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Dysphagia

Evaluation of Pharyngeal Dysphagia with Manofluorography

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Abstract. The purpose of this paper is to analyze cervical dysphagia with a two-modality method using simultaneous fluoroscopy and solid-state computerized manometry (manofluorography). Manofluorography provides functional data that are not obtainable using barium swallow or standard manometry.

Six examples of pharyngeal dysphagia are presented. They show that pharyngeal bolus transit is due to a pressure gradient. Two major generators of this gradient are tongue-driving pressure and the pharyngeal-esophageal segment negative pressure. Dysphagia is analyzed in terms of alteration of the pharyngeal pressure gradient.

Key words: Manometry – Fluoroscopy – Manofluorography – Pharyngeal dysphagia – Aspiration.

This paper illustrates how simultaneous recording of fluoroscopy and solid state manometry, termed manofluorography (MFG), enhances the analysis of dysphagia. Since there is movement of both the pharynx and manometer during swallowing, it is difficult to correlate the pharyngeal pressure generation to bolus transit. Isberg et al. [1, 2] have reported that catheter movement can cause erroneous high-pressure measurements in the pharyngoesophageal (PE) segment. Elevation of the PE segment is 1.2 cm greater than the catheter elevation during normal deglutition. This movement problem is the rationale for displaying the fluoroscopy and manometry on a single screen. With MFG, the position of the manometric sensor can be seen. Of even greater significance, the measured pressure can be related to the passage of the bolus.

Manofluorography is a bimodality method combining solid-state computer manometry and fluoroscopy [3–5]. It generates three data forms: the manofluorograph (Fig. 1), the manofluorogram (Fig. 2), and a 4-channel strip chart recording. The manofluorograph is the simultaneous presentation of fluoroscopy and manometry. The manofluorogram shows the bolus passage in relation to the computerized pressure pattern. The strip chart recording is a continuous display of pressures recorded by the 4 sensors in the pharynx. The technique is designed to study pharyngeal pressure generation and its relationship to bolus transport. The pressure gradients that cause bolus flow can be analyzed.

Other studies have used simultaneously recorded fluoroscopy and manometry to examine pressures in the pharynx [1, 2, 6]. Sokol defined three different types of positive pharyngeal pressure waves: the E, T, and P waves. The E wave occurs in association with laryngopharyngeal elevation. The T wave onset coincides with backward movement of the base of the tongue. The third, and largest, positive wave was termed the P wave, because it coincides with the peristaltic stripping wave seen on the radiologic study. We will designate here the pharyngeal sequential constrictor wave as the C (constrictor) wave instead of P (peristaltic) wave [4].

Method

The pressure recordings are obtained from a solid-state manometric catheter (OD 3.2 mm) inserted into the pharynx via the nose. Four radiopaque microsensors, spaced at 4 cm intervals and oriented posteriorly, measure pressures from the oropharyngeal level, laryngeal introitus, mid PE segment and cervical esophagus. The positioning of the sensors at these locations

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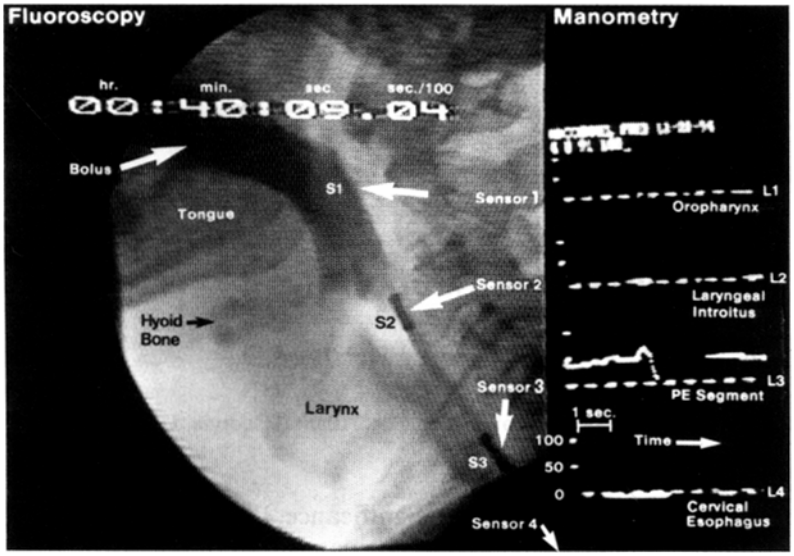


Fig. 1. Normal manofluorograph showing the position of the sensors (S1 through S4) and anatomic designation of their respective levels (L1 through L4).

