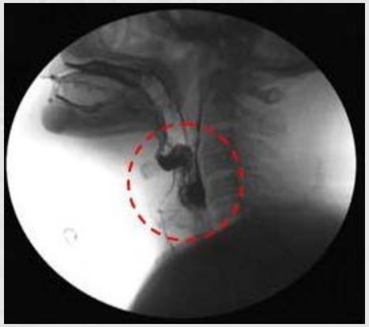
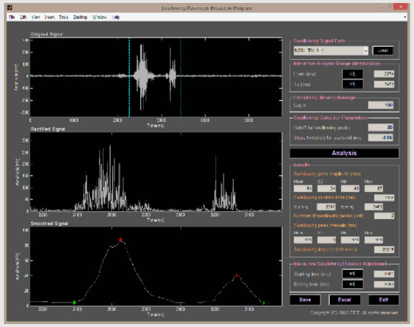
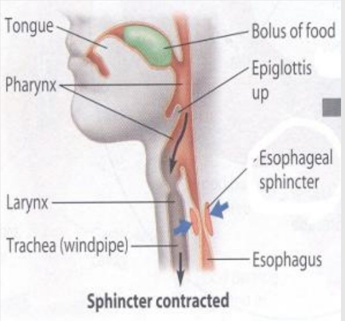
Comparison of Swallowing Characteristics in Patients with Dysphagia and Normal Controls




Swallowing Parameter Extraction Program
File
Edit
View
Insert
Tools
Desktop
Window
Help
Original Signal
Rectified Signal
Smoothed Signal
Analysis
Save
Excel
Exit


Tongue
Pharynx
Larynx
Trachea (windpipe)
Bolus of food
Epiglottis up
Esophageal sphincter
Esophagus
Sphincter contracted

2013. 6. 23

포항공과대학교
산업경영공학과

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Duk L. Na, MD, Ph.D.[2], Heecheon You, Ph.D.[1]

SAMSUNG 삼성서울병원

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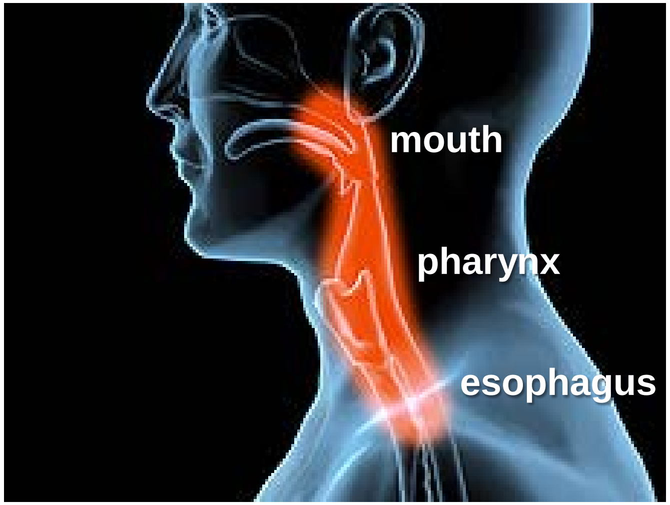
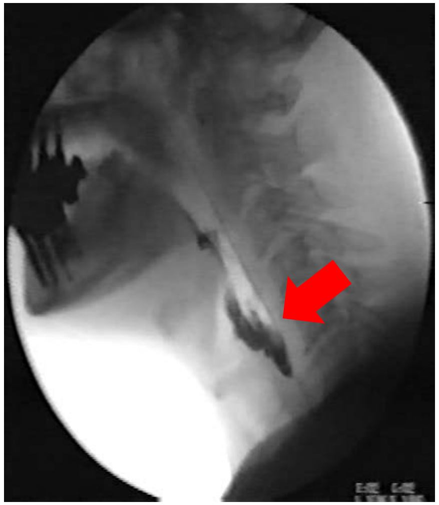
AGENDA

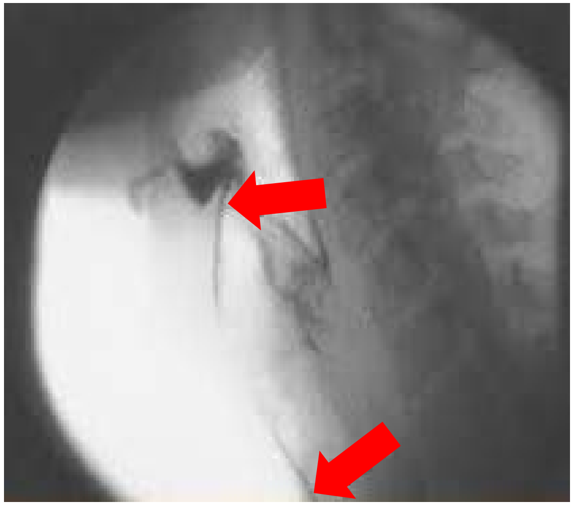
- **Introduction**
  - ✓ Background
  - ✓ Objective of the Study
- **Approach**
- **Results**
  - ✓ Swallowing Characteristics: Controls vs. Patients
  - ✓ Diagnostic Model for Dysphagia
- **Discussion**

Dysphagia: Clinical Significance

- **Definition**: difficulty in swallowing food
- **Etiology**: mainly accompanied by neurologic diseases (e.g., stroke) (Daniels et al., 2006)
- **Symptom**: aspiration, pneumonia, dehydration, malnutrition
- **Prevalence**: increased with age, particularly high among older adults (> 60 yrs.) (Morris, 2006; Robbins and Barczi, 2003)







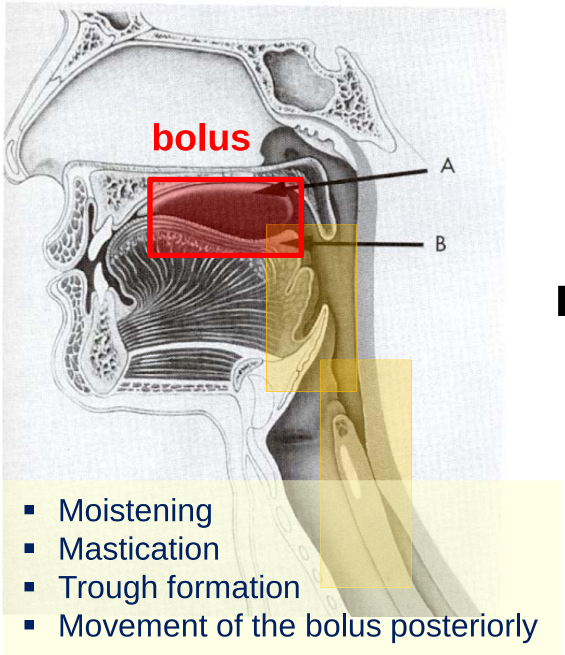
⇒ Because dysphagia improperly diagnosed and/or treated may lead to asphyxiation and death, **early and accurate identification and proper therapy are important**

Swallowing Process

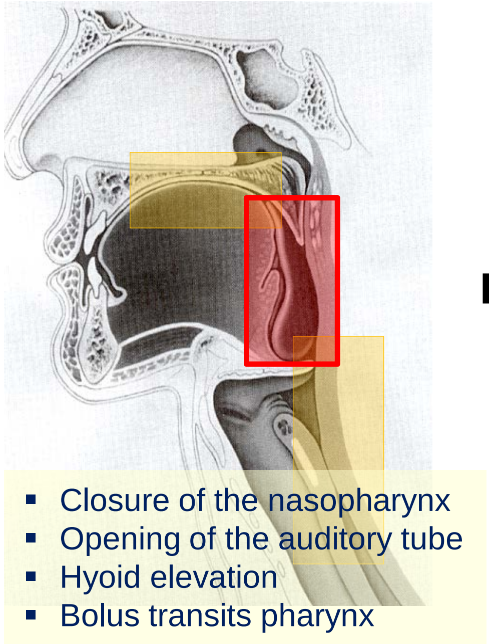
Oral preparatory phase &
Oral phase

Pharyngeal phase

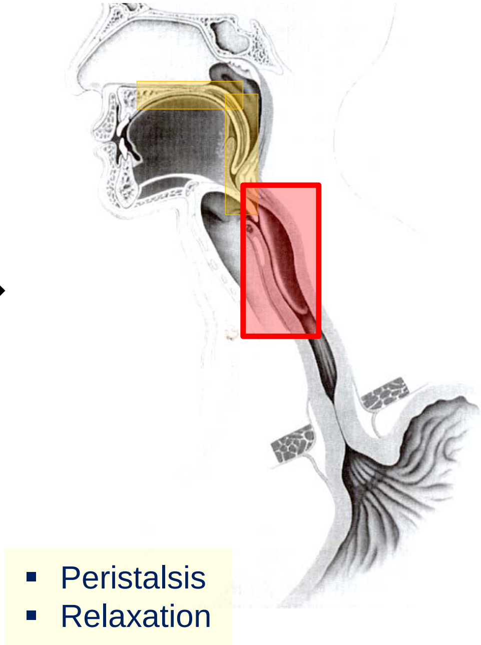
Esophageal phase



- Moistening
- Mastication
- Trough formation
- Movement of the bolus posteriorly



