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AN INTRALUMINAL PRESSURE STUDY OF LARYNGECTOMIZED
SUBJECTS.

The City University of New York, Ph.D., 1973
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AN INTRALUMINAL PRESSURE STUDY OF
LARYNGECTOMIZED SUBJECTS

by

IRIS WEINHOUSE

A dissertation submitted to the Graduate Faculty
in Speech in partial fulfillment of the require-
ments for the degree of Doctor of Philosophy,
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This manuscript has been read and accepted for the Graduate Faculty in Speech in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

INTRALUMINAL PRESSURE STUDIES OF LARYNGECTOMIZED SUBJECTS

by

Iris Weinhouse

Adviser: Professor Boyd V. Sheets

Statement of the Problem

Approximately one-third of the laryngectomy population cannot learn esophageal speech. While considering emotional factors involved, the author undertook to evaluate certain physiological problems. A review of pertinent literature revealed that investigators have concentrated primarily on the pseudoglottis and upper esophagus. It was the purpose of this study to investigate the motility of the entire esophagus during esophageal speech utilizing intraluminal pressure measurements. In studying speakers of various degrees of speech proficiency, pressure changes were examined in the stomach, the upper and lower esophageal sphincters, and the hypopharynx. Other areas under investigation were the influence of certain selected phonemes facilitating esophageal speech and the question of synchronization of pulmonary and phonatory air during esophageal speech.

Equipment

The equipment used in the study consisted of water-filled polyvinyl catheters (three small fused tubes) swallowed by the subject to any desired depth, which were then connected to external transducers. The transducers fed the changes in internal pressure to a preamplifier, which recorded these variations in pressure in terms of millimeters per second on a direct writing recorder. Also, the external movements utilized during respiration and swallowing were recorded through the preamplifier and indicated on the recording chart in the same form.

Method

Eighteen laryngectomized subjects, whose speech ability had been rated, were asked to phonate nonsense syllables and count, as the changes in pressure in the various structures were recorded. The resultant wave form was analyzed in two segments--the pre-phonation and phonation periods. The responses were subjected to, first, a general type of analysis of variance, and then more specific interactions were examined. Finally, the approximate energy expended by the esophagus during the phonation of the speech stimuli was calculated. The data were then subjected to tests of significance.

Results

1. The better speakers revealed significantly lower esophageal pressures and more variability of performance of this structure than the poorer speakers.

2. Epigastric pressures generated during phonation revealed a significantly higher energy level among the poorer speakers.

3. Data revealed significantly higher hypopharyngeal pressures generated by the better speakers.

4. No significant difference was found between the speech of the two groups vis-a-vis the phonation of selected phonemes.

5. There is no significant difference in the patterns of intraluminal pressure between the upper and lower esophageal sphincters in the present study. Both groups exhibited lower mean pressures than have been previously reported in studies of normal sphincteric activity.

6. Synchrony of air flow from the lungs and tracheostomal air ejection during esophageal speech has been confirmed by this study.

Conclusions

1. The poorer speakers utilize a great deal more energy during esophageal speech, which might indicate that they are under more general bodily tension.

2. Esophageal speakers should be encouraged to maintain pre-operative synchrony of pulmonary and speech air

flow, since augmented stomal noises appear due to excessive tension rather than synchrony between pulmonary and esophageal air flow during phonation.

3. This study suggests that the tension of the upper esophageal sphincter is not a critical factor in the learning of esophageal speech.

4. This study indicates that the better speakers use a combination of both the injection and inhalation methods of air intake. In terms of therapy, for the laryngectomee, an eclectic approach to air intake is indicated, since one method may serve some persons well, but not others.

5. The better speaker appears able to control the esophageal mechanism and counteract the pressures of the surrounding structures while maintaining a degree of relaxation. Therapy might then be structured in as relaxed an atmosphere as possible.

6. Important to the rationale of alaryngeal speech therapy is the finding that the ability of the esophageal speaker does not appear to depend on the phoneme being vocalized at the time of air intake. This would indicate that therapy could begin with, and utilize any phoneme, as long as the individual could learn the esophageal speech method.

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CHAPTER I

INTRODUCTION

Since the performance of the first surgical laryngectomy procedure by Billroth in 1873,¹ the surgical techniques and rehabilitation of the laryngectomy population have improved. Gutzmann, as translated by Kallen, reported twenty-five successful laryngectomy operations in 1908, after he had perfected his operative methods.² Morrison reported that by 1931 the post-operative complications had dropped to a ". . . very low rate of incidence."³

Surgically, as these patients were given improved chances of physical recovery, they were left without the means of speaking, and rehabilitative procedures were haphazard. Early reports of laryngectomized speech were made on patients who had not undergone laryngectomies. Svave-Knudsen, translating from the German, stated that Czermak, in the 1880's, was the first to report laryngectomized

¹M. Lall and G. Evison, "Voice production following laryngo-esophagectomy with colon transplant," J. Laryng. and Otol., LXXXII, 1966, p. 1208.

²L. A. Kallen, "Vicarious vocal mechanism," Arch. Otol., XX, 1934, p. 466, citing H. Gutzmann, Sr., "Stimme und sprache ohne kehlkopf," Ztschr. f. Laryng., Rhino., I 1909, p. 221.

³W. W. Morrison, "The production of voice and speech following total laryngectomy," Arch. Otol., XIV, 1931, p. 414.

speech in a girl who had occlusion of the larynx below the glottis, yet, after a tracheotomy, developed speech.¹

Stoerk, as translated by Svave-Knudsen, later reported esophageal speech in a patient with vocal fold adhesions, after an unsuccessful attempt at suicide.² By the early 1900's, Morrison reported cases of successful pseudovoice in laryngectomees by such pioneers in this area of rehabilitation as Gutzmann, Seeman, and Stern.³ Stern, as translated by Morrison, described four types of pseudovoice that may be produced by laryngectomized individuals. They are:⁴

- a. pseudowhispered speech or the true buccal voice;
- b. pharyngeal pseudospeech;
- c. esophageal pseudospeech;
- d. "stomach" pseudospeech.

According to van den Berg and Moolenaar-Bijl, the buccal type voice is produced with the esophagus closed and high pressure located in the mouth, while pharyngeal speech

¹V. Svave-Knudsen, "The substitute voice of the laryngectomee patient," ACTA Otol., LII, 1960, p. 464, citing J. Czermak, "Ueber die sprache bei luftdichter verschliessung des kehlkops," Sitzungsb. d. K. Akad. d. Wissensch., Math. Naturw. Cl. Wien, XXXV, 1859, p. 65.

²Ibid., p. 464, citing K. Stoerk, "Ueber larynxextirpation," Wien Med. Wchnschr., XXXVII, 1887, p. 1535.

³Morrison, op. cit., p. 416.

⁴Ibid., p. 417, quoting H. Stern, "Der mechismus der sprechund stimmbildung bei laryngektomierten, und die derartigen fallen angewandte uebungstherapie," in Denker and Kahler, Handbuch der Hals-Nasen-u. Ohrenbeilkunde (Berlin: Julius Springer, 1926, vol. 5), p. 494.

results when the pharynx acts as the bellows.¹ Greene, translating from the German, cites Stern as defining esophageal speech resulting when the esophagus acts as the source of air.² This, according to van den Berg and Moolinaar-Bijl, is the preferred method of pseudospeech and results in the best voice quality.³ For purposes of this paper, the speech developed by the laryngectomized individual will be referred to as "esophageal speech" or "alaryngeal speech." The term "pseudoglottis" will refer to the laryngectomy's new "vocal folds."