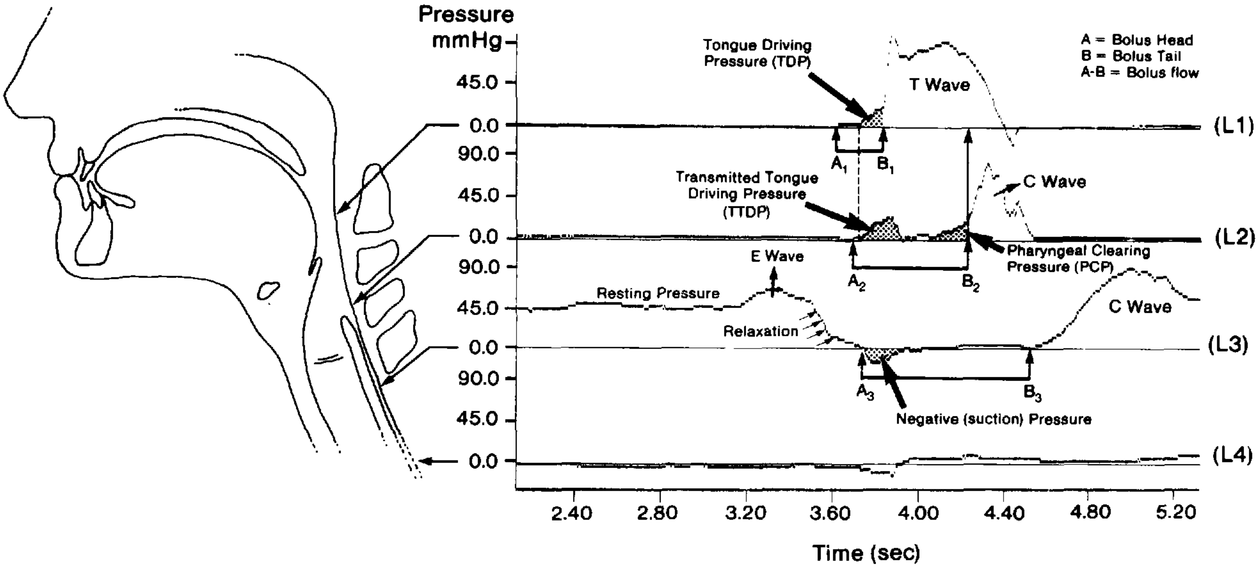


Fig. 2. An example of a computer printout of manometry data from a normal swallow. All relevant driving and absolute pressure waves are indicated. Bolus flow over each level is determined by the AB distance. C wave onset at L2 occurs before the T wave ends.

was based on the results of a previous study in which measurements were made at 1 cm intervals in the pharynx. The lateral view fluoroscopy and manometry patterns are recorded on a split-screen video format on video tape. Electronic timing numbers are also placed on the video tape. The result is a manofluorograph (Fig. 1). Additionally, pressures are continuously recorded on a 4-channel polygraph and also individually stored on a 286 CPU computer. The manofluorogram is the computed printout of the pressure recordings during an 8 s span of time. This printout of the pressure pattern of each of 10 swallows for each patient can be recalled and printed for analysis (Fig. 2).

For each test swallow, the patient holds a measured 10 ml liquid barium bolus in the oral cavity. Upon command, the patient swallows. If aspiration is a problem, the bolus size is reduced to 5 or 2 ml. Analysis is performed by slow motion and still framing of the videotapes of the continuous manofluorographs (60 frames/s) (Fig. 1).

The structure producing each pressure is identified. The time of passage of the head and tail of the bolus past each manometric level is marked (Fig. 2). With this analysis, the amount of pressure applied to the bolus can be determined. It is possible to determine which pressure affects bolus flow and which structure produces the pressure with this technique.

The Normal Swallow

To enhance understanding of the abnormal swallow, the manofluorographic analysis of a normal swallow will be presented.

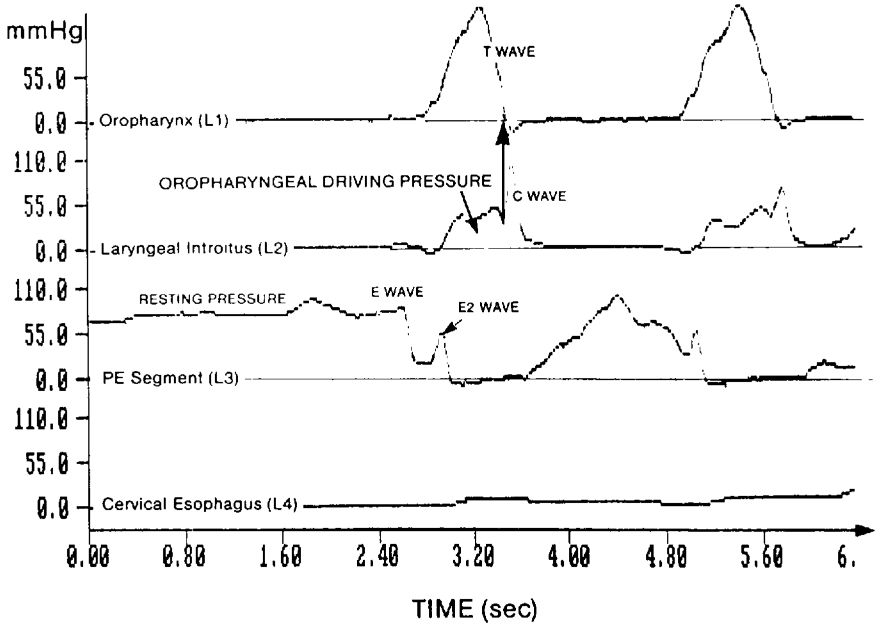


Fig. 3. Patient 1. Manofluorogram of the pressure changes clearly demonstrates the E2 wave. The contraction of the middle pharyngeal constrictor muscle (C wave) coincides with the end of the T (tongue) wave in the oropharynx (*upward arrow*).

