An update on the mechanics of human voice production and control

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Toward a cause-effect understanding of voice production

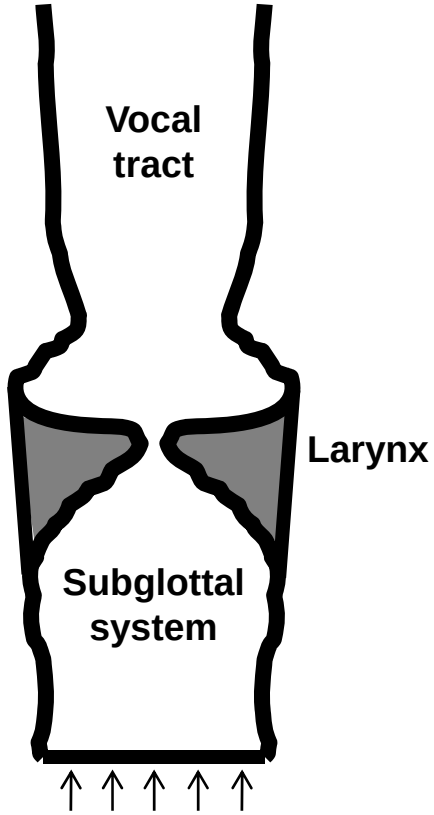
- If a change to the voice production system occurs, how does it affect the produced voice?
- When voice changes, what physiological alteration caused this change?

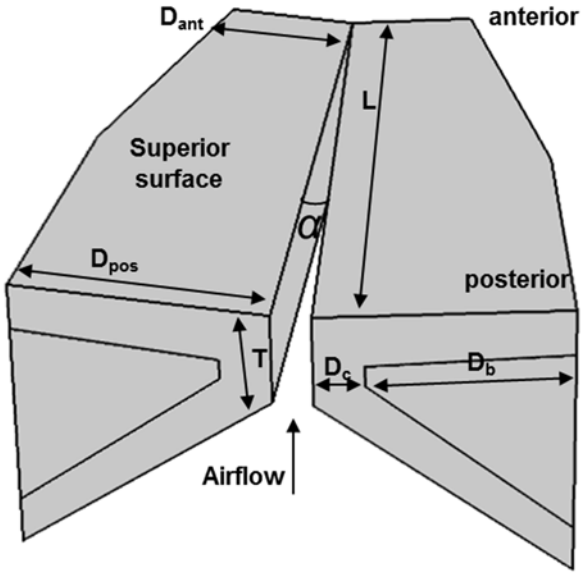
Challenges in establishing causal understanding in human and animal models

- Difficult to reliably control and measure vocal fold geometry and stiffness.
- Geometry and stiffness often co-vary
  - Unable to isolate effects of individual controls.
- Correlation, not causation

Computational modeling

allows changing one parameter at a time, thus causal investigation

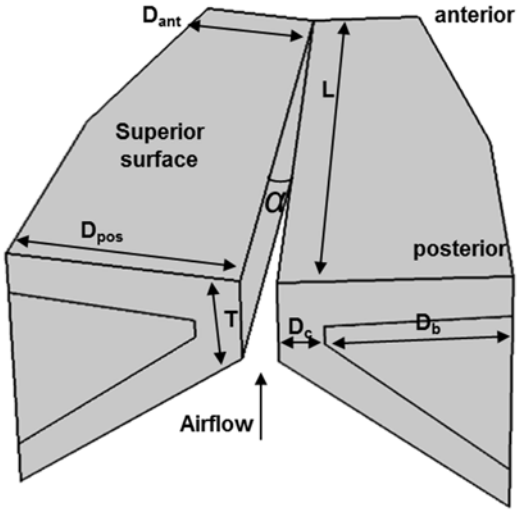




Zhang, JASA, 2015, 2016, 2017.

Simulations with parametric variations in the following:

- Vocal fold geometry
  - Length (front-back)
  - Width (left-right)
  - Thickness (up-down)
- Vocal fold approximation (glottal gap)
  - Glottal angle α
- Vocal fold stiffness (body and cover layers)
  - Longitudinal stiffness (front-back)
  - transverse stiffness in the coronal plane
- Subglottal pressure
- Vocal tract shape



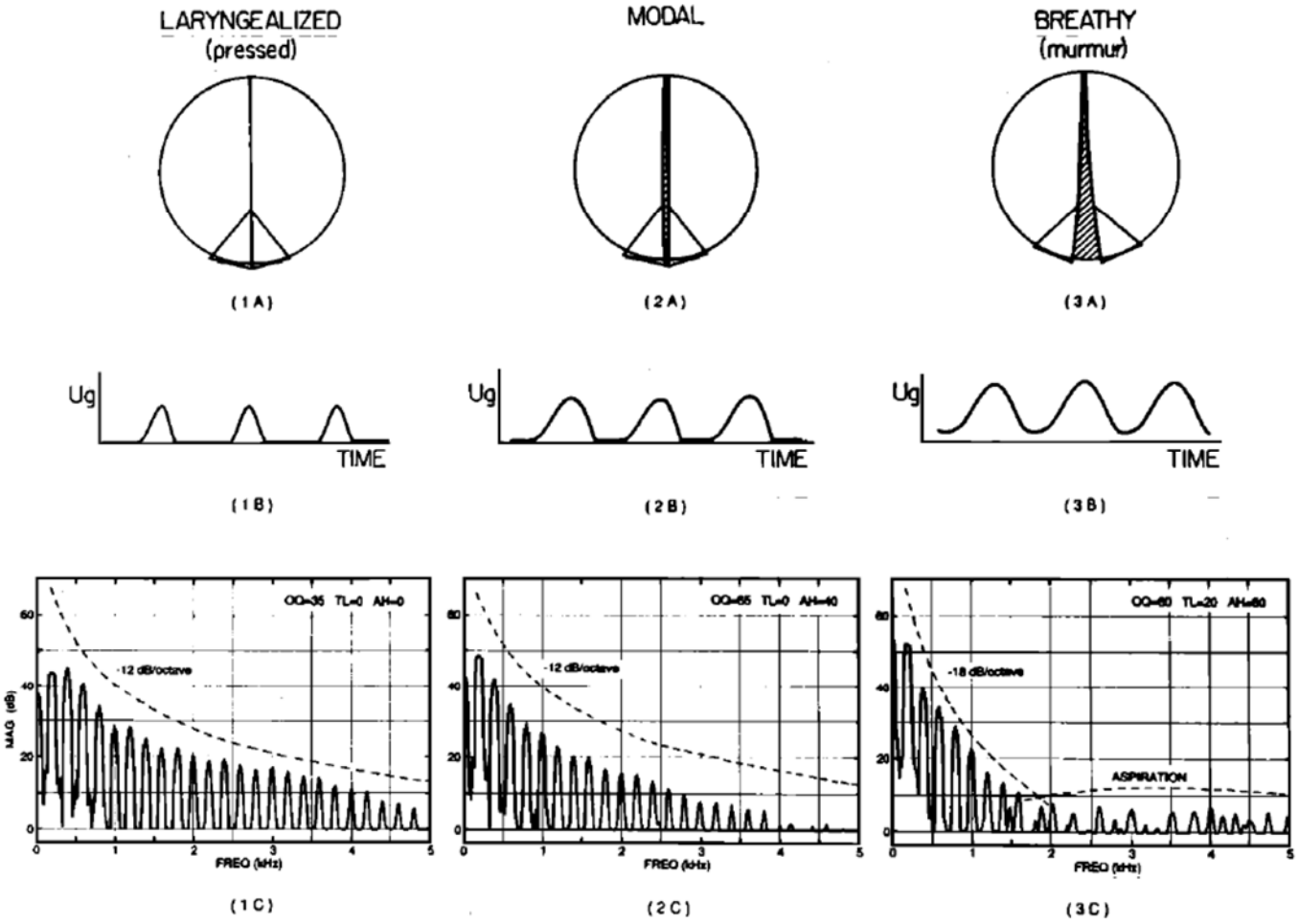
A total of ~300,000 conditions so far

How changes in controls affect the following

- Vocal fold vibration (Zhang, 2016, 2017, 2021, JASA)
  - glottal area amplitude, minimal glottal area, closed quotient
- Aerodynamics (Zhang, 2016, 2017, 2021, JASA)
  - Mean flow, peak-to-peak flow, MFDR, NAQ
- Acoustics (Zhang, 2016, 2017, 2021, JASA)
  - F0, intensity, and spectral shape
- Voice types (Zhang, 2018, JASA)
  - types 1-3; modal, subharmonics, chaotic, creak)
- Contact pressure during collision (Zhang, 2019, 2020, 2021, JASA)

