Aging and Eating Enjoyment: Sustainability and Rehabilitation

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Swallowing/Eating is a biopsychosocial activity that is a key element of Healthy Life.
Swallowing

Moving food, liquid, secretions or medications from the mouth to the stomach, usually by a series of muscle contractions causing pressure changes in the aero-digestive tract

Dysphagia

A swallowing disorder characterized by difficulty...
18,000,000 adults with dysphagia in the U.S.  
(AHRQ, 1999)

MILLIONS OF CHILDREN

Dysphagia is an element of Unhealthy Life
Swallowing as a two-pump system:

- Oropharyngeal propulsive pump – lingual and velopharyngeal dynamics = Positive pressure (+)
- Hypopharyngeal suction pump – hyolaryngeal excursion opens UES = Subatmospheric pressure (-)

Swallowing = a series of pressure changes

(Lungs Esophagus)
Aspiration

Misdirection of oropharyngeal or gastric contents into the larynx and lower respiratory tract
Without effective treatment, dysphagia can lead to:

- mortality
- pneumonia (pulmonary complications)
- malnutrition
- dehydration
- ↓ rehabilitation potential
- ↓ QOL
- ↑ length of hospital stay
- ↑ cost
Pulmonary health may be the most critical of these

Pneumonia is:

- The 5th leading cause of infectious death in the U.S. among persons over 65 years of age
- The 3rd leading cause of death over 80 years of age

(LaCroix et al, Public Health Report, 1989)
Swallowing & Swallowing Disorders: DYSPHAGIA
A “Young” Field
Swallowing Neural Control

Until 1980s:
Bilateral
Brainstem Reflex

- invariant
- output at a “local” level
76-year-old male presents with stroke(s) and mild memory loss

Grade 3, Higher Cortical

Grade 3, Lower Cortical
Bilateral and confluent white matter changes, mild-moderate atrophy
56-year-old female

Grade = 0, Higher Cortical

Grade = 1, Lower Cortical
Single UBO with subcortical region (white small)
Cortical regions reported to be involved in swallowing (fMRI and/or PET)

- Pre-central gyrus
- Post-central gyrus
- Insular cortex
- Anterior cingulate cortex
- Supplementary motor area
- Supramarginal gyrus
- Superior frontal gyrus
- Middle frontal gyrus
- Inferior frontal gyrus
- Superior parietal gyrus
- Middle parietal gyrus
- Inferior parietal gyrus
- Frontal inferior opercularis
- Frontal inferior triangularis
- Rolandic operculum

(Humbert et al, 2009; Malandraki et al, 2009; Robbins et al, 1999; Zald & Pardo, 1999, Martin et al, 2009)
Large-scale distributed swallowing neural network

Patterned Response

Not a reflex in the traditional sense

(Zald & Pardo; Robbins et al, 1999)
Neural Plasticity

Refers to the ability of the brain to change

Changes in the functioning of a neural substrate and the possible alteration in behavior can be secondary to influences such as

• Experience
• Learning
• Aging
• Change in use
• Response to injury
• REHABILITATION

The key to treatment is identification of the etiology for the dysphagia/aspiration; that is, the underlying neurophysiologic or anatomical reasons.
Videofluoroscopic Swallow Study (VFSS) currently is most frequently performed because it permits the determination of:

- Underlying physiologic or anatomical reasons for the dysphagia
- Analysis of bolus flow
- (Bolus) response to treatment

EXAMINATION PROTOCOL (BARIUM)

- liquid
- semi-solid
- solid
- pill
Sarcopenia

Progressive myocyte atrophy and death

Weakness

Muscle function

The Journals of Gerontology

WORKSHOP ON SARCOPENIA: Muscle Atrophy in Old Age
Anatomical MRI Data

38-Yr-Old Female

81-Yr-Old Female
Dysphagia Treatment

Preserve and Compensate
OR
Exercise and Rehabilitate

Exercise to Dine
Behavioral Interventions

• Compensatory methods
  • diet modifications
  • alternating liquids and solids
  • eating slowly
  • postural adjustments
  • maneuvers

• Rehabilitative methods
  • exercise regimens

Chin Tuck
Swallowing as an endurance activity = DINING
Rehabilitative Interventions

Strength, Endurance, Resistance: Conceptual and Physical Differentiation

- **Strength** – ability to exert a force
  Training: High Loads, low repetitions

- **Endurance** – ability to perform repeated muscular contractions
  Training: Low loads, high repetitions

- **Progressive Resistance** – periodically increasing the load; outcome can be manipulated
  Training: Progressive loads, static repetitions

*(Powers et al, 2008)*
Principles of exercise to change neuromuscular framework for improved swallowing:

- Frequency
- Intensity

**OVERLOAD PRINCIPLE:**
A system or tissue must be challenged with an intensity, duration or frequency of exercise at a level beyond which it is accustomed in order for adaptation to occur.

