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Maximum Upper Esophageal Sphincter (UES) Admittance: A Non-Specific Marker of UES Dysfunction

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Running Head: UES admittance in pharyngeal dysphagia

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ABBREVIATIONS:

0.2 sec IRP	0.2 second integrated relaxation pressure
AIM	automated impedance manometry
CPB	cricopharyngeal bar
HRIM	high-resolution impedance manometry
IBP	intrabolus pressure
LES	lower esophageal sphincter
MND	motor neuron disease
PFA	pressure flow analysis
UES	upper esophageal sphincter

- **KEY MESSAGES**

- The UES maximum admittance discriminates patients with both MND and CPB (with likely reduced UES opening) from non-elderly healthy controls
- The 0.2 Second IRP also distinguished patients with MND from young controls, but failed to distinguish CPB.
- Both the UES maximum admittance and 0.2 sec IRP were similar between CPB patients and elderly controls (80+ years)
- UES maximum admittance is an indicator of UES dysfunction and may be a useful marker for swallowing dysfunction during HRIM

ABSTRACT

Background: Assessment of upper esophageal sphincter (UES) motility is challenging, as functionally UES relaxation and opening are distinct. We studied novel parameters, UES admittance (inverse of nadir impedance) and 0.2-sec integrated relaxation pressure (IRP), in patients with cricopharyngeal bar (CPB) and motor neuron disease (MND), as predictors of UES dysfunction.

Methods: Sixty-six healthy subjects (n=50 controls 20-80 yrs; n=16 elderly >80 yrs), 11 patients with CPB (51-83 yrs) and 16 with MND (58-91 yrs) were studied using pharyngeal high-resolution impedance-manometry. Subjects received 5x5ml liquid (L) and viscous (V) boluses. Admittance and IRP were compared by age and between groups. A p-value <0.05 was considered significant.

Key Results: In healthy subjects, admittance was reduced (L: P=0.005 and V: P=0.04) and the IRP higher with liquids (P=0.02) in older age. Admittance was reduced in MND compared to both healthy groups (Young: P<0.0001 for both, Elderly L: P<0.0001 and V: P=0.009) and CPB with liquid (P=0.001). Only liquid showed a higher IRP in MND patients compared to controls (P=0.03), but was similar to healthy elderly and CPB patients. Only admittance differentiated younger controls from CPB (L: P=0.0002 and V: P<0.0001), with no differences in either parameter between CPB and elderly subjects.

Conclusions and Inferences: The effects of aging and pathology were better discriminated by UES maximum admittance, demonstrating greater statistical confidence across bolus consistencies as compared to 0.2 sec IRP. Maximum admittance may be a clinically useful determinate of UES dysfunction.

Keywords: Admittance, upper esophageal sphincter, high resolution impedance manometry, pressure flow analysis

INTRODUCTION

Manometric definition of upper esophageal sphincter (UES) dysfunction has proven challenging [1-3]. The Chicago classification of esophageal function [4] does not currently include any UES metrics. UES relaxation by deactivation of the CP muscle can be recorded using manometry. However UES relaxation is distinct from UES opening which relies on numerous factors including UES distensibility [5], UES distraction by the suprahyoid muscles [6,7], bolus volume and viscosity [6-8] and the absence of physical obstruction [9]. UES opening is traditionally assessed using simultaneous videofluoroscopy [6-9,11,12]. To date, non-radiological measures have not been sufficient to detect UES opening dysfunction.

Recently Omari et al. demonstrated that the addition of impedance in the form of high-resolution impedance manometry (HRIM) may be of value in assessing pharyngeal and potentially upper esophageal sphincter function [13-16]. Impedance has been increasingly used to determine bolus transit and direction during gastrointestinal motility studies [17-20]. In addition, within a hollow viscus, intrabolus impedance changes are related to wall proximity [21]. This determination of luminal cross sectional area [22,23] can allow time and position of nadir impedance to be related to maximal luminal distension. Impedance can thus be used to non-radiologically track the bolus in time and space (as the bolus causes distension as it is propelled), a principle which has led to the development of pharyngo-esophageal pressure flow analysis (PFA) [13-16]. In this context, the nadir impedance value has been shown to relate to UES opening, measured during simultaneous radiology [24]. Similar findings from Kim et al. using esophageal cross sectional area (CSA) as measured by ultrasound indicate maximum admittance (inverse impedance) to have a superior linear correlation with CSA in the esophagus [23] when compared to nadir impedance.

