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Nasopharyngeal pressure gradients during non-phonetic activities of the velopharyngeal valve. Part I

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Abstract

The phonetic activity of the velopharyngeal valve has been the subject of electromyographic, radiological, ultrasonic, endoscopic, and of various acoustic and aeromechanical investigations. The subject of the present study was the non-phonetic activities of the velopharyngeal valve. Ten patients were assessed by nasendoscopic examinations of the velopharyngeal valve. The pressure gradients in the nasopharynx during these activities were recorded. Typical individual nasopharyngeal pressure patterns were revealed inducing a development of a special technique and tests for a further study of the non-phonetic activities of the velopharyngeal valve in correlation with its abnormality and pathological speech activities.

Introduction

The three-dimensional valving mechanism of the velopharyngeal valve (VPV) is based on the fully coordinated function of the muscles contributing to its action. Valving competency is essential for normal speech but is important for non-phonetic activities such as swallowing, blowing, whistling and somewhat for sucking as well. Impaired speech, our most important mode of communication, is what usually brings the patient to the clinician.

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This dominancy of the speech disorders, the fact that we can hear speech and evaluate its abnormality by hearing, and the function of the VPV during phonation appearing to be quite different from its function in the non-phonetic activities [2–4,16,18,22], gave rise to an impressive array of instrumentation for studying the mechanism of the VPV in speech.

Fewer efforts were made for studying the non-phonetic activities of the VPV. The first investigations described were performed in the nineteenth century by Czermak, Hilton and Debru, as described by Fritzell [9] commencing with the cineradiographic [2–4], fiberscopic [16], and ultrasonic [22] studies of the past 30 years.

Today the clinician and the speech pathologist treat the patient suffering of VPV incompetence on the basis of his or her speech disorders. Patient's speech is appraised mainly by perceptual evaluation [17]. In some well equipped centers the clinician utilizes modern devices such as the Tonar [8,21]. Whenever it is possible the decision of the mode of treatment is based also on the information provided by the naso-endoscopic and radiologic examination [1]. While ability to diagnose speech disorders is formidable, we do not know how to diagnose and to evaluate abnormality of the VPV function in the non-phonetic tasks. Nasal regurgitation is the most commonly encountered. Many patients suffering from velopharyngeal valve incompetence (VPI) in speech are considered to have normal swallowing.

The mechanism of velopharyngeal function in non-phonetic activities is complex and patients suffering from velopharyngeal abnormality could utilize various compensatory mechanisms.

In many cases the pathological mechanism of the VPI is not clear. The physician must distinguish between an organic VPI when there is a pathology of the neuromuscular components of the VPV, and a functional VPI caused by misuse of VPV. This discrimination is the cornerstone in the selection between the conservative or the surgical mode as adequate treatment.

If we know that besides the incompetence of the VPV in speech there is also abnormal non-phonetic activity (such as swallowing), we can conclude that this is an "organic" VPI [13].

Theoretically, a patient with VPI comparing his speech to that of those surrounding him could compensate his speech with some degree of success. The non-phonetic activities of the VPV are however impossible to compare for both the examiner and the examinee.

Ingelstedt and Ortegren [11], studying the Eustachian tube function, have measured pressure gradients developing in the nose during swallowing and have shown that individuals have pressure curves of 3 types: positive, biphasic and negative. Gramiak and Kelley [10] tried to explain in anatomophysiologic terms the pressure curves measured during swallowing, by combined manometric measurements through the nostrils, and cineradiographic study. The pressure gradients measured by Ingelstedt and Ortegren [11] were somewhat different from those produced by Gramiak and Kelley [10].

We have developed a new technique for precise measurements of nasopharyngeal pressure gradient curves [6,7]. These curves provide new information on VPV function and show that every person has his own typical nasopharyngeal pressure characteristics. Since nasal airway resistance was not taken into account in previous studies, the measurements were not precise [7]. The aim of the present study was to measure the pressure gradients developed within the nasopharynx during various non-phonetic activities of the VPV and to establish the base for a development of an objective aeromechanical system for evaluation of the non-phonetic activity of the VPV.

