Physiologic variables for videofluoromanometric assessment of dysphagia : an exploratory study

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Abstract

Study Aim : **To assess the physiological variables among Upper Esophageal Sphincter Nadir (UESN), Hypopharyngeal Peak Pressure (HPP) and Pharyngo-Esophageal Pressure Gradient (PEPG) for Videofluoromanometry (VFM).**

Patients & Method : **Exploratory non-randomised prospective study comparing UESN, HPP and PEPG of three cohorts of individuals presumably presenting very distinctive "manometric signatures" based on McConnel's Piston Model of swallowing : 11 non-dysphagic volunteers called the Control Group (CG), 10 dysphagic patients presenting a Myotonic Dystrophy (MD), at various stages of evolution, and 10 patients presenting a Crico-Pharyngeal Barr (CPB), with no post-swallow pharyngeal residue at a previous Modified Barium Swallow (MBS).**

VFM tests are performed using solid-state three unidirectional transducers produced by Gaeltec Inc. The simultaneous display storage of the standard fluoroscopic swallow of 10 ml liquid barium with UESN and HPP measurements, continuously recorded on a 3-channel polygraph, is performed using a Kay-Pentax Swallowing Work Station. PEPG calculations are subsequently made.

Results : **Significant different HPP and PEPG values were observed between the three cohorts. MD patients presented HPP and PEPG below 100 mmHg while CPB patients presented HPP and PEPG above 200 mmHg. The CG presented HPP and PEPG between 100 and 200 mmHg.**

UESN values revealed no significant difference between the three cohorts.

A reading scale is proposed. The aim of the scale is to make a link between HPP or PEPG values and physiopathological (not diagnostic) conditions. Patients presenting an HPP or PEPG below 100 mmHg indicate a High probability of Pharyngeal Propulsion Impairment while patients presenting an HPP or PEPG above 200 mmHg are more likely to have an Increased Flow Resistance with appropriate Propulsion Response.

Pros and cons for calculation of the PEPG, representing a possibly unnecessary step, are discussed.

Conclusions : **In our study, the use of HPP or PEPG as physiological variables provides quantitative data that allow VFM to discriminate three very distinctive swallowing conditions. Further studies are needed to assess the HPP and PEPG obtained with other manometic devices within the same specific populations for them to be considered as universal physiological variables. Eventually, further investigations should answer the question as to whether the calculation of the PEPG represents any value in comparison with HPP measurement alone.** (Acta gastroenterol. belg., **2009**, 72, **312-320**).

Key words : videofluoromanometry, dysphagia, myotonic dystrophy, crico-pharyngeal barr, pharyngeal manometry.

List of abbreviations in order of appearance.

UESN	Upper Esophageal Sphincter Nadir
HPP	Hypopharyngeal Peak Pressure
PEPG	Pharyngo-Esophageal Pressure Gradient
VFM	Videofluoromanometry
CG	Control Group
MD	Myotonic Dystrophy Patients
CPB	Crico-Pharyngeal Barr Patients
MBS	Modified Barium Swallow
UES	Upper esophageal Sphincter
FEES®	Fiberoptic Endoscopic Evaluation of Swallowing
SLP	Speech and Language Pathologist
PF	Propulsion Forces
FRF	Flow Resistance Forces
CTG	Cytosine-Thymine-Guanine
DMPK	Myotonic Dystrophy Protein Kinase
PAS	Penetration-Aspiration Scale
NJ	New Jersey, USA
SWS	Swallowing Work Station
HPZ	High Pressure Zone

Introduction

Videofluoromanometry (VFM), sometimes referred to as manofluorography or videomanometry in the English-written literature, combines simultaneous computer pharyngo-esophageal manometry and videofluoroscopy. It has been advocated since the 1980's by many authors (1-8). It is aimed at studying pharyngeal pressure generation and Upper Esophageal Sphincter (UES) relaxation in relation to bolus motion from the oropharynx towards the cervical esophagus.

VFM offers quantitative information in contrast to others' instrumental dysphagia work-up examinations as Modified Barium Swallow (MBS) or Fiberoptic Endoscopic Evaluation of Swallowing (FEES®). Both examinations widely recognized as the gold standard examinations of dysphagia's work-up arsenal, yet remain qualitative examinations exposed to reliability issues (9-13).