The aims of this study were to measure pharyngeal HRIM in dysphagic patients, with suspicion of restricted UES relaxation and/or opening, in comparison to healthy controls over a range of ages. Both UES maximum admittance and 0.2 second IRP [25] were compared for their ability to distinguish dysphagic patients from controls. Lastly, UES maximum admittance was compared with the 0.2 second IRP [25] in patients, for its ability to manometrically assess UES function and discriminate patients from controls.

MATERIALS AND METHODS

Study Participants

Sixty-six healthy volunteers (aged 20 - 91 years) were recruited through community advertisement (Southern Adelaide Clinical Human Research Ethics Committee; SAC HREC Approval No. 403.10). To elucidate any effects of advanced older age, healthy subjects were stratified into the following 2 groups: younger controls (n=50) and older healthy subjects (>80 years, n=16). Twenty-seven patients were recruited through our institutional swallowing disorders clinic (SAC HREC Approval No. 283.11). Of these, eleven had clinically significant UES narrowing on radiology (cricopharyngeal bar with >50% luminal occlusion) along with oropharyngeal dysphagia symptoms and were included in the CPB cohort (aged 71 ± 9 years). None of the cohort included in this study had Zenker's diverticulum. Sixteen patients were recruited with motor neuron disease (MND) (70 ± 9 years). Of these, eleven had lower motor neuron and five with upper motor neuron involvement and dysphagia symptoms. These patients had likewise been demonstrated to have radiologically reduced UES opening [26].

All subjects were screened via questionnaire and excluded with a history of gastroesophageal reflux disease, previous upper GI surgery or taking medications known to impact on gastrointestinal motility. Control subjects were also screened and excluded if they

gave a history of oropharyngeal or esophageal dysphagia on pre-study interview. All subjects gave written informed consent prior to participation in the study.

Measurement Technique

Participants underwent manometric assessment using a MMS Solar GI HRIM System recording at 20Hz (MMS, Enschede, The Netherlands) and Unisensor catheter (Unisensor, Aticon, Switzerland) with one of two configurations: 25 pressure (P)/12 impedance (I) or 36P/16I. Uni-directional pressure sensors were spaced 1cm and impedance segments 2cm apart. Recordings were performed in a sitting posture with head in a neutral position. The two different catheters used were identical in pressure and impedance sensor configuration, as well as catheter diameter.

Study Protocol

Following nasal administration of co-phenylcaine forte spray and 2% lignocaine gel, subjects were intubated with the sensors in a posterior orientation and allowed a 15 minute accommodation period. Subjects then received five boluses of 5ml of both liquid (0.9% normal saline) and standardized viscous bolus (EFT Viscous Swallow Challenge Medium, viscosity 13,000 cP; Sandhill Scientific, Denver, Co. USA) via a syringe and asked to swallow once on cue. All subjects tolerated the study procedure well, and none reported side effects during or following the procedure.

Data Analysis

Manometric data were exported as ASCII files (CSV format) and analysed using a Matlab routine (Matlab, Natick, NY). Impedance values were converted to their inverse product, maximum admittance ($1/\text{ohms}$, mS). Data are median (IQR) unless otherwise stated.

A region of interest was defined from the HRM pressure topography plot, which accommodated the period of UES relaxation (onset to post-relaxation peak) and the 2cm or more elevation of the sphincter that occurs during UES relaxation [6]. All axial pressures within the limits of high-pressure zone were measured and an 'e-sleeve' approach was used to define the UES pressure profile based on time and location of maximum axial pressure [2]. The UES axial pressure profile was used to determine the 0.2-second upper esophageal sphincter integrated relaxation pressure (IRP), defined as the median of the lowest pressures recorded over 0.2 cumulative, but not necessarily consecutive, seconds [25]. It has been argued for the inclusion of this metric in pharyngeal measurements as the physiological equivalent of the 4 second IRP for the lower esophageal sphincter. The 0.2 or 0.25 second interval used is based on the 5th percentile for 5 and 10ml swallows as per Ghosh et al. [2].

Figure 1 shows images from a control subject who underwent simultaneous HRIM and radiological investigation as part of a previous study investigating UES function [26]. Following bolus determined neurogenic triggering the UES first relaxes, indicated by a drop in UES pressure, after which it opens, represented by a rise in admittance up to a maximum, which occurs at the point of maximal luminal distention.

The simultaneously recorded UES admittance measurements, mapped to the time and position maximum axial pressure, were then used to derive a corresponding UES admittance profile. The highest level of UES admittance reached during relaxation was defined as UES maximum admittance (see figure 2 for example [26]).