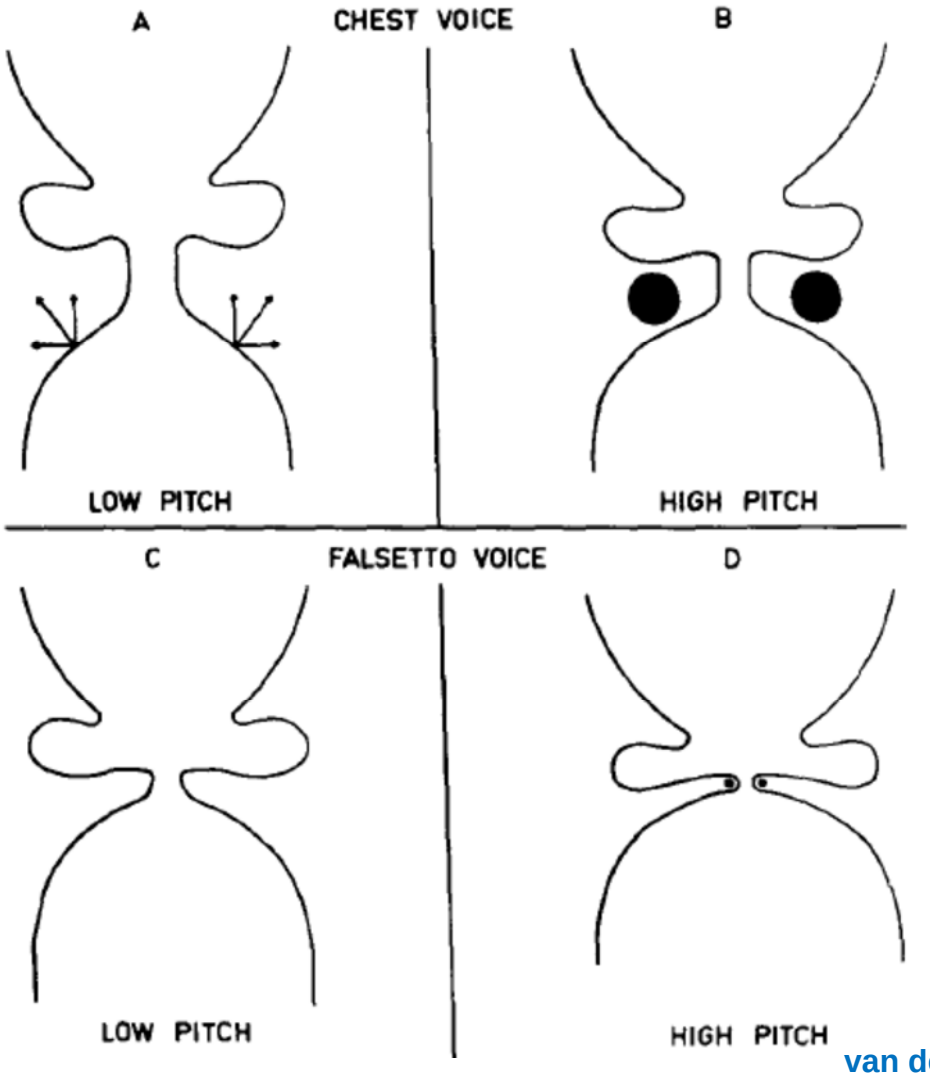
- Regulation of the glottal closure pattern
  - closed quotient, closing quotient
  - spectral shape
- The role of vocal fold medial surface shape in the vertical dimension

Current research and clinical intervention often focus on glottal closure in a 2D plane viewed from above



Klatt & Klatt, 1990, JASA, 87, 820-856.

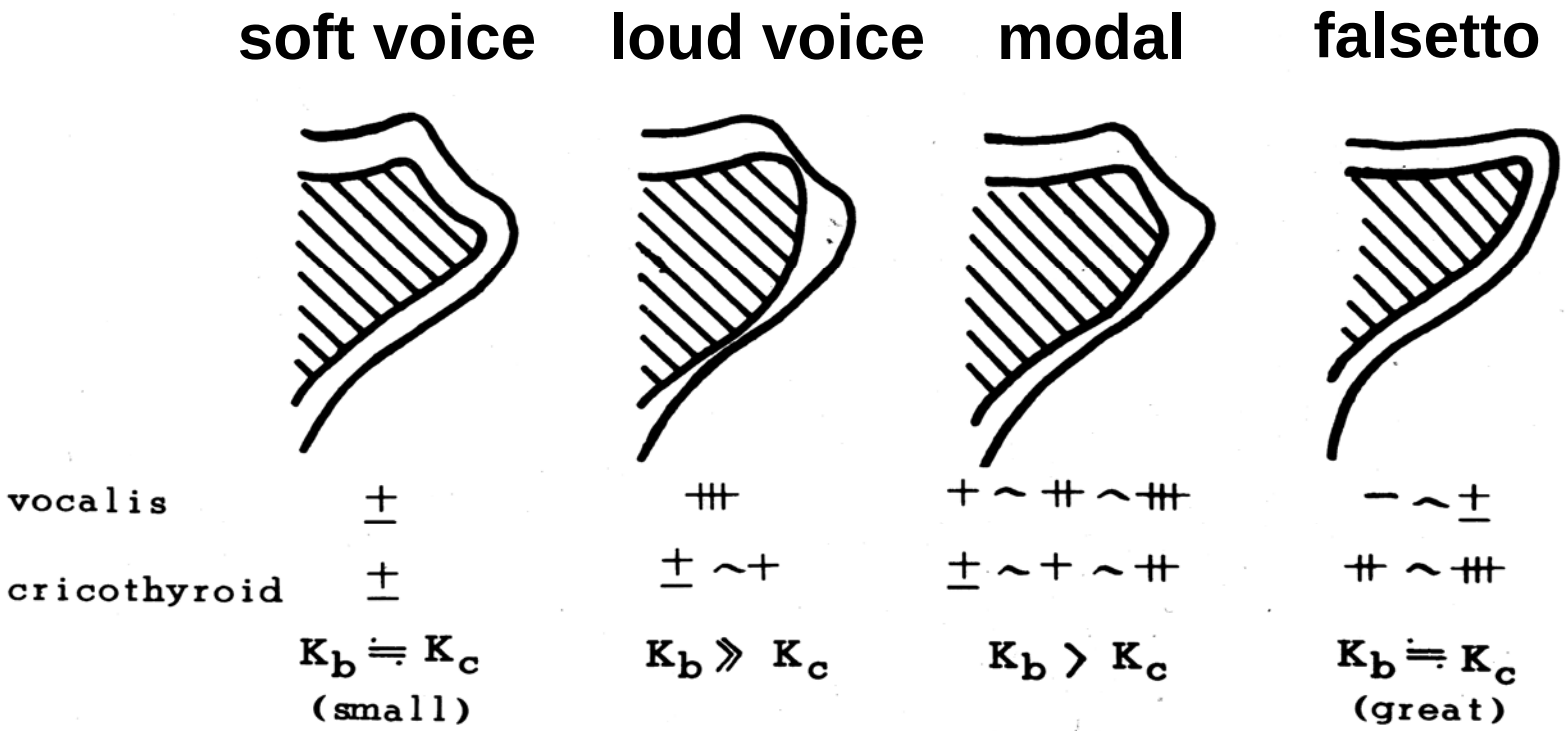
Effects of medial surface vertical thickness (van den Berg, 1968)



- Thick folds : Chest
- Thin folds: Falsetto

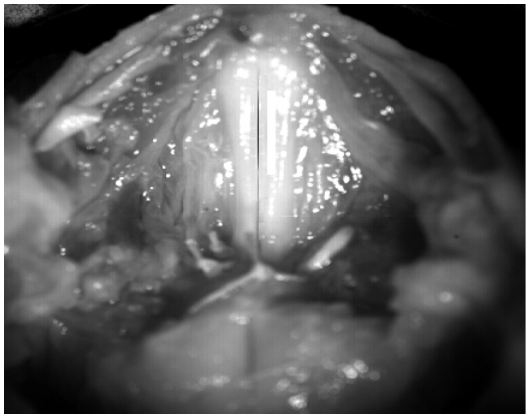
van den Berg, 1968, Ann. N.Y. Acad. Sci., 155, 129-134.

Four laryngeal adjustments of Hirano (1974)

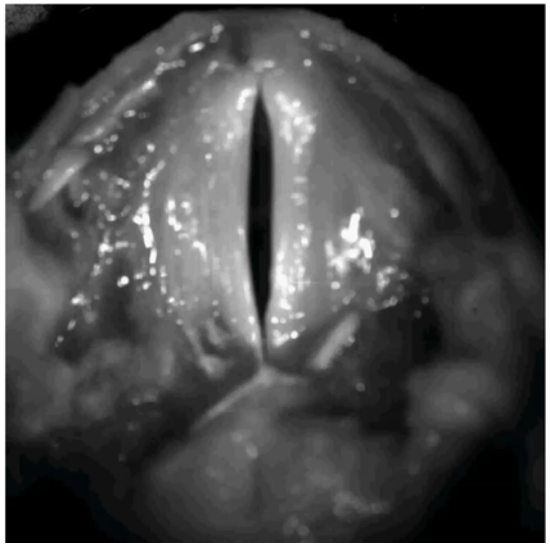


Is the difference in stiffness or thickness?

Hirano, 1974, Folia Phoniatr. 26, 89-94.



At rest



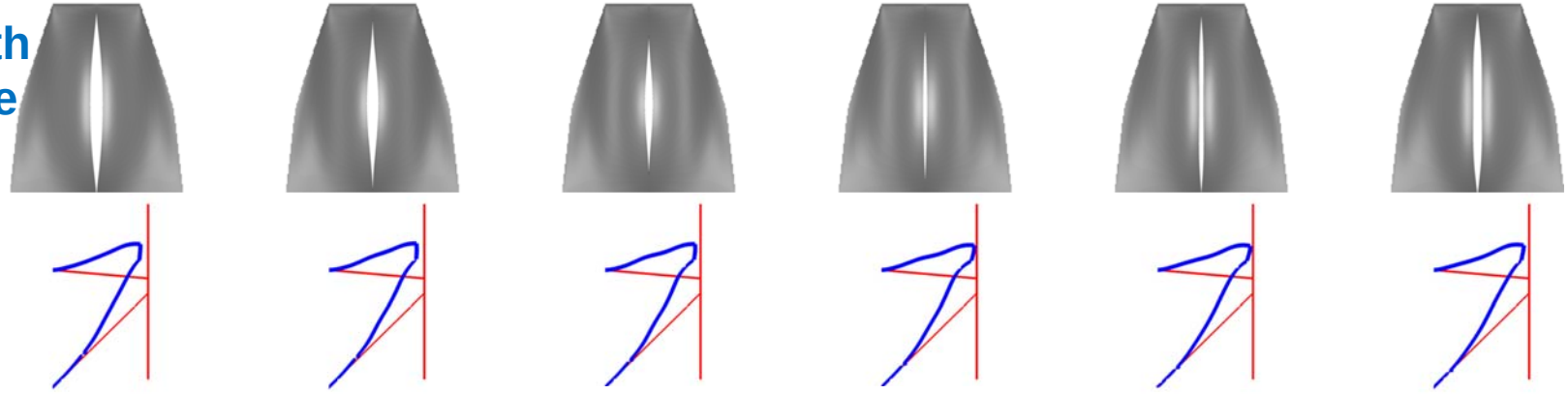
With airflow

Vocal fold approximation is a necessary condition, but insufficient to guarantee complete glottal closure during phonation.