- Closure of the nasopharynx
- Opening of the auditory tube
- Hyoid elevation
- Bolus transits pharynx

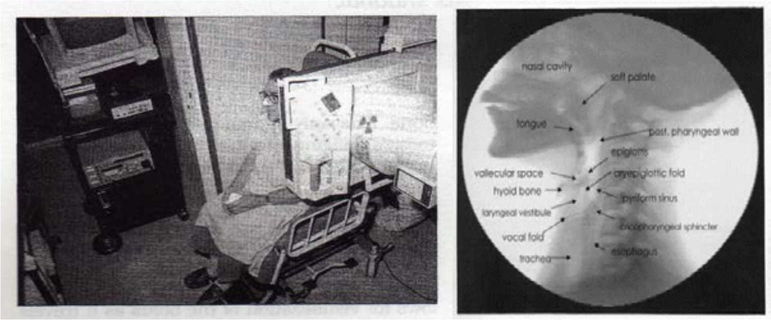
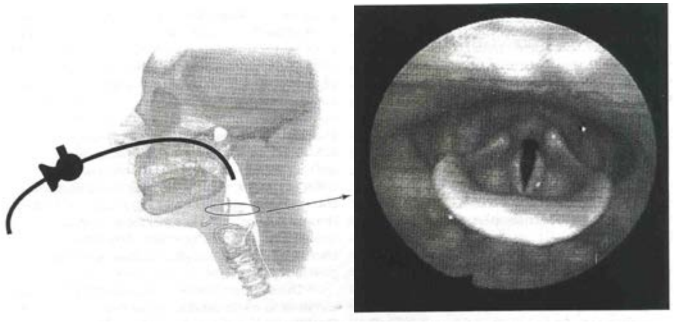


- Peristalsis
- Relaxation

⇒ Oral phase: easy to observe

⇒ Pharyngeal phase: difficult to observe → need a **specialized device** to examine swallowing of food inside the pharynx

Diagnosis Methods for Dysphagia

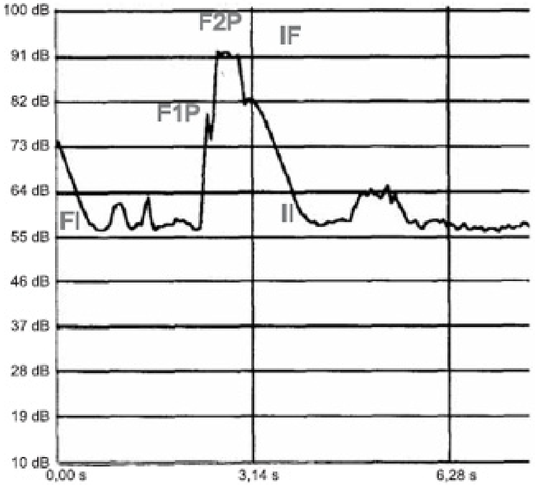
	VideoFluorocopic Swallowing Study (**VFSS**)	Fiberoptic Endoscopic Evaluation of Swallowing (**FEES**)
Illustration	 nasal cavity soft palate tongue post. pharyngeal wall epiglottis vallecular space aryepiglottic fold hyoid bone pyriform sinus laryngeal vestibule cricopharyngeal sphincter vocal fold esophagus trachea	
Method	Record fluoroscopy images by X-ray and evaluate dysfunctions of swallowing	Insert a flexible endoscope through the nose
Limitation	▪ Radiation exposure	▪ Invasiveness
	▪ General-purpose device with high price ▪ Qualitative assessment ▪ Not usable in daily activities ▪ Lack of therapeutic functions for dysphagia	

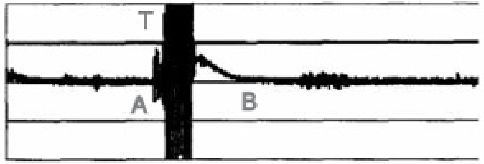
⇒ Need to develop a **device specialized** to dysphagia with **high safety and usability**

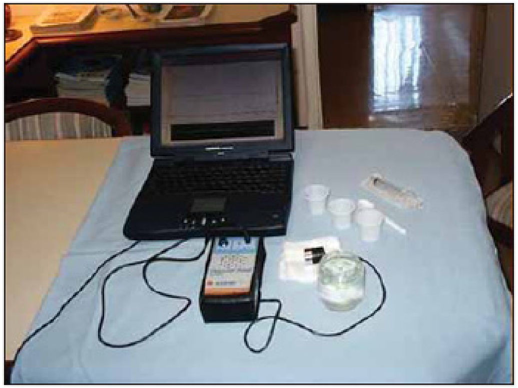
Recent Studies for Measurement of Swallowing

❑ Swallowing sound measurement by sonar Doppler

	Santos and Macedo-Filho (2006)	Cagliari et al. (2009)
Title	Sonar Doppler as an Instrument of Deglutition Evaluation	Doppler Sonar Analysis of Swallowing Sounds in Normal Pediatric Individuals
Participants	Brazilian 50 persons (25 females, 25 males; mean age: 32 years, 18 ~ 50 years)	Brazilian 90 persons (45 females, 45 males; 3 groups: 2~5, 5~10, 10~15 years)
Apparatus	▪ H/W: Sonar Doppler ▪ S/W: VOX METRIA	▪ H/W: Sonar Doppler ▪ S/W: VOX METRIA
Swallowing food (volume)	▪ Saliva ▪ Liquid (10 ml of water) ▪ Pasty (10 ml)	▪ Saliva ▪ Liquid (N.S.) ▪ Pasty (N.S.)
Measures	▪ Peak intensity ▪ Peak frequency ▪ Swallowing duration time	▪ Peak intensity ▪ Peak frequency ▪ Swallowing duration time
Analysis	▪ Mean ± 95% C.I.	▪ Mean ± 95% C.I. ▪ Gender, age, swallowing food effects (ANOVA)







⇒ **Limitation**: Sounds measured include those not related to swallowing (e.g., respiration, voice production)

Research Objective

Comparison of Swallowing Characteristics

in Patients with Dysphagia and Normal Controls

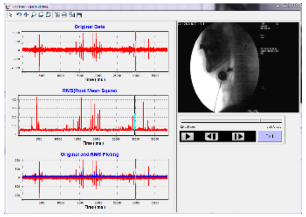
Using a Ultrasonic Doppler Sensor

1. **Development** of a swallowing measurement and analysis system
2. **Quantification** of the swallowing function in the pharyngeal phase
3. **Comparison** of dysphagic patients with normal controls
4. **Establishment** of a diagnostic model for dysphagia

Research Protocol

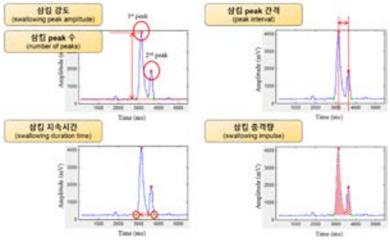
S1. System development

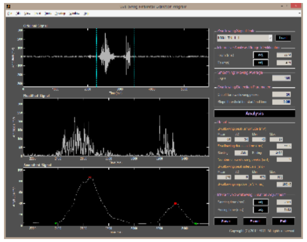
- Ultrasonic Doppler sensor
- Swallowing measurement S/W