Analysis of pharyngeal pressure flow metrics (AIM analysis) were performed as previously described [14].

Statistical Analysis

Data were analysed using SPSS v 22.0 (IBM, Armonk, NY) and Prism Plus 6.0 (Graphpad, San Diego, Ca). Comparison between groups were made through determination of one way

ANOVA and independent samples t-test or Mann Whitney U-test when non-normally distributed. A P-value of <0.05 was considered statistically significant.

RESULTS

Effects of Older Age on UES Parameters

For healthy subjects aged >80 years, UES maximum admittance was lower when compared to younger controls, during both liquid (4.3 (3.6 – 5.3) vs. 5.6 (4.8 – 6.2) mS; P=0.005) and viscous (3.8 (3.0 – 4.2) vs. 4.1 (3.8 – 4.3) mS; P=0.04) swallows (figure 3).

The 0.2 second IRP for the UES was increased with liquids in older healthy subjects (3.5 (-0.1 – 8.0) mmHg) compared to younger controls (-1.6 (-3.0 – 2.2) mmHg; P=0.02) (figure 4), but age had no effect on the IRP with viscous bolus.

Patients with Cricopharyngeal Bar (CPB)

In patients with a CPB, the maximum admittance was lower when compared to younger healthy controls with both liquid (3.9 (3.7 – 4.2) vs. 5.6 (4.8 – 6.2) mS; P=0.0002) and viscous boluses (3.2 (2.8 – 3.5) vs. 4.1 (3.8 – 4.3) mS; P<0.0001). However, there was no significant difference in maximum admittance between CPB patients and the oldest group of healthy subjects (>80 years) for either bolus consistency.

There was a trend for a higher IRP 0.2 sec in CPB when compared to younger controls with liquids (3.75 (0.5 – 5.7) vs. -1.6 (-3.0 – 2.2) mmHg; P=0.06), but there was no significant difference during viscous swallows, or when compared to the older healthy group for either consistency.

Patients with Motor Neuron Disease (MND)

For patients with MND, the UES maximum admittance was significantly lower than younger controls, during both liquid (2.7 (2.5 – 3.3) vs. 5.6 (4.8 – 6.2) mS; P < 0.0001) and viscous (2.8

(2.3 – 3.2) vs. 4.1 (3.8 – 4.3) mS; $P < 0.0001$) swallowing (figure 3). Admittance was also reduced in MND patients when compared to the older healthy group with liquid ($P < 0.0001$) and viscous ($P = 0.009$) boluses. In the patient groups, maximum admittance was higher in those with CPB when compared to MND during liquid ($P = 0.001$; figure 3A), but not viscous, swallowing.

The IRP 0.2 sec in MND patients was higher when compared to young controls with liquids (3.6 (1.0 – 6.12) vs. -1.6 (-3.01 – 2.2) mmHg; $P = 0.03$), and a strong trend was seen with viscous bolus (5.8 (3.8 – 12.6) vs. 3.4 (0.8 – 8.9) mmHg; $P = 0.05$) (figure 4). There were no differences in 0.2 sec IRP between patients with MND and either the older healthy group or patients with CPB.

Comparison of UES Parameters between Aged Controls and CPB and MND patients

There was no significant difference in maximum admittance or 0.2 IRP between the oldest healthy group and patients with CPB; whilst maximum admittance, but not IRP, was significantly different between MND patients and elderly controls (Figures 3 and 4). Of the two parameters, UES admittance showed a clear continuum of decrease in relation to the pathologies with increasing severity of oropharyngeal dysphagia (OPD).

Pressure Flow Analysis

Pressure flow data are displayed for liquid (Table 2) and viscous (Table 3) swallows.

Pressure-flow data for MND patients show higher hypopharyngeal intrabolus pressures (PNadImp), consistent with increased flow resistance, and lower pharyngeal peak pressure (PeakP) consistent with weaker pharyngeal propulsion. For viscous swallows, TNIPP, indicative of distention-contraction latency was shorter, consistent with perturbation of sensory modulation of motor functions. The swallow index was highest in the MND patients, which was consistent with this group having the clinically most severe OPD. Of the six MND

patients with a hypopharyngeal IBP in excess of the 90th percentile during liquid swallows, four had a low pharyngeal PeakP and all of these had a bulbar variant of MND. Three of these patients also had a raised hypopharyngeal IBP during viscous swallows, along with two subjects with normal pharyngeal PeakP (upper limb variant of MND).