Vocal folds have to be sufficiently thick to achieve glottal closure during phonation

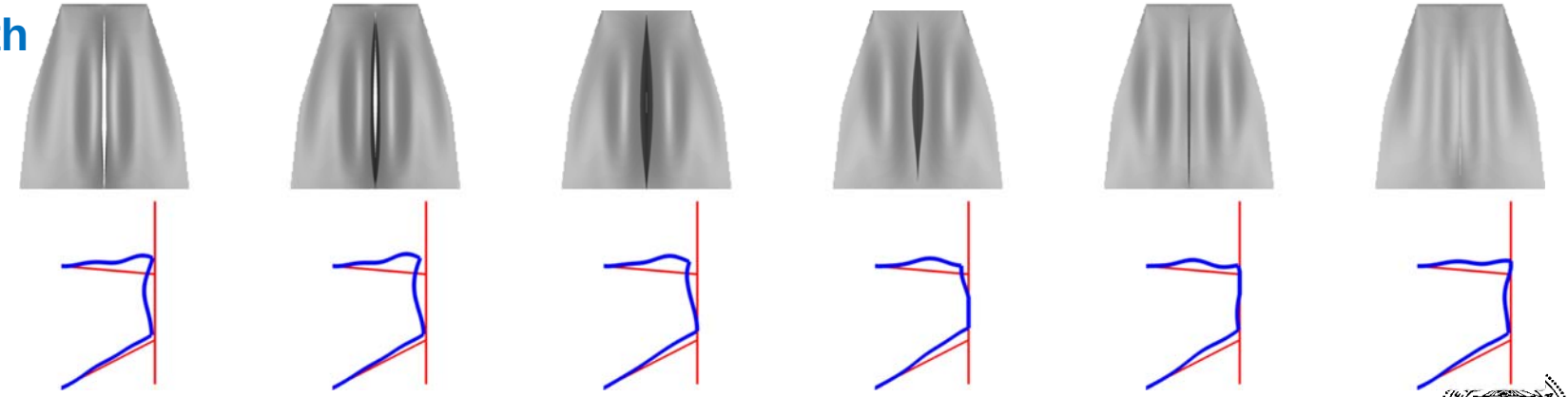
Thin folds vibrate with incomplete closure

Thin folds (T=1mm)



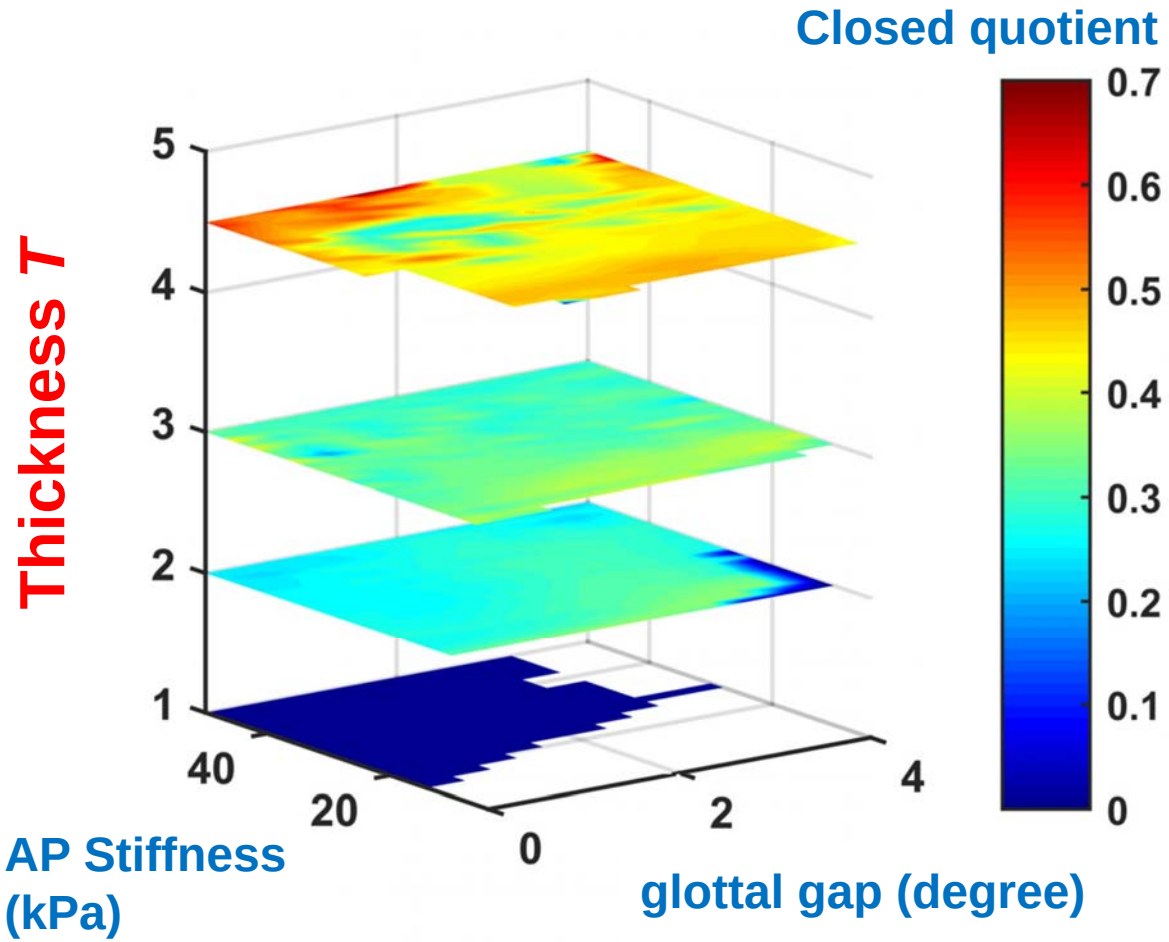
Thick folds vibrate with complete closure

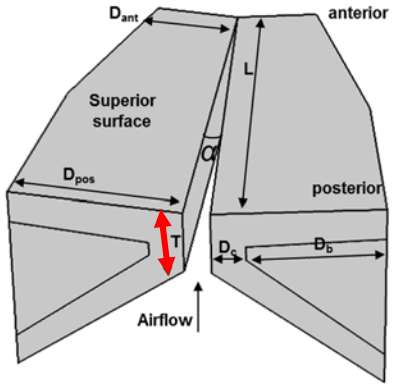
Thick folds (T=4.5mm)



Zhang, 2016, JASA, 139, 1493-1507.

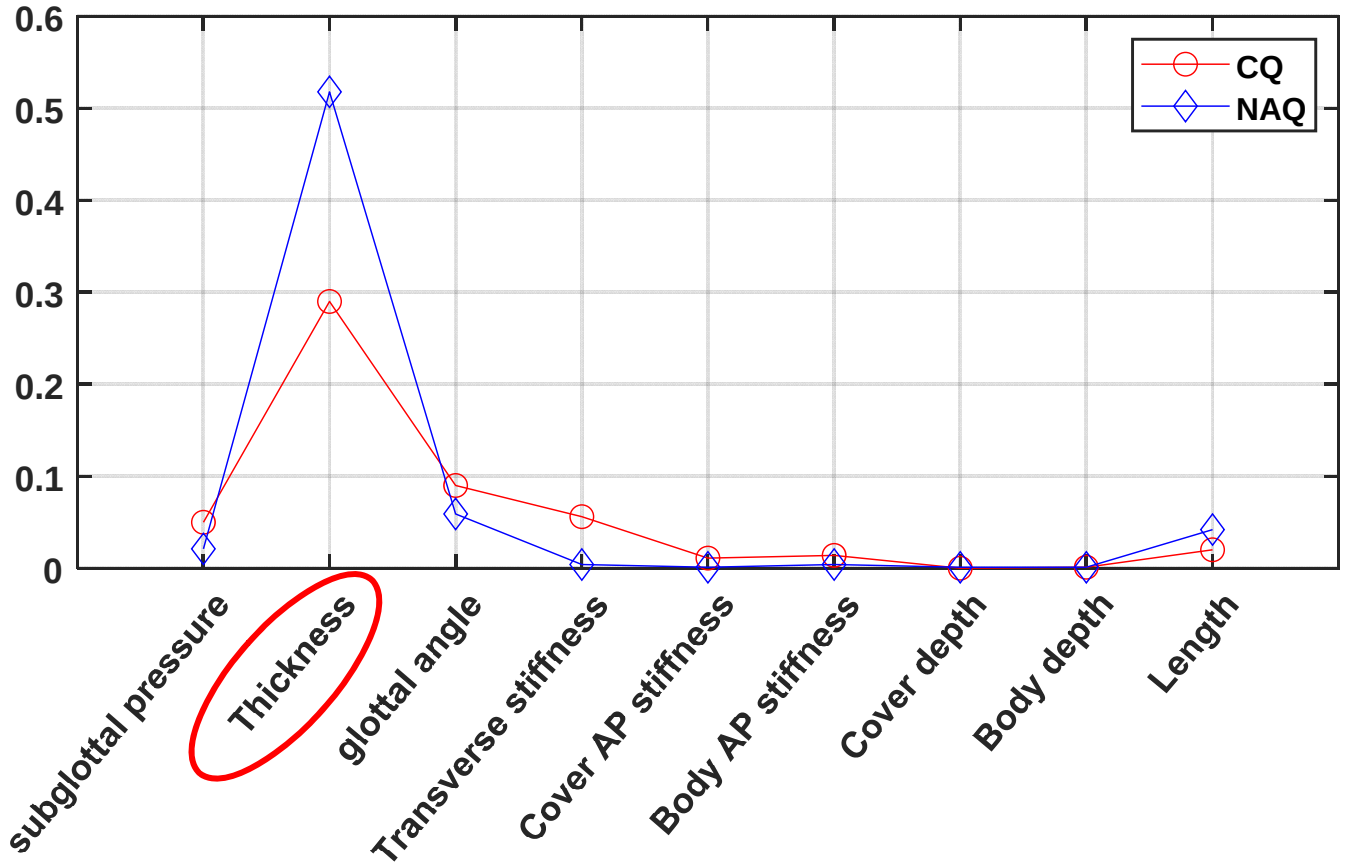
Medial surface thickness determines the duration of glottal closure during phonation





