except for primates the axial skeleton is roughly parallel to the pharynx separating the foramen magnum and the pharynx
- The pharynx is under little anatomical constraint
- The tongue resides in the oral cavity
- Basoflexion of the skull (with bipedalism) in primates begins to changes this relationship

From TM Davidson ‘The Great Leap Forward: the anatomic basis for the acquisition of speech and OSA’; Sleep Medicine 4(2003) 185-194
- In nonhuman primates the elongated splanchnocranium allows the tongue to reside in the oral cavity
- Larynx is close to the skull base increasing airway stability

From TM Davidson 'The Great Leap Forward: the anatomic basis for the acquisition of speech and OSA'; Sleep Medicine 4(2003) 185-194
In humans the development of speech came at the expense of our sleep
- Splanchnocranium is shortened displacing the tongue posteriorly into the pharynx
- Larynx is descended: Collapsible pharynx not protected by a skeletal/cartilaginous framework and more dependent on neuromuscular tone

From TM Davidson ‘The Great Leap Forward: the anatomic basis for the acquisition of speech and OSA’; Sleep Medicine 4(2003) 185-194
- Neonates and children are highly resistant to OSA
  - Larynx is near skull base
  - Decoupling of respiration and deglutition
  - Less distensible Pharynx
  - Larynges descend slowly in childhood
  - Tongue transitions from oral cavity to pharynx

From TM Davidson ‘The Great Leap Forward: the anatomic basis for the acquisition of speech and OSA’; Sleep Medicine 4(2003) 185-194
Craniofacial Anatomy

- Anatomical differences exist as a function of ethnicity
- Anatomically this is generally manifested in craniofacial structure
  - Example: some Asian populations more prone to maxillary hypoplasia
Physiologic Function of the Upper Airway (UA) & Upper Aerodigestive Tract (UADT)

- Supports ventilation by transmitting, filtering, and humidifying air
- Olfaction
- Deglutition
  - Closes off the velopharynx and diverts food away from the glottis and to the hypopharynx
- Produces phonation and speech
  - Glottic generation
  - Pharyngeal and sinus contributions
- Immunologic function: Waldeyer’s ring
- Protects against negative pressure collapse (particularly important in humans)
Neuromuscular Control of the UA

- Cranial Nerve V: contribute to mandibular and laryngeal stabilization; palate (Tensor P.)
- Cranial Nerve VII: nasal dilator (alae nasi)
- Cranial Nerve IX: Pharyngeal stabilization. (Stylopharyngeus)
- Cranial Nerve X/XI complex: all palatal and pharyngeal muscles except for tensor palatini and stylophyaryngeus
- Cranial Nerve XII: intrinsic and extrinsic muscles of the tongue (except palatoglossus)
- Cervical spinal contribution to laryngeal stabilization & accessory respiratory muscles
Sensory Innervation of the UA

- Cranial Nerve V: Oral/nasal cavity, nasopharynx
  - Pressure sensors in NC
- Cranial Nerve IX: Pharyngeal sensation
  - Carotid body: Primarily O\textsubscript{2} sensing. Lesser role in CO\textsubscript{2} and pH sensing
- Cranial Nerve X: Laryngeal sensation
  - Upper airway neuro-reflex: flow and mechanoreceptors supplied by the Superior laryngeal branch of CN X
Upper Airway Reflex

- Afferent branch of arc includes CNX (SLN)
- Efferent branch of arc includes CNX and XII supplying palatal and lingual muscles
- Negative pressure reflex: more robust in humans due to UA collapse susceptibility
- Respiratory modulated vs. tonic muscles
  - Genioglossus vs. Tensor palatini
- With age the reflex is less robust
- OSA patients appear to have more vigorous reflex (but still insufficient)
Upper Airway Pressure dynamics

- Luminal pressures are the sum of airway pressure and pressures related to airflow.
- Tissue (collapsing) pressure: influenced by all factors that affect the pharyngeal soft tissues.
- Transmural pressure: opening force that is the sum of tissue pressure and luminal (airway) pressures.
- Critical closing pressure ($P_{crit}$): the pressure at which tissue pressure exceeds luminal pressure (in the context of OSA).
Upper Airway Pressure dynamics

- **Non-apnea**: $P_{TM} > P_{US} > P_{DS}$
- **Apnea**: $P_{US} > P_{DS} > P_{TM}$
- **Snorer**: $P_{US} > P_{TM} > P_{DS}$
Oronasal flow partitioning

- Oral breathing during sleep increases UA resistance
  - Mechanism debated
  - Patients with patent nasal cavities but forced to mouth breath in sleep become apneic
- Inability to transition between nasal and oral airflow has been implicated in OSA
  - Related to nasal pressure receptors and palatal function
Pathophysiology: Nose

- Association between nasal obstruction and OSAS (with/without obesity) is well documented
  - Anatomic deformity of nasal cavity structures
  - Dynamic nasal valve collapse
  - Nasal polyps or tumors anywhere in the UADT
  - Maxillary hypoplasia or retraction
Pathophysiology: Pharynx