Original Data
RMS(Root Mean Square)
Original and RMS Plotting

S2. Quantification

- Swallowing measures
- Quantification S/W





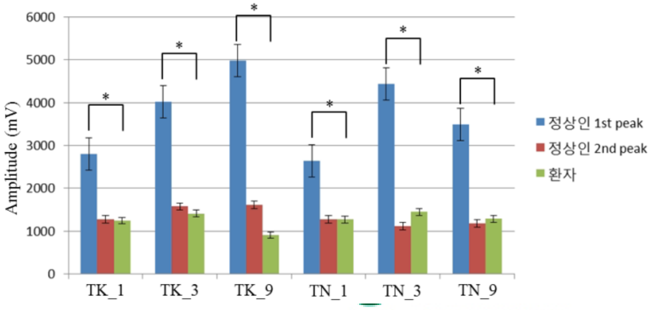
S3. Experiment

- Dysphagic patients vs. normal controls
- Various swallowing types and volumes

[redacted]
[redacted]

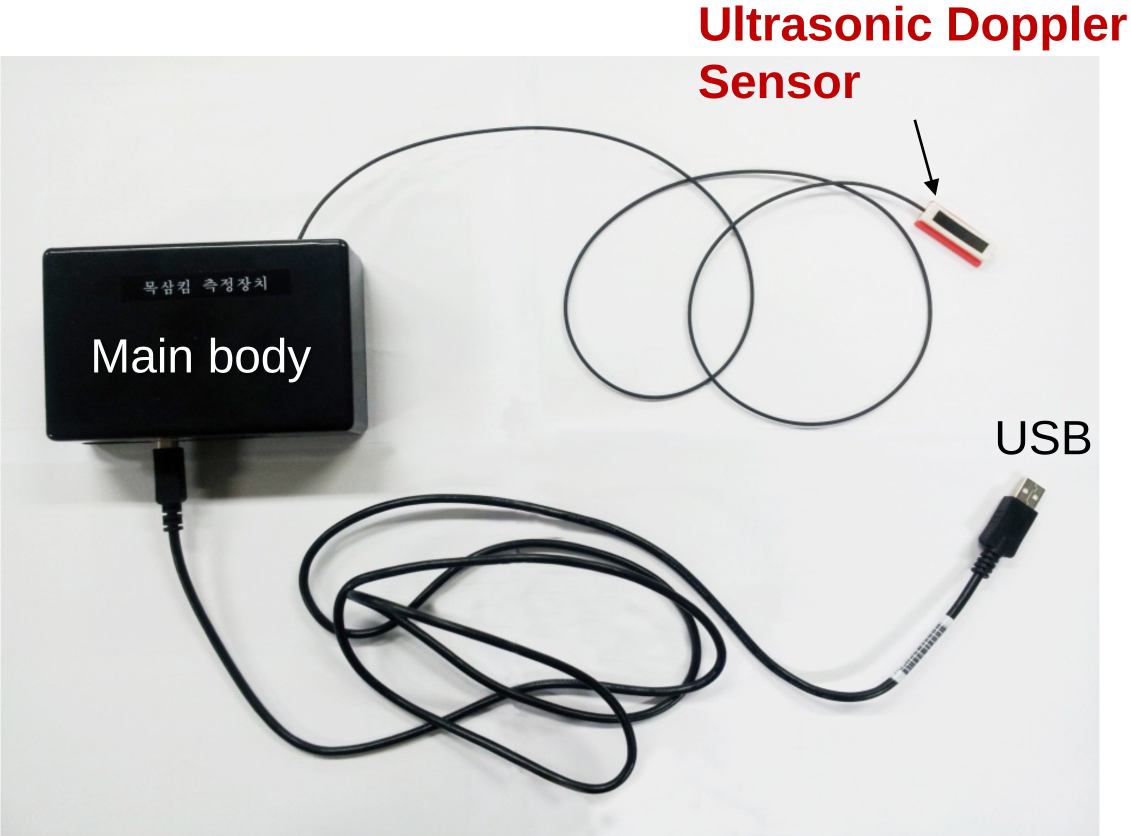
S4. Analysis

- Pairwise comparison
- Diagnostic model



S1. Development: Swallowing Measurement Device

- **Measurement: movement of organs related to the pharynx**

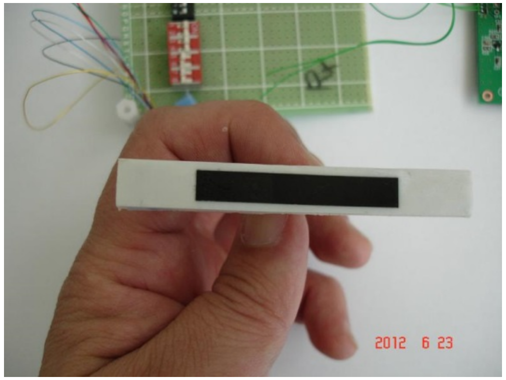

Ultrasonic Doppler Sensor
목삼킴 측정장치
Main body
USB

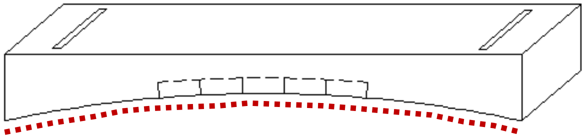
Sensor specification
(Model: DEPST-D2M5C)

Frequency	2 MHz
Element count	5
Element length	5 mm
Kurf	1 mm
Pitch	6 mm
Element width	6 mm
Wire	Micro coaxial cable (100pF)
Transducer surface radius	158R

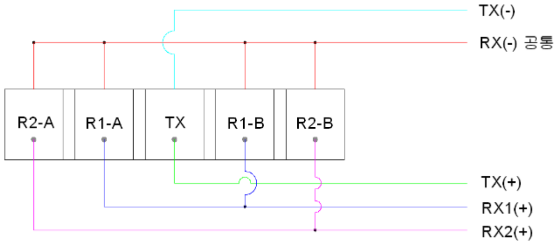
S1. Development: Case & Band

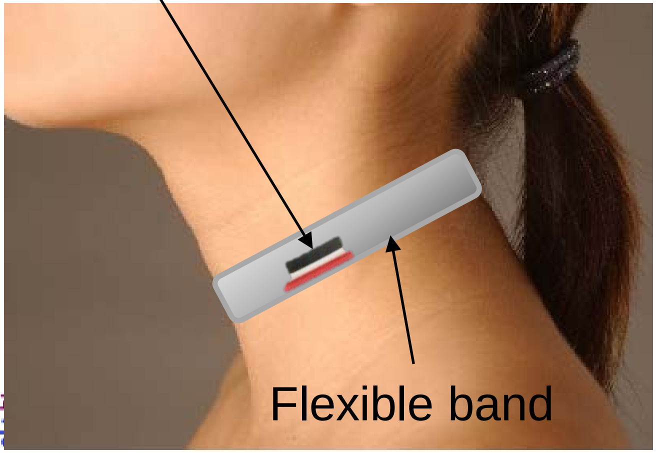
- ❑ **Case for housing the sensor; flexible band for locating the sensor to the neck securely.**





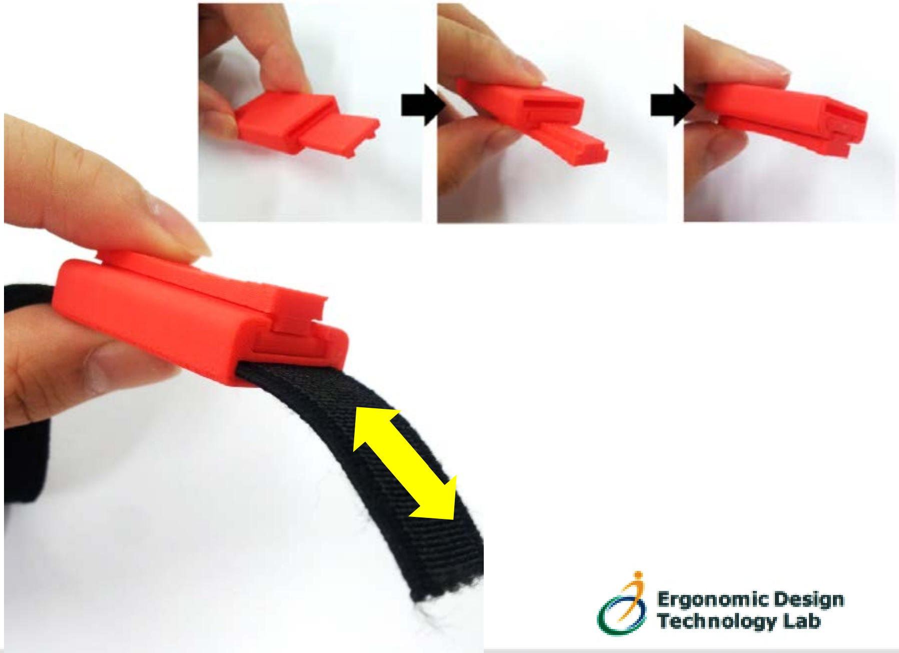
Curved surface
for adhering to the neck


TX(-)
RX(-) 공통
R2-A
R1-A
TX
R1-B
R2-B
TX(+)
RX1(+)
RX2(+)