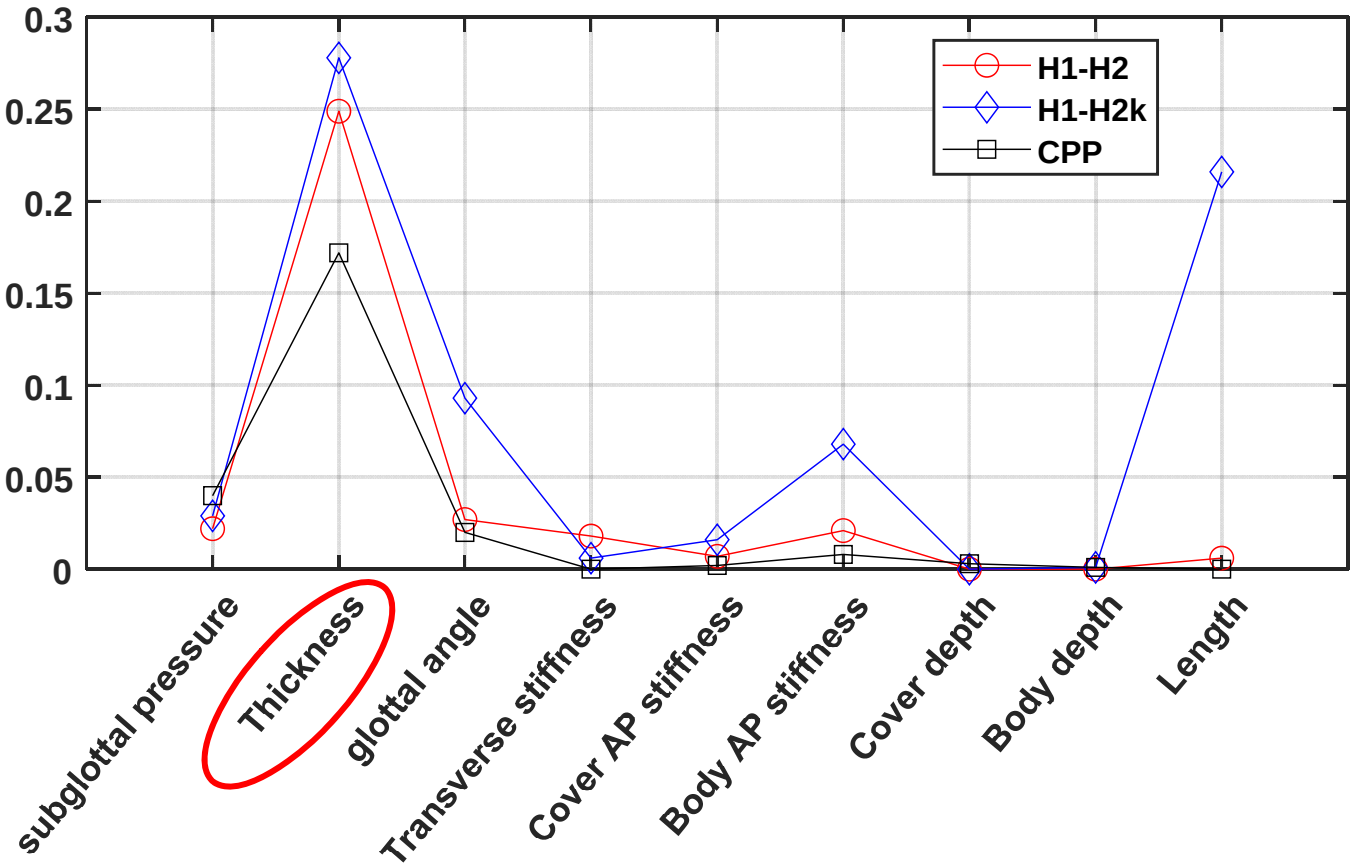
Zhang, 2016, JASA, 139, 1493-1507.

Effect sizes of physiological controls on glottal closure



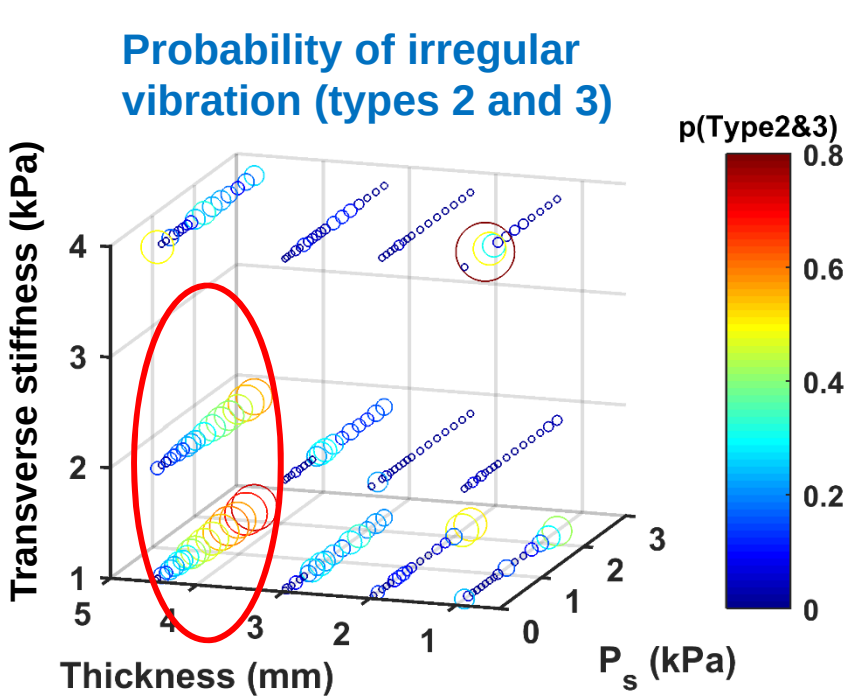
Zhang, 2021, JASA, 150(6), 4511-4521.

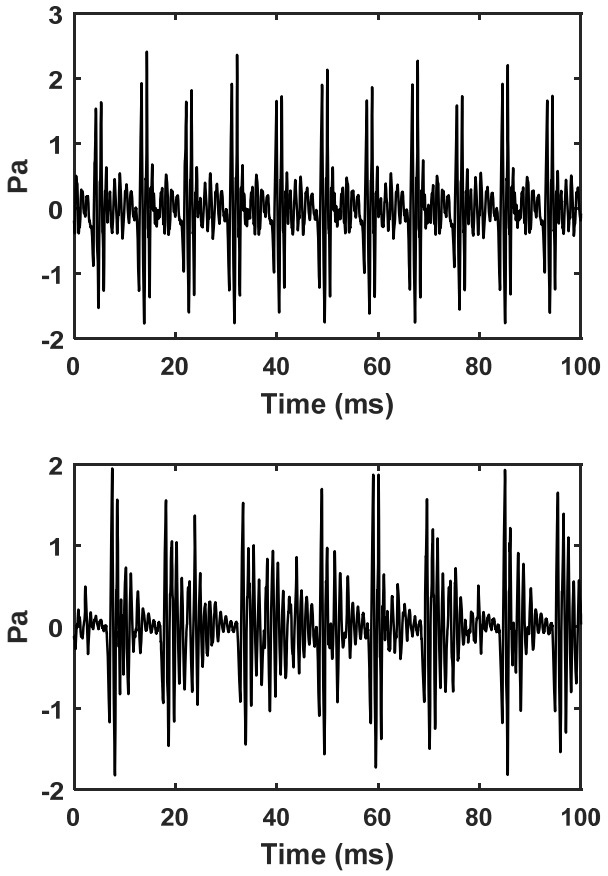
Effect sizes of physiological controls on spectral shape



Zhang, 2021, JASA, 150(6), 4511-4521.

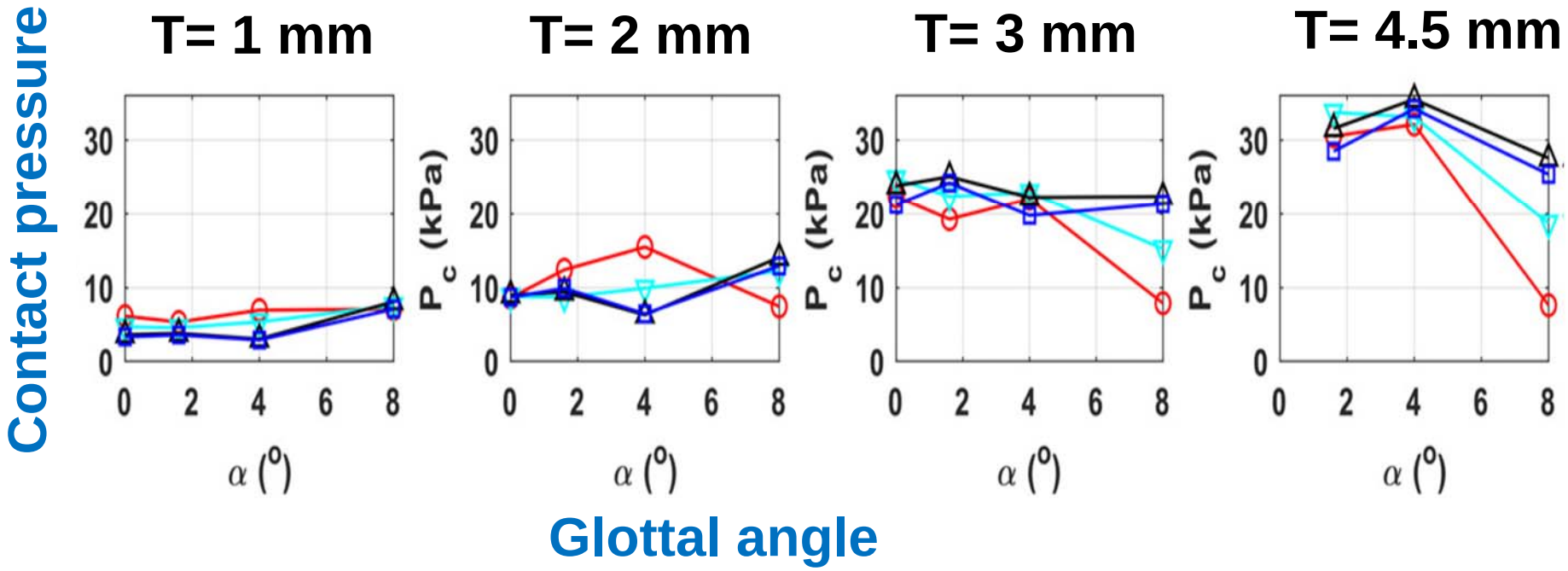
When too thick and too soft, vocal folds are more likely to exhibit irregular vibration (subharmonic or chaotic)