In contrast with MND patients, CPB patients did not have higher hypopharyngeal intrabolus pressures (PNadImp); hence, these data were not consistent with increased flow resistance. However, CPB patients, like those with MND, showed evidence of sensory modulation of motor function i.e. shorter latency from distension to contraction (TNIPP) (viscous only) and lower PeakP. The Zn/Z integral was highest in the CPB patients, which was consistent with this group having more post-swallow residue on radiology.

DISCUSSION

The findings of this study support the use of maximum admittance as a measure of upper esophageal sphincter (UES) dysfunction, discriminating dysphagic patients from non-elderly healthy controls. Maximum admittance also distinguished MND patients from elderly subjects, unlike the 0.2 sec IRP. Furthermore, maximum admittance was reduced in older age, in keeping with a reduced UES compliance reported with aging [27,28]. The 0.2 second IRP was increased in patients with MND compared to younger controls, although there were no demonstrable effects in CPB. Interestingly, there were no significant differences between either the IRP or maximum admittance in patients with CPB compared to healthy subjects over eighty years. Based on pressure flow parameters, both clinical cohorts demonstrated evidence of dysfunction in relation to the sensory modulation of motor functions

The 0.2 second integrated relaxation pressure in the UES has been proposed as a measure of UES restriction [25]. However, the UES is normally tonically contracted and does not relax

completely [7,29,30]. Some degree of residual pressure in the UES is thus normal and any intra-bolus pressures at the proximal margin of the UES will usually be captured in the IRP measurement, which is based on the E-sleeve concept. It could be argued that dry swallows may represent a better estimate of completeness of UES relaxation based on the IRP.

Bolus volume and viscosity are of great importance in determining UES opening [6-8]. The pharyngeal stripping wave is typically of greater amplitude and velocity than esophageal contractions. Increased hypopharyngeal IBP has been shown to be one correlate of UES dysfunction caused by obstruction [31], but probably only applies if the pharyngeal contraction is of a sufficient vigor. However many conditions causing oropharyngeal dysphagia, such as motor neuron disease, have markedly reduced pharyngeal amplitude. It remains challenging discriminating subtypes of UES dysfunction in this context and patient groups with CPB and MND may have both reduced UES opening and pharyngeal weakness. Further work is needed to disentangle reduced UES opening due to reduced tongue base movement or pharyngeal constrictive weakness from those with restrictive UES pathology. We have previously demonstrated that patients with MND have profound changes in neuromechanical states within the UES, with functional consequences leading to reduced pharyngeal bolus clearance [26]. In this study, UES opening, inferred by maximum admittance, was markedly reduced in MND patients when compared to age-matched controls, most probably due to reduced action of the suprahyoid muscles on UES distraction. The current study demonstrates that both lower UES maximal admittance and increased 0.2 second IRP identify the reduced UES relaxation seen in MND.

Interestingly, there was no significant difference in both the maximum admittance and 0.2 sec IRP between patients with CPB and oldest group of healthy controls aged over eighty years. Posterior pharyngeal impressions (typically rmed cricopharyngeal bars) occur at similar rates in elderly patients with dysphagia and healthy volunteers [32]. No radiology

data are available for our control subjects, as this was not clinically indicated. However, it is conceivable that some of the asymptomatic elderly individuals may have had an undiagnosed CPB which may become clinically significant as swallowing functional reserve diminishes further with age. This could have influenced both the UES maximum admittance and 0.2 sec IRP data in this 80+ age cohort. In addition, 6 of the patients with CPB had marked pharyngeal weakness, likely explaining at least in part their dysphagia symptoms. Interestingly only one CPB patient had a markedly increased hypopharyngeal IBP which, like many in the MND cohort, paradoxically occurred in association with pharyngeal pressures weaker than those measured in controls. Taken together these findings add weight to the idea that the presence of a CPB on radiology does not necessarily imply that this is the cause for dysphagia symptoms [33] and an obstructive pathology should not necessarily be assumed in this setting. Indeed, the lack of increased hypopharyngeal intrabolus pressures argues against an obstructive pathology in the current study. Our data suggest that concomitant sensory dysfunction and pharyngeal (motor) weakness leads to residue retention in the presence of a CPB, this may be the root cause of symptoms in this cohort. Further investigation of the radiological correlation of UES maximum admittance and UES diameter using simultaneous radiology in both the lateral and AP planes are required.