While the bolus is in the oral cavity, the pharyngeal stage of swallowing starts with the superior motion of the tongue base, hyoid bone, and the larynx. The hyoid bone and the tongue base then move anteriorly, allowing the bolus to fill the oropharynx.

The anterior elevation also opens the hypopharynx to receive the bolus. Manometrically, this is accompanied by a positive pressure increase (E wave) in the PE segment (Fig. 2). The E wave is a pressure elevation greater than the PE segment resting pressure. After the E wave, the pressure in the PE segment drops toward 0 mmHg. These PE segment pressure changes are followed by the onset of positive pressure in the oropharynx. The positive pressure wave (T wave) is produced by the tongue base compressing the oropharyngeal space (Fig. 2). We have found that only the initial portion of the T pressure wave is applied to the bolus (Fig. 2). The mechanism of the oropharyngeal pressure generation has been compared to a pump, with the tongue base being the plunger and the pharyngeal walls being the chamber [6, 7].

This tongue pressure drives the bolus down the pharynx into the open PE segment. The tongue-driving pressure is transmitted by the bolus and recorded at the level of the laryngeal introitus as transmitted tongue-driving pressure (TTDP), with an average of 18 mmHg pressure (Fig. 2). With the continuation of hyoid bone anterior motion and laryngeal anterior elevation, a prebolus negative PE segment pressure (mean −20 mmHg) is recorded. With a 10 ml bolus, the bolus transit is affected by the pressure gradient produced by two pressure generators: the positive tongue-driving pressure (an average of 18 mmHg) and the PE segment negative pressure (an average of −20 mmHg). There is thus a pressure gradient of 38 mmHg responsible for bolus transport. (These values were determined on 26 normal subjects.) The pharyngeal contraction pressure (an average of 18 mmHg) clears the bolus from the level of the laryngeal introitus, preventing aspiration. The C wave, which occurs immediately after, is applied onto the empty pharyngeal lumen. The C wave in the PE segment occurs up to 100 ms after the bolus tail has passed this sensor.

Reduction of these pressures, their uncoordinated occurrence, or the production of prebolus obstructive pressures, will cause dysphagia. The case reports that follow are examples obtained from MFG records from over 100 patients.

Case Reports

Case 1: Wallenberg Syndrome

A 62-year-old man presented with aspiration. An MFG study revealed several abnormalities of which the most prominent was the uncoordinated manometric pattern of the PE segment. The rapid decline of the E wave was not delayed (Fig. 3). However, at the time of the expected negative pressure occurrence, a new positive-pressure wave occurred (55 mmHg, with a duration of 180 ms). This abnormal prebolus pressure (E-2 wave) caused bolus stoppage at the superior postcricoid level and postponed the occurrence of the pressure gradient necessary for establishment of the bolus flow.

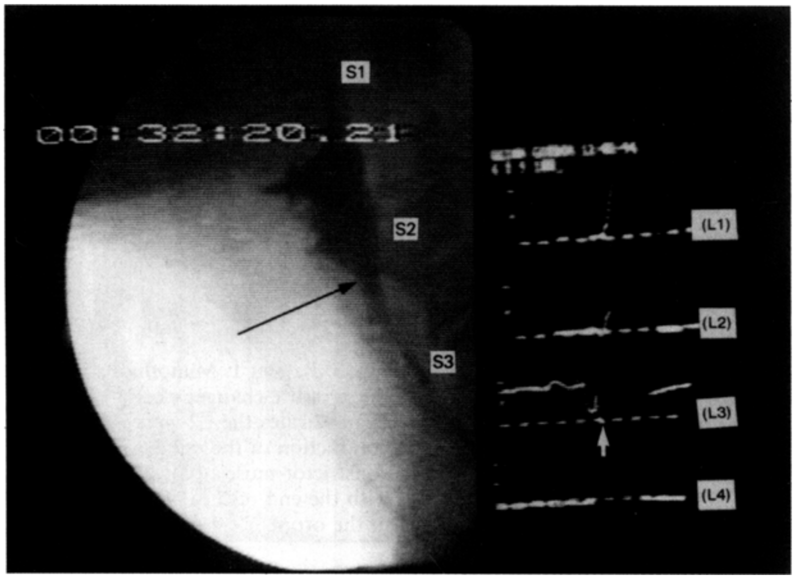


Fig. 4. Patient 1. Manofluorograph shows that the abnormal obstructive pressure wave has ceased (*white arrow*, L3). The pressure drop to 0 mmHg at the PE segment is simultaneous with the bolus entering the PE segment (*black arrow*).