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Indeed, Stoeckli *et al.*, established a kappa coefficient for MBS ranging from 0.1 to 0.56 for inter-observer reliability depending on the parameters being identified (14). The presence of aspiration seems to represent the most reliable parameter (15). Finally, some very recent data shows that training to aspiration detection would lead to an acceptable inter-rater reliability (16). Little has been published regarding FEES inter-judging reliability, but available literature shows results comparable or slightly better than MBS (17,18,19).

Nevertheless, MBS and FEES remain cornerstone examinations widely used by physicians and Speech-Language Pathologists (SLP) around the world, mainly for its accessibility and ease of use.

On the other hand, the use of VFM, one of the few instrumental examinations offering quantifiable data on swallowing capabilities, remains limited.

There are several rationales explaining this somewhat incongruous situation :

- Access to equipment allowing VFM is limited, notably in Europe.
- Numerous VFM technical standards have been proposed since 1987 none of which may be considered as universally adopted (20). This is largely due to the variety of material in which teams have invested around the world. Material heterogeneicity is an issue.
- The positioning of the VFM probe within the pharyngo-esophageal segment, passing through the nasal fossa may be somewhat intimidating to some SLPs or even some physicians. Indeed, although many people treating dysphagic patients are used to transnasal procedures, the presumed tediousness of the technique could be an issue.
- The scope of indications for VFM is not clearly defined despite the case examples available in the literature (21).
- Eventually, the available quantitative reading scales for VFM are rather complex or purely qualitative (22-25). There is a need for quantitatively based reading scale.

These are valid hypotheses explaining why VFM is so scarcely utilized in clinical practice but one of the most concrete hypothesis was advanced by Peter J. Kahrilas *et al.* in an Editorial published in *Dysphagia* ten years ago (26).

In this editorial titled "First Measurements Standards, then Catheter Standards for Manofluorography", Kahrilas stated that for manometry to add to the diagnostic potential of MBS, two conditions have to be met, upfront :

"(1) Families of disease conditions must exist exhibiting similar fluoroscopic abnormalities (or no fluoroscopic abnormality) but distinct manometric signatures and (2) a standardized methodology of VFM must be feasible to optimally discern among these possibilities". The same author stated further : *"Viewed from this perspective, the methodology of VFM must first be examined from the vantage point of what physiological variables you need to measure and secondly, on how to detect them."* The authors eventually ended their argument by writing *"if condition number one is not met, there is simply no point to developing the technique."*

Ten years later, these questions still remain unanswered.

In an attempt to answer to Kahrilas' concerns, the purpose of this paper is to compare VFM results of two very different dysphagic populations to a healthy control group, using a precise VFM standardized methodology.

The two dysphagic populations were chosen based on their opposite aetiopathology based on McConnel's "Piston Model" of swallowing. The hypothesis formulated here, is that these two disease conditions would present very different "manometric signatures". The physiological variables observed in our study are : the Upper Esophageal Sphincter Nadir (UESN), the Hypopharyngeal Peak Pressure (HPP) and the Pharyngo-Esophageal Pressure Gradient (PEPG).

Contrary to Kahrilas' wishes, while attempting to explore HPP, UESN and PEPG as pertinent physiological variables, we compared "manometric signatures" that were similar to "radiological signatures" rather than dissimilar. From our point of view, the fact that VFM offers measurable quantitative data represents a value added, *per se*, even if imaging alone would have allowed the diagnosis.

The final goal of this paper is to assess which physiological variable would offer a reliable reflection of the physiopathological conditions that are at stake within the very specific observed samples.

Patients and Methods

Model on which pathologic cohorts were selected : the McConnel's "Piston Model"

Of the many models used to describe the pharyngeal phase of swallowing, McConnel's "Piston Model", proposed in 1988, remained the most widely used around the world. The "Piston Model" is based on the following assumption : the primary function of the pharynx is to generate a pressure gradient for swallowing without aspiration.

Citing McConnel : "*the tongue base acts like a plunger or a 'Piston' to develop a propulsive bolus-driving force*". According to this model the bolus-driving force will depend on two somewhat interdependent elements : (1) the Propulsion Forces (PF) and (2) the Flow Resistance Forces (FRF).

The PF are largely dependent on two elements : (a) the tongue appearing as the major pressure-generator and (b) the resistance of the pharyngeal walls acting as a dynamic chamber for the tongue.

In contrast the FRF are mainly determined by the upper esophageal sphincter (UES) behavior (hypo-relaxed, hyper-contracted, lack of passive opening etc...).

In order to assess the studied physiologic variables on the two edges of the "Piston Model" spectrum, two different cohorts of patients are investigated : (1) patients with low PF presumably presenting low PEPG and (2) patients with a high FRF presumably presenting high PEPG.