An analysis of the pressure flow data as described demonstrates the complex nature of patients with cricopharyngeal bars in combination with weak pharyngeal peristalsis and motor neuron disease in combination with reduced UES opening, in terms of discriminating between neuromuscular and obstructive causes of UES dysfunction. The similarities between UES admittance in healthy elderly subjects and patients with CPB suggests that the finding of a CPB on radiology needs to be interpreted with some caution, as this structure may not necessarily be causing significant mechanical obstruction of the lumen. However, it should be noted that the elderly group were 15 years on average older than both clinical

cohorts and, despite these age differences and in stark contrast to IRP measurements, a continuum of reducing UES admittance was apparent (Figure 3). This observation is in line with deteriorating swallowing function consistent with the clinical severity of dysphagia reported in the different groups.

There are several limitations in interpreting the findings of this study. Although the method of recording motility and flow in the pharyngeal segment is technically difficult, the use of high-resolution manometry overcomes most of these challenges and presents the optimum way of obtaining an adequate recording from this region. However, the impedance segments in the assembly are 2 cm apart, and the UES moves superiorly by up to 2cm during swallowing. Tracking the UES maximal pressure throughout the study in order to identify UES superior movement (figure 2) provides a solution to this. Bolus volume influences UES opening aperture and volume effects on both admittance and 0.2sec IRP are worthy of further study. The majority of patients, but not healthy controls, had concurrent radiology in this study, so no firm conclusions can be drawn on the correlation between UES maximum admittance and radiological UES opening. More studies examining this relationship are needed. Due to the radial asymmetry of the UES [34], it is possible pressure measurements (made with uni-directional sensors) may have been less reliable and this could have contributed to loss of sensitivity of IRP of the UES.. The appeal in pressure flow analysis techniques is that measurements during distension and timing relationships, may be less susceptible to error. Such errors may be inherent when determining luminal forces generated by a non-symmetrically contracting structures. . Further studies are needed to compare the reliability of unidirectional vs. circumferential sensing of UES pressures.

Finally, it is important to recognize that the measurement of maximum admittance is a non-specific marker of pharyngeal dysfunction(s). A reduced UES diameter, inferred by lower

levels of admittance, may have multiple causes. These include, structural pathology, reduced distension due to a weak lingual propulsion and/or weak pharyngeal stripping contraction and reduced swallow volume due to 'piecemeal swallowing' and retention of some of the administered bolus in the oral cavity. Nevertheless, the maximum admittance when below normal limits may present as a useful non-specific marker of swallowing dysfunction that may be measured longitudinally over time and following interventions designed to promote UES opening (dilation, myotomy, Shaker exercise).

In conclusion, this study shows that UES maximum admittance is a non-specific marker of UES opening dysfunction that reduces with aging. When compared to the 0.2 second IRP, a marker of UES relaxation, it better able to discriminate patient groups known to have pharyngeal motor abnormalities.. Pharyngeal and UES manometry remains technically challenging, but recent advances using high-resolution impedance manometry and subsequent pressure-flow analysis appear to provide grounds for devising a clinically useful classification of pharyngeal and UES abnormalities.

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Author Contributions

CC and TO developed study concept and design, data analysis and writing the manuscript; LB performed the research, data analysis and writing the manuscript; SK performed the research and data analysis; CB and AT performed the research; RH and RJF in study design, data interpretation and critical revision of manuscript

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No competing interests declared.

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FIGURE LEGENDS

Figure 1: UES pressure (solid line) and admittance (broken line) during UES relaxation and opening. Admittance follows UES opening and thus the upslope in admittance only occurs after complete UES relaxation. The UES likewise closes prior to contraction representing the pharyngeal stripping wave, which follows the bolus tail through the UES. Maximal admittance occurs at maximal UES diameter. UES movement and opening is tracked on simultaneous radiology in this example. *(Note: Previously published image of simultaneous video-manometric recording from a control subject included for illustrative purposes [26]).*

Figure 2: Methodology for measuring UES nadir impedance (maximum admittance), whilst tracking UES movement. P max in the UES region is used in order to track UES movement and maximum admittance is determined through the UES region along this P max line. *(Note: Previously published image of simultaneous video-manometric recording from a control subject for illustrative purposes [26]).*