(Powers & Howley, 2009)
(Adapted from Fiatarone et al, 1990; Narici et al, 1989)
8-week Progressive* Exercise Program

(Proof of Concept)

- 30 reps
- 3x/day
- 3x/week
- 8 weeks

*60% of one repetition max (1RM) week 1: The load one can bear with maximal effort to complete a single repetition

*Readjust to 80% max every 2 weeks
Healthy Normals (>65yo)

Results: Change in **Isometric** Pressures (n=10)

* *p ≤ 0.002

*(Robbins et al, JAGS, 2005)*
Stroke Subjects

- N=10
- Age (51-90yrs)
- Ischemic stroke
- Acute (6)
- Chronic (4)
- *acute:< 3 mos. post-stroke

(Robbins et al, Arch Phys Med Rehabil, 2007)
Post-Exercise Isometric (IOPI) Lingual Pressures > Normal

Anterior Tongue

Week 0: 63%
Week 4: 37%
Week 8: 37%

Posterior Tongue

Week 0: 76%
Week 4: 24%
Week 8: 24%

Anterior & Posterior Strength ($p < .0001$)

% Total Increase > During First 4 Weeks

(Nudo RJ et al, Science, 1996)
Significantly reduced mean Pen/Asp scores:

- 10mL liquid ($p=0.001$)
- 3mL liquid ($p=0.02$)
Anatomical Outcomes

Lingual Volume
- Outline muscles of interest (26 slices)
- Area of slice \(\times 3\text{mm slice thickness}\)
- Average \(\uparrow 4.35\%\)

Muscle Composition
Pursuing Another Level of Evidence/Outcome

BOLD fMRI activity indicating the neural extent of treatment-related plasticity

**Stroke**

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Post 8 Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Baseline" /></td>
<td><img src="image2.png" alt="Post 8 Weeks" /></td>
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</table>

**fMRI/Lingual Exercise**

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Post 8 Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3.png" alt="Baseline" /></td>
<td><img src="image4.png" alt="Post 8 Weeks" /></td>
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</table>

**Healthy Age-matched Normal**

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Post 8 Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image5.png" alt="Baseline" /></td>
<td><img src="image6.png" alt="Post 8 Weeks" /></td>
</tr>
</tbody>
</table>
Device-Facilitated Isometric Progressive Resistance Oropharyngeal (I-PRO) Strengthening

Madison Oral Strengthening Therapeutic (MOST) Device

- Requires pressure generation
- 5 sensor custom fit mouthpiece
- Unit with adjustable target values and knowledge of results to user

[Image of MOST device and laptop with interface]

U.S. patent # 6702765  FDA Registered
Case Study

- 58-year-old female
- 2 years post-cva(s) – brainstem+
- Sub-acute bacterial endocarditis
- Post-stroke dysphagia/aspiration
- Tracheostomy
- 10-lb weight loss
- Multiple cricopharyngeal dilations (ENT)
- Swallowing therapy (SLP)
- G-tube for all nutrition/hydration
- Expectorating saliva into cup
Severe Dysphagia
MOST–Facilitated
I-PRO Therapy (8 weeks)
Post Treatment
Stimuli = “What goes in ...”

Levels/Categories of Liquids
Thin < Nectar < Honey
(e.g., water) (e.g., tomato juice) (e.g., karo syrup)
INFLUENCE OF BIOMECHANICS/NEUROPHYSIOLOGY ON DYNAMICS OF BOLUS FLOW:

- Direction (Penetration/Aspiration)
- Duration
- Clearance (Residue)

1. Diagnose dysphagia
2. Determine treatment target
3. Evaluate response to potential intervention
4. Evaluate response to manipulations of rheological properties

(Robbins et al, 1999)
Rheology

• The science of flow of fluids

• Viscosity
  – Resistance of a material to flow
    • Water has low viscosity
    • Corn syrup has high viscosity

• Flow characteristics
  – Does a fluid flow easily when poured or pumped
  – How thick a layer forms on a surface
  – How easily it is swallowed
Thin Barium
Standardization of Barium Products
(Varibar®, Bracco Diagnostic Imaging)

Non-Standardized
“Off the Shelf”

(Patent Number U.S. 6461589, Wisconsin Alumni Research Foundation)
NIH Protocol (201)
Thickened Barium
Disadvantages of Current Beverage Products

Available Thickened Beverages
  • xanthan gum
  • starch

• Do not match the diagnostic standards
• Stringent preparation practices
• Time-dependent
• Patient dissatisfaction
• Non-compliance
• Dehydration
Thickened Fluids

• Thickened beverages currently are described solely by apparent viscosity
• However, there is no evidence that swallowing dynamics related to fluids are governed by apparent viscosity alone
• Lack of research linking sensory attributes of thickened fluids to both swallowing kinematics and rheological properties
• Research project: evaluating swallowing characteristics and sensory experience related to the rheological properties of thickened fluids
  - How do the rheological properties and chemical structure of each hydrocolloid influence sensory properties and swallowing behavior?
USDA Funded Project

Development of **Biophysically-Based Fluids for Swallowing Disorders**

Co-PIs: Richard Hartel, PhD, UW Food Science and JoAnne Robbins, PhD, UW SMPH

- Goal = Palatable, safe, and thirst-quenching thickened liquids
- Variety of hydrocolloids
- 30 beverages (15 nectar-thick/15 honey-thick) → 6 beverage subset
- Assess sensory perceptions, rheological properties, and swallowing parameters
Increase knowledge from “Critical interplay among oropharyngeal pressure generation and bolus flow and sensory perception with biophysically designed fluids (various rheologic properties) ...”
Tribology (discipline): “... understand oral processing of fluids or foods, their texture and perceptual attributes while accounting for the rheologic properties as well as the properties of the interacting anatomical surfaces which are in relative motion (physiology) ...”