Patients and Methods

Ten patients, 9 males and one female, who have undergone nasal septal surgery, were examined. These patients were selected for this study, as it is our common procedure to insert ventilation tubes in their nasal packing [6,7]. In all patients bilateral anterior nasal packing with antibiotic impregnated gauze strips was inserted. The age of the patients ranged from 22 to 58 years with a mean of 36 years. All the patients suffered from nasal airway abnormality only.

The preoperative examination included:

(1) A complete E.N.T. and speech pathologist examination with a careful check of the oral cavity to rule out abnormalities of the uvula, velum, hard palate, maxillary arch and pharynx.

(2) An assessment of speech which excluded any speech abnormality.

(3) Careful nasendoscopy of the VPV during non-speech activities. The nasendoscopic examination performed by using the flexible fiberscope Olympus ENF-2 type P. The technique employed is described elsewhere [16,20]. The nasal lumen was anesthetized with 2% pantocaine, and 2% ephedrine solution. The fiberscope was inserted through the nostrils to reach the nasopharynx at a point as high as possible. Whenever possible the endoscope was inserted above the middle turbinate, so that the tip could be flexed at 90° and be oriented sufficiently superior to the plane of VP closure. The purpose of this technique is to view the VPV movement with minimal deformity and to prevent causing a physiological disturbance.

The patients were asked to perform the following non-phonetic tasks:

(1) Drinking: to draw some water through a cut No. 16 Nelaton catheter inserted in a glass of water and to swallow. The patients were instructed to open their mouth as soon as swallowing was completed, thereby producing an abrupt termination of the pressure curve.

(2) Swallowing: to draw some water and to hold the water in the oral cavity. On a command to swallow and subsequently open the mouth.

(3) Gulping: to gulp water through the catheter. In other words to accomplish a quick series of drawing water and swallowing it.

(4) Empty (dry) deglutition: on command to perform acts of empty (dry) deglutition. As soon as swallowing was completed to open their mouth.

(5) and (6) Sucking and blowing will be described in Part II.

Details of shape and mobility of the VPV were noted, with special attention to closure pattern and level of closure. The patterns of VP valving were categorized according to Skolnick et al. [22] and as also described by Croft et al. [5]:

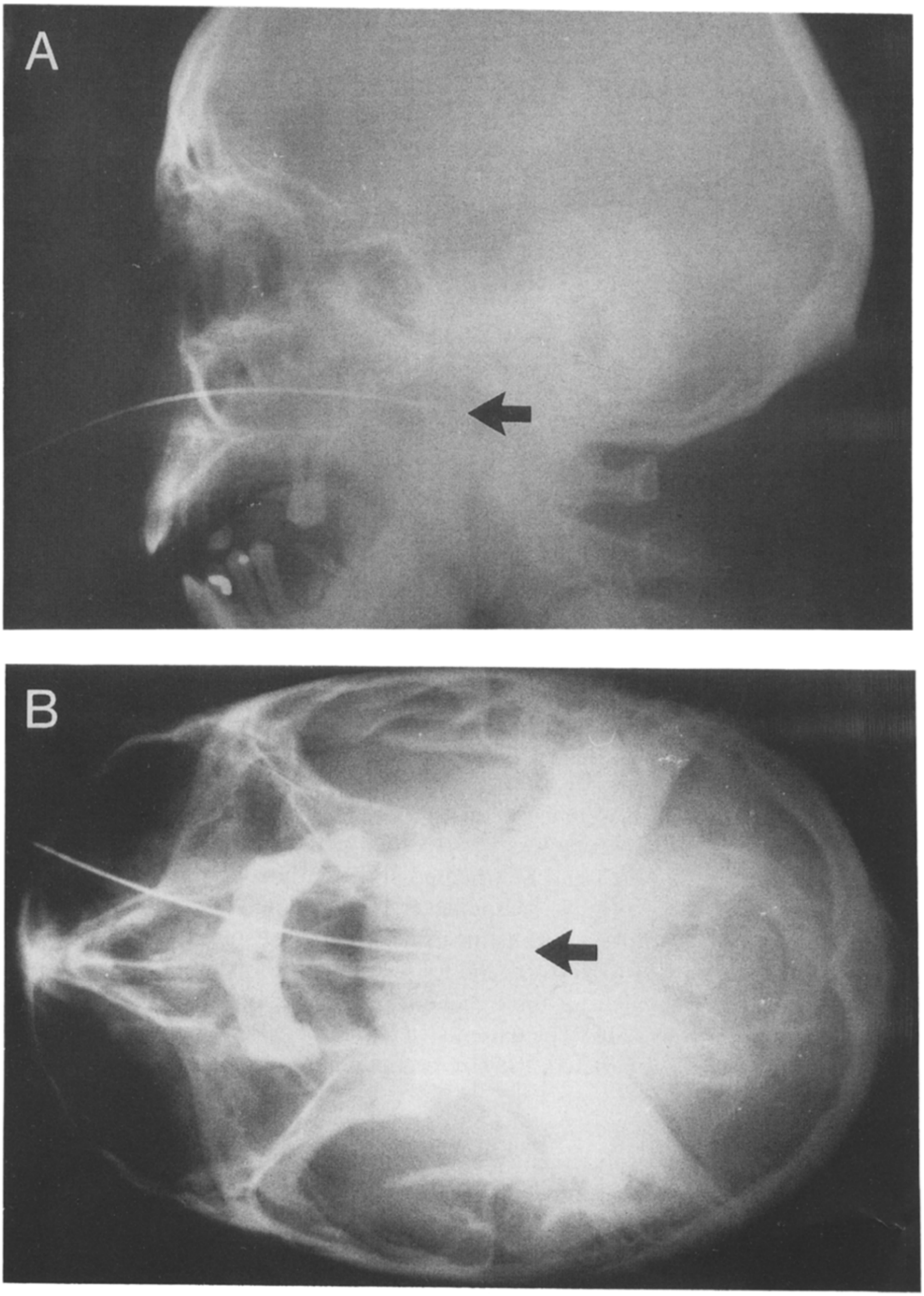

Fig. 1. The Nelaton catheter is inserted via the nasal cavity into the posterior nasopharyngeal wall; arrows show catheter tips. A: lateral view. B: basal view.

Coronal: the major component of the velopharyngeal valving is the velum. The lateral pharyngeal walls move medially to approximate the lateral edges of the velum.

Sagittal: the major component of the velopharyngeal valving is the lateral pharyngeal walls. The velum moves posteriorly only slightly, approximately to the anterior edge of the abulted lateral walls.

Circular: there is an equal amount of movement of the velum and lateral pharyngeal walls closing the velopharyngeal part at the midline.

Circular with Passavant's ridge: as in the circular pattern, there is equal contribution to closure of the velum and lateral walls, but there is also anterior movement of the posterior pharyngeal wall (Passavant's ridge) resulting in a truly sphincteric closure pattern.

The upper limit of level of closure of the VPV in relation to the rostrum of the torus tubarius and the lateral pharyngeal wall movement, the salpingopharyngeal fold and tail of the torus were noted as well.

The intraoperative procedure

In order to measure the pressure developing in the nasopharynx, we inserted a No. 16 Nelaton catheter between the layers of one of the nasal packs with the funnel connector of the catheter outside. The tubes were obliquely cut, their length adjusted proportionally, after measuring the distance from the nasal vestibulum to the posterior pharyngeal wall (Fig. 1). The nasal cavities were occluded and the catheters inserted directly into the nasopharynx ready for pressure measurements.

Postoperative measurements

A 'Grason-Stadler' 1723 middle ear analyzer was used to record the pressure gradients within the nasopharynx. The analyzer used for testing Eustachian tube function in patients with perforated drums is practically transformed to a pressure

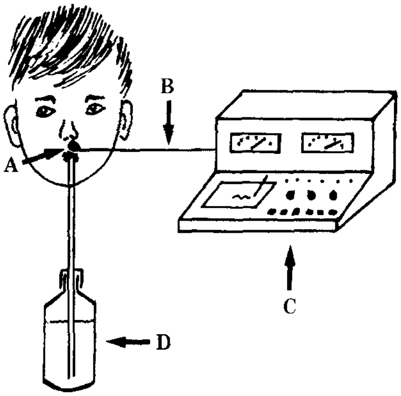

Fig. 2. Manometric measurements of pressure gradients developed within the nasopharynx: a: the probe is applied to the funnel connector of the catheter. B: the electrical cord to the pressure transducer (C). D: the bottle of water from which the patient is swallowing (drawing) water through an elastic tube.

transducer recorder when the manual pressure knob is set to zero. In the recordings of pressure variations, the horizontal axis represents time: 5 mm/s, and the vertical axis represents pressure: 7.5 mm/100 mm water. Positive pressure is recorded as upward curves and negative pressure as downward curves. Before the actual measurements were taken, the calibration of the system was tested by a water manometer, within pressure ranges of +450 to −400 mm water.