In analyzing the reasons for the inability of some laryngectomees to learn alaryngeal speech, both physiological and psychological factors have been proposed. The laryngectomee who is placed in the hands of the speech clinician has undergone, not only major surgery, but the fear of recurring cancer and the post-surgical trauma of being unable to communicate orally. In presenting a questionnaire of five questions to seventy laryngectomees, Greene reported that in their responses to the diagnosis of cancer, the majority became depressed and apprehensive,

¹J. van den Berg and A. J. Moolinaar-Bijl, "Cricopharyngeal sphincter, pitch, intensity and fluency in oesophageal speech," Practica Oto-Rhino-Laryng., XXI, 1959, p. 298.

²J. S. Greene, "Laryngectomy and its psychological implications," N.Y. J. Med., XLVII, 1947, p. 417, citing H. Stern.

³Van den Berg and Moolinaar-Bijl, op. cit., p. 298.

while three contemplated suicide.¹ In answering the question about their feelings when they attempted to speak just after the operation, Greene reported that sixty-three of the seventy subjects reported feeling depressed.² Greene has theorized that the ". . . psychic trauma incident to laryngectomy as might be expected tends to exaggerate certain (pre-morbid) personality traits."³ Pitkin administered his own questionnaire to sixty-five of his laryngectomized patients, and reported that some had feelings of post-operative depression lasting four to six months.⁴ He contended that the emotional aspect of the patient is the most important factor in learning esophageal speech.⁵ His statements, however, are based solely on his subjective analysis of the questionnaire he developed. Stoll has simply listed what he felt to be some of the fears plaguing the laryngectomized individual. These include:⁶

¹Greene, op. cit., p. 54.

²Ibid.

³Ibid., p. 55.

⁴Y. N. Pitkin, "Factors affecting psychologic adjustment in the laryngectomized patient," Ann. Otol., LVIII, 1953, p. 43.

⁵Ibid., p. 47.

⁶B. Stoll, "Psychological factors determining the success or failure of the rehabilitation program of laryngectomized patients," Ann. Otol., LXVII, 1958, pp. 551-552.

1. fear of reoccurrence of the tumor and death;
2. fear of the new physiological problems encountered (breathing, coughing, bathing, cosmetic);
3. fear of old age and uselessness;
4. fear of being unable to establish old patterns of relationships;
5. fear of being unable to learn the new speech method.

These reports seem to indicate that the laryngectomee not only comes to the speech clinician with an altered physiological structure to which he must learn to adjust, but psychological problems that are unique to him as a laryngectomee. Diedrich and Youngstrom state that, even when the patient is assured that the cancer has been eradicated and the patient is communicating with esophageal speech, there may be residual psychological problems.¹

While considering these emotional problems, further examination, however, can be undertaken to evaluate the ability of the laryngectomee to learn alaryngeal speech by investigating certain physiological factors. A review of pertinent literature (discussed in Chapter II) indicates that investigators have primarily analyzed the nature and action of the pseudoglottis and the upper esophagus. Research media have included cinefluorography, x-ray techniques, and to a lesser extent, intraluminal esophageal pressure studies. Still other investigations have attempted

¹W. M. Diedrich, and K. A. Youngstrom, Alaryngeal Speech (Springfield, Ill.: Charles C. Thomas, 1966), p. 125.

to analyze the method of air intake and synchrony of pulmonary and air used for speech. While some attention has been given to the entire esophagus during esophageal speech with still x-ray films, no study was found which focused on intraluminal pressure vis-a-vis motility of the entire esophagus during esophageal speech.

Statement of the Problem

The present study was devised to provide additional physiological data concerning esophageal speech, by analyzing total esophageal motility patterns, both internally via intraluminal pressure measurements and externally through the use of cinefluorography and a thermo-couple unit. Using these data sources the following hypotheses are proposed:

1. There is no difference between the changes in air pressure in the stomach of good and poor esophageal speakers during phonation.

2. There is no difference between the changes in air pressure in the body of the esophagus of good and poor esophageal speakers during phonation.

3. There is no difference in the changes in air pressure in the lower esophageal sphincter of good and poor esophageal speakers during phonation.

4. There is no difference in the changes in air pressure in the upper esophageal sphincter of good and poor

esophageal speakers during phonation.

5. There is no difference in the changes in air pressure in the hypopharynx of good and poor esophageal speakers during phonation.

6. There is no difference in the changes in air pressure in the esophagus of esophageal speakers during the phonation of selected phonemes.

7. There is a synchrony of pulmonary and phonatory air during esophageal speech in good and bad speakers.

CHAPTER II

SOME PHYSIOLOGICAL ASPECTS OF ESOPHAGEAL

SPEECH: A REVIEW OF THE LITERATURE

In order to clarify the abnormal speech mechanism adopted by laryngectomees, it will be necessary to review briefly the normal processes of phonation, respiration, and deglutition.

Normal Anatomy

Phonation

The normal individual uses the combination of several organs to produce phonation. Zemlin has described this process as follows:¹

The larynx produces glottal tones by generating a rapid series of short-duration air pulses, which excite the supralaryngeal air column so as to produce a complex tone. . . . The vocal folds are adducted . . . to restrict the flow of air from the lungs. At the same time, the forces of exhalation produce an increasing amount of air pressure beneath the folds, and when it becomes sufficient they are literally blown apart, thus releasing a puff of air into the vocal tract. The release of air results in an immediate decrease of pressure beneath the vocal folds, and the elasticity of the tissue, plus the reduction of air pressure, simply allows them to snap back into their adducted

¹W. R. Zemlin, Speech and Hearing Science (Englewood Cliffs, N.J.: Prentice-Hall, 1968), p. 115.

position, to be blown apart again, once the air pressure has again built up.

Von Leden further proposed that the frequency of vibrations of the vocal folds and the resulting pitch are controlled by the ascending air pressure and the resistance of the folds. In addition, he stated that there is a need for a bellows, which, in the speech process, is furnished by the lungs and a need for resonating chambers, furnished by the pharynx, oral and nasal cavities.¹

Zemlin has postulated that the main biological functions of the larynxis valvular are: to prevent air from escaping from the lungs; to prevent foreign bodies from entering the lungs; and to close off the trachea so as to forcibly expel foreign material.²

In the evolutionary process, man has been able to adapt various parts of his anatomy in order to produce oral speech. Negus has summarized some of the evolutionary changes:³

1. As man walked in a more erect position the larynx descended, thereby increasing the length of the pharynx.
2. The increased reliance of man on sight rather than smell.

¹H. von Leden, "The mechanism of phonation," Arch. Otol., LXXIV, 1961, p. 661.

²Zemlin, op. cit., p. 114.

³V. E. Negus, "The mechanism of the larynx," Laryngoscope, LXVII, 1957, p. 982.

3. The resulting separation of the epiglottis from the soft palate.
4. The reduction of the length of the arytenoid cartilage and the resulting elongation of the membraneous portions of the vocal folds.

Negus proposed the idea that the larynx developed as a passive sphincter to prevent water from entering the lungs of the early lung fish as it moved from air into water.¹ In man, he stated, the larynx developed as an active rather than a passive sphincter. Gradually relying more heavily on sight and beginning to stand erect, man's larynx and epiglottis descended.² This change left a gap between the larynx and soft palate, where eddies of air and friction could occur.³ While this descent facilitated phonation by providing a resonating chamber, and aided man's ability to articulate with his oral structures, Negus pointed out that it reduced his respiratory efficiency.⁴ When primitive man descended from his aboreal habitat, the action of his laryngeal valve degenerated, but this further aided phonation by providing a more flexible vibratory mechanism.⁵ The vocal folds lost their sharp-edged characteristics and took on a more elastic and pliable nature which proved more advantageous in developing an improved

¹Ibid., p. 962. ²Ibid., p. 967. ³Ibid., p. 969.

⁴V. E. Negus, The Mechanism of the Larynx (London: Wm. Heinemann, 1929), p. 478.