Zhang, 2018, JASA, 144, 1216-1230.

Thicker vocal folds experience higher vocal fold contact pressure and higher risk of injury



Vertical dimension matters

Thickness

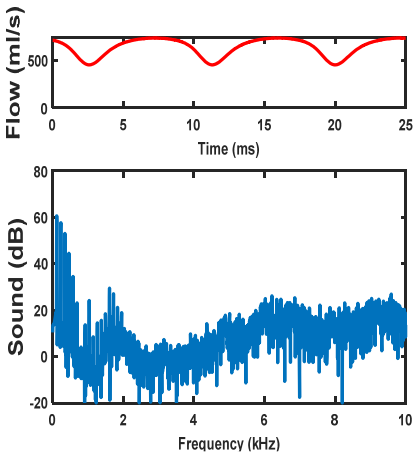
Too small: **conversational** **Too large:**

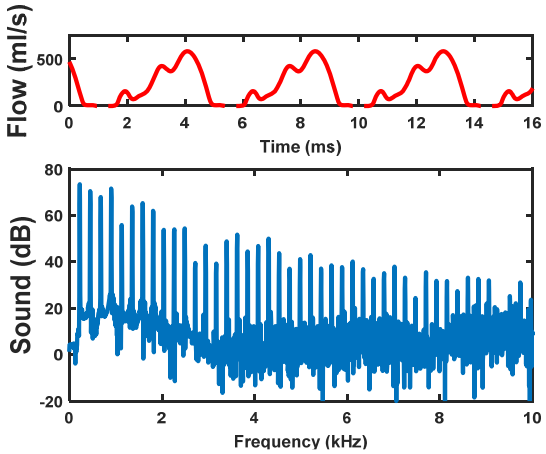
Hypo-adduction

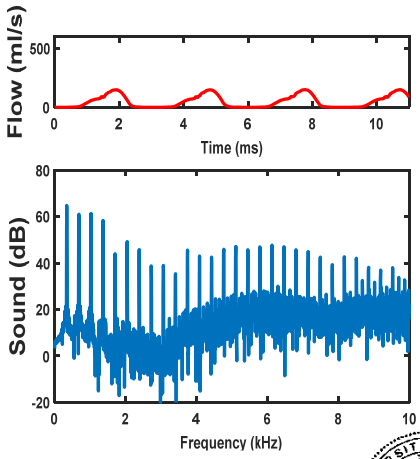
- **Incomplete closure**
- **High airflow consumption**
- **Smooth airflow waveform**
- **High H1-H2**
- **Weak harmonics**

Hyper-adduction:

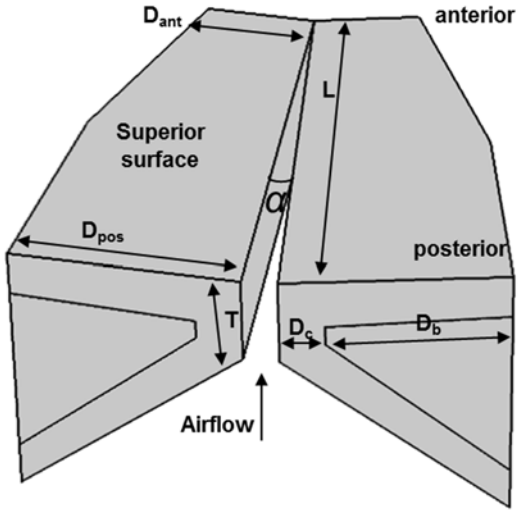
- **Long glottal closure**
- **Low airflow usage**
- **Skewed airflow waveform**
- **Low H1-H2**
- **Strong harmonics**
- **Irregular vibration**
- **High risk of injury**

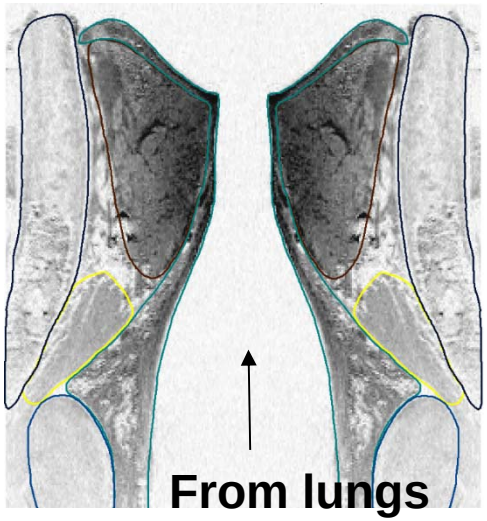




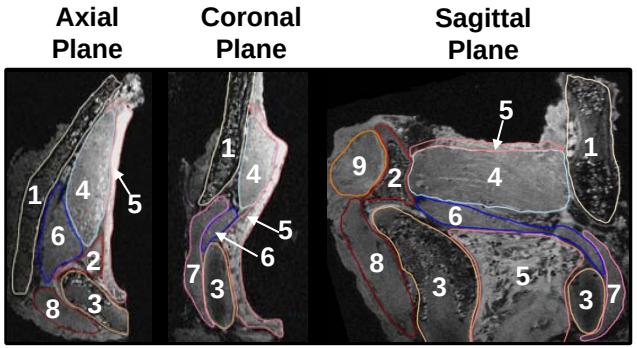


Does the same observation apply to vocal folds with realistic geometry?

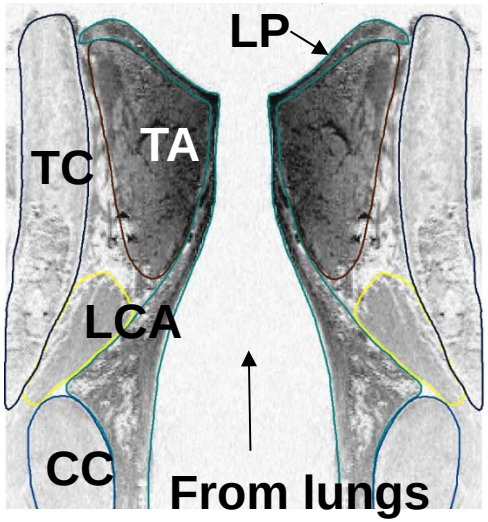


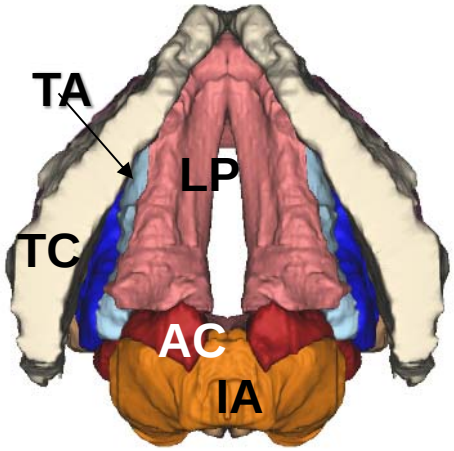


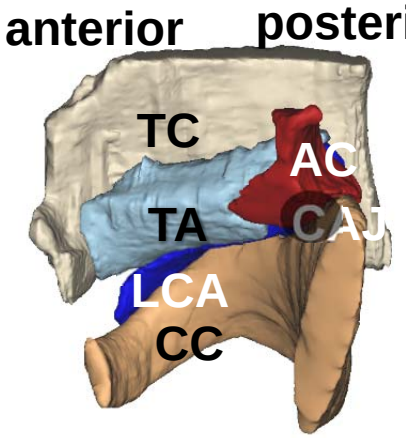
MRI of the 3D human larynx

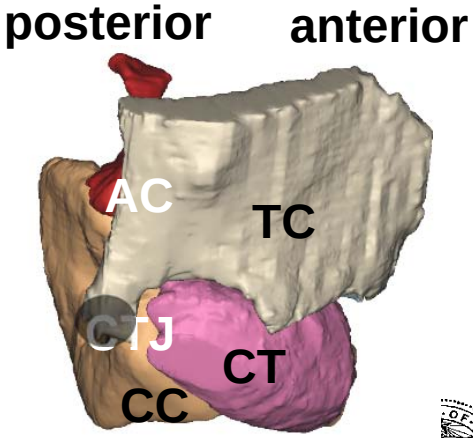


1 – Thyroid Cartilage; 2 – Arytenoid Cartilage;
3 – Crycoid Cartilage; 4 – Thyroarytenoid (TA) muscle;
5 – Cover layer (lamina propria & epithelium);
6 – Lateral cricoarytenoid (LCA) muscle;
7 – Cricothyroid (CT) muscle;
8 – Posterior cricoarytenoid (PCA) muscle;
9 – Interarytenoid (IA) muscle.