The measurements were made in the first and the second postoperative days. The probe of the transducer was applied to the funnel connector of the catheter (Fig. 2) after the patency of the intranasal catheter was assured. The patients in a sitting position were instructed to drink water through the elastic tube, to hold the water in the oral cavity and to swallow it on a command, to gulp water and to perform empty (dry) deglutitions exactly as done preoperatively during the nasendoscopic examination. In the first part of our report we describe only the various swallowing activity experiments. Other functions will be discussed in Part II.

Results

Patients profile, nasendoscopic findings and various measurements are presented in Table I. During deglutition the pressure curves measured within the nasopharynx are basically biphasic. In Fig. 3 the major pressure change events are identified. A modification of the description by Gramiak and Kelley (1966) is presented.

Task No. 1. Drinking

During DP (see for abbreviations legend of Fig. 3) the pressure within the nasopharynx generally does not change. In patient No. 5 (Fig. 6A, top) a depression of −100 mm water is seen. After the DP an IND can be inconsistently seen in patients No. 1 and 2 (Fig. 4A, top and bottom). During deglutition there is the

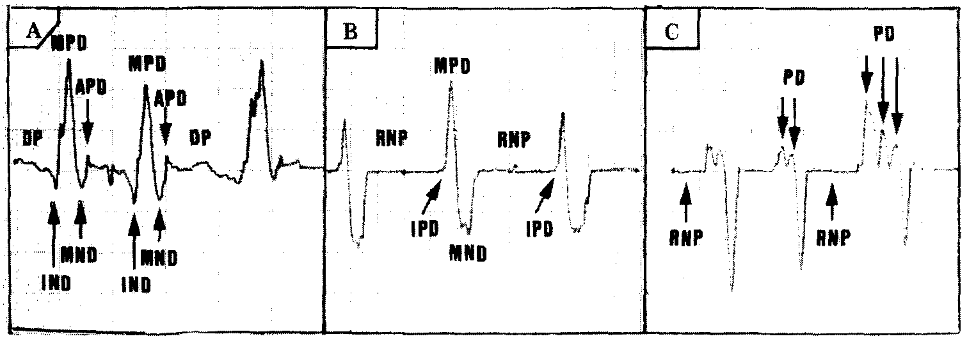

Fig. 3. Representative nasopharyngeal pressure during deglutition. The major pressure events are identified and explained in the text. IND: initial negative deflection; MPD: maximal positive deflection; MND: maximal negative deflection; APD: abrupt positive deflection; DP: drawing phase (the interwave phase in tasks No. 1 and 3); RNP: resting nasopharyngeal pressure (the nite wave phase in tasks No. 2 and 4); PD: positive deflection (only in dry deglutition: task No. 4).

TABLE I

Patient profiles, nasendoscopic findings, and manometric measurements (data)

Time measurement was of the widest complex.

Patient No.	*F/M*	*Age*	*Closure pattern*	*Upper limit of VPV closure*	*Maximum positive deflection*	*Minimal negative deflection*	*Maximal pressure gradient in a single curve*	*Time: drinking and swallowing*	*Time: empty deglutition*	*No. of deglutitions in 5 s gulping.*	*Fig.*
1	M	56	Coronal	Below torus	+240	−150	390	1.2	2.3	4	4 top
2	M	57	Coronal	Medial 1/3	+150	−380	530	1.2	1.4	4	4 bottom
3	M	22	Coronal	Inferior 1/3	+200	−200	400	1.0	2.0	10	5 top
4	M	28	Circular and Passavant	Inferior 1/3	+200	−220	420	1.0	1.5	7	5 bottom
5	M	58	Circular	Inferior 1/3	+450	−100	550	1.2	3.0	5	6 top
6	M	24	Coronal	Below torus	+50	−200	200	1.3	2.2	3	6 bottom
7	M	25	Circular and Passavant	Inferior 1/3	+230	−150	370	1.2	1.2	12	
8	M	34	Coronal	Middle 1/3	+190	−140	300	1	2.16	4	
9	M	25	Circular	Inferior 1/3	+150	−180	260	0.9	1.3	4	
10	F	30	Coronal	Below torus	+100	−290	340	1.4	1.4	4	