Figure 3: Upper esophageal sphincter (UES) maximum admittance for liquid (A) and viscous (B) swallows. Maximum admittance is significantly lower, indicating a narrower aperture, in patients with motor neuron disease (MND), when compared to health (young and older) and patients with cricopharyngeal bar (CPB). Subjects with CPB differ from the younger controls, but not from those aged over eighty years. Admittance was reduced in older age. * $P < 0.05$, ** $P < 0.01$, # $P < 0.001$, ## $P < 0.0001$ vs. control; ^ $P < 0.01$, ^^ $P < 0.0001$ vs. >80 yrs; § $P = 0.001$ vs. MND

Figure 4: Upper esophageal sphincter 0.2 second integrated relaxation pressure (0.2 sec IRP) for liquid (A) and viscous (B) swallows. 0.2 Sec IRP failed to distinguish MND patients from age-matched controls. 0.2 Sec IRP was however higher in controls over 60 yrs and both

patients with cricopharyngeal bars (CPB) and motor neuron disease (MND), when compared to controls aged 20-39 yrs during liquid swallowing in in patients with CPB during viscous swallowing. * $P < 0.05$ vs. controls

FIGURE 1

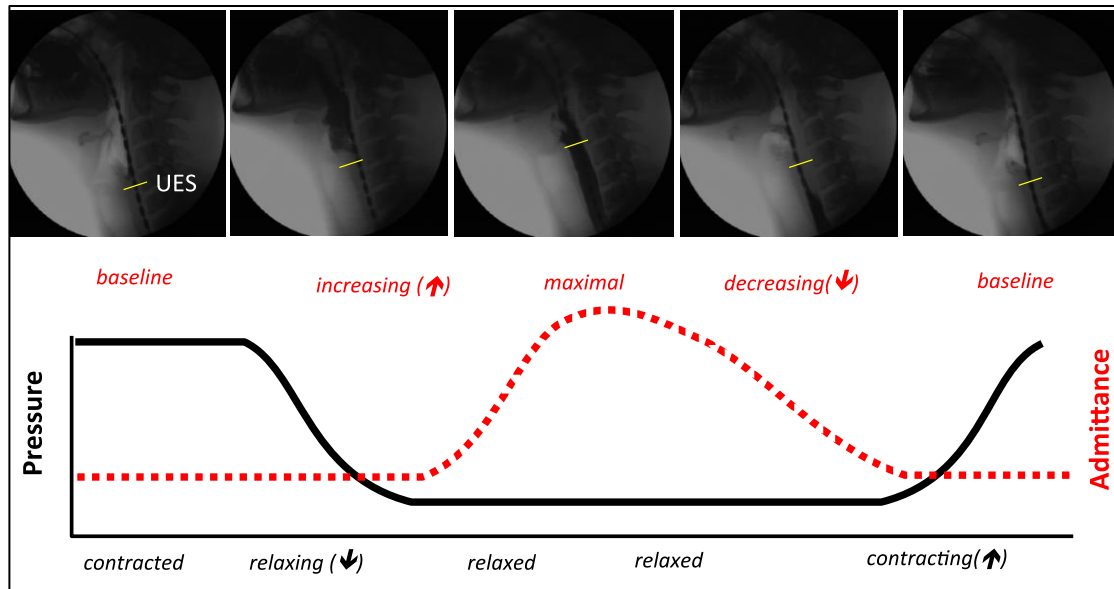


FIGURE 2

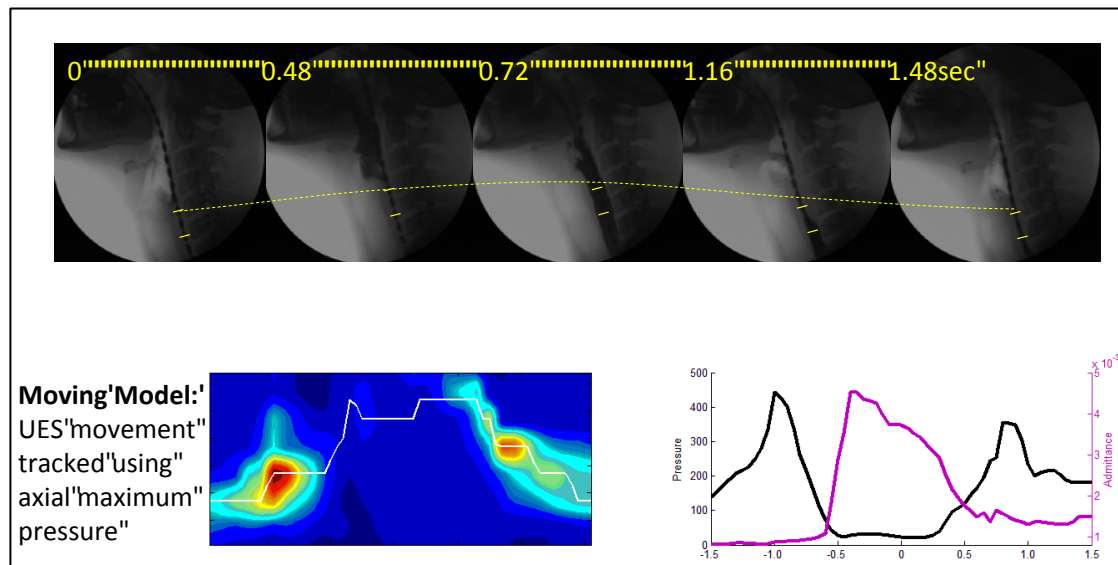


FIGURE 3

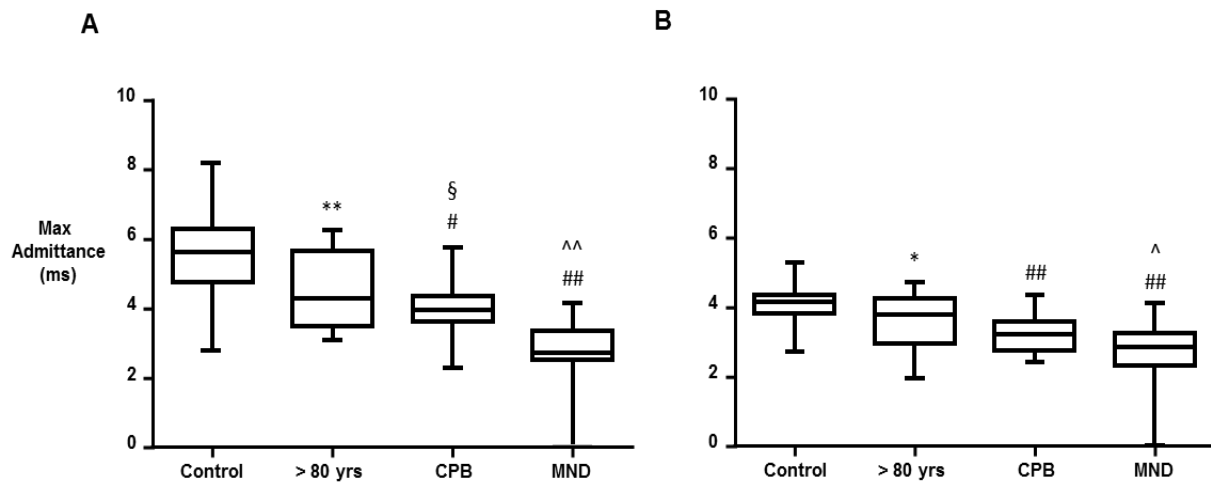


