Integrating respiration and deglutition: Function, disorders & treatment

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Research Collaborators

Support and Disclosures

- NIH/NIDCD K24, Research and Mentoring on Swallowing Impairment and Respiratory-Swallow Coordination, 2013-2018
- NIH/NIDCD R01, Standardization of Swallowing Assessment in Bottle-fed Children, 2010-2016
- Mark and Evelyn Trammell Trust, 1993 – 2019
- VA RR&D, Respiratory Phase Training in Dysphagic Veterans with Oropharyngeal Cancer, 2010 – 2013
- Northern Speech Services, 2010 – present
- Medtronic, 2013 – present

Anatomic and Functional System Overlap

- Respiratory
- Digestive
- Phonatory

COPD

- Emphysema
- Bronchitis

Physiologic Impairment

- Lingual motility
Physiologic Impairment

- Labored mastication

Physiologic Impairment

- Delayed initiation of the pharyngeal swallow
- Delayed laryngeal vestibular closure

Physiologic Impairment

- Low resting position of the larynx

Physiologic Impairment

- Delayed and decreased laryngeal vestibular closure (early)
  - Arytenoid to epiglottic base compression

Physiologic Impairment

- Incomplete laryngeal vestibular closure (height of swallow)

Physiologic Impairment

- Superior-anterior hyoid excursion
**Physiologic Impairment**

- **Pharyngoesophageal segment opening (PESO/UES)**

**Normal Pharyngeal Stripping**

- Normal pharyngeal stripping

**Physiologic Impairment**

- Delayed initiation of pharyngeal swallow
- Decreased anterior hyoid displacement
- Decreased tongue base retraction
- Incomplete laryngeal vestibular closure

**Physiologic Impairment**

- Distended pharynges
- Weakness
- Penetration

**Impaired Pharyngeal Stripping Wave**

- Pharyngeal stripping

**Physiologic Impairment**

- Esophageal clearance
Respiratory-Swallow Coordination

- N = 13
- Experimental: Group 1 (n = 6)
  - All males (mean age: 23 years; range: 17 – 32)
- Control: Group 2 (n = 7)
  - 4 males, 3 females (mean age: 21 years; range: 17 – 30)
- Fiberoptic endoscopy, Respiratory recording, and EMG
- 4 swallows (3 trials each)
  - 3, 10, and 20 ml of water via syringe
  - 100 ml of water via straw

Respiratory-Phase Relationship

- Major findings
  - Each swallow characterized by consistent, brief and easily distinguishable break in respiration
  -Expiration was the phase associated with swallow-induced cessation (“deglutition apnea”)
  - Respiratory and swallowing events occurred in a consistent and well-time pattern
  - Straw swallows resulted in prolongation of respiratory cessation
  - Higher occurrence of post-swallow inspiration

"The respiratory glottic configuration appears to reach a set point, in that the undulating glottis usually fixes in an intermediate or paramedian expiratory position until just prior to the onset of laryngeal elevation."

~ Martin-Harris (1991)
Breathing and swallowing dynamics across the lifespan.


Breathing and Swallowing across Lifespan

- N = 76
- 5, 10, 15-ml liquid bolus
- Major findings
  - 4 respiratory-phase patterns identified
  - Predominant pattern was swallowing occurring in a pause during the expiratory phase of respiration
  - Significant difference found in mean age between respiratory phases

Fig. 1. Example of simultaneous videofluoroscopy (A) and respiratory trace data (B) as seen on the Kay Digital Swallowing Workstation (model 7100, Kay Elemetrics, Lincoln Park, MI). The green portion of the tracing represents expiration and the red portion represents inspiration. The black portion of the line along the abscissa indicates no air movement or apnea.
Swallowing and Respiration in Sequential Swallows

- N = 70
- 29 males, 41 females
- Age range: 23 – 91
- 50-ml liquid
- Sequential swallows from cup