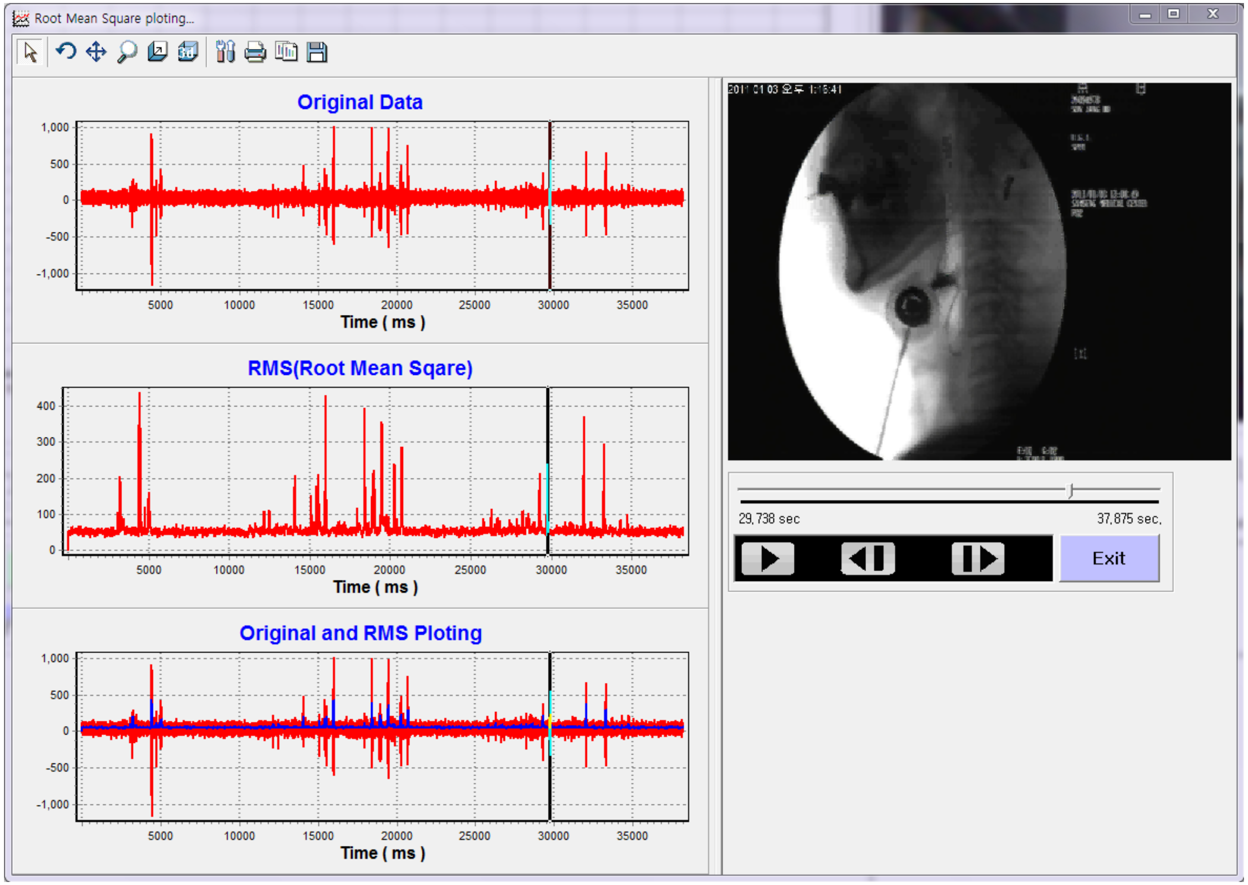
Ultrasonic Doppler Sensor

Flexible band



S1. Development: Analysis S/W

- ☐ Real-time plotting of swallowing signal measurements
- ☐ Interoperating with VFSS images


Root Mean Square ploting...
Original Data
1,000
500
0
-500
-1,000
5000
10000
15000
20000
25000
30000
35000
Time (ms)
RMS(Root Mean Sqare)
400
300
200
100
0
5000
10000
15000
20000
25000
30000
35000
Time (ms)
Original and RMS Ploting
1,000
500
0
-500
-1,000
5000
10000
15000
20000
25000
30000
35000
Time (ms)
2011 01 03 오후 1:16:41
29,738 sec
37,875 sec.
Exit