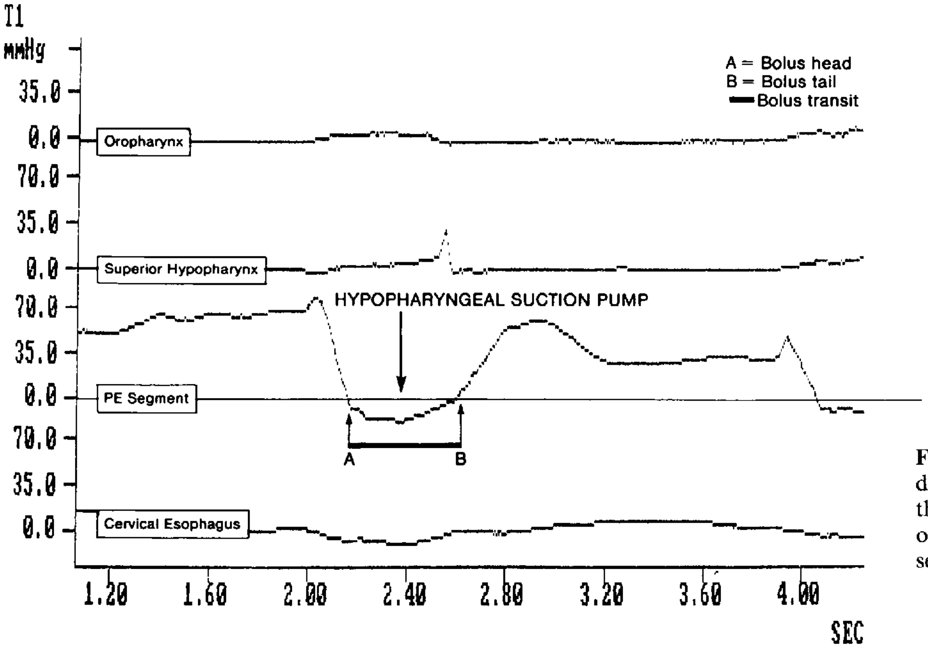


Fig. 5. Patient 2. Manofluorogram demonstrates minimal pressures at the first two levels. The development of negative pressures in the (PE) segment is normal.

With cessation of the E-2 wave, a pharyngeal pressure gradient of 58 mmHg was established and the bolus flow occurred again (Fig. 4). Up to 50 of the 58 mmHg (lasting 550 ms) was due to the increased oropharyngeal driving pressure that developed while the bolus was trapped above the transitory obstruction. Up to −8 mmHg was due to the reduced development of the PE segment negative pressure (Fig. 3). The minimal production of a negative pressure in the PE segment and a narrow bolus stream in the postcricoid segment demonstrated the impaired opening of the postcricoid segment. The increased driving force compensated for shorter and incomplete opening of the PE segment. Termination of the T wave (oropharynx) at the time of the C wave onset (laryngeal introitus) resulted in lack of bolus clearance from the level of the laryngeal entrance. A bolus residue was aspirated following laryngeal reopening. Three to four repeated swallows were required to eliminate the bolus remnants completely.

Case 2: Guillain-Barré Syndrome

A 32-year-old man presented with dysphagia and aspiration secondary to Guillain-Barré syndrome. He received food via a nasogastric tube. The MFG analysis showed that the only effective pressure generator was the PE segment. No tongue-driving pressures in the oropharynx and no oropharyngeal driving pressure at level 2 were recorded. Small T and C waves were seen (Fig. 5). The bolus entered the pyriform sinuses due to gravity and some residual lingual motion and stopped there. The lack of any significant positive driving pressures applied to the bolus tail made the bolus elimination depend entirely on the negative PE segment pressure. During every swallowing attempt, a negative pressure between −15 and −20 mmHg occurred in the PE segment. The duration of the bolus flow coincided precisely with the duration of the negative pressure (Figs. 5, 6). There was a pharyngeal pressure gradient of up

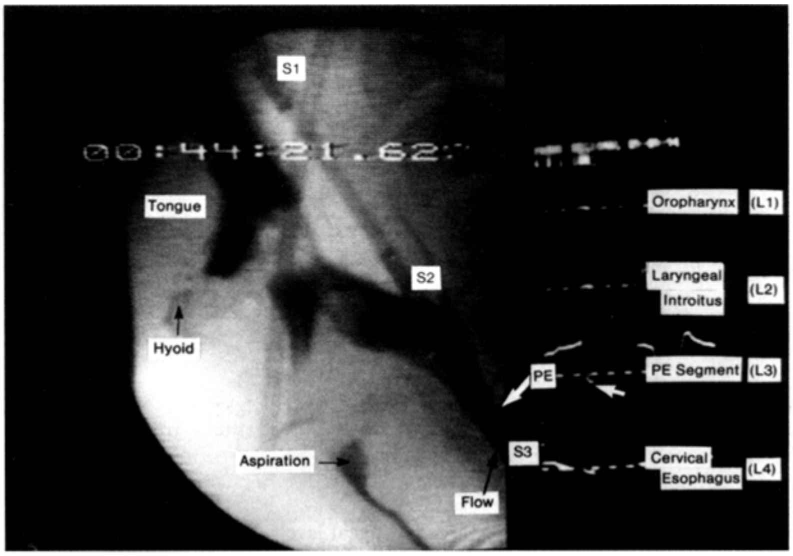


Fig. 6. Patient 2. Manofluorograph shows how the bolus flow through the PE segment (*black arrow*) corresponds to the development of the negative pressure in the PE segment (*white arrow*, L3).