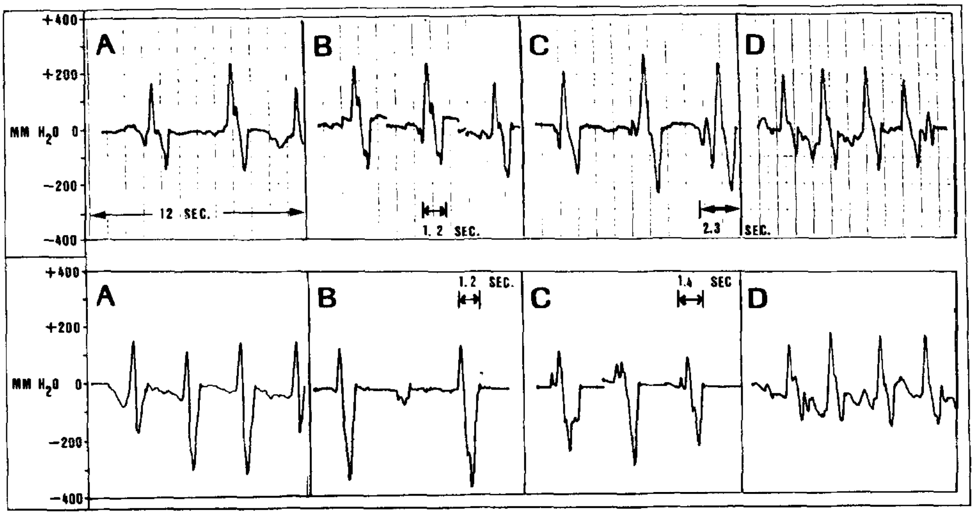

Fig. 4. Nasopharyngeal pressure recordings during: A, drinking; B, deglutition; C, empty (dry); D, gulping. Patient No. 1 (top) and patient No. 2 (bottom).

pressure wave which has a minimum of two phases. Following the component of positive pressure a negative phase was recorded. The pressure gradients ranged from MPD as high as +350 mm water in patient No. 5 (Fig. 6A, top), to the MND as low as −320 mm water in patient No. 2 (Fig. 4A, bottom). The total pressure gradient varied from 460 (patient No. 2) to 250 mm water (patient No. 6). Sometimes an APD was recorded at the end of the pressure wave after the negative phase (Fig. 6A, bottom, arrow).

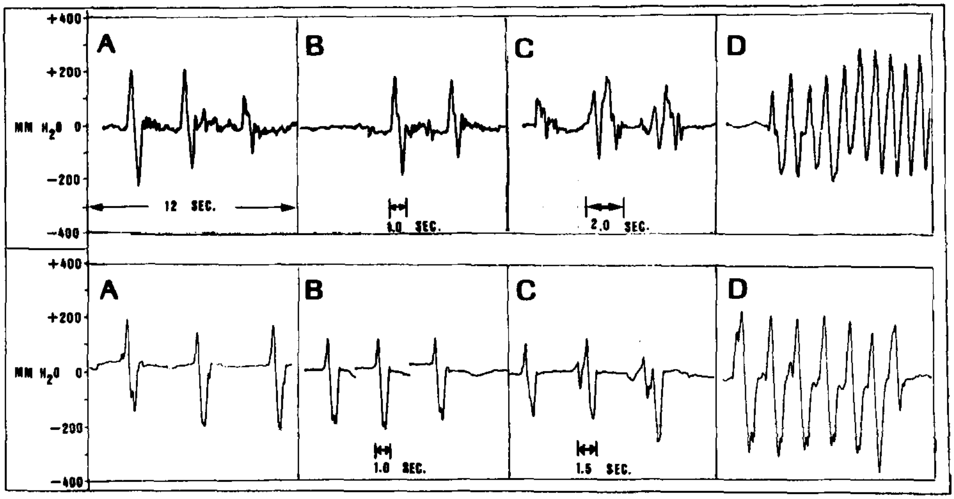

Fig. 5. Nasopharyngeal pressure recordings in patient No. 3 (top) and patient No. 4 (bottom).