⁵Ibid., p. 78.

vocal quality. All these changes occurred, Negus stated, as man developed his intellect and lost some of his vocal strength and capacity for exertion.¹

Respiration

The normal respiratory cycle has also been adapted by man for the function of phonation. As Kaplan has stated: "Respiration is a process used primarily for gas-and-energy exchange between an organism and its environment, and breathing for speech is a secondary function. In spite of this fact, respiration is very importantly involved in speech. It provides the air that will be phonated, resonated, and articulated into meaningful sounds."²

The diaphragm, according to Zemlin, is the most important muscle functioning during respiration.³ This muscle is ". . . a thin, arched, musculo-tendinous partition, located between the thoracic and abdominal cavities."⁴ Because the esophagus passes through this muscle, the description of the diaphragm is of particular interest to this study.

¹Ibid.

²H. M. Kaplan, Anatomy and Physiology of Speech (New York: McGraw-Hill, 1960), p. 87.

³Zemlin, op. cit., p. 62.

⁴Ibid.

The periphery of the diaphragm consists of muscular fibers, which course upward and inward to insert into a central tendon. It is dome-shaped, resembling an inverted bowl, according to Zemlin.¹ Mosher described the diaphragm as meeting in a mid-line, dipping into a cone in front of the spleen, with the tip of the cone formed by the crura.² The crura, as defined by Zemlin, are ". . . two stout pillars of muscle fibers with the right crus thicker and longer than the left. It [the right crus] arises from the upper three or four lumbar vertebrae and their intervertebral discs. Its fibers fan out as they course upward and medially. They decussate and encircle the esophagus before inserting into the central tendon. . . . [The left crus] fibers course steeply upward and medially to insert into the central tendon."³

The relationship of the crura and the apertures of the diaphragm can be seen in Figure 1. In this diagram there are several openings in the diaphragm. Most important to this paper is the one through which the esophagus passes, known as the esophageal hiatus. According to Zemlin, it is located posterior to the middle of the

¹Ibid., p. 64.

²H. P. Mosher, "Anatomical and clinical observations on the lower end of the esophagus and the diaphragm," Trans. Amer. Laryng. Ass., XLV, 1923, p. 59.

³Zemlin, op. cit., p. 64.

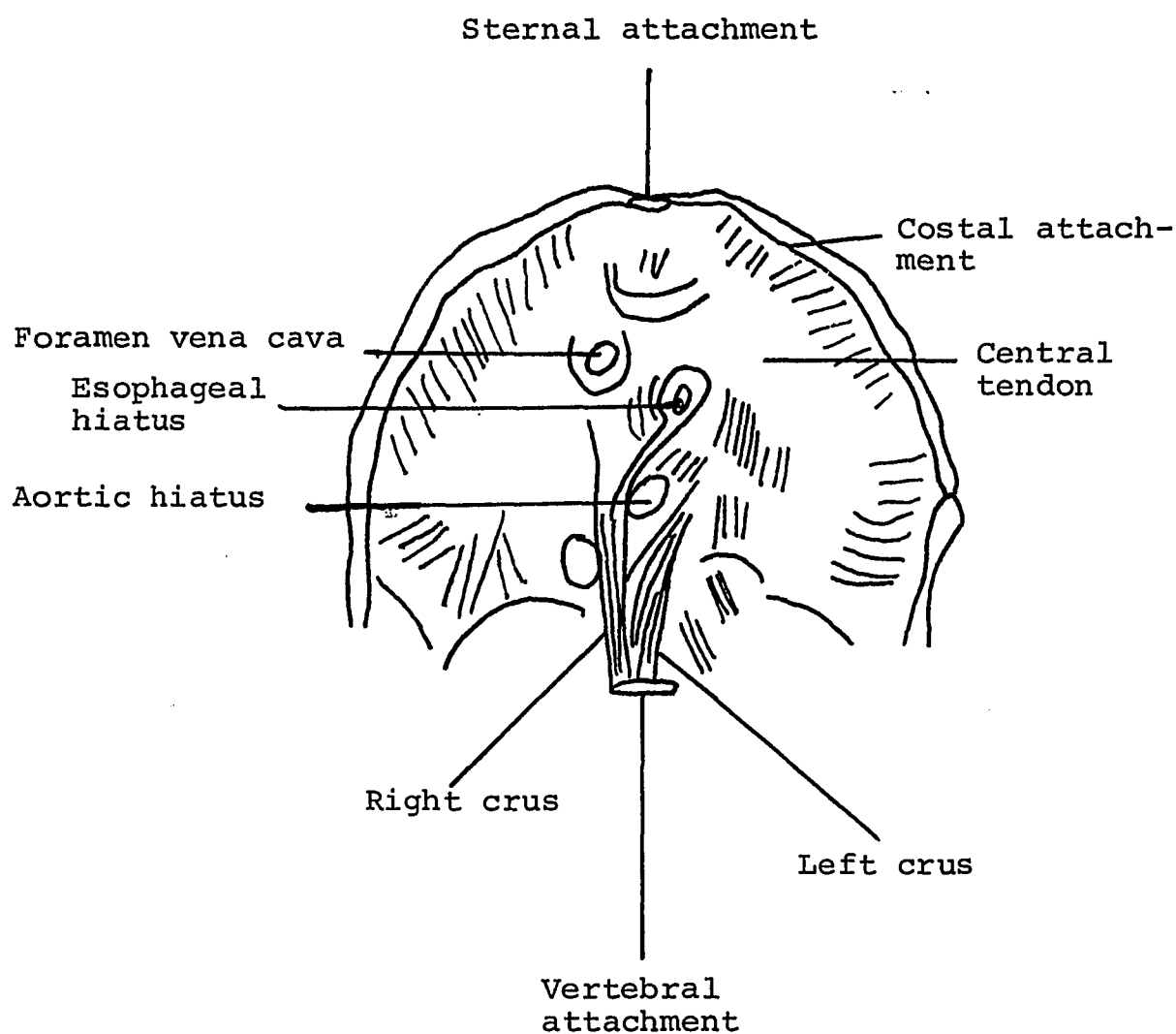


Fig. 1.--Diaphragm as viewed from beneath
(from Zemlin, Speech and Hearing Science).

central tendon and is oval shaped.¹ Collis et al. have stated that the esophageal hiatus is formed by the fibers of the right crus (see diagram). As the fibers from the right crus arise from the main tendon, the fibers of the extreme left of the right crus pass upward, cross over to form the right margin of the hiatus, while the fibers from the side of the right crus pass upward and form the left side of the hiatus.² They further stated that the hiatus consists of two distributions of muscles: longitudinal bands from the crura to the central tendon and oblique and crossing muscle bands.³ The significance of these will be discussed later in reference to the lower esophageal sphincter.

In this diagram, the aortal hiatus, which, as Zemlin indicated, begins at the level of the last thoracic vertebra, and the foramen vena cava, is located at the level of the eighth thoracic vertebra.⁴

During quiet and forced respiration, Zemlin noted that the diaphragm contracts, pulling the central tendon down and forward and increasing the vertical dimensions of

¹Ibid.

²J. L. Collis, T. D. Kelly, and A. M. Wiley, "Anatomy of the crura of the diaphragm and the surgery of hiatus hernia," Thorax, IX, 1954, p. 175.

³Ibid., p. 184.