Type of study and cohorts inclusion criteria

The presented study is a non-randomized prospective trial comparing manometric values of three different cohorts recorded between June 2003 and June 2006. Cohorts were constituted as follows :

- 11 healthy volunteers, called the Control Group (CG)
- 10 dysphagic patients presenting a Myotonic Dystrophy (MD) at various stages of evolution
- 10 dysphagic patients presenting a radiological Crico-Pharyngeal Barr (CPB) with no significant post-swallow pharyngeal residue at a previous MBS.

Table 1 shows the age and gender characteristics of the three cohorts.

The CG cohort : all individuals were free of dysphagic complaints at the time of investigation. They did not present any medical history of dysphagia nor neck or brain surgery. None had undergone a previous VFM, Esophageal Manometry, MBS or FEES. Women at risk of being pregnant at the time of investigation were dismissed.

Individuals under medication potentially affecting their swallowing capacity were also eliminated from the study. All volunteers signed a consent form.

The MD cohort : MD is an autosomal dominant hereditary disorder with an incidence of 1 in 8000. Two types of MD are recognized : non-congenital and congenital MD. Clinically, MD has been categorized into three somewhat overlapping categories : mild MD, classical MD and congenital MD. Mild MD is characterized by cataract and mild myotonia with a normal life span. Classical MD is characterized by cataract, important myotonia, muscle weakness and often, cardiac conduction abnormalities with a possibility of shortened life span. Finally, congenital MD is characterized by mental retardation, severe myotonia and weakness at birth causing respiratory insufficiency leading to early death. All patients included in cohort MD were classical MD presentations. Diagnosis had been confirmed by a 100% sensitive DNA-based test detecting an expansion of the CTG trinucleotides repeated in the DMPK gene (27,28).

The impairment of palatal, lingual and pharyngeal muscle groups, leading to dysphagia and aspiration pneumonia, is well known (29,30). More recently, R.J. Leonard *et al.*. stated that weakness associated with the disease, as opposed to myotonia, was the most significant contributor of impairment (31). Therefore the MD group is expected to present a low PF at VFM.

All individuals of the MD cohort complained about some dysphagia ranging from slight to severe. None though had a history of pulmonary infection requiring hospital care, prior to investigation. All of them were exclusively fed orally. Some of them were spontaneously fed using swallowing rehabilitation maneuvers and/or food texture adjustments. None of the patients had experienced formal swallowing rehabilitation before examination.

MD patients were carefully interviewed to exclude any other medical or drug-induced dysphagia.

VFM was performed within the frame of the classic neuromuscular clinic swallowing impairment work-up.

The CPB cohort : Individuals of the CPB cohort complained of dysphagia more often described as a lump-in-the-throat rather than a cough or any other penetration-aspiration symptom. Three of the CPB individuals avoided solid food.

The CPB patients were carefully interrogated to eliminate any other medical or drug-induced dysphagia.

To be included in this cohort, individuals must have shown a CPB at a previous MBS done in-house or externally. Importance of the crico-pharyngeal narrowing was irrelevant. What was relevant though, was the ability for the pharynx to clear any barium residue after two swallows and a Rosenbeck-Robbins Penetration-Aspiration Scale (PAS) of stage 1 (32).

Individuals presenting a PAS Stage of 2 or more were not included. Assessments of PAS and pharyngeal residue were blindly performed by a radiologist and otolaryngologist, according to criteria defined by Eisenhuber *et al.* (33).

The purpose here was to select individuals presenting a high FRF with no evident sign of PF impairment.

Material characteristics

Pressure recordings were obtained from a Gaeltec CT/S3™ three uni-directional sensor manometric catheter, manufactured by Gaeltec, Hackenzak, NJ. Our catheter is a 100 cm long, 2.1 mm diameter pressure transducer presenting the following spacing between sensors : 3 cm between the tip of the catheter and the third-distal-sensor (positioned at the level of the UES), 3 cm between the third and the second sensor (positioned at the level of the hypopharynx) and eventually 2 cm between the second and the first–proximal-sensor (positioned approximately at the level of the oropharynx).

Table 1. — **Age and gender characteristics of cohorts**

Cohort	Mean	Range	Median	Gender
CG	*34*	*24-62*	*29*	*2F/9M*
MD	*42*	*20-70*	*42*	*3F/7M*
CPB	*65*	*37-92*	*65*	*4F/6M*

CG : Control Group ; MD : Myotonic Dystrophy ; CPB : Crico-Pharyngeal Barr.