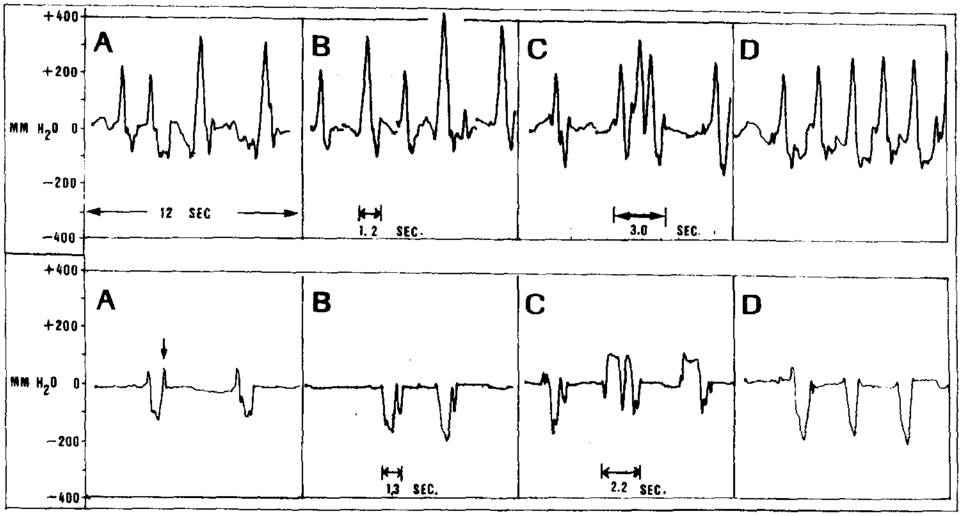

Fig. 6. Nasopharyngeal pressure recordings in patient No. 5 (top) and patient No. 6 (bottom).

There is a noticeable uniformity of the appearance of the pressure curves in each patient tested. In some of them the quantity of water swallowed in a single bolus can affect the amplitude of the wave as in patient No. 2 (Fig. 4A, bottom). The pressure waves are from biphasic positive predominant (patient No. 5, Fig. 6A, top), a simple biphasic (patient No. 4, Fig. 5A, top) to biphasic negative predominant (patient No. 6, Fig. 6A, bottom).

The endoscopic examination revealed in patient No. 5 during the DP a depression of the anterior pharyngeal wall anteriorly, probably into the oral cavity toward the base of the tongue. This finding appeared inconsistently in patients No. 1 and 2. During deglutition it seems that the ascending of the anterior pharyngeal wall occurs in two phases. This wall comes up and after a pause continues to ascend to complete closure with more or less participation of the lateral pharyngeal wall according to the closure pattern. During deglutition no convincing correlation was found between the pattern of VPV closure or the level of VPV closure (Table I).

Task No. 2: swallowing

Here the interwave phase (the interval between the waves) is defined as RNP since this is the recording which is formed by zero line for manometric determination of the pressure initiated when the patient is holding water in the oral cavity separated from pharynx and before swallowing. This is contrary to the DP in the drinking task. The aim of this task is to isolate the swallowing pressure curve from the possible changes of the DP.

The pressure gradients ranged from MPD of +450 mm water in patient No. 5 to the MND as low as −380 mm water in patient No. 2. The total pressure gradient varied from 520 mm water in patient No. 5 to 200 mm water in patient No. 6.

The timing of the pressure events was determined from the IPD (Fig. 3) to the end of the biphasic curve at the return to the RNP. The time lapse was from 0.9 to 1.4 s (Table I).

Task No. 3: empty (dry) deglutition

After the RNP as the patient continued to perform this act, PD were recorded as in patient No. 2. These deflections became biphasic in patients No. 1 and 4 and were followed by a successful act of deglutition. The act of empty deglutition became longer up to 3 s in patient No. 5. On the other hand, patients No. 7 and 10 repeated their empty deglutition with no hesitance and no elongation of time was found. The results are resumed in Table I. On nasendoscopic examination an up and down movement of the velum before a complete closure was seen. In patient No. 4 repeated inward–outward movement of the lateral pharyngeal walls were observed before the ascending of the anterior pharyngeal wall.