⁴Zemlin, op. cit., pp. 64-65.

the thorax.¹ At the same time, according to Kaplan, the upward motion of the ribs increases the anteroposterior and lateral thoracic diameters.² Zemlin stated ". . . this action [of the diaphragm] results in an increase in volume and a decrease in pressure within the thoracic cavity. In addition, there is a decrease in volume and an increase in pressure within the abdominal cavity. . . . That is, the descending diaphragm compresses the abdominal viscera, causing them to be displaced downward and forward against the passive resistance of the abdominal muscles."³

A pneumographic study by Wade on normal subjects revealed the close coordination of chest expansion and movements of the diaphragm. He noted that ". . . movements of chest expansion differ from diaphragmatic movements in that they can to some extent be inhibited voluntarily, at any rate in trained subjects."⁴ He has pointed out that while these trained subjects can inhibit thoracic (rib) movements, they have little control over the action of the diaphragm itself.⁵

¹Ibid.

²Kaplan, op. cit., p. 94.

³Zemlin, op. cit., p. 65.

⁴O. L. Wade, "Movements of the thoracic cage and diaphragm in respiration," J. Physiol. (London), CXXIV, 1954, p. 211.

⁵Ibid., p. 210.

According to Zemlin, as the thoracic cavity is enlarged, it results in a negative pressure in the lungs in relation to atmospheric pressures. The air then rushes into the lungs to equalize the intrapulmonary pressure. The abdominal muscles and viscera push on the diaphragm during exhalation, and, together with the elastic recoil of the thoracic muscles, force the diaphragm upward, increasing intrapulmonic pressure, and the air is expelled from the lungs to equalize it once more with the atmosphere.¹

In summary, then, phonation is a combination of the interaction of controlled air pressure from the lungs (the bellows) acting on the laryngeal components (the sound generator) and modified by the resonating chambers and articulators.

Esophagus

Since the laryngectomee, as will be shown later, uses his esophagus as an air reservoir for speaking, the anatomy and motility of this organ is of particular interest to this study and will be discussed in detail.

Topographic Relationships

Ingelfinger has stated, ". . . the function of the esophagus is to convey material from pharynx to stomach and

¹Zemlin, op. cit., p. 107.

sometimes vice versa."¹ In order to perform this function, the esophagus, according to Netter et al., starts in the neck at about the level of the sixth cervical vertebra. This corresponds to the level of the cricoid cartilage.² They stated that ". . . [the esophagus] extends downward through the lower portion of the neck and the superior and posterior mediastina of the thorax. It then passes through the esophageal hiatus of the diaphragm to join the cardia of the stomach at about the level of the tenth thoracic vertebra."³ Ingelfinger defined the cardia as ". . . a term very loosely employed by many writers. . . . [It is] the line separating the saccular cavity of the stomach from the tubular lumen of the esophagus. . . . By definition, however, the cardia may be established at the level where the lateral wall of the esophagus and medial aspect of the dome of the stomach meet at an angle known as the . . . angle of His."⁴

Netter et al. stated that the ". . . over-all length of the esophagus varies to some extent, generally, in

¹F. J. Ingelfinger, "Esophageal Motility," Physiol. Rev., XXXVIII, 1958, p. 533.

²F. H. Netter, N. A. Michels, G. A. G. Mitchell, and M. L. Som, "The Anatomy of the Esophagus" in Upper Digestive Tract, Part 1, Vol. III of Digestive System, ed. by E. Oppenheimer (4 vols.; Summit, N.J.: CIBA Publications, 1959), p. 34.

³Ibid.

⁴Ingelfinger, op. cit., p. 563.

accordance with the length of the trunk of the individual."¹ Lerche indicated that "the length of the esophagus is only partly proportioned to the length of the body,"² but he does not elaborate on this statement.

Anatomists generally divide the esophagus into three sections. Netter et al. listed these as the cervical, thoracic, and abdominal portions of the esophagus.³ Ingelfinger defined these three sections as ". . . an upper or cervical third, a middle third lying between the base of the neck and the aortic arch, and a lower or distal third. The middle and lower thirds make up the thoracic esophagus."⁴ In more detail, Lerche has defined these sections as: ". . . the cervical section from the cricoid cartilage to the manubrium of the sternum; the upper thoracic section from the manubrium to the bifurcation of the trachea; and the lower thoracic section from the bifurcation to the cardia of the stomach."⁵ The following drawing, taken from Netter et al., illustrates the relationship of the esophagus to the pharynx and stomach. (See Figure 1A.) In this illustration the approximate measurement of the length of

¹Netter, op. cit., p. 35.

²W. Lerche, The Esophagus and Pharynx in Action (Springfield, Ill.: Charles C. Thomas, 1950), p. 21.

³Netter, op. cit., p. 34.

⁴Ingelfinger, op. cit., p. 533.

⁵Lerche, op. cit., p. 21.

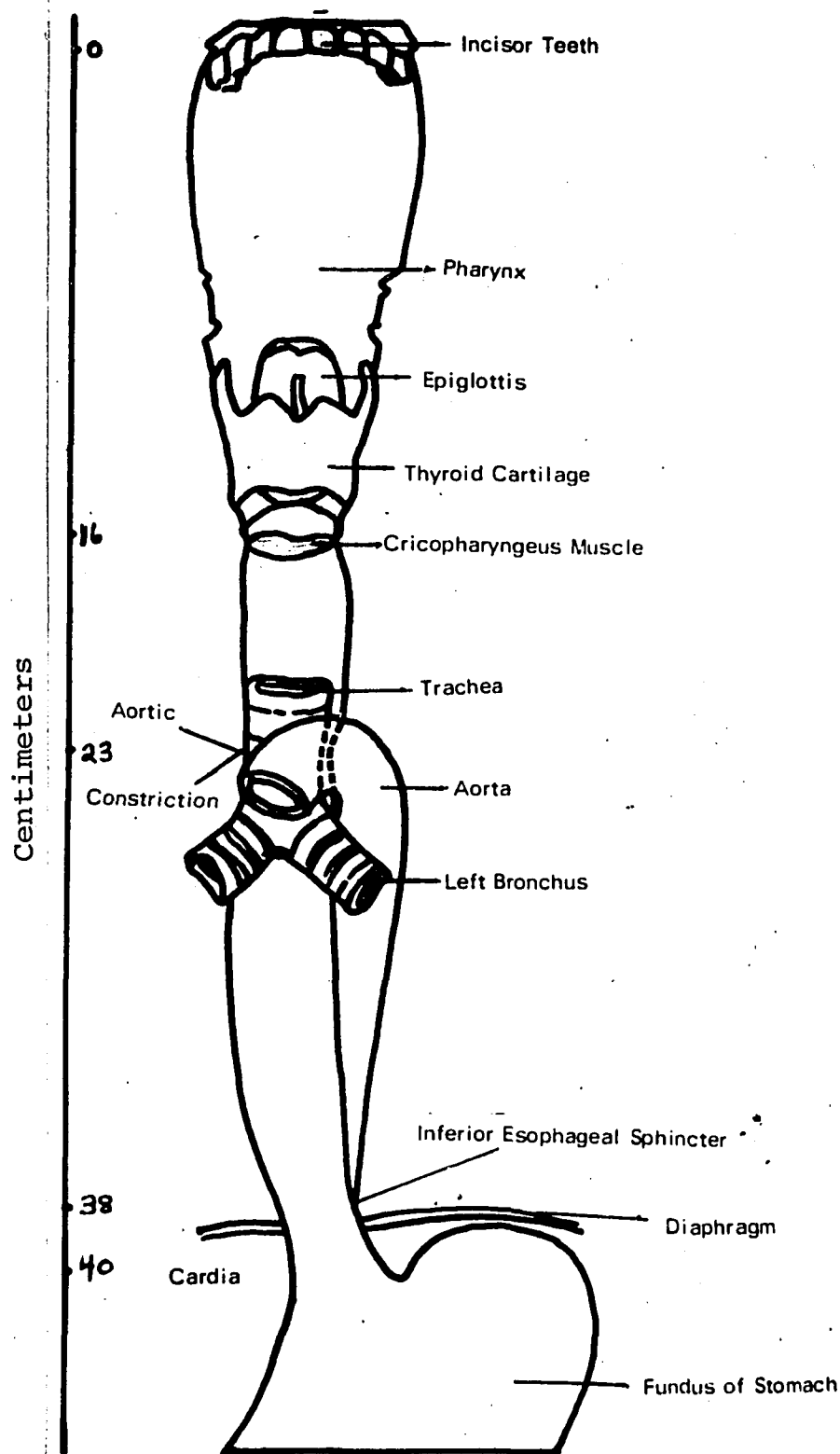


Fig. 1A.--Diagram illustrating the esophagus and surrounding structures (from Netter et al., The Upper Digestive System).