S2. Quantification: Signal Processing

1 / 3

S1. Signal rectification: (-) values → (+) values

S2. Smoothing by the moving average method

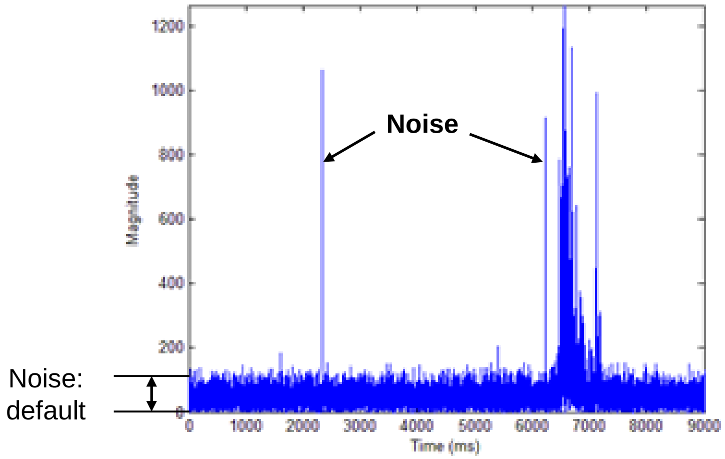
- Lag *n* = 50

S3. Starting and ending points detection

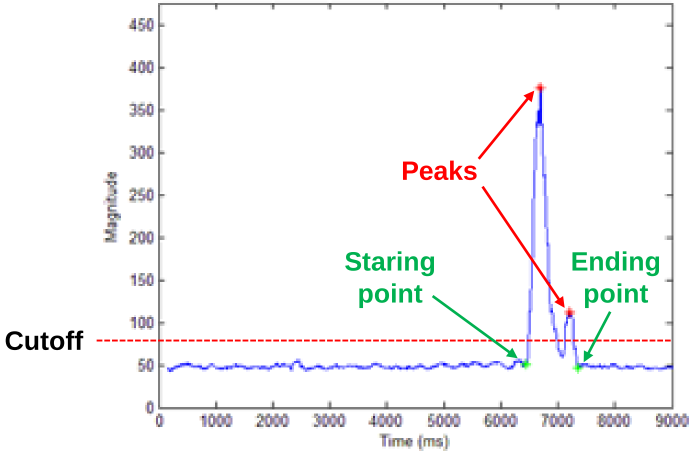
- Detecting slope = 0.9

S4. Peak detection

- Cutoff = 50



Rectified signal

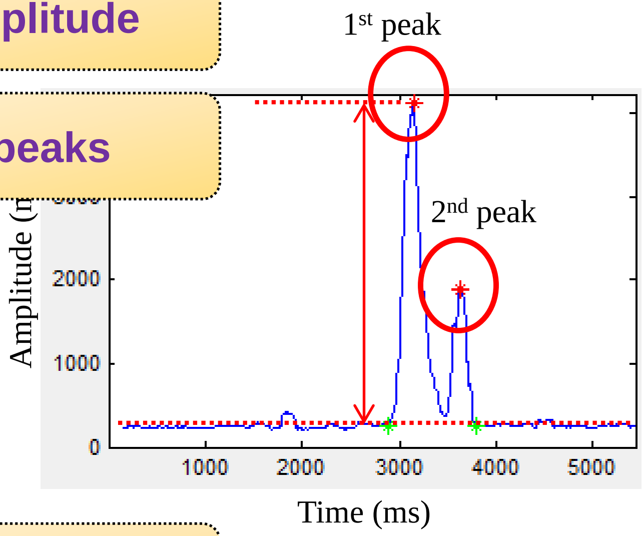


Smoothed signal

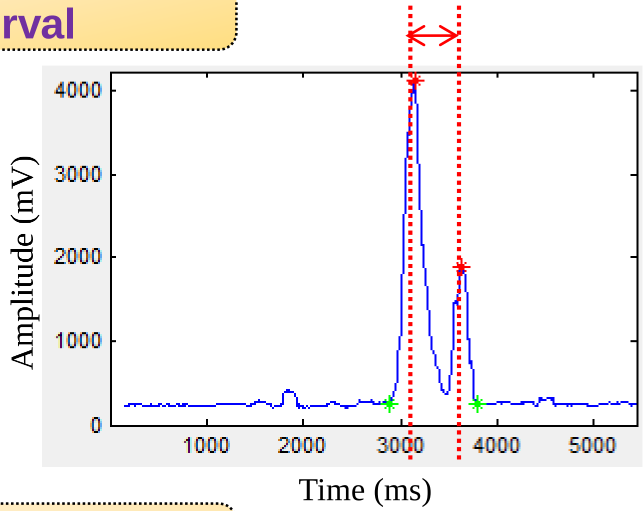
S2. Quantification: Measures

Peak amplitude

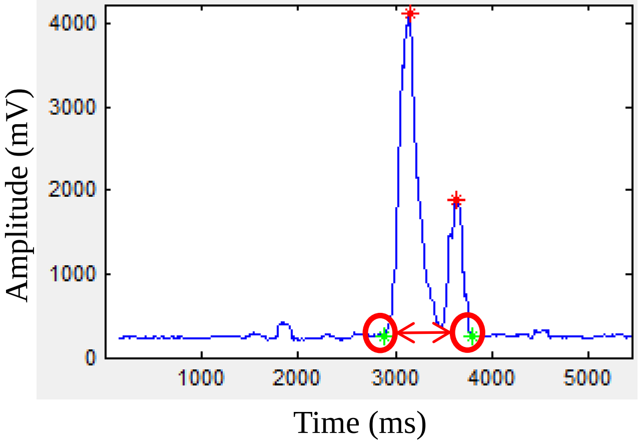
No. of peaks



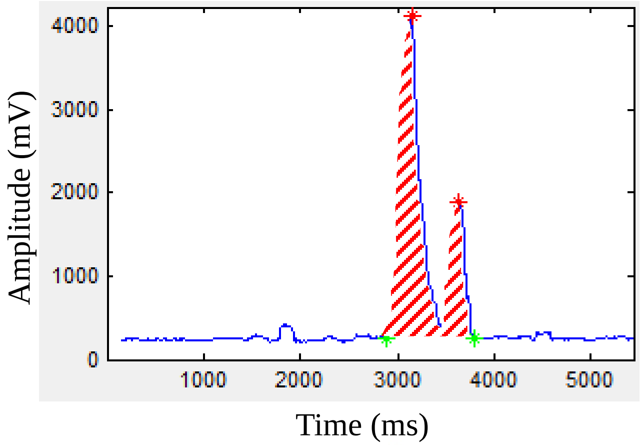
Peak-to-peak interval



Duration



Impulse



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Ergonomic Design
Technology Lab

S2. Quantification: **Analysis S/W**

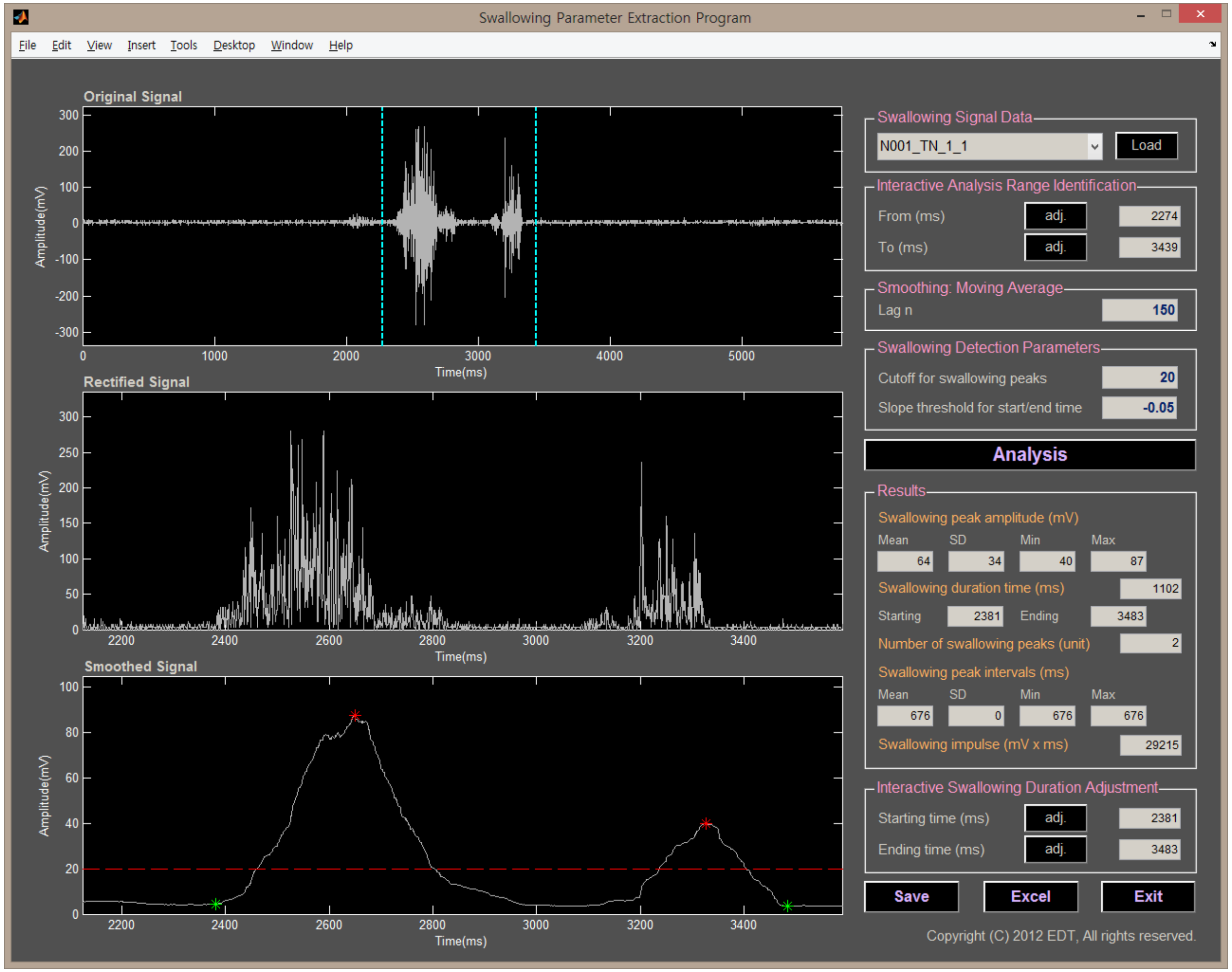
3 / 3

❑ **Automatic extraction** of five swallowing quantification measures

Original signal

Rectified signal

Smoothed signal


Swallowing Parameter Extraction Program
File
Edit
View
Insert
Tools
Desktop
Window
Help
Original Signal
Amplitude(mV)
300
200
100
0
-100
-200
-300
0
1000
2000
3000
4000
5000
Time(ms)
Rectified Signal
Amplitude(mV)
300
250
200
150
100
50
0
2200
2400
2600
2800
3000
3200
3400
Time(ms)
Smoothed Signal
Amplitude(mV)
100
80
60
40
20
0
2200
2400
2600
2800
3000
3200
3400
Time(ms)
Load
adj.
Analysis
Save
Excel
Exit

Swallowing Signal Data
N001_TN_1_1

Interactive Analysis Range Identification
From (ms) 2274
To (ms) 3439

Smoothing: Moving Average
Lag n 150

Swallowing Detection Parameters
Cutoff for swallowing peaks 20
Slope threshold for start/end time -0.05

Results

Swallowing peak amplitude (mV)

Mean	SD	Min	Max
64	34	40	87

Swallowing duration time (ms) 1102
Starting 2381 Ending 3483
Number of swallowing peaks (unit) 2

Swallowing peak intervals (ms)

Mean	SD	Min	Max
676	0	676	676

Swallowing impulse (mV x ms) 29215

Interactive Swallowing Duration Adjustment
Starting time (ms) 2381
Ending time (ms) 3483

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Input:
Parameters
- Lag *n*
- Slope
- Cut off