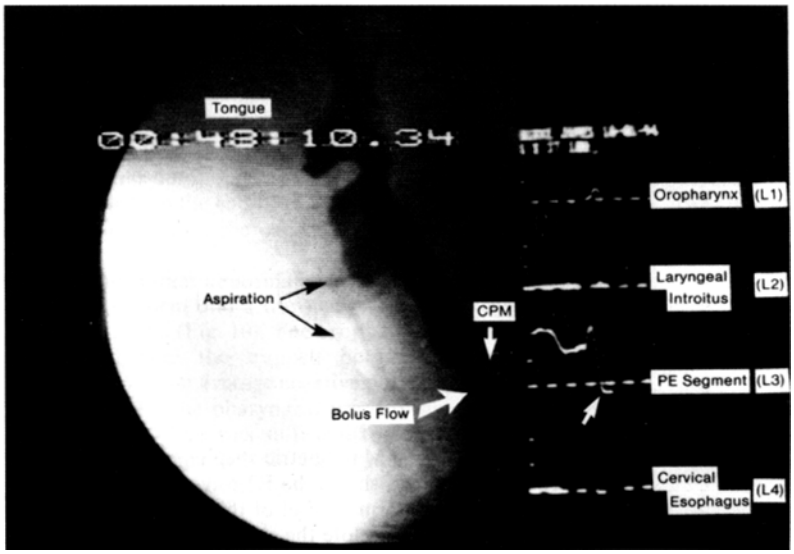


Fig. 7. Patient 3. Manofluorograph shows the bolus flow through the PE segment while the pressure is negative (*arrow*, L3). Barium is seen at the level of the glottis as well as in the trachea.

to 20 mmHg (0 mmHg pressure in the pyriform sinuses and up to −20 mmHg negative pressure in the PE segment). This pressure gradient, labeled the hypopharyngeal suction pump, was capable of eliminating only a small amount of the bolus. Repeated swallows were necessary to eliminate the bolus from the pyriform sinuses. Aspiration occurred because the bolus size exceeded the volume accepted in the pyriform sinuses.

Case 3: Oculopharyngeal Muscular Dystrophy

A 70-year-old man experienced progressive swallowing difficulties and aspiration for several years. Barium swallow films revealed a prominent cricopharyngeal muscle (CPM). A diagnosis of CPM dysfunction had been made elsewhere and the patient was referred for cricopharyngeal myotomy. Prior to surgery, MFG evaluation demonstrated significantly reduced tongue and hyoid bone mobility with no tongue-driving pressure. No contraction of the pharyngeal constrictors was seen on fluoroscopy nor was a C wave measured. Repeated tongue motion and gravity were required to deliver the bolus to the oropharynx and pyriform sinuses. Minimal absolute pressures were recorded in the oropharynx and at the level of the laryngeal entrance; 30 and 25 mmHg, respectively. The PE segment showed a resting pressure up to 160 mmHg. The negative pressure up to −20 mmHg occurred whenever the swallowing reflex was triggered (Fig. 7).

The intermittent development of a negative pressure correlated precisely with bolus flow through the PE segment (Fig. 7). A pharyngeal pressure gradient of 20 mmHg was recorded during bolus flow. Although visible on fluoroscopy (Fig. 7), the CP muscle did not cause obstruction to the bolus flow. The PE segment was the only functional pressure-generator in this patient. Aspiration occurred following laryngeal reopening if the bolus size exceeded the volume of the pyriform sinuses. A CPM myotomy was not performed.

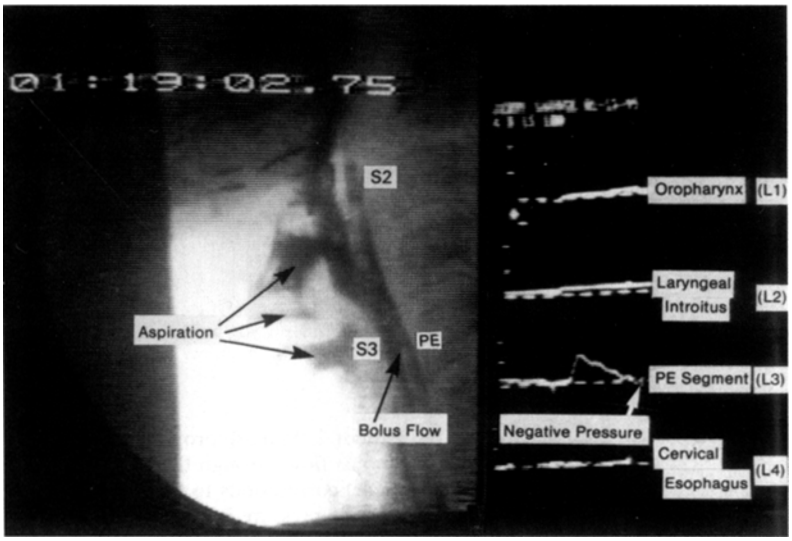


Fig. 8. Patient 4. Manofluorograph of the swallow in progress. Bolus flow is established during the brief development of negative pressure. Aspirated material is seen at all three laryngeal levels (*arrows*).