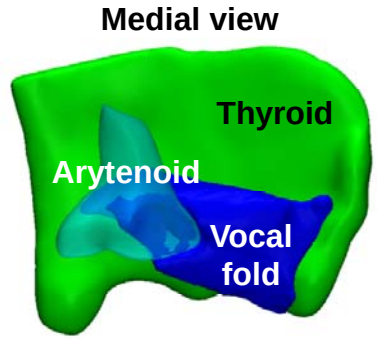


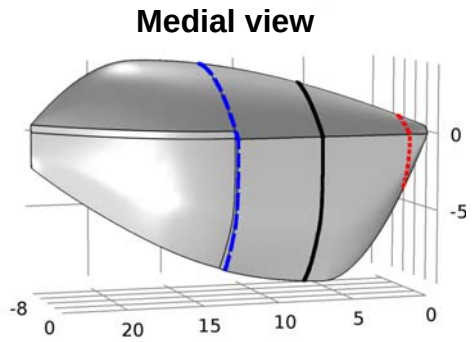


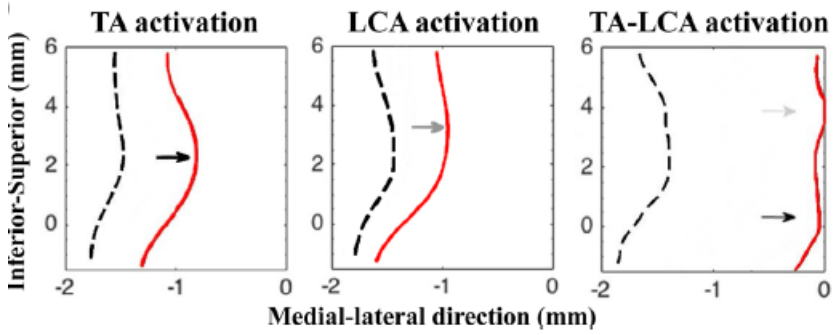


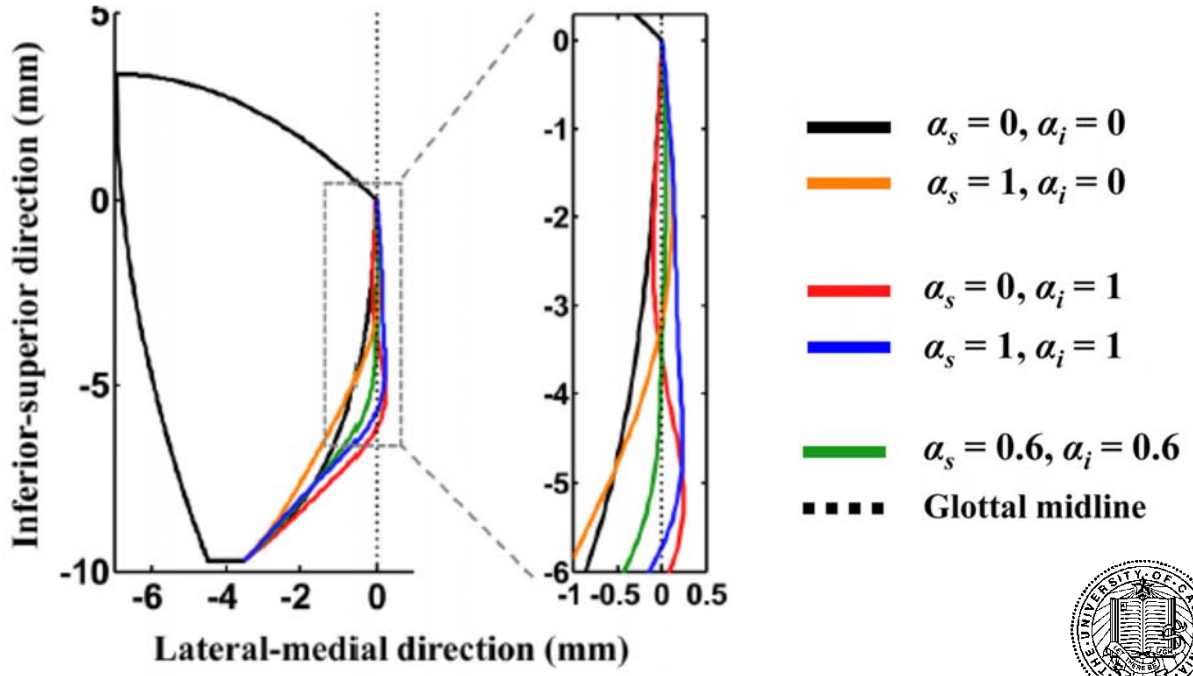


Effect of medial surface shape on phonation

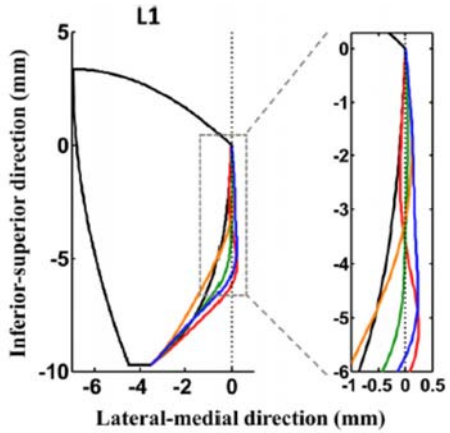




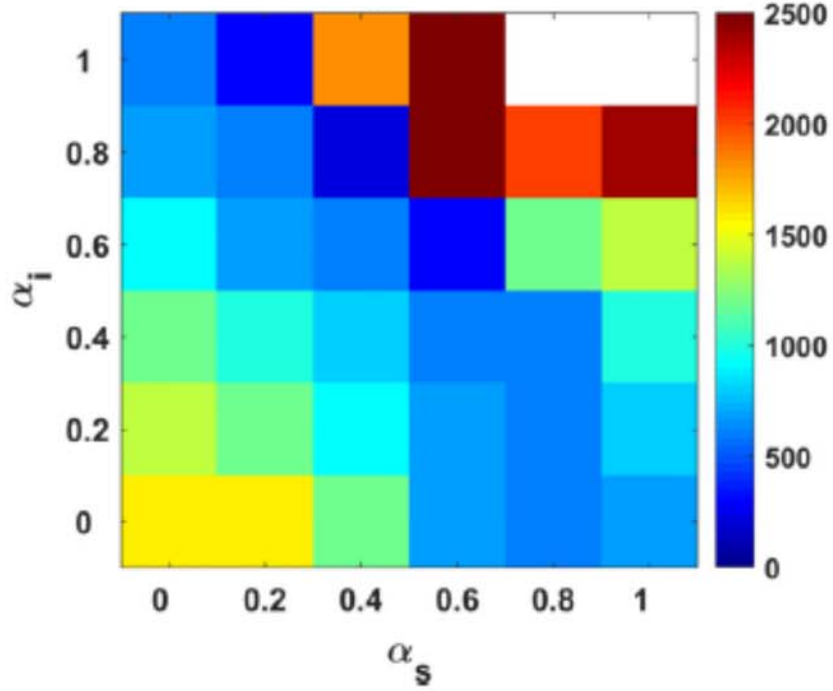




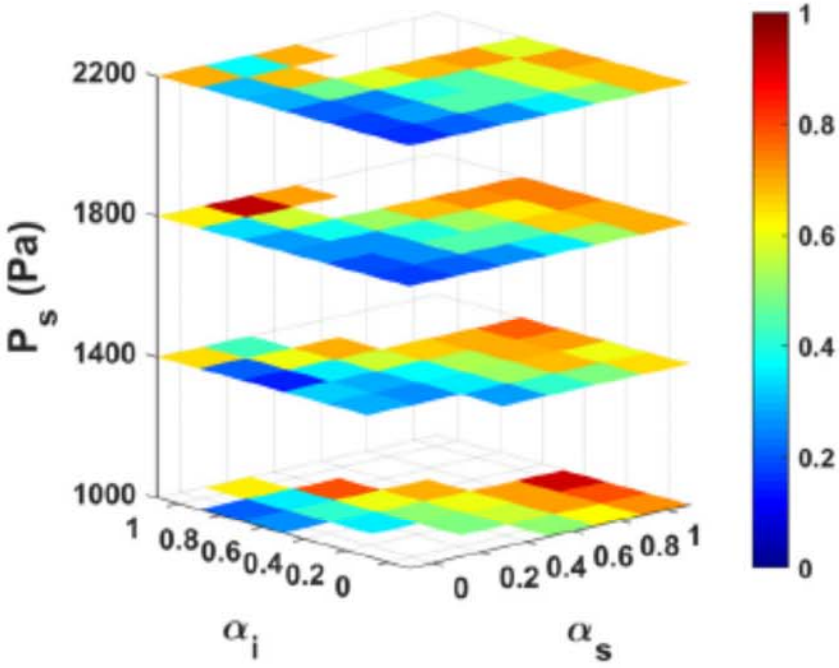
Effect of medial surface shape on phonation



Phonation onset pressure (Pa)