FIGURE 4

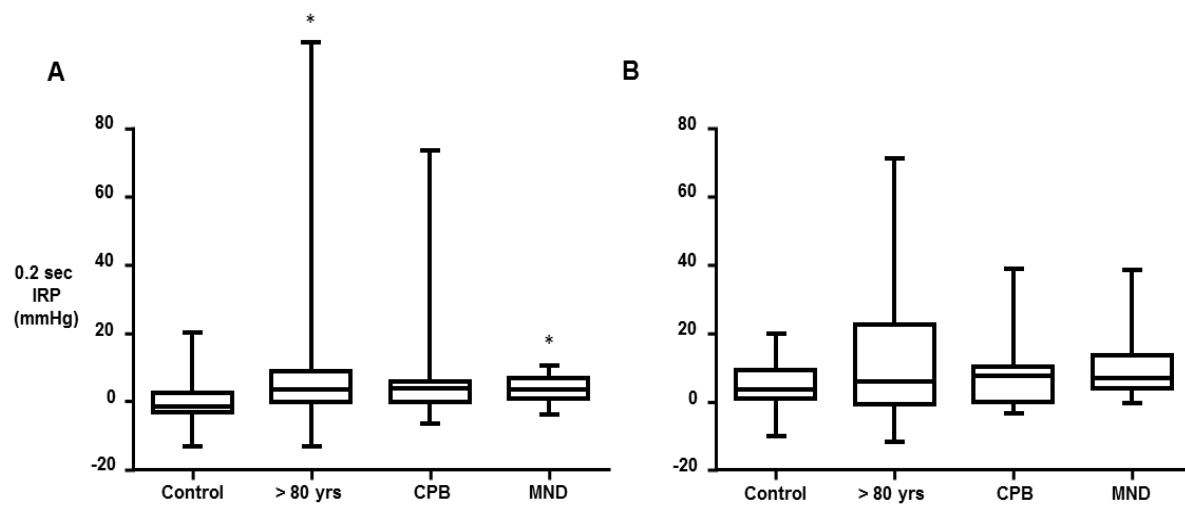


TABLE 1**Demographic data and characteristics of study participants**

	Controls	Aged (>80 yrs)	CPB	MND
Age (\pmSD) yrs	48 \pm 18	85 \pm 4 ^{***}	71 \pm 9 ^{***,###}	70 \pm 9 ^{***,###}
Gender (M:F)	20:30	10:6	6:5	10:6
Dysphagia	None	None	Mild	Moderate to Severe
Recruitment	Community	Community	Swallowing disorders clinic	Swallowing disorders clinic
Group Characteristics	Healthy volunteers	Healthy volunteers, independent living, self-caring	Independent living, self-caring	Independent living, care assistance (median AKPS 60-70%), none tube fed

*** p < 0.001 compared to controls; ### p < 0.001 compared to aged. AKPS = Australian Karnofsky Performance Scale

TABLE 2

Impedance/pressure metrics (median, IQR) derived from AIMplot analysis during liquid swallows

	Controls	Aged (>80 yrs)	CPB	MND
PeakP (mmHg)	136[104;208]	161[117;221]	80[55;113] ^{***,###}	77[57;118] ^{***,##}
PNadImp (mmHg)	8[3.4;13.6]	8.9[4.2;17.9]	6.6[4.2;17.9]	13[7.6;21.5] [*]
TNIPP (s)	0.46[0.40;0.49]	0.44[0.38;0.50]	0.41[0.25;0.45]	0.40[0.30;0.50]
FI (s)	0.44[0.32;0.69]	0.87[0.62;1.29] ^{**}	0.81[0.51;1.23] [*]	1.20[0.75;1.45] ^{***}
SRI	1.6[0.7;3.8]	5.2[1.3;10.3] [*]	6.3[2.7;17.9] ^{**}	16.3[10.9;30.3] ^{***,##}