This catheter configuration is aligned with standards proposed by Salassa *et al.* (34).

The simultaneous display storage of the standard fluoroscopic swallow along with the HPP and UESN measurements, continuously recorded on a three-channel polygraph, were performed using a Kay-Pentax Inc. Swallowing Work Station (SWS). It is important to note that the proximal sensor, located at the level of the base of tongue, was not used at all for the purpose of the study.

Procedure Protocol

After appropriate calibration of the sensors, the catheter is dipped into a 2% xylocaine gel. It is introduced into the right nostril. The catheter is blindly pushed within the nasal cavity keeping tight contact with the nasal floor.

The tip of the probe is positioned just above and behind the arytenoid cartilages under fluoroscopic guidance. The patient is then asked to perform a dry swallow. Once the larynx is elevated, the catheter is rapidly pushed into the cervical esophagus. This stage sometimes needs to be repeated if failed. During a last fluoroscopic guidance, the catheter is carefully pulled on while asking the patient to breath through his mouth. This is done in order to achieve a proper positioning of the distal sensor at the level of the cricoid cartilage coinciding with the level of the UES. Sensors are oriented posteriorly by rotating the catheter.

Although many authors consider the cricoid cartilage as the anatomical landmark of the UES, others prefer to define the UES as the "high pressure zone" (HPZ) of the pharyngo-esophageal segment. We arbitrarily decided not to seek this HPZ for two main reasons : (1) the precise location of this HPZ is highly debated but appears to be always above the crico-pharyngeal muscle and thus the cricoid cartilage, (2) the manometric catheter is moved upward during the pharyngeal swallow by the erection of the soft palate. According to Cook's review, by locating the distal sensor at the level of the cricoid cartilage, just above the presumed HPZ, investigators still have a reasonable chance to keep the distal and middle sensors within the "manometrically" interesting pharyngo-esophageal segment (35).

Eventually, the catheter is solidly taped to the nasal tip.

The patient's mouth is then loaded with 10 mL of barium while being asked to wait for the observer's signal before swallowing. The patient is then asked to try swallowing the entire bolus at once, exactly as he would do at home. Compensating head positioning is allowed.

Once images and waveforms are obtained on the SWS screen, the manometric time-cursor is moved along the first effective bolus swallow waveform, to the level of the second (middle or hypopharyngeal) sensor peak intensity. The HPP and the UESN pressures are recorded at this moment. The PEPG is calculated subsequently by subtracting the UESN value from the HPP value.

Further swallows are not considered.

In this study, the radiological part of the VFM is only used for 3 different purposes :

- To allow appropriate positioning of the manometry sensors
- To check the bolus oral clearance
- To visualize the very first effective swallow when the HPP and the UESN will be measured.

Statistics

As the UESN, the HPP and the PEPG did not show a normal distribution, the comparison between the three groups, CG, MD and CPB, was made using the Kruskall-Wallis Test. A p-value of 0.005 was considered as significant. The calculation was made with SAS version 9.

Results

No adverse events such as nasal bleeding, nausea or vomiting were observed during the procedures. Gagging reflex immediately after esophageal insertion of the catheter was avoided by telling the patient to breathe through his/her mouth.

Neither patient, nor volunteer asked to interrupt the procedure. Only two patients of the MD cohort spontaneously used the cephalic flexion or extension to swallow. All other individuals swallowed with a standard cephalic position.

Figures 1-3 show VFM recordings of three CG volunteers. Differences in pharyngeal and oesophageal manometric line aspects are noteworthy. Where pharyngeal signal appears acute and preceded by a ramping curve in Figure 2, it appears wide based and somewhat irregular in Figures 1 and 3. Likewise, post-swallow UES pressure increases present a signal of very different shape and amplitude. This is to underline that qualitative appraisal of manometric signals may vary considerably among healthy individuals, and from swallow to swallow. Figures 4 and 5 show VFM recordings of a MD and a CPB patient, respectively.

Table 2 summarizes the UESN and the HPP measured together with the calculated PEPG of each patient in each cohort.

HPP measures and PEPG calculation differences between the three cohorts were found to be statistically significant ($p < 0.001$).

Contrarily, UESN measures did not show any significant differences between the three groups.

Figure 6, 7 and 8 illustrate the HPP, UESN and PEPG values corresponding to each cohort respectively.