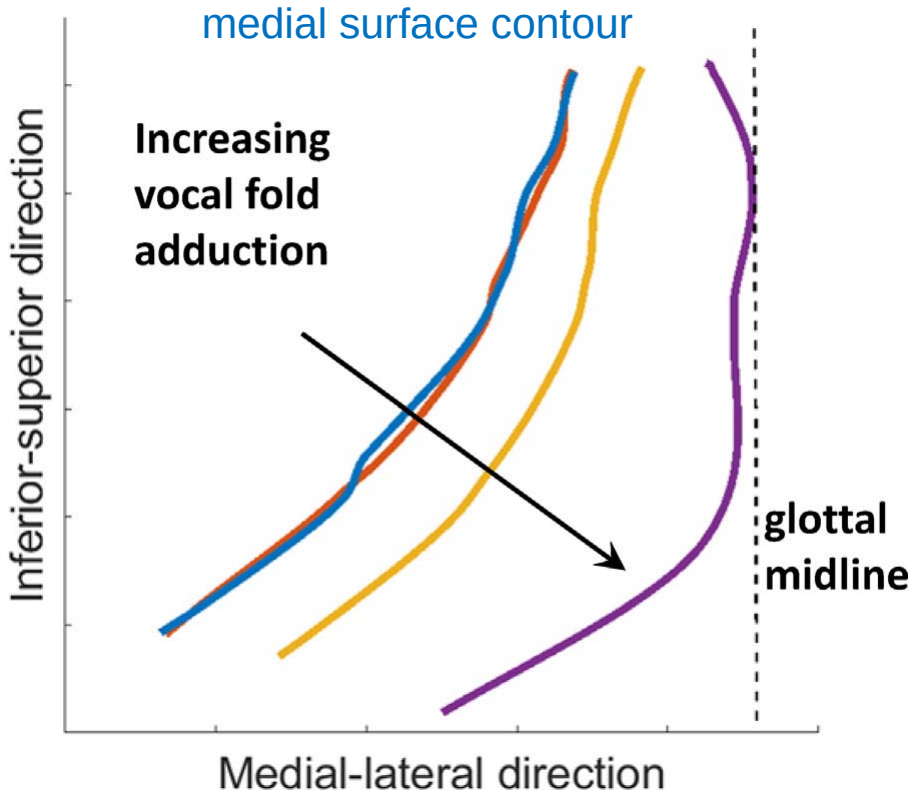
Closed quotient



Implications for voice research

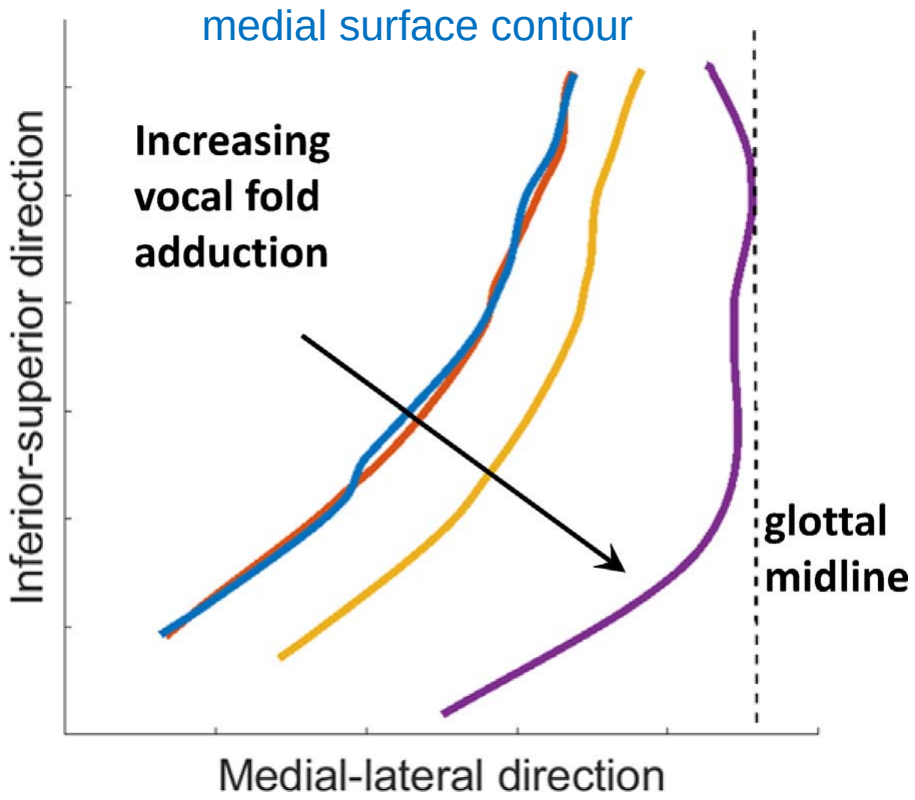
- In addition to the superior view, voice research should pay more attention on shape changes in the vertical dimension.

Vocal fold adduction=approximation + thickening



- Vocal fold adduction not only medializes the vocal folds, but also changes medial surface shape
- Hypo- and hyper-adduction should be differentiated by both the glottal gap and thickness
  - hypo-adduction: too thin
  - hyper-adduction: too thick

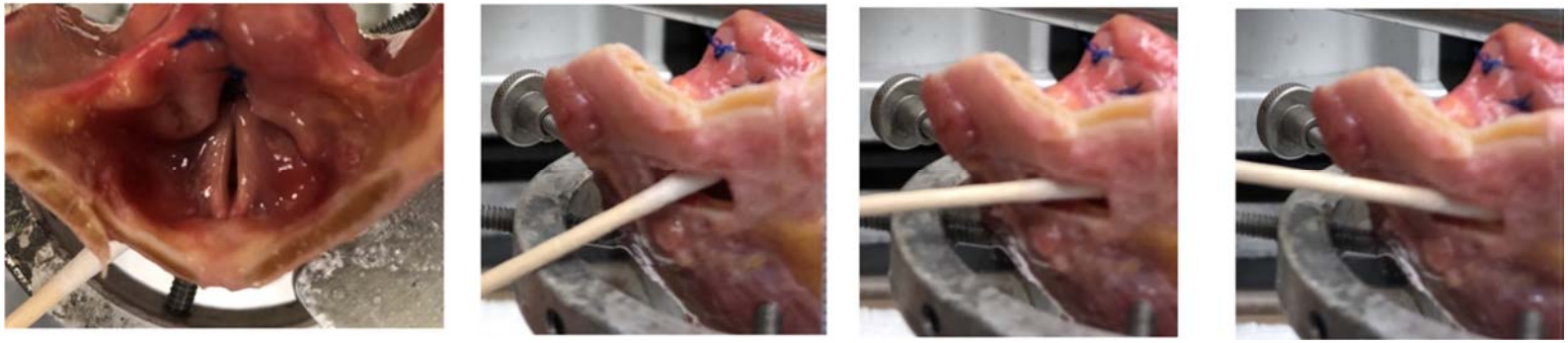
Implication for medialization surgery

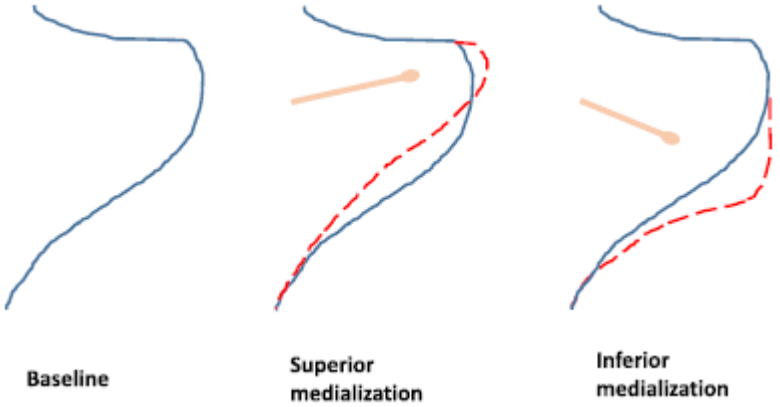


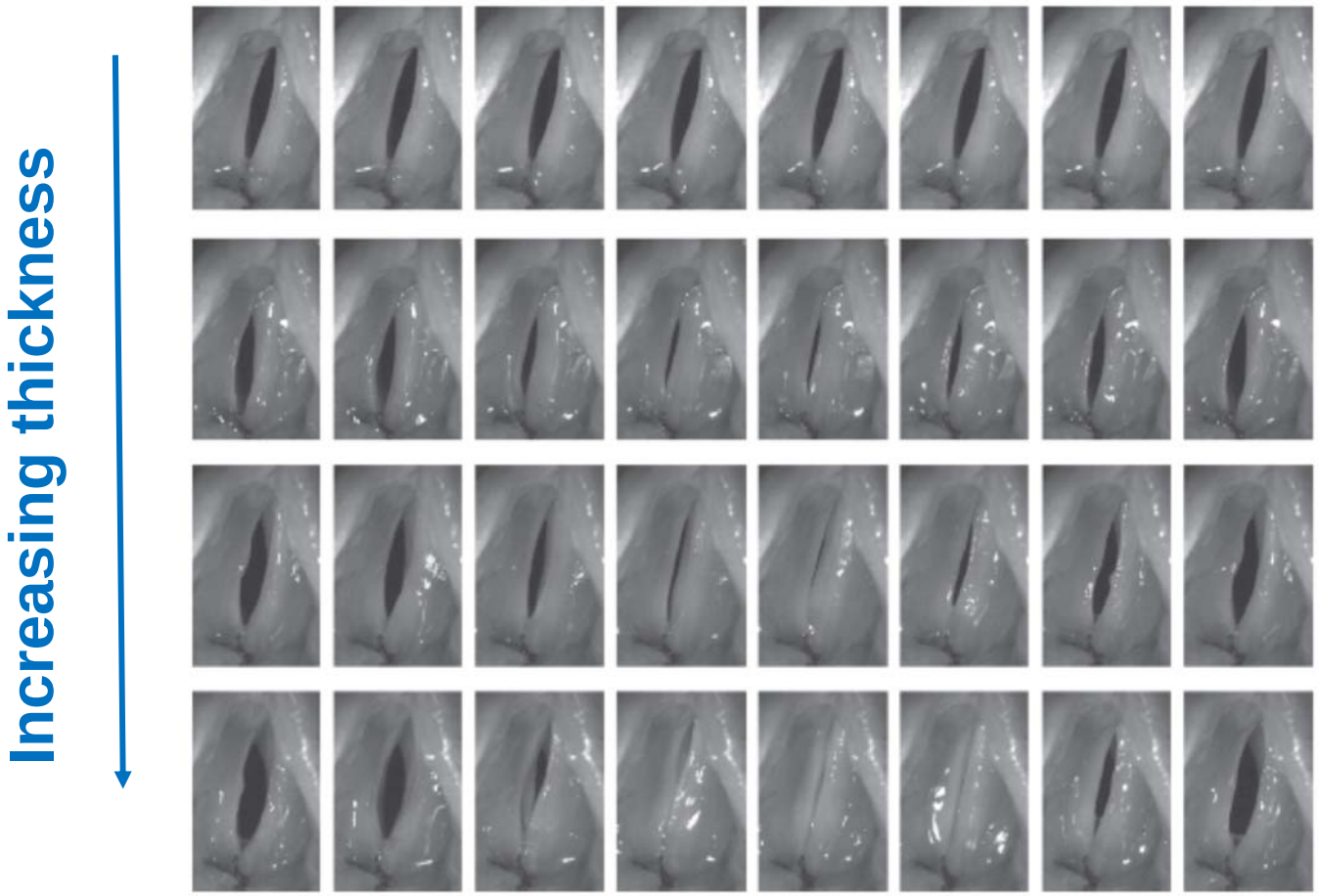
- Needs to both medialize vocal folds and restore optimal medial surface shape

Zhang, Z. Contribution of undesired medial surface shape to suboptimal voice outcome after medialization laryngoplasty, J. Voice, in press.