Output:
swallowing quantification measures

Interactive adjustment function

S3. Experiment: Method

- ❑ Participants: 120 normal controls (NC), 36 dysphagic patients (DP)
- ❑ Swallowing types and volumes (# repetitions = 3)
  - ✓ Dry saliva (DS)
  - ✓ Thin liquid (TN; water): 1, 3, 9 ml
  - ✓ Thick liquid (TK; beverage with thickener): 1, 3, 9 ml

NC	20s	30s	40s	50s	60s	70s	80s	Total
Female	10	10	10	10	10	10	-	60
Male	10	10	10	10	10	10	-	60
Total	20	20	20	20	20	20	-	120

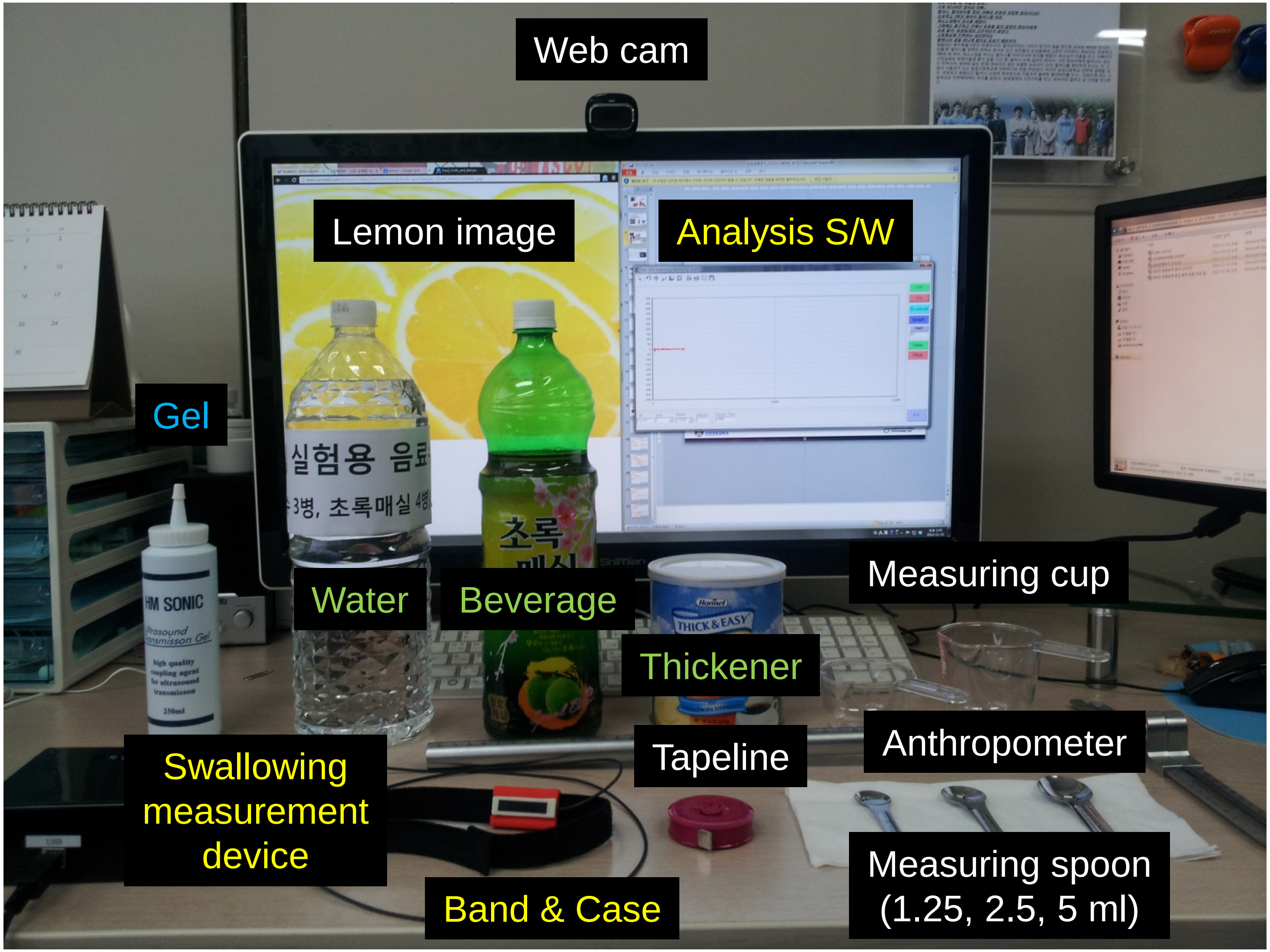
DP	20s	30s	40s	50s	60s	70s	80s	Total
Female	-	1	-	1	1	4	3	10
Male	-	-	1	6	12	5	2	26
Total	-	1	1	7	13	9	5	36

⇒ Age distribution of DPs over age 50 = 94%

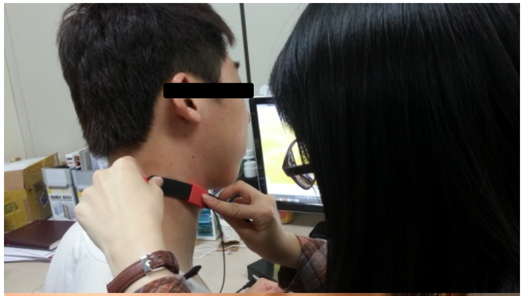
⇒ Gender ratio of DPs → female: male = 2: 5

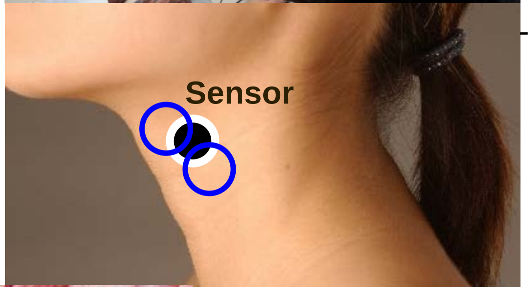
⇒ Swallowing volumes of DPs in the study: up to 3 ml (difficult to swallow 9 ml)

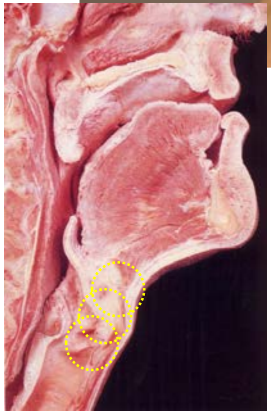
S3. Experiment: Apparatus


Web cam
Lemon image
Analysis S/W
Gel
Water
Beverage
Measuring cup
Thickener
Swallowing measurement device
Tapeline
Anthropometer
Band & Case
Measuring spoon (1.25, 2.5, 5 ml)

S3. Experiment: Protocol


[redacted]





Finding a location on the neck for good signal acquisition

Experiment time: 20 min

S1. Informed consent

(3 min)

S2. Practice

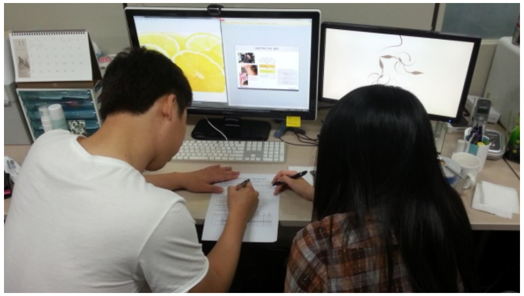
(5 min)

S3. Main experiment

(7 min)

S4. Debriefing

(5 min)