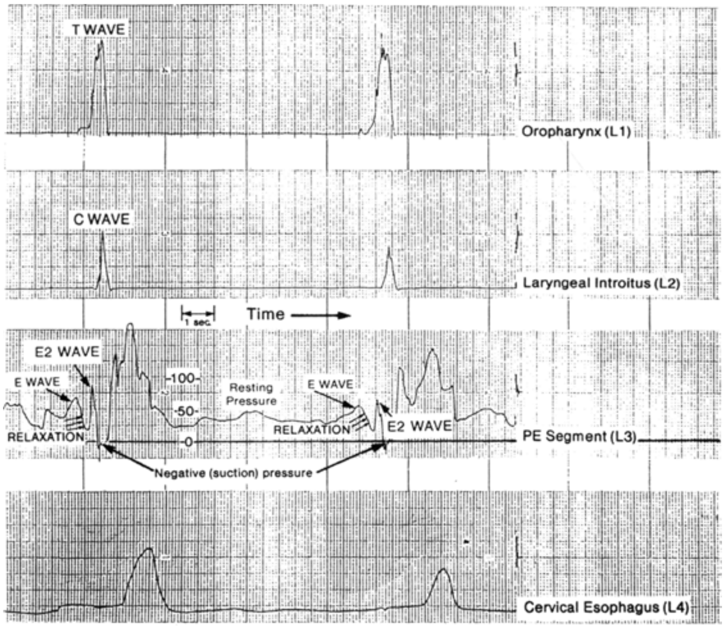


Fig. 9. Patient 5. Manometric strip chart recording of two dry swallows shows the E2 wave and its relationship to the initially normal onset of the cricopharyngeal muscle relaxation. Note the short duration of the two instances of negative pressure in the PE segment (*arrows*).

Case 4: Aspiration

A 72-year-old man, who appeared ill, was sent for MFG evaluation of progressive aspiration that had started 3 months earlier. The patient had had a radical neck dissection 14 years earlier and had undergone irradiation of a tongue base carcinoma. Aspiration, leading to pneumonia, started 4 months before the MFG test.

MFG revealed severely impaired pharyngeal deglutition. The motions of the hyoid bone and the base of the tongue were greatly restricted. Minimal tongue motions and gravity allowed the bolus to pass the oropharynx and to fill the pyriform sinus. The larynx did not elevate and thus remained unprotected. Most of the bolus entered the larynx. During deglutition, the patient required several attempts to open the postcricoid segment successfully. When it opened, it was for a very short time and only a small amount of bolus passed through the postcricoid segment (Fig. 8).

Manometry revealed the lack of both tongue and pharyngeal contraction pressure waves. A low resting pressure of 10–15 mmHg was recorded at the PE segment level. The negative pressure (up to −15 mmHg) in the PE segment occurred occasionally and was of a very short duration; only 50–75 ms. The usual duration is 358 ms. For immediate relief from aspiration, feeding via a nasogastric tube was recommended.

Case 5: Pharyngeal Dysphagia

A 48-year-old woman stated that for the past 3 years she experienced the sensation of food "getting stuck in her throat" when swallowing. She had been examined by a number of different physicians and given the diagnosis of "globus hystericus."

The MFG examination revealed a transient stoppage of the bolus flow above the postcricoid segment. The cause of the bolus flow delay was identified as an extra, positive pressure

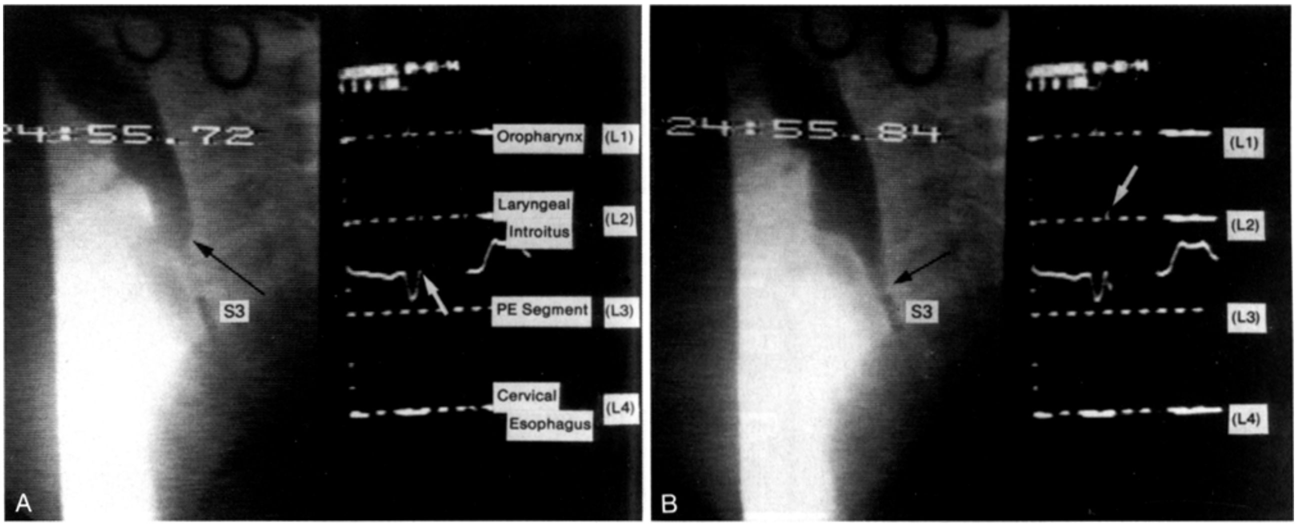


Fig. 10. Patient 5. **A** Manofluorograph shows the bolus head that has arrived at the superior level of the postcricoid segment and has stopped (*black arrow*). This stoppage is due to the development of the obstructive pressure wave (E2), which has reached its peak (*white arrow*, L3). **B** Manofluorograph shows the bolus compressed by the tongue. This is seen manometrically at the second level as an increase of the transmitted tongue-driving pressure (*white arrow*, L2). With the cessation of the E2 wave (L3), the bolus head enters the postcricoid area (*black arrow*).

wave recorded in the entire postcricoid segment. This was labeled as the E-2 wave, with up to 150 mmHg pressure and up to a 250 ms duration (Fig. 9). This obstructive pressure wave occurred close to the end of the cricopharyngeal muscle relaxation and just before the expected occurrence of the negative pressure.