Swallowing and Respiration in Sequential Swallows

- Main findings
  - Mean number of swallows: 4.35
  - Mean number of ingestion cycle (IC): 3.28
  - Higher ingestion cycles in individuals whose larynx was always open after each swallow

| TABLE 1. Respiratory Phases Before and After First Ingestion Cycle Compared With Single 5 mL Swallow Results |
|-------------------------------------------------|--------|--------|--------|
| Before first ingestion: 50 mL                   | Exhale| inhale| Exhale| inhale|
| E1/hale                                        | 31    | 44%   | 77%   | 39    | 56%   | 23%   |
| After first ingestion: 50 mL                    | E1/hale| inhale| E1/hale| inhale|
| 50                                             | 50    | 79%   | 93%   | 15    | 21%   | 7%    |
Subjects

- 20 normal, healthy volunteers (M=10, F=10)
- Average age = 36 years, range = 26 to 75 years
- Exclusion criteria:
  - No known history of disorders of the masticatory, respiratory, or swallowing systems, medical conditions or medication use affecting swallowing or breathing, previous surgery altering airway passages, pulmonary disorders or smoking

Methods

Variety of swallowing tasks:

<table>
<thead>
<tr>
<th>Sleep Condition</th>
<th>Vomiter/Reason</th>
<th>Method of Recovery</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Yes</td>
<td>Syringe for recovery</td>
<td>Un-cool</td>
</tr>
<tr>
<td>Water</td>
<td>No</td>
<td>Syringe for recovery</td>
<td>Cool</td>
</tr>
<tr>
<td>Water</td>
<td>No</td>
<td>Transpose for recovery</td>
<td>Cool</td>
</tr>
<tr>
<td>Water</td>
<td>Yes</td>
<td>No sedation, no self-administration</td>
<td>Un-cool</td>
</tr>
<tr>
<td>Water</td>
<td>Yes</td>
<td>No sedation, no self-administration</td>
<td>Cool</td>
</tr>
<tr>
<td>Water</td>
<td>Yes</td>
<td>Ice, chawing cap, no self-administration</td>
<td>Un-cool</td>
</tr>
<tr>
<td>Water</td>
<td>Yes</td>
<td>Ice, chawing cap, no self-administration</td>
<td>Cool</td>
</tr>
<tr>
<td>Water</td>
<td>No</td>
<td>Sedentary, self administered</td>
<td>Un-cool</td>
</tr>
<tr>
<td>Water</td>
<td>No</td>
<td>Sedentary, self administered</td>
<td>Cool</td>
</tr>
<tr>
<td>Solid</td>
<td>Yes</td>
<td>Luma Dow, sedentary, unconscious</td>
<td>Un-cool</td>
</tr>
<tr>
<td>Solid</td>
<td>Yes</td>
<td>Luma Dow, sedentary, unconscious</td>
<td>Cool</td>
</tr>
<tr>
<td>Solid</td>
<td>No</td>
<td>Self-administered</td>
<td>Un-cool</td>
</tr>
</tbody>
</table>

Lung Volume at Swallow Initiation (LVSI)

- Mean LVSI across subjects and experimental tasks ranged from 254 ml (31% of vital capacity) for liquids and 117 ml (28% of vital capacity) for solids
- Swallows were initiated at mid to low quiet breathing lung volumes relative to REL
- Mean lung volume averaged across all experimental tasks was 226 ml.
Results

Mode of Delivery

- Five ml syringe swallows were initiated at significantly lower quiet breathing lung volumes when contrasted with 5 ml spoon presentations (mean syringe = 128 ml; p = 0.006).
- Average LVSI was significantly lower in 5 ml syringe swallows compared to 5 ml cup swallows (mean cup = 288 ml; p = 0.001).
- There was no significant difference in average LVSI comparing 5 ml spoon to cup swallows (p = 0.13).

Bolus Type

- Water swallows were initiated at significantly higher quiet breathing lung volumes compared to pudding swallows (mean water = 254 ml; p = 0.03).
- Average LVSI for water swallows was significantly higher compared to solid swallows (mean solid = 117 ml; p=0.003).
- There was no significant difference in average LVSI comparing pudding to solid swallows (p = 0.06).

System Overlap:
Cross System Interactions

- Most common pattern is for swallowing to occur during a pause in the expiratory phase of respiration at mid to late expiratory phase

Hypothesis:

- Important mechanical advantages to swallowing function
  - Facilitates superior/anterior hyoid and laryngeal
  - Laryngeal closure
  - Facilitates pharyngeal and esophageal clearance
Respiratory-swallow phase patterns and swallowing impairment in patients treated for oropharyngeal cancer.  