※ Swallowing order: **randomized**

※ Rest time bwn. swallowing: **5 sec**

< Example >

Session 1: thin liquid 3, 1, 9 ml

30 sec

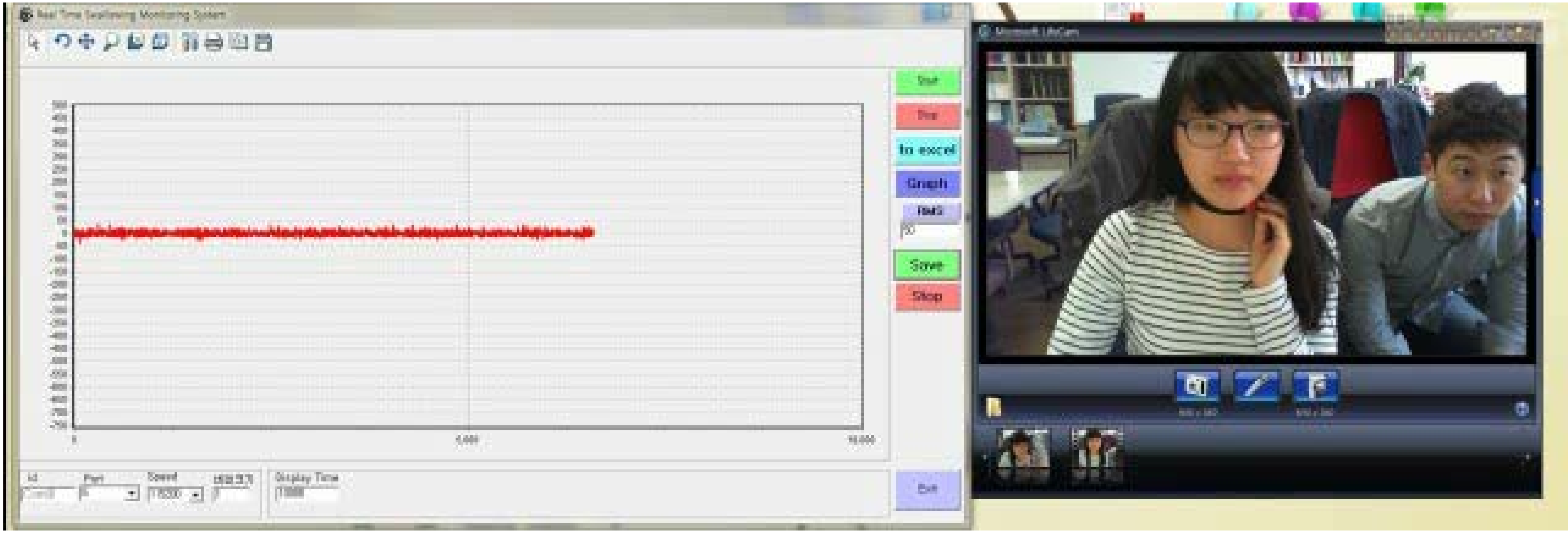
Session 2: saliva

30 sec

Session 3: thick liquid 9, 3, 1 ml

[redacted]

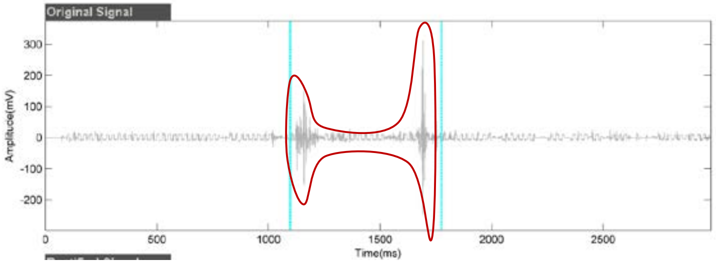
S3. Experiment: Demonstration


Real Time Swallowing Monitoring System
Start
Stop
In excel
Graph
RMS
Save
Stop
Exit
Id
Port
Speed
Display Time
5,000
10,000
Microsoft LifeCam

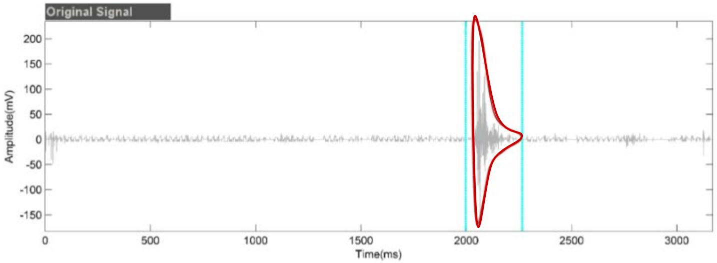
S4. Result: Swallowing Peak Types

Normal controls

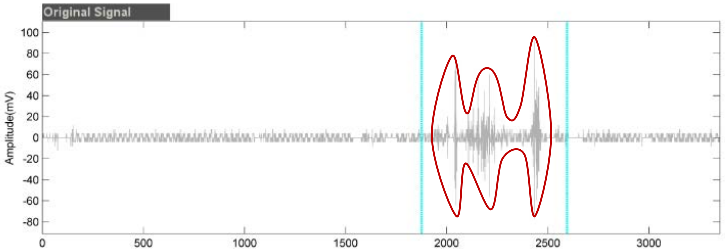
Short-double peak signal (43%)



Short-single peak signal (39%)

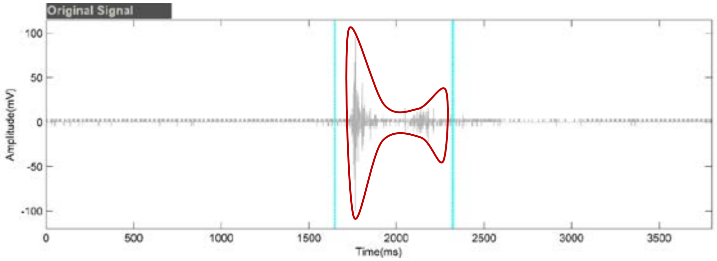


Short-multiple peak signal (18%)

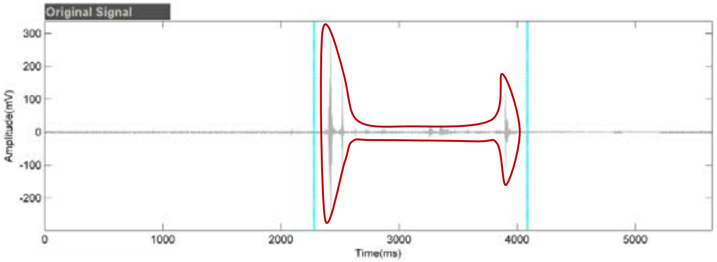


Dysphagic patients

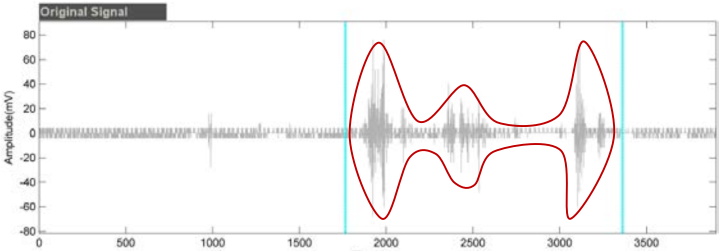
Short-double peak signal (58%)



Long-double peak signal (33%)



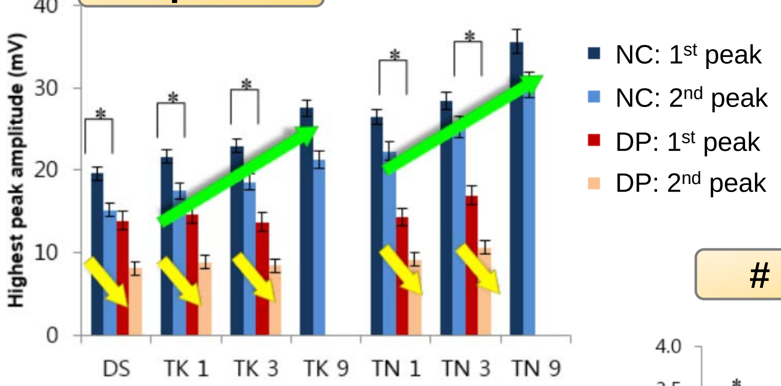
Long-multiple peak signal (9%)



