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Videomanometric Aspects of Pharyngeal Constrictor Activity

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Abstract. Pressure changes were registered with videomanometry (simultaneous manometry and barium swallow) in the pharynx and in the pharyngoesophageal segment (PES) during swallowing. A considerable longitudinal asymmetry was found. Peak pressure was highest in the PES, lower in the inferior constrictor area, and lowest at the level of the tongue base. The rate of pressure rise was highest at the level of the PES. The speed of propagation of the contraction wave was 13 (± 2) cm/sec. There was no correlation between the measured variables (i.e., peak pressure, rate of pressure rise, and speed of contracting wave). Our findings can partly be explained by different mechanical constraints at different levels of the pharynx but may also reflect the organization of neural control of swallowing in the brainstem. Knowledge of transducer position and orientation is essential for the evaluation of pharyngeal pressure during swallowing. Such knowledge is best achieved by performing manometry simultaneously with fluoroscopy, i.e., videomanometry.

Key words: Pharynx — Pharyngoesophageal segment — Manometry — Radiology — Dysphagia — Deglutition — Deglutition disorders.

Pressure changes registered during pharyngeal manometry reflect the activity of the tongue base and pharyngeal constrictor musculature, including the pharyngoesophageal segment (PES). Such pressure changes have by and large been used as indicators of events, i.e., for timing purposes [1]. Other studies have analyzed the contractile aspects such as strength of the tongue base and the constrictors [2–8]. Radial and longitudinal asymmetry as well as the elevation of soft palate, larynx, and pharynx during swallow has, however, made the measurements unreliable. Videomanometry now offers a method for control of the position of the monitoring device. It also allows a proper distinction between intrabolus pressure and contractile pressure, which is important in understanding the physiology of deglutition.

The aim of the present study was therefore to analyze qualitative and quantitative aspects of the tongue base, pharyngeal constrictor, and PES activity during videomanometry.

Material and Methods

Ten healthy, nondysphagic volunteers were included in this study. There were 6 males and 4 females aged 24–53 (mean 34). The study was approved of by the ethical committee of the University of Lund.

The manometry system was an intraluminal solid state transducer system. The manometry catheter had a diameter of 4.6 mm and there were four solid-state-pressure transducers positioned 3 cm apart. The three proximal sensors were standard microtransducers (Konigsberg Instruments Inc., Pasadena, CA) with a single recording site measuring 120°. The distal transducer (Konigsberg) was circumferential allowing 360° measurements.

The system was noncompliant; the volumetric compliance was 7×10^{-6} mm^3/mmHg, and the pressure rise rate was over 2,000 mmHg/sec. The analogue signal was digitized by a Polygraph A/D converter (Synectics, Stockholm, Sweden).

The computer was a commercial IBM-compatible 386 computer and the software was Polygram Upper-GI-Edition by Gastrosoft Inc./Synectics Medical (Synectics). All pressure values were expressed in mmHg (1.0 mmHg = 133 N/m^2, 7.5 mmHg = 1 kPa, 50 mmHg = 68 cm H_2O). The system was calibrated at 0 and 50 mmHg. The calibration was done at 37°C. All given values are referred to atmospheric pressure. The sampling frequency was 64 Hz.

All sensors were radiopaque and easy to identify during fluoroscopy.

The manometry catheter was introduced through the nose and fluoroscopically positioned with its distal transducer in the PES. The three proximal transducers were positioned with the recording sites in a dorsal direction. The resting PES pressure was measured after the catheter had rested for a minimum of 10 sec in the PES. During swallowing the pharynx-larynx-elevation moved the PES in a cranial direction. When the catheter was correctly positioned in the cranial part of the upper esophageal sphincter (UES), a characteristic "M"-shaped

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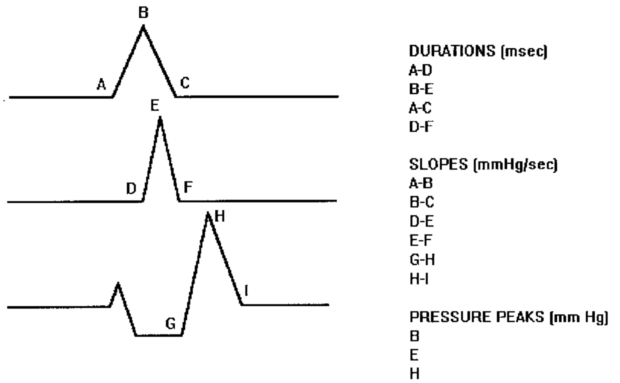

Fig. 1. Schematic drawing of manometry in the pharynx at three levels. Measured variables are indicated.

configuration of the manometry wave appeared during swallowing, as described by Castell et al. [2].

Simultaneous videoradiography and pharyngeal manometry (videomanometry) was performed in an upright position. All participants were instructed to swallow 10 ml of a barium contrast medium (60% w/v). At least three wet swallows and three dry swallows were recorded. The videofluoroscopic image and the manometric registration were mixed using a Microeye Video Output Card (Digihurst Ltd, Roystone, GB) displayed together on a monitor and recorded together on videotape (S-VHS). Video analysis was performed by slow motion and frame by frame analysis.