- Hypertrophy of UADT lymphatic tissue
- Fat deposition in the UADT
  - Tongue
  - Lateral pharyngeal walls
- Mandibular/maxillary hypoplasia or retrusion
- Peripheral neuromuscular disorders
Pathophysiology

- Blunting of peripheral mechanical and flow receptors in the UA (can be related to obesity)
- Central neurological deficits
- Rostral fluid shifts: Shift of ECF from the LE to the head & neck region while supine
- Vascular congestion with increased ECF
- Mucosal desiccation and increased surface tension
Pathophysiology

- Gastro-Esophageal Reflux and laryngopharyngeal reflux associated with UA inflammation and possibly OSA
- Snoring as an independent risk factor for SDB related morbidity?
  - Atherosclerosis of carotid arteries with higher risk of CVA related to snoring (independent of OSA based on PSG parameters)
  - UA inflammation
Anatomical Based UA Evaluation

- Body habitus, neck size & BMI
- Vocal quality
- Craniofacial structure & Morphology
- Comprehensive nasal exam
  - Septum, Turbinates, Nasal valve, Adenoids
- Oral Cavity
  - Tongue size/position, Palatal length, dentition/occlusion
- Oropharynx
  - Tonsils, Vertical redundancy/crowding
- Nasopharyngolaryngoscopy
  - Grade UA: VOTE (velopharynx, oropharynx, Tongue, epiglottis)
Oral Cavity/Oral Pharynx

- **Tonsillar hypertrophy grading scale.**
  - 0 Tonsils are absent.
  - 1+ Tonsils occupy less than 25% of hemi-pharyngeal diameter or remain within tonsillar fossa
  - 2+ Tonsils occupy less than 50% of hemi-pharyngeal diameter or protrude just beyond the tonsillar fossa
  - 3+ Tonsils occupy less than 75% of hemi-pharyngeal diameter or protrude out of fossa but are non-obstructing
  - 4+ Tonsils occupy 75% or more of hemi-pharyngeal diameter and are mostly obstructing

Figure from SleepMedicineBoardReview.com
Oral Cavity/Oral Pharynx

- Tongue/palate relationship: grading the degree of anterior tongue obstruction
  - Class I: soft palate, fauces, uvula, pillars all visible
  - Class II: soft palate, fauces, portion of uvula visible
  - Class III: soft palate, base of uvula visible
  - Class IV: hard palate visible

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How not to evaluate the tongue position

- The tongue needs to be in the resting 'natural' position for proper evaluation
Surgical Evaluation-Site Specific

- Muller Maneuver
  - Reliability?
- Natural Sleep Endoscopy
  - Practicality?
- Drug Induced Sleep Endoscopy (DISE)
  - Expense

UAW Anatomy

1. Nasopharynx
2. Velopharynx
3. Oropharynx
4. Hypopharynx

Pharynx (Collapsible Site)
Retropalatal (Velopharyngeal) Airway in DISE

- Arrow indicates nasal side of soft palate
- Asterisk marks back side of uvula
Retrolingual (Tongue Base) Airway in DISE

- Arrows indicate epiglottis
- Arrow heads indicate true vocal folds
- BOT=base of tongue
- Stars indicate lingual Tonsils

Normal

Severe obstruction with lingual tonsil hypertrophy

Apparently non-obstructive tongue base with floppy and obstructive epiglottis
Treatment

- Pneumatic splinting (PAP) generally most effective at opening the airway in sleep
- Dental appliance for mild-moderate OSA
  - Less effective than CPAP but more portable: targets retrolingual UA but can have effect on retropalatal UA as well
Surgical treatment can be curative but is very often adjunctive

- Often done in combination with lifestyle changes
- Can be used to lower the pneumatic splinting pressure (PAP) necessary for elimination of respiratory events

Outcomes of surgery best evaluated using both PSG & non-PSG metrics

Setting realistic expectations is CRITICAL
Surgical Algorithm

- Surgery is site specific
- Soft tissue
  - Ablative
  - Tissue Rearrangement or suspension
  - Functional ElectroStimulation (pending FDA approval)
- Skeletal
  - Advancement/Orthognathic
  - Distraction Osteogenesis (primarily pediatric)
- Preoperative counseling is crucial--surgical treatment is often a staged process
The Surgical “Cure” to OSA

- Tracheotomy
  - Last resort
  - Bypasses all upper airway obstruction
  - Requires significant acclimation
  - Is compatible with normal speech and swallowing
  - Reversible
What Place Does Surgical Treatment Have in the Treatment of OSA

- When obvious obstruction exists
- When CPAP not successful (salvage)
- Site specific anatomic obstruction
- Often in stages
- As an adjunct to other treatments
- Expectations must be realistic for both surgeon and patient
Summary

- OSA is unique to people and related to the complex functions of the UADT
- Elaborate control mechanisms have evolved in people to maintain these numerous functions
- Pathophysiology of OSA is diverse and complex
- The approach to the OSA patient must reflect this complexity
- Surgical options range from soft tissue ablation and skeletal restructuring to tracheotomy
- Functional electrostimulation is a novel and promising surgical approach