Task No. 4: gulping

There are two typical patterns. The typical pressure waves with DP between them (patients No. 1 and 6) and a to and fro appearance (patient No. 3). In patient No. 4 a short plateau is observed.

On nasendoscopic examination two patterns were mainly observed. A closed VPV with up and down movements parallel probably to the to and fro appearance of the pressure recordings. The second pattern is repeated in full closure and opening of VPV. The number of acts counted in 5 s ranged from 3 to 5 in the first type, and from 6 to 10 acts in the to and fro type.

Discussion

The swallowing process is the end result of the harmonic function of the muscles of the mouth, pharynx, larynx and the neck. The classic classification of this process is that of Magendie [14].

The first phase is the voluntary phase in which the voluntary contraction of the muscles of the tongue and floor of the mouth carries the bolus to the oropharynx. This phase, according to another classification, is the oral phase. Here the base of the tongue and the bolus stimulate the receptors located in the mucosa of the soft palate and oropharynx thus eliciting the second phase which is the involuntary phase [15]. According to another classification this is the pharyngeal phase. In this phase the VPV disconnects the oropharynx from the nasopharynx. The contraction of the superior constrictor and the VPV muscles carries the bolus to the esophagus and so to the third phase. The pressure changes within the closed nasopharynx were already the subject of attention for Toynbee [24]. Perlman's explanation [19] for the pressure fluctuations in the nasopharynx is that at the beginning of deglutition, the pressure rise is the result of the movement of the soft palate and further contraction of pharyngeal muscles. The following negative pressure is the result of dilatation of the oro- and hypopharynx followed by relaxation of the cricopharyngeal muscle.

Gramiak and Kelley [10] have shown by a study of combined cineradiography and manometric measurements in the nose, that the pressure fluctuations are the result of the interplay among the soft palate, the pharyngeal constrictor, cricopharyngeus and the tongue. According to these authors, the PD is mainly the result of the progressive, rolling contraction wave of the tongue when it crosses the zone of transition between the hard and soft palate, followed by the elevation of the soft palate and VPV closure. The impact of the tongue against the elevated soft palate produces the MPD.

During the negative deflection the events are: downward movement of the soft palate and descent of the hyoid bone during closure of the cricopharyngeus. During the ADP, separation of velopharyngeal seal and of faucial pillars occurs.

Finkelstein et al. [6,7] measured pressure gradients directly from the nasopharynx and compared them to measurements in the same patients but in the nostrils. The nasal airway resistance altered the original curves and therefore all the preceding measurements cannot be considered absolutely accurate.

Every person has his own typical pressure waves developing within the closed nasopharynx during deglutition. The biphasic nature of these waves is demonstrated. Among different subjects we can find variations: from a biphasic wave with positive predominant to a biphasic wave with negative predominant.

In the present study we attempted to find the factors that determine the specific pressure waves. The nasendoscopic examination failed to show a convincing correlation between the pattern of VPV closure or level of closure and the various pressure waves. We think that the main cause of these pressure variants is the baseline volume of the nasopharynx at rest, as the difference between this volume and the volume at the top of the swallowing act (MPD) is the factor of the pressure created. An assessment of nasopharyngeal volume by nasendoscopy is unpractical. We know that even an estimation of lateral pharyngeal wall movement is not reliable [12]. The PDs in the dry swallowing are probably the result of the recurrent impacts of the tongue against the soft palate until this friction of palatal mucosa instead of a bolus promotes the involuntary phase and the termination of swallowing. The nasendoscopic observation of the up and down movement of the velum confirms this explanation. The PDs can be the grading for dry swallowing difficulty. In some patients when attempting to perform dry swallowing, medial and lateral movements of the lateral pharyngeal wall or Passavant's ridge were observed until the VPV closure was completed.

In conclusion, the knowledge of non-phonetic activities of the VPV is important and could provide an additional practical information for evaluation of a patient with any kind of VPV dysfunction or incompetence. In our work we show that there is a good physiological basis for further research and for the development of aeromechanical technique for this purpose. In Part II of this study we shall further describe our observations and measurements in the non-phonetic activities of the VPV: forced sucking and blowing.

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