(Chen & Stokes, 2012)
Hydrocolloid Options

• Numerous options exist although not all give proper rheology or sensory attributes.

<table>
<thead>
<tr>
<th>Table 1.1</th>
<th>Source of commercially important hydrocolloids</th>
</tr>
</thead>
</table>

**Botanical**
- trees
  - cellulose
- tree gum exudates
  - gum arabic, gum karaya, gum ghatti, gum tragacanth
- plants
  - starch, pectin, cellulose
- seeds
  - guar gum, locust bean gum, tara gum, tamarind gum
- tubers
  - konjac mannan

**Algal**
- red seaweeds
  - agar, carrageenan
- brown seaweeds
  - alginate

**Microbial**
- xanthan gum, curdlan, dextran, gellan gum, cellulose

**Animal**
- Gelatin, caseinate, whey protein, soy protein, egg white protein, chitosan

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**Fig. 23.2** Schematic representation of the microstructure of drinks with protein particles with various types of hydrocolloids, with accompanying viscosity profiles. The dashed lines indicate the profile for a drink without thickeners.
## Final Thickener Selection

- **15 thickeners**

<table>
<thead>
<tr>
<th>Hydrocolloid</th>
<th>Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agar</td>
<td>Gelidium/Gracilaria</td>
</tr>
<tr>
<td>Alginates</td>
<td>Sodium alginate</td>
</tr>
<tr>
<td>Carrageenans</td>
<td>Iota (ι) carrageenan</td>
</tr>
<tr>
<td>Cellulosics</td>
<td>Cellulose gum, Methyl cellulose, Microcrystalline cellulose</td>
</tr>
<tr>
<td>Gums</td>
<td>Guar gum, Konjac gum, Tara gum, Xanthan gum</td>
</tr>
<tr>
<td>Proteins</td>
<td>Calcium caseinate (pH = 6.8)</td>
</tr>
<tr>
<td>Pectins</td>
<td>High methoxyl pectin, Low methoxyl pectin</td>
</tr>
<tr>
<td>Starches</td>
<td>Rice starch, Acetylated distarch phosphate (corn)</td>
</tr>
</tbody>
</table>
PROTOTYPE THICKENER
SELECTION 15 → 6
(3 NECTAR 300+70CPS, 3 THIN HONEY 1500+250CPS)

2 based on rheological similarities to diagnostic fluids:
  Apparent viscosity
  Flow index
  Consistency

4 based on sensory attributes rated at extremes
  Minimal or maximal thickness
  Mouth coating
  Adhesiveness
  Slipperiness

...to best represent a wide range of fluid parameters
# SUBJECTS

N = 42

<table>
<thead>
<tr>
<th>Healthy</th>
<th>Dysphagic</th>
</tr>
</thead>
<tbody>
<tr>
<td>n = 23</td>
<td>n = 19</td>
</tr>
<tr>
<td>m = 6</td>
<td>m = 4</td>
</tr>
<tr>
<td>f = 18</td>
<td>f = 11</td>
</tr>
<tr>
<td>Age (R) = 40 (22-72)</td>
<td>67 (23-92)</td>
</tr>
</tbody>
</table>
• Nectar barium (p=0.003)
  • Agar
  • Methylcellulose
  • Xanthan gum

• Thin Honey barium (p=0.89)
  • High methoxyl pectin
  • Iota carrageenan
  • Tara gum

PENETRATION/ASPIRATION SCALE
DYSPHAGIC POST-SWALLOW RESIDUE

1500(± 250)CP

Residue scale 0= no residue, 1= coating, 2= pooling

*p<0.0001
Healthy

Dysphagic

THIRST QUENCHING

most thirst quenching

least thirst quenching

300 (± 70) cP

1500 (± 250) cP

(p < 0.0001)

agar
methylcellulose
xanthan gum
high methoxyl
iota carrageenan
tara gum

Healthy

Dysphagic
OVERALL LIKING

Healthy vs. Dysphagic

Comparison:
- 300(± 70)cP: (p<0.0001)
- 1500(± 250)cP: (p<0.05)

Likability:
- best liked
- least liked

Ingredients:
- agar
- methylcellulose
- xanthan gum
- high methoxyl
- iota carrageenan
- tara gum

Significance:
- * indicates statistical significance.
Biophysically Designed New Beverages
Rheologic Perceptual and Nutritional Optimization

Combine Interventions – Compensatory and Rehabilitative
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