iZ/Zn	91[51;151]	171[126;296] ^{**}	267[114;409] ^{***}	234[177;335] ^{***}
IRP0.2 (mmHg)	-1.6[-3;2.3]	3.6[-0.2;8.7] [*]	3.7[-0.1;5.8]	3.6[0.7;6.9] [*]
UES Max Adm (mS)	5.6[4.7;6.3]	4.3[3.5;5.6] ^{**}	4[2.5;3.4] ^{***}	2.7[2.5;3.4] ^{***,###,\$\$}

* P<0.05, ** P<0.01, *** p < 0.001, vs. controls; ## P<0.01, ### P<0.001, vs. aged; \$\$ P<0.01 vs. CPB

TABLE 3

Impedance/pressure metrics (median, IQR) derived from AIMplot analysis during viscous swallows

	Controls	Aged (>80 yrs)	CPB	MND
PeakP (mmHg)	141[98;201]	141[114;244]	84[59;120]**,###	69[64;109]**,###
PNadImp (mmHg)	10[4.9;16.5]	17[8.9;32.5]*	10.1[3.3;19.9]	18.7[12.3;24.1]**
TNIPP (s)	0.38[0.34;0.42]	0.39[0.36;0.44]	0.32[0.25;0.36]**,###	0.31[0.30;0.41]*,#
FI (s)	0.43[0.37;0.73]	0.81[0.63;1.28]**	0.78[0.51;1.28]**	1.15[0.73;1.38]**
SRI	2.2[0.9;5]	6.3[4.4;12.8]**	5.9[1.7;11.6]	18.4[8.8;33.5]**,###,§
iZ/Zn	126[69;211]	183[120;314]	215[126;587]	266[203;329]**
IRP0.2(mmHg)	3.4[0.8;9.1]	5.8[-0.8;23]	7.5[0.1;10.2]	6.9[3.8;13.6]
UES Max Adm (mS)	4.1[3.8;4.3]	3.8[2.9;4.2]*	3.2[2.8;3.6]**	2.9[2.3;3.3]**,###

* P<0.05, ** P<0.01, *** p < 0.001, vs. controls; # P<0.05, ### P<0.01, #### P< 0.001, vs. aged; § P<0.05 vs. CPB