Respiratory-Swallow Patterns in HNC

- Main findings
  - Impairments in HNC
    - Initiation of swallow
    - Anterior hyoid excursion
    - PES opening
    - Tongue base retraction
    - Pharyngeal residue
  - E-E dominated in healthy controls (73%)
  - Only 38% in patients with HNC

System Overlap: Cross System Interactions

- Cancer patients had altered phase patterning, including inconsistent or unstable patterns (“non-optimal”)
- Cancer patients had significantly increased severity of penetration/aspiration (PAS) and swallowing impairment (MBSImP™©)
Purpose

- Test novel therapeutic regimen
- Train optimal respiratory-swallow pattern in patients with HNC
- Primary outcome measures
  - MBSImP™© scores
  - PAS scores
  - MDADI scores

Power Analysis

- Expected mean MBSImP™© difference: 4.53
  - One-sided test for mean differences ($\alpha = .05$, $\beta = .90$)
  - Sample size: 29
- Difference in safety of swallow: 1.8 PAS score change
  - Experimental effect size is 0.7 (1.8/2.6)($\alpha = .05$, $\beta = .80$)
  - Sample size is 26

Methods

- Volunteers recruited from head and neck cancer clinics at MUSC and Ralph H. Johnson VAMC
- KayPENTAX Digital Swallow Workstation
  - Continuous videofluoroscopic imaging (30fps)
  - Respiratory kinematic data (Inductotrace)
  - Nasal airflow data

MBSS

- All patients underwent pre- and post-modified barium swallow study (MBSS)
- Liquids only (thin, nectar, honey)
  - 5-mL teaspoon (tsp)
  - 15-mL cup
  - Patient-controlled volume from cup
- 2 trials for each consistency and volume (maximum: 18 trials)

Synchronized Respiratory & Swallowing Recording

- Respiratory Flow
- Chest Kinematics
- MBS
MBSS Inclusion Criteria

- MBSImP™© (scores total ≥5)
- PAS scores ≥3 on 10% of trial swallows
- Non-optimal or inconsistent (E-I, I-E, or I-I) respiratory phase pattern on ≥60% of trial swallows

E-I: Expiration-Inspiration; I-E: Inspiration-Expiration; I-I: Inspiration-Inspiration

Training Protocol

- Intervention phase divided into 3 learning modules (total of 24 goals)
  1. Identification (≥ 80% accuracy)
  2. Acquisition/Performance (≥ 80% accuracy)
  3. Mastery (≥ 90% accuracy)
- Pre- and post-treatment MBSS
- Detraining
  - 1 month follow-up

Respiratory Swallow Phase Training

- Initiation of swallow during expiratory phase at mid-to-low lung volume – with and without visually assisted feedback

Results

- Training time = 6.5 sessions (SD: 1.4; Range: 4-8)
- Significant increase in optimal respiratory-swallowing pattern (p < .0001)

Results

- 93% (27/29) achieved the optimal pattern

Results

- Significant increase in MDADI scores (p = .001)
  - 30% had a clinically significant improvement in MDADI score (≥10 points)
- Significant decrease in PAS scores

Results
**RST - Laryngeal Vestibular Closure**

\[ p = 0.0001 \]

**RST Effect – Tongue Base Retraction**

\[ p < 0.0001 \]

**RST Effect – Pharyngeal residue**

\[ p = 0.017 \]

**Physiologic Improvements with RST**
Conclusions

- Respiratory-swallow coordination can be trained
- No adverse events or effects
- Swallowing during expiration at mid-to-low lung volumes improves aspects of airway protection, bolus propulsion and pharyngeal clearance.

Future Directions

- Long-term goals
  - Develop optimal respiratory-swallow phase training methods and regimens
  - Alone or combined with traditional swallowing treatments
  - Home training program
  - Improve swallowing function in the acute phases of recovery
  - Larger clinical trial

- Expands therapeutic procedure to other patient groups that have indications of respiratory-swallow impairments

References