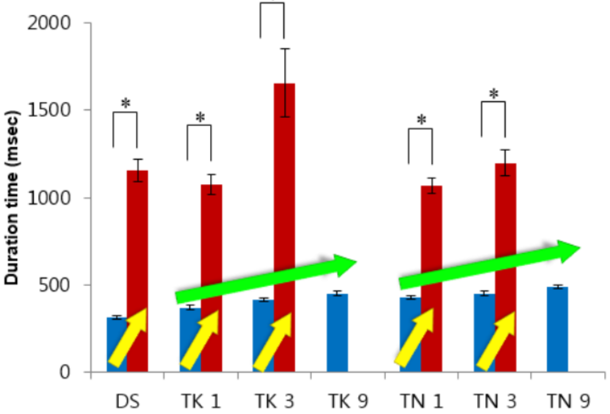
S4. Result: NC vs. DP

* $p < 0.05$

Amplitude

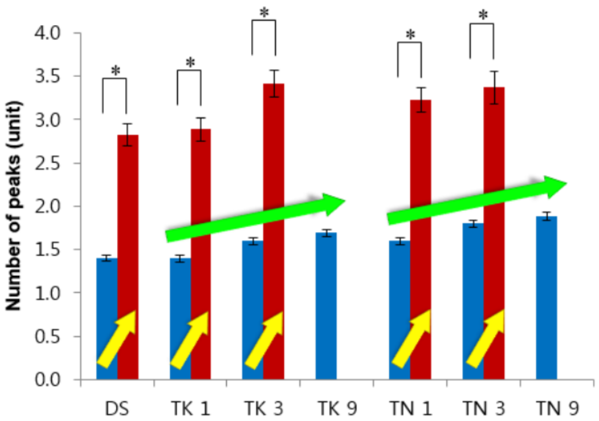


Duration

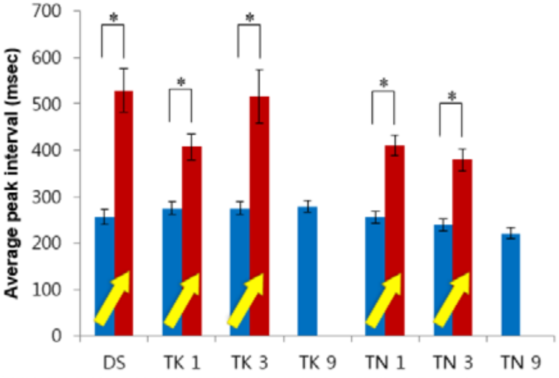


Measure	NC		DP
Amplitude	1	>	0.63 ⇓
Duration	1	<	2 ~ 4 ⇑
# peaks	1	<	2 ⇑
P-P interval	1	<	2 ⇑
Impulse	1	>	0.67 ⇓

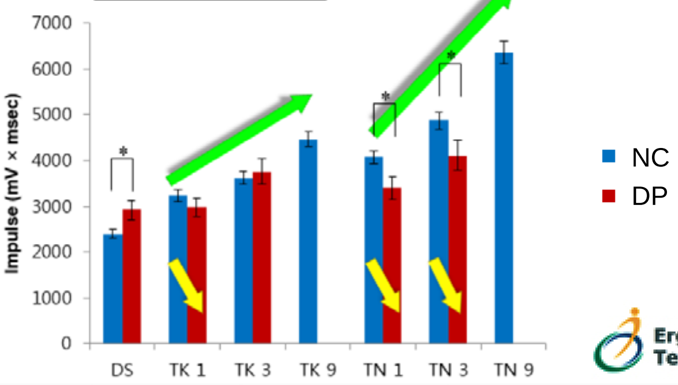
# peaks



P-P interval



Impulse



S4. Diagnostic Model: Method

Covariates

Amplitude
(mV)

- Highest peak
- 2nd highest peak
- Highest - 2nd highest peak
- Average peak

Duration
(msec)

# peaks
(unit)

Interval
(msec)

- Longest peak interval
- 2nd longest peak interval
- Highest - 2nd highest interval
- Average peak interval

Impulse
(mV x msec)

	20s	30s	40s	50s	60s	70s	80s	Total
Mild	-	1	-	5	8	4	1	**19**
Moderate & Severe	-	-	1	2	5	5	4	**17**
Total	-	1	1	7	13	9	5	36

Factors

Age
(year)

Gender
(female, male)

Cumulative *logit* model

(ordinal logistic regression)

Degree of dysphagia

- 0: normal
- 1: mild
- 2: moderate / severe

⇒ Used data: TN 1 ml for practicality

⇒ Eliminated data of 5% by ±2SD and CV < 0.5

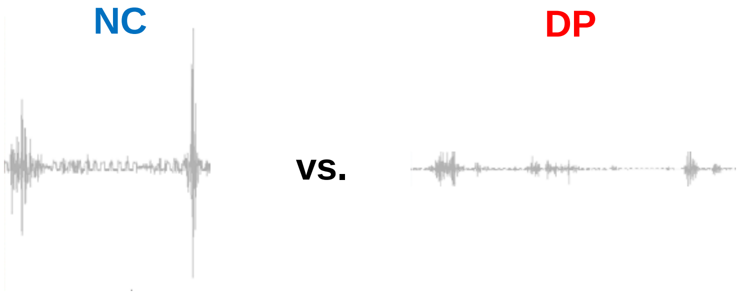
S4. Diagnostic Model: Performance

	※ *n* = 151	Actual class		
		Normal	Mild	Moderate & Severe
Predicted class	Normal	120	0	1
	Mild	0	13	0
	Moderate & Severe	0	4	13

- Specificity = 100%
- Sensitivity for mild = 76%
- Sensitivity for moderate/severe = 93%

Discussion

- ❑ Quantitative swallowing assessment of the movement of the phalangeal organs using an ultrasonic Doppler sensor



Measure	NC		DP
Amplitude	**1**	>	**0.63** ⇓
Duration	**1**	<	**2 ~ 4** ⇑
# peaks	**1**	<	**2** ⇑
P-P Interval	**1**	<	**2** ⇑
Impulse	**1**	>	**0.67** ⇓

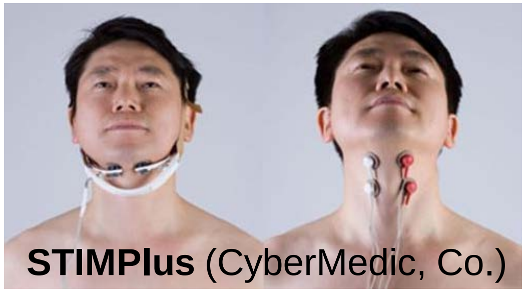
⇒ Dysphagic patients: more swallowing due to impaired movement in the pharynx by stenosis or dysfunction → amplitude ⇓, duration ⇑

- ❑ Diagnostic model development for the severity of dysphagia: normal, mild, moderate/severe (specificity = 100%, sensitivity for mild = 76%, sensitivity for M/S = 93%)

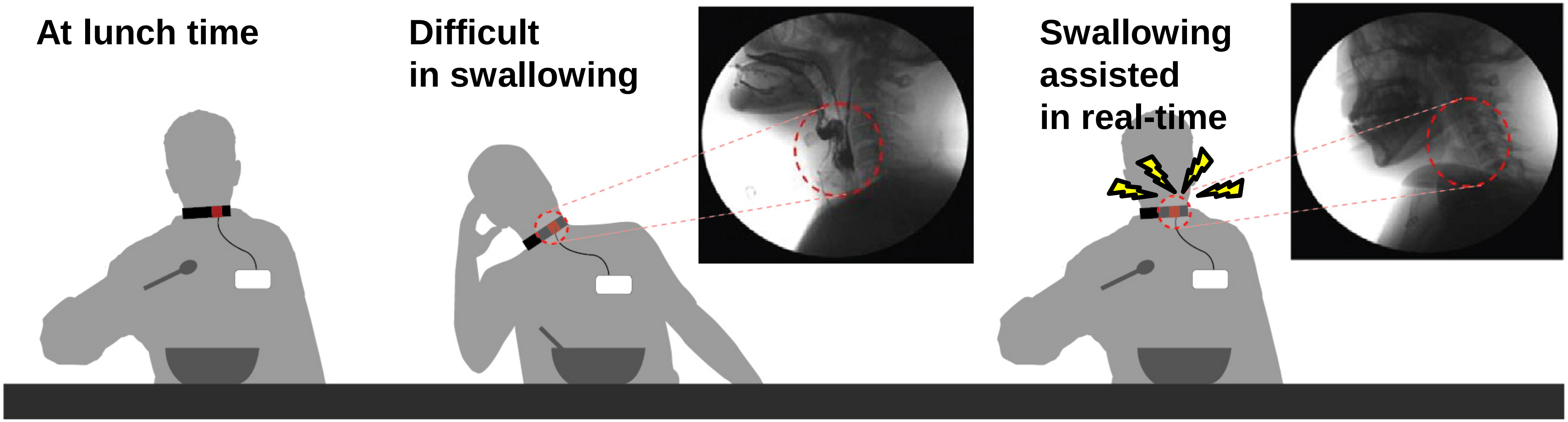
⇒ Clinically effective system for dysphagia diagnosis using measurements from swallowing only 1 ml of water

Future Study

- ❑ Interoperation with dysphagia therapy technology



STIMPlus (CyberMedic, Co.)



At lunch time

Difficult in swallowing

Swallowing assisted in real-time

⇒ **Assist swallowing in real-time by interoperating with a functional electrical stimulation (FES) system (automatic stimulation of neck muscle at the right time)**

Q & A

Thank You for your attention!