Contact pressure was defined when the pharyngeal walls were directly in contact with the transducer, as determined on the videofluoroscopic image. In like manner the intrabolus pressure was defined when the transducer was within the fluid, i.e., the contrast medium.

Thirteen variables were defined and measured as indicated in Figure 1 and Table 1. Although there was some intra- and interindividual variation and the samples were rather small (only six swallows per subject; three each in the wet and the dry condition), it seemed reasonable to assume that these variables were approximately normally distributed. Thus, parametric statistics were used for the calculations in order to increase the statistical efficiency and power [1–4]. The computations were aided by using Microsoft Excel and StatView II programs on a Macintosh LC II computer.

For the statistical analysis, the arithmetic mean and standard deviation of each variable were first computed separately for the wet and dry swallowing condition for each of the 10 subjects. Analysis of variance (ANOVA) of these data revealed no tendency to a difference between the two conditions, nor any consistent differences between the subjects. Therefore, the data from the wet and dry swallows were concatenated and the arithmetic mean of each of the 13 variables was calculated based on each subject's six swallows. From these means, the overall means, standard deviations, and coefficients of variations of the variables for all 10 subjects were calculated.

Based on these statistics, ANOVA was again applied. The p values given below referring to differences are derived from one-factor ANOVA for repeated measures. In looking for associations between variables, conventional correlation coefficients r (least squares method) were calculated. The p values in these cases again derive from ANOVA. To avoid the possible problem of "mass significance" due to multiple testing, the results were interpreted with caution and only statistical significances at 99% or better were accepted. Bonferroni corrections were then considered unnecessary.

Results

The indentation in the posterior pharyngeal wall could regularly be discerned on the video image at the beginning of the pressure rise in that particular segment according to the manometric registration. At peak pressure the segment always was bolus free. Air was not seen in the segment until the pressure was back to zero. As already mentioned, there was no significant difference in our measured variables when dry and wet swallows were compared. The results are summarized in Table 1.

The peak pressure varied at different levels in the pharynx and was highest at the PES level, lower at the inferior pharyngeal constrictor level, and lowest at the level of the tongue base ($p = 0.0023$).

The rate of the pressure rise varied considerably at different levels within the pharynx. It was highest at the level of the PES and lowest at the level of the tongue base ($p = 0.0204$). The rate of the pressure fall was highest at the level of the inferior constrictor, lower at the cricopharyngeus, and lowest at the level of the tongue base (nonsignificant; $p = 0.3129$).

The duration of contraction was somewhat longer at the tongue base compared with the inferior constrictor level ($p = 0.0174$).

The speed of propagation of the contraction wave between the middle and inferior pharyngeal constrictors was 13 ($\pm$ 2) cm/sec for the beginning of the upstroke (A-D) an 17 ($\pm$ 3) cm/sec for the peak of the contraction wave (B-E).

Within subjects there were no statistically significant correlations between the variables, except possibly for the up- and down-slope at the level of the inferior constrictor ($r = 0.92$; p not computed).

Between subjects, however, hardly surprising correlations were found between all of the components of the pressure wave shapes, viz, the pressure buildup rate, the peak pressure, and the pressure decay rate, at each of the three manometer levels. The correlation coefficient r was typically in the 0.8–0.9 vicinity, the highest being $r = 0.97$ ($p = 0.0001$) between the up-slope D-E and the down-slope E-F at the inferior constrictor level; and the lowest being $r = 0.73$ ($p = 0.0165$) between the peak pressure B and the down-slope B-C at the tongue base. In other words, subjects with the faster rises have the higher peaks and the quicker falls of pressure, and vice versa.

What was interesting, however, was the complete lack of correlation between, on the one hand, the strength and speed of contraction (as reflected in the pressure wave shapes) and on the other hand, the speed of propagation of the contraction wave. Thus, between the pressure buildup rate A-B at the tongue base and the propagation time A-D from the tongue base to the inferior constrictor, the correlation coefficient was only $r = 0.36$ ($p = 0.3039$);

Table 1. Thirteen variables and their measurements

Variable		Mean (n = 10)	SD	CV (%)
Durations				
A–D	Propagation time from tongue base to inferior constrictor level	240 msec	46	19
B–E	Time between pressure peaks from tongue base to inferior constrictor level	182 msec	30	17
A–C	Pressure wave duration at tongue base	685 msec	106	16
D–F	Pressure wave duration at inferior constrictor level	591 msec	83	14
Slopes				
A–B	Pressure buildup rate at tongue base	403 mmHg/sec	92	23
B–C	Pressure decay rate at tongue base	−393 mmHg/sec	77	20
D–E	Pressure buildup rate at inferior constrictor level	602 mmHg/sec	219	36
E–F	Pressure decay rate at inferior constrictor level	−501 mmHg/sec	180	36
G–H	Pressure buildup rate at cricopharyngeus level	685 mmHg/sec	238	35
H–I	Pressure decay rate at cricopharyngeus level	−416 mmHg/sec	194	47
Peaks				
B	Peak pressure at tongue base	129 mmHg	38	29
E	Peak pressure at inferior constrictor level	144 mmHg	53	37
H	Peak pressure at cricopharyngeus level	223 mmHg	62	28

and between the peak pressure B at the tongue base and the time interval B-E of the pressure peaks at the tongue base and the inferior constrictor, the correlation coefficient was r = 0.52 (p = 0.1268).