the esophagus is 24 cm. or 10 inches. Measurements of the total esophagus are often taken from the incisor tooth to the cardia and Netter et al. stated that this is circa 40 cm.¹ Lerche, citing a study by von Hacker in which one hundred esophagus measurements were taken on cadavers, noted that only six exceeded 41 cm.² In the diagram (Figure 1A) it is approximately 16 cm. from the incisor tooth to the cricopharyngeus muscle, which is the beginning of the esophagus, and, at approximately 23 cm., the aorta crosses the esophagus causing a slight constriction in this organ. The esophagus passes through the diaphragm at about 39 cm. This is approximately 1 cm. below the beginning of the esophageal vestibule, while the cardia is approximately 1-2 cm. below this hiatus. According to Ingelfinger, the vestibule, which, he stated, is sometimes called the cardiac antrum, refers ". . . to the terminal 2-4 centimeters of the human esophagus and including any sphincteric mechanisms that may be present in this zone. By definition, the vestibule is thus the esophageal segment which normally passes through the diaphragmatic hiatus. . . ." ³ These relationships will be discussed in more detail when the lower esophageal sphincter is considered.

¹Netter et al., op. cit., p. 35.

²Lerche, op. cit., p. 21, citing V. R. von Hacker, "Über die nach Verätzungen entstehenden Speiseröhren-verengerungen" (Wien: Alfred Holder, 1889).

³Ingelfinger, op. cit., p. 533.

Lerche noted that approximately ". . . two-fifths of the esophagus is above the [tracheal] bifurcation, of which one-fifth is the cervical segment and one-fifth the upper thoracic segment, while three-fifths of the esophageal length is below the bifurcation."¹

As the esophagus descends, Netter et al. described it as following the curvature of the vertebral column in general, except in the lower portion. When viewed from the front, the esophagus can be seen to curve twice so that it forms a gentle "S" shape. The first curvature in the upper thorax is convex to the left and the second, commencing just below the tracheal bifurcation, is convex to the right. Just above the hiatus, as reported by these authors, it turns sharply to the left again as it passes through the diaphragm.²

Posteriorly the esophagus lies against the vertebral column until about the level of the fourth thoracic vertebra, where according to Netter et al., the aorta passes behind and then alongside the esophagus. At about the eighth thoracic vertebra, the aorta comes to lie behind the esophagus. Anteriorly the esophagus ". . . continues to lie posterior to the trachea as far as the level of the fifth thoracic vertebral body, where the trachea bifurcates.

¹Lerche, op. cit., pp. 21-22.

²Netter et al., op. cit., p. 34.

The trachea deviates slightly to the right at its lower end, so that the left main bronchus crosses in front of the esophagus. Below this point the esophagus is separated anteriorly from the left atrium of the heart by the pericardium. In the very lowest portion of its thoracic course, the esophagus passes behind the diaphragm to reach the esophageal hiatus."¹

Laterally on the left side, the esophagus, as described by Netter et al., is in contact with the left subclavian artery, until the fourth thoracic vertebra, when it comes into contact with the left mediastinum.² On the right, the esophagus lies in contact with the right parietal pleura (mediastinum) except at about the level of the fourth thoracic vertebra when the azygos vein intervenes.

In Figure 2 Mosher has demonstrated the relationship of the esophagus to the various surrounding structures.⁴ The top diagram is a cross-section of an adult cadaver through the ninth dorsal vertebra. The aorta is posterior to the esophagus, and the esophagus is in close contact with the lungs and pericardium. Mosher stated, ". . . from the bifurcation of the trachea to the tip of the diaphragmatic cone the lungs are in close relationship

¹Ibid., p. 35.

²Ibid., p. 34.

³Ibid.

⁴Mosher, op. cit., p. 74.

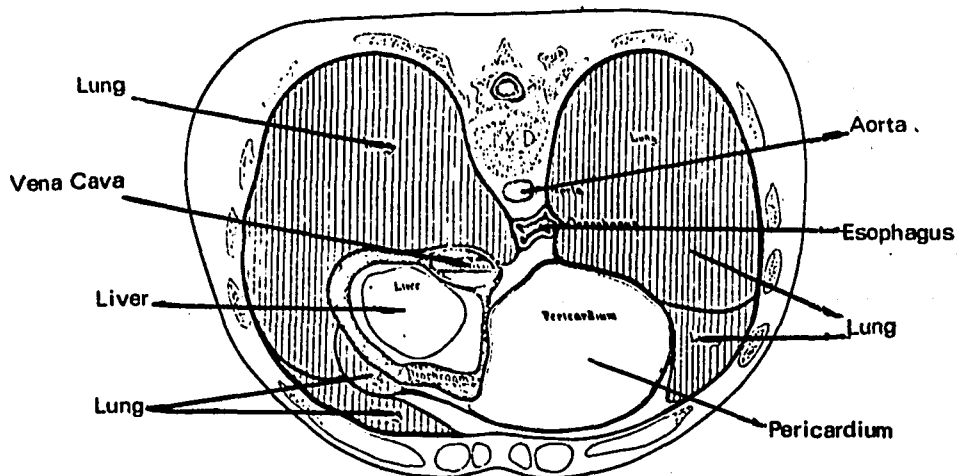


FIG. 14.—Drawing from a tracing of a frozen section of an adult cadaver through the ninth dorsal vertebra. The drawing shows the intimate relationship between the lungs and the esophagus at this level.

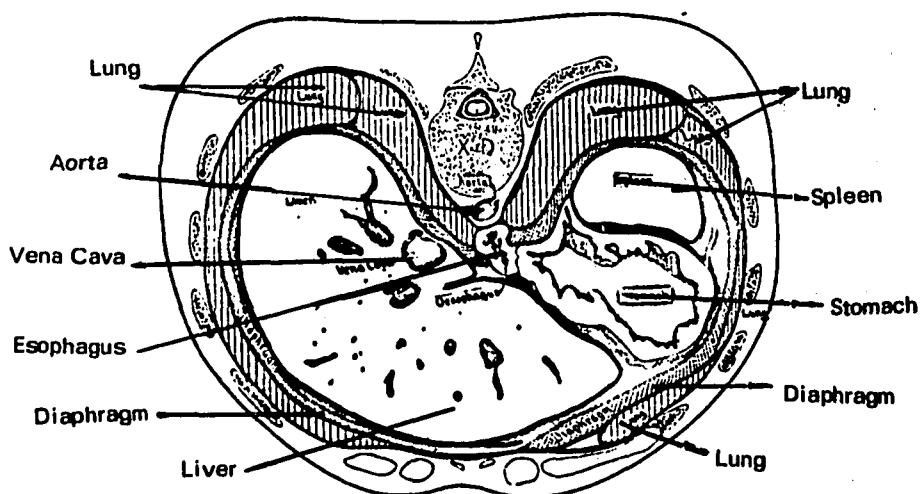


FIG. 15.—Drawing from a frozen section of the same cadaver shown in Fig. 14. The section is made a vertebra lower down. The drawing shows the intimate relationship between posterior basal lung tips and the esophagus. Notice how the long axis of the esophagus has become antro-posterior, instead of transverse as in the section above. This the writer believes is due to the pressure of the expanded lung tips.