Discussion

There is a general opinion among dysphagia specialists, whether SLPs or physicians, to deplore a limited use

Fig. 1. — Simultaneous display of MBS and PEPG measurements of CG's Patient #4
PEPG = 147 mmHg – 17 mmHg = 130 mmHg
Note that the first pharyngeal signal does not correspond to any bolus swallow.
According to the procedure protocol, it is considered an artifact.

CG : Control Group ; MBS : Modified Barium Swallow ; PEPG : Pharyngo-Esophageal Pressure Gradient.

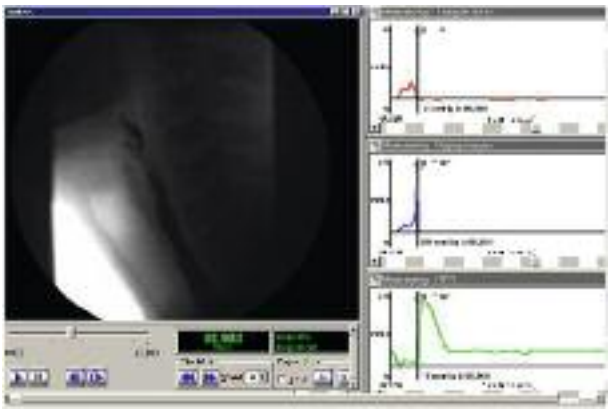

Fig. 2. — Simultaneous display of MBS and PEPG measurements of CG's Patient #2
PEPG = 139 mmHg – 14 mmHg = 125 mmHg

CG : Control Group ; MBS : Modified Barium Swallow ; PEPG : Pharyngo-Esophageal Pressure Gradient.

of pharyngeal manometry in dysphagia work-ups. They are convinced about the potential of pharyngeal manometry at large, and of VFM in particular, but do not see any clear way to clinically exploit it on a large scale. As previously written, access to the technology, lack of technical standardization and fuzzy clinical indications largely contribute to this paradox.

Access to technology

According to data graciously provided by Kay-Pentax Inc., eighty-eight Gaeltec CT/S3 Manometric probes,

Fig. 3. — Simultaneous display of MBS and PEPG measurements of CG's Patient #11
PEPG = 163 mmHg – 10 mmHg = 153 mmHg

CG : Control Group ; MBS : Modified Barium Swallow ; PEPG : Pharyngo-Esophageal Pressure Gradient.

customized following Salassa / McConnel's standards, have been sold around the world between 1999 and 2007. This number contrasts greatly with the minute number of publications made regarding this technology. Technology provider's guess is that the VFM technology, rather than being used on a day-to-day clinical basis by only a few teams, is either used for research purposes or not used at all ! The technology is more widespread than thought but with little or no use at all.

Standardization

English literature provides numerous papers written by very prestigious authors on measurement and technique standardizations of VFM. There is an ongoing discussion about which measurements to look for and which technical manometric standards should best be used. All these efforts are aiming towards the same goal : to minimize the effects of technical and patient-related parameters affecting the accuracy of pharyngeal manometric measurements. Indeed, multiple factors, as summarized in Table 3, can explain the wide variety of measurement standards obtained while performing UES manometric measurement tests (36-41). So much so, that Pouderoux listed at least ten UES resting manometric values described in the literature ranging from 55 mmHg up to 218 mmHg (42) !

In our study, the UES resting pressure values obtained were similar to those described by June A. Castell *et al.* (43). These values are comparable to those of teams using a solid-state unidirectional manometer with similar sensor positioning (44-46).

Nevertheless, many researchers, most of them coming from the gastro-intestinal field, use other types of sensors like circumferential transducers, perfused sleeves, microsleeves or an arterial balloon dilatation catheter. They are believed to take into better consideration all the

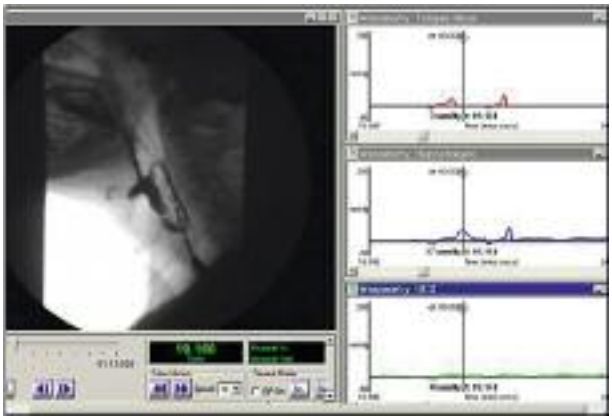

Fig. 4. — Simultaneous display of MBS and PEPG measurements of MD's Patient #5
PEPG = 37 mmHg – 8 mmHg = 29 mmHg
Note the adapted hyper-extended head position of the patient.