The functional abnormality consisted of delayed opening of the PE segment and a transient stoppage of the bolus flow for up to 130 ms (Fig. 10). The oropharyngeal driving pressure increased behind the trapped bolus and elevated up to 50 mmHg. With an average negative pressure in the PE segment of −15 mmHg, the pharyngeal pressure gradient in this case was 65 mmHg. This was sufficient to compensate for the delayed bolus entrance into the PE segment and successful bolus elimination without bolus residue.

Case 6: Dermatomyositis

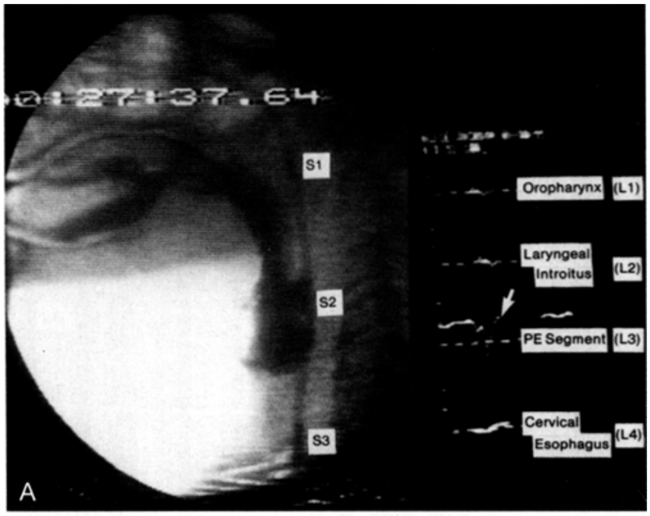
A 70-year-old woman with the diagnosis of dermatomyositis was referred for MFG evaluation because of dysphagia. The MFG study revealed impairment of pharyngeal deglutition at three levels: the oropharynx, superior hypopharynx, and PE segment. The negative pressure in the PE segment occurred as in the normal swallow, but after 100 ms it was followed by an abnormal positive pressure wave of up to 70 mmHg (Fig. 11 A). This obstructed and postponed the bolus entrance into the postcricoid area for 150 ms (Fig. 11 B). Trapped in the superior hypopharynx, the bolus was compressed by the tongue base, which caused elevation of the oropharyngeal propulsion pressure in the second lead. After the termination of the obstructive pressure wave, there was a period of negative pressure of only 20 ms when bolus flow began (Fig. 11 B). The pressure in the PE segment returned to 0 and remained at 0 mmHg during the bolus flow. The oropharyngeal propulsive pressure in the second lead increased to 60 mmHg even after the PE segment opened (Fig. 11 C). This higher pressure indicated the persistence of a relative obstruction of the open, but narrow, PE segment.

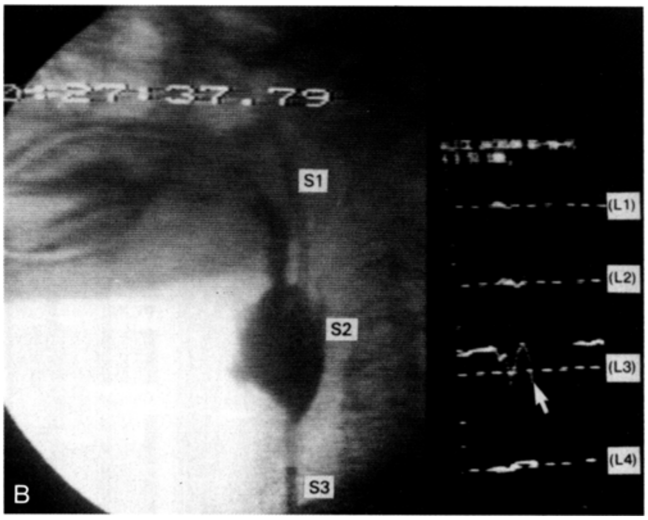
In the superior hypopharynx, no pharyngeal constrictor pressures were seen during the swallow. The only pressure recorded at the level of the laryngeal introitus was the transmitted pressure wave generated in the oropharynx. The established pressure gradient between oropharynx and the PE segment was 60 mmHg. True (bolus stoppage) and relative obstruction (narrow PE segment) to the bolus flow in the PE segment, together with the lack of pharyngeal contraction, caused an impaired clearing of the bolus. An increased pressure gradient was not sufficient to compensate fully for all impairments, especially not for the lack of pharyngeal clearing force. Almost half of the initial bolus remained above the postcricoid area. Three to four repeated swallows were required to pass the entire bolus into the esophagus.

Discussion

The primary function of the pharynx is to generate a pressure gradient for swallowing without aspiration. To be able to develop this pressure gradient, the biomechanics of the pharynx are different from the rest of the alimentary tract. In the oropharynx, the tongue base acts like a plunger or a piston to develop a propulsive bolus-driving force. In the hypopharynx, the prebolus pressure is lowered by laryngeal elevation and constrictor relaxation and a negative pressure is produced. Manofluorography allows analysis of the generation of the pharyngeal pressure gradient.