Fig. 2.--Cross-sections of a cadaver (from Mosher, "Anatomical and clinical observations of the lower end of the esophagus and the diaphragm").

with the esophagus. The posterior median basal tips of the lungs fill the cone of the diaphragm on either side of the esophagus and the aorta. The basal tips of the left lobe extend farther down than the tip of the right lobe. Each tip sends a slender ligament downward and inward to become attached to the diaphragm close to the esophagus."¹ This relationship is shown in the bottom diagram, which is a cross-section made at the tenth dorsal vertebra and shows the proximity of the lung tips and the esophagus. Mosher pointed out the change in the dimensions of the esophagus from a transverse axis in the top diagram to an antero-posterior axis in the bottom one. This he ascribed to the pressure of the expanded lung tips.²

There is a close relationship between the esophagus and the lungs, and movement of one might conceivably affect the other. Ingelfinger stated that the resting intra-esophageal pressures ". . . are determined by forces arising outside of the esophagus. In the thorax, consequently, these pressures reflect intra-thoracic pressures, falling with inspiration and rising with expiration."³ Netter et al. stated that the walls of the esophagus are in approximation during its resting state, but the width or diameter will vary depending on its state of tonus. The average

¹Ibid., p. 72.

²Ibid., p. 74.

³Ingelfinger, op. cit., p. 542.

resting width is approximately 2 cm.¹

Esophageal Attachments

Netter et al. stated that "the anterior wall of the esophagus is firmly applied to the posterior tendinous wall of the trachea in its upper portion where the two organs are attached to each other by fibro-elastic membranous tissue containing some muscle fibers."² Lerche has divided this attachment into two sections: ". . . a superior [membrane], the tendon of the longitudinal muscle layer, which springs from the upper part of the posterior surface of the cricoid cartilage, and 2) an inferior [membrane], the phreno-esophageal elastic membrane, which springs from the pillars and fascia of the diaphragm and, passing upward, enters both muscle layers at the lower end of the esophageal wall to become fastened in the inferior esophageal sphincter above the diaphragm."³ Both of these divisions of the membranes function to maintain the proper relationship between the esophagus, the diaphragm, and the stomach. "The ascending one serves to restrain excessive shortening of the esophagus during the contraction of the longitudinal muscle layer, . . . and the descending division . . . serves as a barrier

¹Netter, op. cit., p. 35.

²Ibid., p. 36.

³Lerche, op. cit., p. 65.

against intra-abdominal pressure."¹ This latter point will be discussed in more detail when the lower esophageal sphincter is described.

Peters dissected twelve human cadavers to examine the hiatal structures, and reported a diaphragmatic-oesophageal ligament of an elastic nature. He described it as a white membrane, one millimeter thick in adults, bridging the space of the hiatus and inserting around ". . . the circumference of the oesophagus with upward and downward extensions which blend with the oesophageal adventitia. It appears to be an extension of the aponeurosis of the under surface of the diaphragmatic muscle, itself forming a diaphragm within the oesophageal hiatus."² He further concluded that this ligament is relatively fixed and prevents the cardia from passing up through the hiatus during inspiration.³

Mosher also found ligaments of an elastic nature that attach from the lungs to the diaphragm and the esophagus at the rim of the hiatus.⁴ He also noted that the

¹Ibid., p. 67.

²P. M. Peters, "Closure mechanism at the cardia with special reference to the diaphragmatico-oesophageal elastic ligament," Thorax, X, 1955, pp. 32-33.

³Ibid., p. 35.

⁴Mosher, op. cit., p. 59.

esophagus is bound more firmly anteriorly than posteriorly.¹

It appears then that the esophagus is not a freely moving structure within the thoracic cavity, but can be manipulated because of its various attachments to other structures in the thorax and abdomen.

Esophageal Musculature

Not only does the laryngectomee use the esophagus as his air reservoir, but studies, to be reviewed later, reveal that the upper portion of the esophagus, in particular the cricopharyngeus muscle, appears to be the site of the "pseudoglottis." Therefore it is important to understand the musculature of the esophagus, since the laryngectomee has learned to adapt this portion of the digestive system to function as part of his phonatory mechanism.

As Netter et al. stated, the musculature of the esophagus consists of an outer longitudinal layer of muscle and an inner circular muscular layer.² Lerche, in translating and summarizing the findings of Laimer, also described these two muscle layers. The longitudinal layer, according to Laimer, arises from the dorsal surfaces of the cricoid cartilage and receives fibers from the cricopharyngeus muscle. These fibers form a thick longitudinal mass, mainly on either side of the esophagus as they course downward. Some fibers cross to the other side and unite with the

¹Ibid., p. 60.

²Netter, op. cit., p. 36.

fibers there, meeting at an acute angle, leaving a triangular space dorsally where there are no longitudinal fibers.¹ This area Netter et al. refer to as the V-shaped area of Laimer.

Abel, basing her findings on dissections she performed, has demonstrated that the longitudinal muscle layer of the esophagus consists of two bands of muscle fibers that emerge from either side of the interior constrictor muscle. They pass downward and inward and converge circa three and one-half centimeters below the inferior constrictor muscle, leaving the V-shaped notch, through which the inner circular fibers can be seen.³ She summarized her findings as follows: "Briefly, therefore, the longitudinal muscular layer originates in two muscular bundles attached by a common tendon to the posterior surface of the cricoid. The bundles fuse some distance below this cartilage and form the uniform outer muscular layer of the oesophagus."⁴ Laimer, according to Lerche, stated that the esophagus may receive some muscle fibers from its surrounding structures and that these might become part of the longitudinal muscle

¹Lerche, op. cit., p. 11, citing E. Laimer, "Beitrag zur anatomie des oesophagus," Med. Jahr-bucher, Jahrg., (Wien), 1883, pp. 333-338.

²Netter et al., op. cit., p. 36.

³W. Abel, "The arrangement of the longitudinal and circular musculature of the upper end of the esophagus," J. Anat. and Physiol., XLVII, 1913, p. 383.

⁴Ibid., p. 387.

layer and help anchor the esophagus.¹

Not only does the esophagus contain an outer layer of longitudinal muscles, but there is also an inner layer of muscle fibers that, according to Netter et al., is called the circular muscle layer.² Lerche stated that this inner layer receives no fibers from the cricopharyngeus muscle and is therefore independent of any group of muscle fibers.³ Abel, in her dissections, found that ". . . the circular fibres are therefore continuous posteriorly with the inferior constrictor, while anteriorly the uppermost fibres are attached to the common tendon for the longitudinal bundles."⁴ She felt that this inner layer has the common arrangement found in all striate muscles, i.e., they all form some fixed point of attachment.⁵ Netter et al. stated that the question of attachment of the circular band of muscles has still not been resolved.⁶

The inner muscular layer is not a true circular band of muscles, according to Lerche. On the basis of Laimer's descriptions and his own dissections, he has drawn the inner

¹Lerche, op. cit., p. 14, citing Laimer, op. cit.

²Netter et al., op. cit., p. 36.

³Lerche, op. cit., p. 14.

⁴Abel, op. cit., p. 388.

⁵Ibid., p. 389.