Experimental validation in excised human larynx

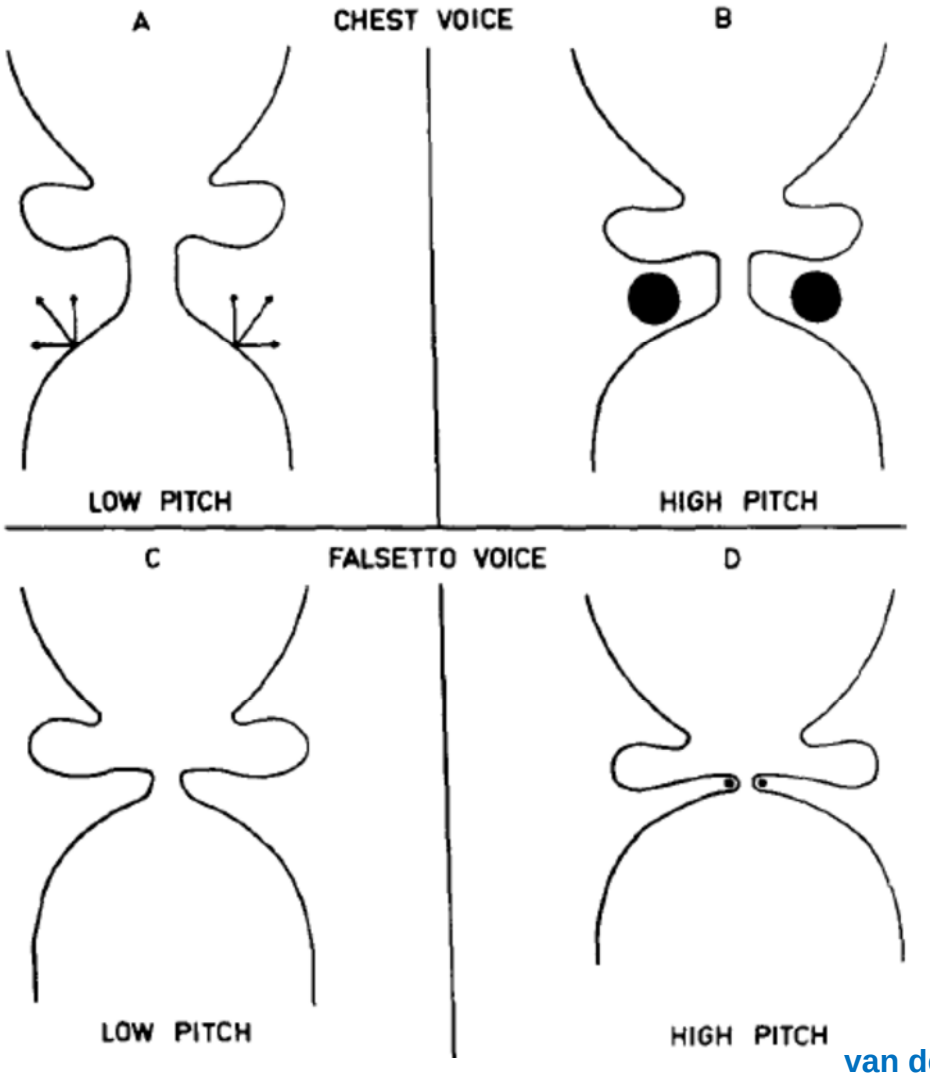






Even if the vocal folds appear to be sufficiently medialized when viewed from above, the glottal closure pattern can vary significantly, depending on medial surface shape.

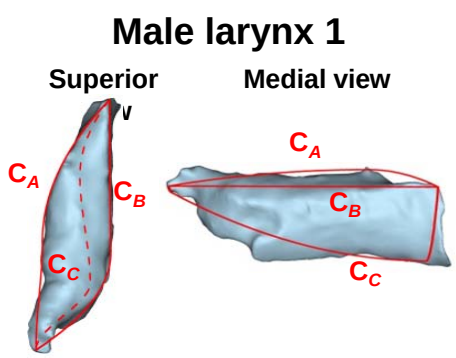
Registers: a thickness effect

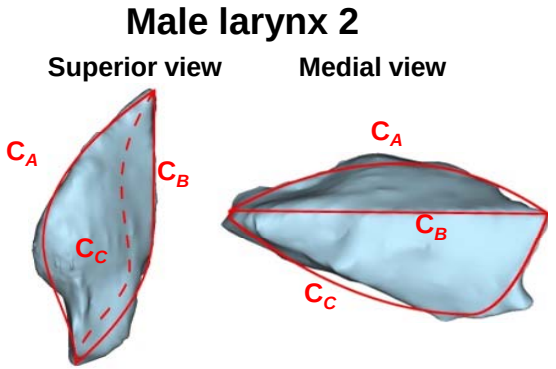


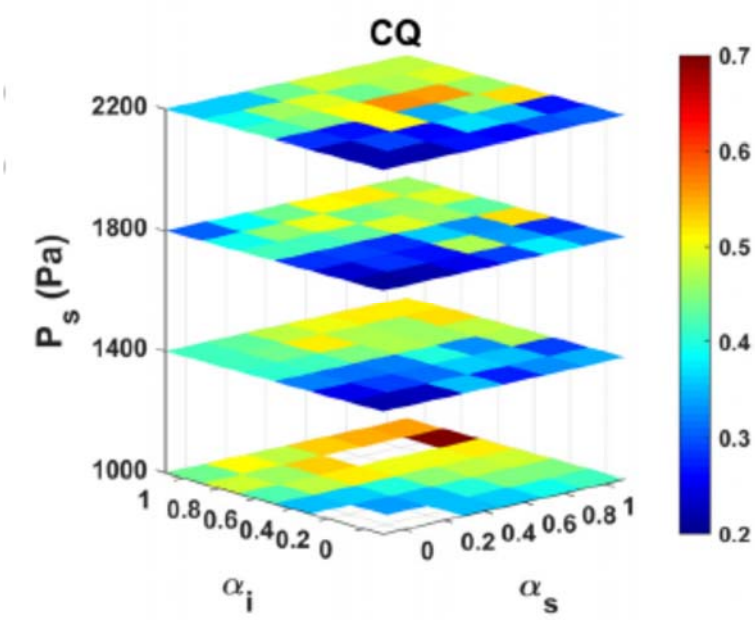
- Thickness plays an important role.
- Because thickness co-varies with stiffness, registers will co-vary with pitch:
  - low registers: thick, short, and soft folds at low pitches
  - High registers: thin, long, and stiff folds at high pitches

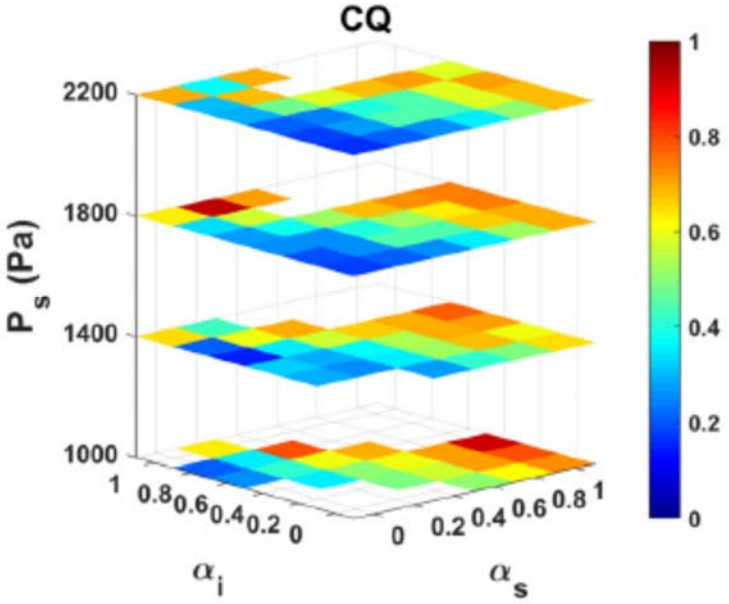
van den Berg, 1968, Ann. N.Y. Acad. Sci., 155, 129-134.

Each larynx is different!









The resting medial surface shape at least partially determines individual speakers' vocal range or capabilities.

Male-female differences

- Length difference explains male-female differences in F0, vocal efficiency, airflow consumption.
  - F0, flow rate, vibration amplitude, SPL
- Thickness difference explains male-female differences in closure pattern (CQ, NAQ) and spectral shape measures.
  - moderate contribution to F0.
- Reducing vocal fold thickness in a male larynx produces a more female-sounding voice.
  - Transgender voice care may benefit from consideration of thickness manipulation.

Zhang, 2021, JASA, 150(6), 4511-4521.

Thank you!