MD : Myotonic Dystrophia ; MBS : Modified Barium Swallow ; PEPG : Pharyngo-Esophageal Pressure Gradient.

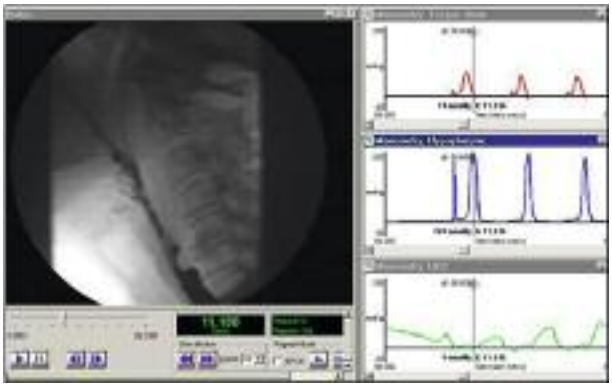

Fig. 5. — Simultaneous display of MBS and PEPG measurements of CPB's Patient #2
PEPG = 249 mmHg – 5 mmHg = 244 mmHg
Note that the first pharyngeal signal does not correspond to any bolus swallow.
According to the procedure protocol, it is considered an artifact.

CPB : Crico-Pharyngeal Barr ; MBS : Modified Barium Swallow ; PEPG : Pharyngo-Esophageal Pressure Gradient.

parameters influencing manometric measurements, thus resulting in more accurate measures (47-49).

The debate between solid state and perfused recording systems, each of them presenting strengths and weaknesses, is largely ongoing. The choice of any particular system depends largely on the nature of the organ under scrutiny. Indeed, the pharynx, composed of striated muscle with rapid rate of contraction, is best assessed with solid state intraluminal transducers while the UES, presenting a marked radial asymmetry, is best assessed with a perfused recording system (50).

To conclude, one can make the statement that there is presently no consensus on the type of material and technique that VFM should rely on.

Nevertheless, as Karhilas *et al.* wrote ten years ago, there is no need to discuss which technical standard would be superseded, as long as investigators do not agree on which physiological variable should be looked at and in which type of populations. In a second phase, one could assess whether radiological and manometric "signatures" would be similar or dissimilar and infer the diagnostic usefulness of VFM.

This study supports the HPP measurement and the PEPG calculation as two possible valid physiological variables that are significantly correlated with three stereotyped populations. The data obtained do not support the UESN as a valid physiological variable with the important caveat that the recording technique being used (solid state system) is much more appropriate to pharyngeal manometry than to UES manometry for the reasons above mentioned.

Furthermore, the PEPG calculation may represent an unnecessary step, the HPP representing a possibly valid physiological variable in itself. Several arguments though suggest that further studies should be considered before dismissal of the PEPG calculation.

(a) The size of the investigated groups is small. The significance of PEPG versus HPP significance should be reassessed and compared in further studies with a larger number of subjects.

(b) The PEPG concept is more in line with McConnel's initial postulate where pressure within the "pharyngo-esophageal segment" is the result of two somewhat interdependent forces. Those being, on one hand, a force driven by the base of the tongue acting as a propulsion pump, within a dynamic chamber, and on the other hand, the EUS nadir, acting as a suction pump.

(c) Anatomical and physiological variability among individuals is important. Hypothetically, the calculation of the PEPG based on data provided by two sensors would therefore soften these potential differences.

Further studies should investigate the HPP and PEPG obtained with more refined manometric techniques in order to, on one hand, add support to HPP and/or PEPG's validity and on the other hand, propose more refined technical standards.

Nevertheless, our study provides exploitable data that allow us to propose a reading scale based on one particular standardized technique and material that is available to at least eighty-eight teams around the world.