⁶Netter et al., op. cit., p. 36.

muscle band of the esophagus, as illustrated in Figure 3.¹ In the upper third of the esophagus, shown in Figure 3, the muscles can be seen to be in an elliptical pattern, with the anterior portion lower than the posterior portion. At the junction of the middle and upper third of the esophagus the fibers take on a more truly horizontal pattern. Then, as one descends, the fibers become elliptical once more, but the reverse of the upper third, and the anterior section is higher than the posterior section. The lower third of the esophagus contains spiral-like fibers that pass around the esophagus as they progress downward and around the esophagus. Both Lerche and Netter et al. indicated that these fibers are not independent of one another, but may overlap and cross and even exhibit clefts between them.²

Type of Muscle Tissue in the Esophagus

The composition of the muscle to be found in the esophagus is of importance in studying laryngectomees. If these individuals are to use their esophagus as an air reservoir and as the site of their psuedoglottis, they must be able to control the structures involved, since speech represents a voluntary act. Of the three types of muscle tissue found in the human body, the striate and smooth

¹Lerche, op. cit., p. 19.

²Ibid., p. 17; Netter et al., op. cit., p. 37.

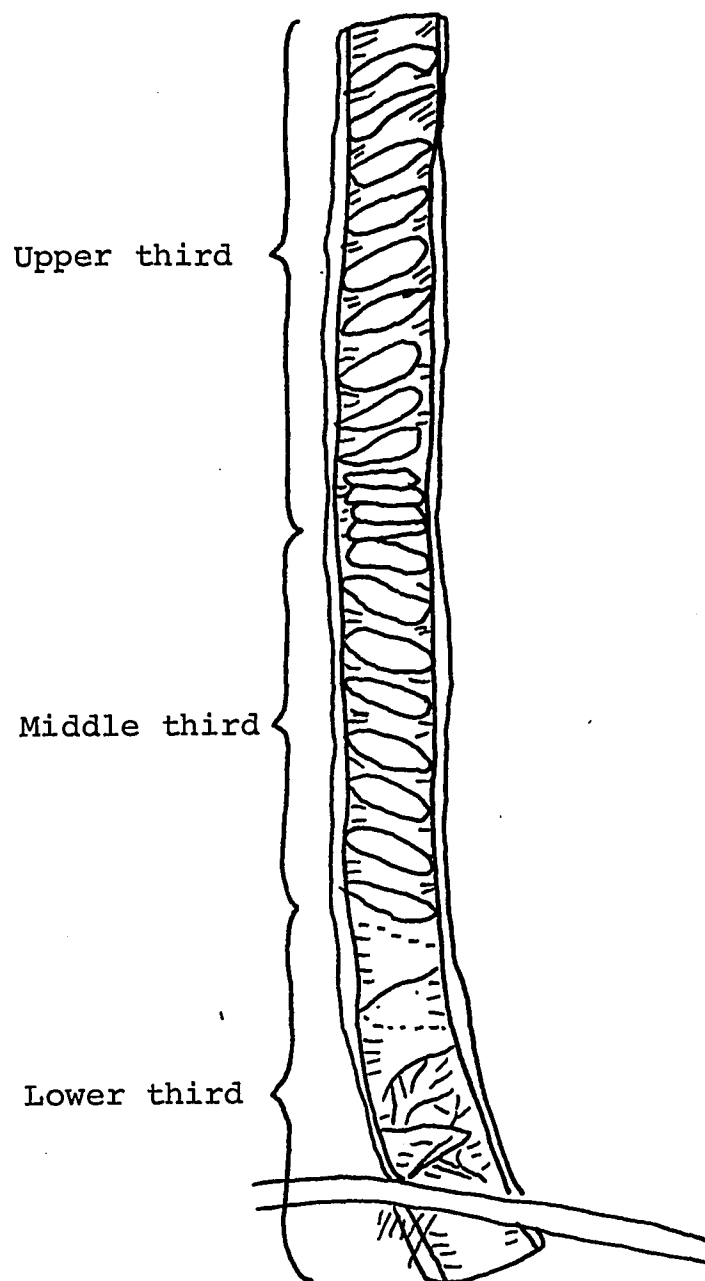


Fig. 3--Lerche's diagram illustrating the arrangement of inner muscle layer fibers of the esophagus, as described by Laimer (from Lerche, The Esophagus and Pharynx in Action).

muscles are germane to the discussion of the esophagus. Smooth muscle, as defined by Zemlin, is a more primitive type of muscle, and is independent of voluntary control. It is sometimes referred to as involuntary muscle.¹ Striate muscle tissue, on the other hand, according to Zemlin, is often called voluntary muscle, with attachments primarily to the skeletal system.²

Researchers agree that both types of muscle fibers are to be found in the esophagus. In his review of the literature, Ingelfinger stated that the striated muscles of the esophagus are to be found in the cervical end, and the transition point between striated and smooth muscle fiber is roughly the junction of the cervical third and thoracic esophagus.³ Netter et al. disagreed slightly with this concept. They stated that it is the first quarter of the esophagus that is comprised of striated muscle, while the transition point, where both smooth and striate muscle fibers are to be found, is the second fourth, the lower half being comprised of only smooth muscle.⁴ Arey and Tremaine, in 1933, dissected seventy-four cadavers and concluded that there was skeletal muscle fiber in both layers

¹Zemlin, op. cit., p. 22.

²Ibid., p. 20.

³Ingelfinger, op. cit., p. 551.

⁴Netter et al., op. cit., p. 37.

of the esophagus in the upper quarter, while the second quarter represented the transitional portion and the lower half contained smooth muscle only.¹ They found that striate muscle fibers, which earlier researchers had discovered in the lower esophagus, are not typical in man.² Abel reported, ". . . on dissection of the part [upper esophagus] it is seen that the muscles simply fuse and that there is no break or division between them. This continuity is histological as well as anatomical, since both the fibres of the inferior constrictor and of the upper part of the oesophageal circular coat are striated."³

At whatever level the transition takes place, the evidence clearly indicates that the upper portion of the esophagus is comprised of striate muscle fibers, which are presumably capable of voluntary control, and therefore could be used by the laryngectomee in alaryngeal speech.

Upper Esophageal Sphincter

Researchers, such as Damste, Hoople and Brewer, Lindsay et al., and Robe et al., believe that the pseudo-glottis used by laryngectomees is comprised mainly of the

¹L. B. Arey and M. J. Tremaine, "The muscle content of the lower oesophagus of man," Anat. Rec., LVI, 1933, p. 315.

²Ibid., p. 319.

³Abel, op. cit., p. 388.

cricopharyngeus muscle.¹ That this muscle should be selected as the pseudoglottis in the laryngectomy is not surprising, since it is considered to be the muscle responsible for the upper sphincteric action found in normal individuals. Netter et al. and Ingelfinger concurred that, even at rest, the muscle tonus in this area can be felt when performing an esophagoscopy.² The sphincter only relaxes ". . . prior to the entrance of the bolus into the hypopharynx."³

Evidence supporting the location of this upper sphincter has not come just from clinical observations. Fyke and Code, in 1955, using a single transducer attached to the end of a rubber tube which was swallowed to various depths into the esophagus and then withdrawn, tested the pressure in the upper esophagus, the upper sphincter, and the pharynx during rest and deglutition in fifteen normal subjects. They observed that between the upper esophagus and hypopharynx there was a zone of high pressure during

¹P. H. Damste, Oesophageal Speech after Laryngectomy (Groningen, 1958), p. 41; G. D. Hoople and D. W. Brewer, "Voice production in the laryngectomized patient," Ann. Otol., LXIII, 1954, p. 650; J. R. Lindsay, R. H. Morgan, and J. M. Wepman, "The cricopharyngeus muscle in esophageal speech," Laryngoscope, LIV, 1944, p. 62; E. Y. Robe, P. Moore, A. H. Andrews, and P. H. Hollinger, "A study of the role of certain factors in the development of speech after laryngectomy: 2. Site of the pseudoglottis," Laryngoscope, LXVI, 1956, p. 396.

²Netter et al., op. cit., p. 74; Ingelfinger, op. cit., p. 533.