Nor was there any correlation between the peak pressures or the pressure wave shapes when the three manometer levels were compared with each other. For instance, between the pressure buildup rate at the tongue base and at the inferior constrictor, the correlation coefficient was practically zero (r = 0.03; p = 0.9393).

Due to movements of the catheter and the elevation and descent of the pharynx during swallowing, it was difficult to measure the duration of the contraction in the cricopharyngeus as well as the propagation speed of the contraction wave between the inferior constrictor and the cricopharyngeus.

Discussion

Activity in the pharyngeal constrictors, when of proper timing and strength, clears bolus material from the pharynx by propelling it into the esophagus. Therefore, the pharyngeal constrictor activity is one of the major components of the pharyngeal swallow [2,3,9]. When the pharyngeal constrictor activity is impaired, bolus material is retained in the pharynx and may penetrate into the larynx and trachea.

The radiologic barium swallow has until recently been the only practical technique for evaluation of pharyngeal function and dysfunction [10–12]. Radiology provides information about bolus transport through the pharynx and also gives information about aspiration. Manometry, however, provides details of the force of the pharyngeal contraction and also specific timing.

Although the peak pressure and the speed of propagation of the constrictor wave varied between individuals, they did not correlate, i.e., high speed does not mean high pressure. This is probably an expression for the fact that different pharyngeal constrictor functions are controlled from different localizations within the central nervous system. It is likely that the speed of the propagation of the constrictor wave is preprogrammed in the ventral swallowing center of the brainstem [13–16]. Pressure recordings within the pharynx depend very much on axial and longitudinal asymmetry. It is probably much easier to obliterate the lumen within the pharyngoesophageal sphincter than it is at the level of the vallecula where the lumen is much bigger, has cartilagenous elements anteriorly, and will have more resistance to closure. Therefore, manometric characteristics are determined as much by mechanical constraints as by muscle characteristics.

The common radiologic observation of propagation speed was based on the indentation into the barium column due to the beginning of the contraction. This occurred well before the pressure rise.

Our figures for peak pressure are in accordance with other studies [6,17]. Still others have reported lower peak pharyngeal pressure [3,8]. In prior radiologic studies, normals and patients with pharyngeal dysfunction were found to have a speed of propagation of the constrictor wave of 12 cm/sec [18,19]. This corresponds to the beginning of the upstroke in this series of 13 cm/sec. The finding that the propagation of the pressure peak was faster than the start of the pressure rise may be due to the fact that the pressure rise was more than twice as high at the inferior pharyngeal constrictor level than at the middle pharyngeal constrictor level. This may reflect that the two muscles derive innervation from different, but closely located, areas within the nucleus ambiguus. This separate innervation may therefore lead to differences in contraction pattern.

Our observation of a peak pressure increasing towards the distal pharynx is in line with other recent studies that found a conspicuous longitudinal asymmetry within the pharynx [4,20–22]. Furthermore, in prior studies, radial asymmetries with the highest pressure anteroposteriorly (about 150 mmHg) and the lowest transversely (about 100 mmHg) have been shown [4,7]. Radial asymmetry was very pronounced just above the cricopharyngeus, whereas at the level of the tongue base that radial asymmetry disappeared.

Our study shows a fundamental difference between radiologic and manometric monitoring of pharyngeal swallow, namely, their relation to the bolus. Though the radiologic test to a great extent is preoccupied by the bolus and its transportation through the pharynx, manometry only reveals a glimpse of the bolus, namely, the small and nonconspicuous intrabolus pressure which at least in a normal person swallowing a liquid bolus in an erect position, is low: 0–40 mmHg. However, for a more viscous bolus, the intrabolus pressure can be substantial. Brasseur and Dodds [23] have elaborated intraluminal pressure differences in the circumstance of peristalsis and found elevated intrabolus pressure only within a narrow zone ahead of the occluding walls. Radiology also reveals the elevation of the larynx and pharynx, and movements of different anatomical structures in and around the pharynx, such as the hyoid bone and the laryngeal vestibule. Manometry gives no information about these events. Interestingly enough, however, the radiologic study more or less is over when the bolus has left the pharynx. This is in contrast to manometry that starts to record pressure events in a particular segment of the pharynx, basically a couple of milliseconds after that segment has become free of bolus. Therefore, manometry is mainly confined to immediate postswallow events.

In conclusion, our results have shown substantial longitudinal asymmetry in pharyngeal pressure response in normal subjects. Knowledge of transducer position and orientation is essential for evaluation of pharyngeal pressure during swallowing. Such knowledge is best achieved by performing manometric studies simultaneously with fluoroscopy, i.e., videomanometry.

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