Concerning our normal swallow data, it is important to note that our control group was not age-matched, in particular when compared with the CPB group. It is now common knowledge that age influences swallowing capacities. Likewise, there are some arguments in the literature indicating that anatomical cricopharyngeal protrusion is closely associated with aging (51,52). One can understand the difficulty to obtain an asymptomatic, radiologically disease-free, control group that perfectly

Table 2. — **HPP, UESN, PEPG in mmHg obtained for each individuals of each cohort**

Patient # CG	HPP mmHg	UESN mm Hg	PEPG mm Hg	Patient # MD	HPP mmHg	UESN mm Hg	PEPG mm Hg	Patient # CPB	HPP Mm Hg	UESN mm Hg	PEPG mm Hg
1	*171*	*8*	*163*	1	*22*	*19*	*3*	1	*251*	*56*	*195*
2	*139*	*14*	*125*	2	*84*	*8*	*76*	2	*250*	*6*	*244*
3	*191*	*7*	*184*	3	*9*	*-6*	*15*	3	*252*	*7*	*245*
4	*147*	*17*	*130*	4	*27*	*6*	*21*	4	*221*	*14*	*207*
5	*202*	*16*	*186*	5	*37*	*8*	*29*	5	*252*	*24*	*228*
6	*173*	*4*	*169*	6	*39*	*2*	*37*	6	*248*	*6*	*242*
7	*140*	*12*	*128*	7	*16*	*10*	*6*	7	*212*	*16*	*196*
8	*160*	*10*	*150*	8	*20*	*4*	*16*	8	*251*	*12*	*239*
9	*115*	*6*	*109*	9	*71*	*-3*	*74*	9	*215*	*5*	*210*
10	*192*	*6*	*186*	10	*111*	*11*	*100*	10	*249*	*6*	*243*
11	*163*	*10*	*153*	–			–	–			–

CG : Control Group ; MD : Myotonic Dystrophy ; CPB : Crico-Pharyngeal Barr ; HPP : Hypopharyngeal Peak Pressure ; UESN : Upper Esophageal Sphincter Nadir ; PEPG : Pharyngo-Esophageal Pressure Gradient.

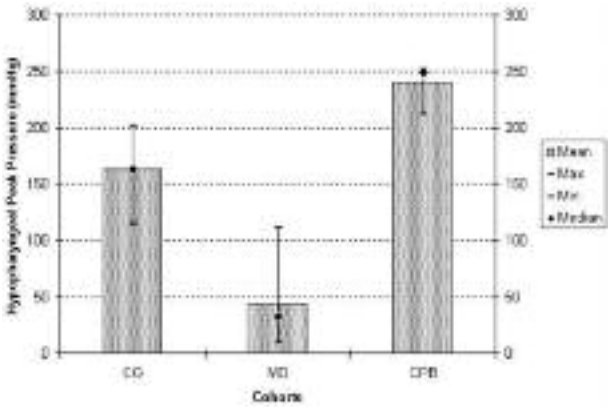

Fig. 6. — Mean, median and minimum and maximum HPP for each cohort

HPP : Hypopharyngeal Peak Pressure.

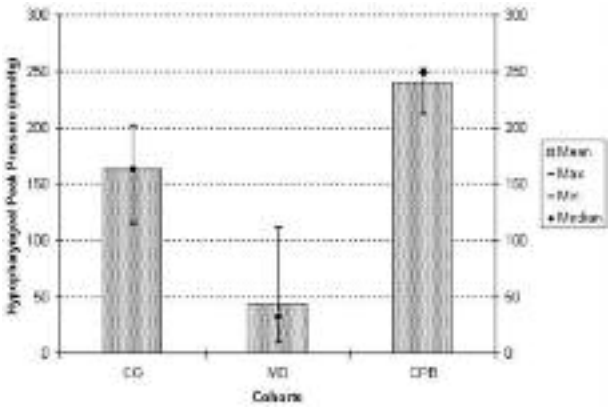

Fig. 7. — Mean, median and minimum and maximum UESN for each cohort

UESN : Upper Esophageal Sphincter Nadir.

matches the age characteristics of the two others cohorts.

Eventually, our results confirm the hypothesis that different disease conditions presenting specific pharyngo-esophageal manometric signatures, translated into HPP and PEPG values, exist. Further studies should also investigate the MBS versus manometry relationship (if there is one) for various "disease families" in order to detect eventual MBS/manometry patterns or profiles, which could be specific to certain pathological conditions.

PEPG reading scale

Dysphagia is not an On-Off bimodal type symptom. As a matter of fact, it exists as a continuum between slight, moderate and severe dysphagia. Dysphagia may also result from rare aetiology or the association of multiple aetiologies.

Our results allow authors to propose a concept of aetiological continuum between (a) pharyngeal propulsion impairment characterized by low HPP or PEPG values (below 100 mmHg), (b) normal or balanced pharyngeal propulsion characterized by moderate HPP or PEPG values (between 100 and 200 mmHg and eventually, (c) excess of pharyngeal propulsion in reaction to an increased resistance to bolus flow, characterized by high HPP or PEPG values (above 200 mmHg).