A number of different investigative modalities have been used to study the pharyngeal swallowing mechanisms in humans and experimental animals: the standard barium swallow [8], cinefluoroscopy [9, 10], videofluoroscopy [11–13], manometry





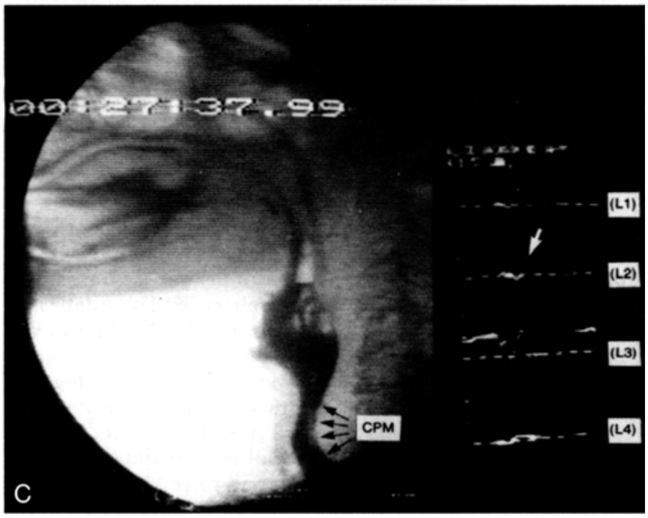


Fig. 11. Patient 6.
A Manofluorograph shows that after the negative pressure was created at the cricopharyngeal muscle level, an abnormal, positive-pressure wave was recorded (*arrow*, L3). The bolus filled the pyriform sinuses where it will remain trapped for the next 150 ms.
B As the negative pressure is established again (*arrow*, L3), the bolus begins to enter the postcricoid area.
C Manofluorograph shows a large and prominent cricopharyngeal muscle (CPM) narrowing the hypopharyngeal lumen. The oropharyngeal propulsive pressure is elevated to 60 mmHg (*white arrow*, L2).

[14–17], electromyography [18], manometry with electromyography [19], and scintigraphy [20]. None of the aforementioned methods allows analysis of the pressure gradient in relationship to the bolus.

The case presentations show a spectrum of degrees of dysphagia from a "lump in the throat" (case 5) to a total inability to complete a swallow (case 6).

The least severe dysphagic problem occurs when the bolus transport remains unaffected. Patient 5 had an abnormally high postbolus pressure recorded at the level of the laryngeal entrance, which explained the patient's "unpleasant" sensation during swallowing.

The most severe dysfunction seen in our cases was the patient with irradiation dysphagia (patient 4). He had not only severely restricted tongue motion with no measured propulsive pressure but also only minimal negative pressure production. This patient required a permanent gastrostomy. The absence of both an oropharyngeal propulsive pressure and the PE segment pressure made this patient a total swallowing cripple. He did have a C wave measured from the pharyngeal constrictor contraction. However, an effective pressure gradient could not be generated because aspiration resulted. Bolus flow was dependent solely on gravity. With the lack of laryngeal elevation and the PE segment closed, the larynx remained completely unprotected from aspiration.

Pharyngoesophageal Segment Negative Pressure

A major pharyngeal pressure-generator for developing a pressure gradient is the PE segment. This was first discussed by Barclay [21]. A negative pressure is generated by laryngeal elevation and opening of the PE segment before bolus arrival. Bolus flow can be obstructed in the PE segment by three different mechanisms: (1) impaired laryngeal elevation (patients 1, 4), (2) lack of cricopharyngeal muscle relaxation, or (3) extra constrictor contraction in the PE segment (patients 1, 5, 6).

Patients 1, 5, and 6 had an abnormal prebolus positive-pressure wave in the PE segment that caused true bolus stoppage. In patients 2 and 3, the PE segment is the only effective pressure-gradient generator. There was no propulsive pressure being generated in the oropharynx.

Tongue Pressure

The primary role of the tongue in producing the propulsive force is a different concept from a peristaltic wave of the pharyngeal walls driving the bolus. (By definition, peristaltic refers to "worm-like" motion that propels the bolus [Dorland's Medical Dictionary]. No action of the pharynx is "worm-like.") This concept of the tongue being the major force of the oropharyngeal pump has been demonstrated in patients who have undergone laryngectomy with and without tongue impairment and in timed studies of normal swallowing [3, 4]. Three patients (2, 3, and 4) had impaired tongue base mobility that resulted in a decreased bolus propulsive pressure. The tongue appears to be the major pressure-generator in the oropharynx. The oropharynx pressure-generation mechanism is best compared to a pump. The tongue is the plunger. However, if the walls of the pump do not provide a chamber, little pressure is generated. The pharyngeal walls act as a dynamic chamber for the tongue. Patient 3, with paralysis of the pharyngeal constrictors, shows an example of a chamber deficiency affecting the pressure-generating ability of the oropharyngeal propulsive pump. The oropharyngeal constrictor muscles did not contract to form the chamber for the backward-moving tongue base; therefore, little tongue-driving pressure was generated.

As illustrated by the case histories, cervical dysphagia can be analyzed in functional terms by measuring the alteration in pressure generation. The MFG records the pressure gradient and makes possible determination of the pathologic basis of a defective pressure generator.

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