Figure 9 summarizes the HPP / PEPG reading scale. Patients with HPP / PEPG values at the left side of the scale present a high probability of propulsion impairment while patients at the right side of the scale present

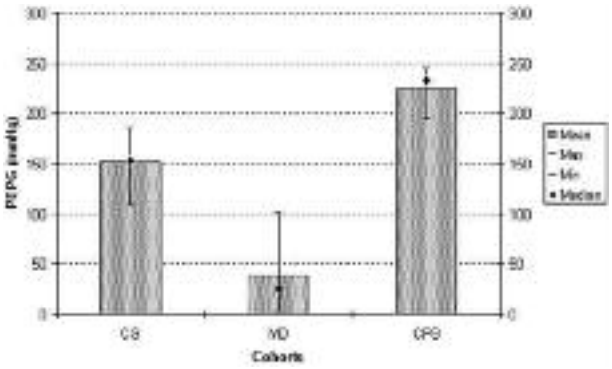

Fig. 8. — Mean, median and minimum and maximum PEPG for each cohort.

PEGP : Pharyngo-Esophageal Pressure Gradient.

Table 3. — **Non-exhaustive list of factors affecting pharyngo–esophageal manometric measurements**

- Patient Characteristics
  - Age
  - Gender
  - Head Position
- Anatomical Features
  - Radial and Longitudinal Asymmetry of the Human Pharynx
  - Radial Asymmetry of the UES
- Type of Transducers and Measurement Techniques
  - Solid-state Unidirectional
  - Solid-state Circumferential
  - Sleeve (micro) / Perfused
  - Arterial Balloon Dilatation Catheter

a high probability of increased resistance to bolus flow with an appropriate propulsive response. Patients with mixed etiologies will present HPP/ PEPG results similar to the non-dysphagic control group.

It is important to note that the position on the proposed scale does not reflect, by any means, the severity of the disease characterized by the penetration-aspiration scale and/or the deficit of oral feeding capacities leading to nutritional deficiency.

Likewise, VFM will not replace FEES and MBS in order to detect dysphagia, nor to assess its severity. Indeed, neither the measurement of the HPP nor the calculation of the PEPG tells the investigator if the patient is inhaling. What it does offer though, particularly when interpreted with the presented scale, is to give important insights about the physiopathology related to symptoms and other data provided by other instrumental investigations.

Conclusion

According to the literature, VFM represents an insightful complementary instrumental examination to FEES and MBS. Moreover, some recent data indicates that VFM could unveil clinically relevant parameters in children as well (53). Surrogate measures to HPP meas-

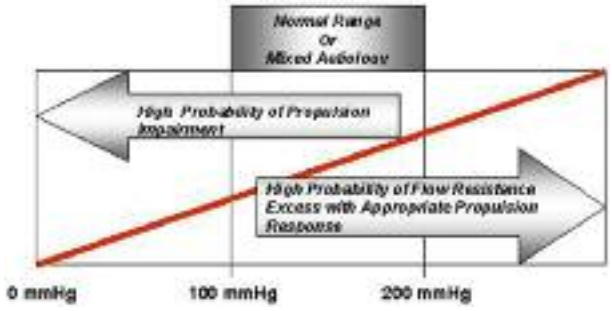

Fig. 9. — HPP / PEPG Reading Scale.

HPP : Hypopharyngeal Peak Pressure ; PEGP : Pharyngo-Esophageal Pressure Gradient.

ured by VFM, such as the "Pharyngeal Constrictor Ratio", are developed for teams who do not have access to VFM (54).

However, clinical potential of VFM is still, unfortunately, unrealized despite many authors claiming its utility over the last two decades (55,56).

The discovery of physiologic variables correlated with stereotyped dysphagic conditions and easily obtained on a clinical basis, would certainly contribute to provide data and eventually answer the question about the clinical usefulness of VFM.

According to the data provided by this study, the calculation of PEPG, a relative value instead of an absolute value, does reflect the physiological feature at stake.

Further studies should assess the same physiological variables obtained with other manometry devices within the same specific populations in order to validate (or invalidate) the HPP and/or PEPG as a universal measurement standard and propose technical standards refinement.

Once agreement on measurement standards and technical standards are sequentially obtained, further studies should be launched where HPP and PEPG values would be compared with MBS results for various disease conditions in order to determine disease-specific VFM patterns. If those patterns do exist, VFM would definitively prove its clinical utility and would eventually achieve its full potential.

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