³Netter et al., loc cit.

rest, located at the level of the cricoid cartilage, corresponding to the inferior pharyngeal constrictor muscle and the cricopharyngeal muscle.¹ During deglutition, these authors noted a drop in pressure from a mean of 41 cm. of water to -12 cm. of water, with a re-establishment of a high pressure zone after the wave of deglutition passed the area.² They concluded that an upper sphincter does exist and that it is in a tonic contraction state during rest, and relaxes during deglutition.³

Atkinson et al., in 1957, using instrumentation similar to Fyke and Code, measured resting pressures in the esophagus, upper esophageal sphincter, and the pharynx of sixteen normal subjects. They, too, reported a high pressure zone corresponding to the level of the cricoid cartilage, with pressures varying between 10 and 60 mm. of mercury. This zone of high pressure lasted from 1 to 4 cm. in axial length.⁴

There is little question that an upper esophageal sphincter exists, which separates the hypopharynx and upper

¹F. E. Fyke, Jr. and C. F. Code, "Resting and deglutition pressures in the pharyngo-esophageal region," Gastroenterology, XXIX, 1955, p. 27.

²Ibid., pp. 27-28.

³Ibid., pp. 30-31.

⁴M. Atkinson, P. Kramer, S. M. Wyman, and F. J. Ingelfinger, "The dynamics of swallowing: 1. Normal pharyngeal mechanisms," J. Clin. Invest., XXXVI, 1957, p. 583.

esophagus by remaining closed during rest and relaxing during deglutition. The muscular composition of this sphincter presents a complex situation. Most researchers attribute this sphincteric action to the cricopharyngeus muscle. The fibers of the cricopharyngeus muscle were first identified by Valsalva in 1717 and, according to Batson, they are often confused with the inferior pharyngeal constrictor muscle.¹ Anatomically Batson described these fibers as having:²

. . . Their attachment to the cricoid cartilage laterally at the junction of the annular portion with the "signet" portion of the cartilage. From these attachments the fibers form a horizontal band-like sling which enclosed the mucous membranes of the lower end of the pharynx. This is the narrowing of the pharynx into the esophagus. This band of fibers is 10-12 mm. high.

There is some question as to whether the cricopharyngeus muscle constitutes an independent muscle or is part of the inferior pharyngeal constrictor. Lerche defined it as the latter, and so does Netter et al.: ". . . the cricopharyngeus muscle, although strictly speaking a muscle of the pharynx, . . . is nevertheless of great importance in the function . . . of the esophagus."³

¹O. V. Batson, "The cricopharyngeous muscle," Ann. Otol., LXIV, 1955, p. 47.

²Ibid., p. 50.

³Lerche, op. cit., p. 12; Netter et al., op. cit., p. 37.

They concurred with Negus that the fibers of these muscles meet posteriorly in the median raphe of the inferior pharyngeal constrictor muscle.¹ Lerche stated that it is the upper fibers of the cricopharyngeus muscle that unite in the middle raphe, while the lower fibers run more horizontally and interdigitate, without interruption, with the fibers from the other side.² He identified two layers of fibers of the cricopharyngeus muscle, again translating Laimer. A superficial layer is described which interdigitates with the fibers from the other side; also a deeper layer, which converges with the longitudinal muscle layer in a different manner. He stated that some of the lowest fibers of the cricopharyngeus muscle unite with the longitudinal layer on the ipsilateral side, while some unite by crossing over to the opposite dorsal esophageal wall and then descending.³

The upper esophageal sphincter, according to Schreiber, as translated by Lerche, ". . . when it is not in action during swallowing is closed by the inferior pharyngeal constrictor, by the larynx resting against the posterior wall of the pharynx, and by the circular muscle

¹Netter, loc. cit.; V. E. Negus, "The mechanism of swallowing," J. Laryng. and Otol., LVIII, 1943, p. 53.

²Lerche, loc. cit.

³Ibid., p. 142, citing Laimer, op. cit.

layer of the cervical esophagus."¹ Lerche subsequently ascribed several contributory factors controlling the upper esophageal sphincter. Ingelfinger supported the concept of a multiple mechanism of sphincteric action. He noted that, while Atkinson et al. found the high sphincteric pressure present over an axial distance of 1-4 cm., Batson's anatomical study revealed that the cricopharyngeus muscle is only 1.2 cm. in length. Ingelfinger concluded that ". . . both cricopharyngeal and esophageal muscles contribute to the [sphincteric] mechanism."²

Templeton and Kredel, in 1943, studied spot x-rays of this area using normal subjects during rest and in performance of the Valsalva maneuver. They observed that during rest there is a mass of tissue with a lumen of .5 cm.-1.0 cm. in width. This they assumed to be the cricopharyngeus muscle. During the performance of the Valsalva maneuver, this lumen narrowed.³ They concluded that the cricopharyngeus muscle is a true sphincter, whose contraction is intensified upon performance of the Valsalva

¹Ibid., p. 141, citing J. Schreiber, "Ueber den verschluss-vorrichtung am beginn der speiserohre," Arch. f. Verdauungskrank, XXI, 1915, pp. 179-195.

²Ingelfinger, op. cit., p. 535.

³F. E. Templeton and R. A. Kredel, "The cricopharyngeal sphincter: a roentgenologic study," Laryngoscope, LIII, 1943, pp. 6-7.

maneuver.¹ Negus, too, on the basis of his anatomical studies, categorized the cricopharyngeus muscle as the upper esophageal sphincter.²

The research just cited indicates that, on the basis of both anatomical and motility studies, an upper esophageal sphincter does exist in normal individuals. Most researchers agree that the cricopharyngeus muscle is either part of its muscular structure or the whole muscle that comprises this sphincter. However, there is the question, still not resolved, as to whether the cricopharyngeus muscle is a separate entity or just the caudal portion of the inferior pharyngeal constrictor muscle.

The Lower Esophageal Sphincter

According to Ingelfinger, evidence exists supporting the theory that some mechanism prevents reflux of gastric material into the esophagus. This mechanism should remain closed except when ". . . it is physiologically advantageous for the organism that the luminal contents flow one way or the other."³

Several manometric studies have indicated that the pressure in the resting stomach is generally higher than

¹Ibid., p. 12.

²Negus, "The mechanism of swallowing," p. 53.

³Ingelfinger, op. cit., p. 561.

the resting esophageal pressures. Research in this area was carried out by Spiro and Nagler in 1960. They observed esophageal and stomach pressures in an unreported number of normal and abnormal subjects during rest and deglutition. Their equipment consisted of three fused polyethylene catheters, which were swallowed by the subjects. Each catheter contained a lateral hole, 5 cm. from the opening in the other catheters. In this manner they obtained simultaneous recordings of pressure changes in the sites tested. They reported that in normal subjects the resting pressures in the stomach are higher than those in the esophagus.¹ They further noted a zone of high pressure between the two structures mentioned, extending from 1 cm. below to 2 cm. above the hiatus, which they defined as the inferior esophageal sphincter.² Ingelfinger reported a gradient of about twenty between the generally positive pressures in the stomach and the generally negative pressures in the thoracic esophagus.³ If there were no sphincteric mechanism, the pressures would then tend to equalize, rather than remain different.

¹R. Nagler and H. M. Spiro, "Esophageal motility studies in the clinical diagnosis of esophageal disease," Conn. Med., XXIV, 1960, p. 2.

²Ibid.

³Ingelfinger, op. cit., p. 561.

Peters stated that there are three possible mechanisms which prevent regurgitation of material from the stomach into the esophagus. These he listed as:¹

1. external sphincteric action of the diaphragm;
2. intrinsic sphincter action in the distal esophagus;
3. valvular action between the esophagus and the cardiac of the stomach.

In order to investigate each theory, he dissected twelve human hiatal structures. He observed that the esophagus and diaphragm were intimately associated by means of ligaments surrounding the esophageal hiatus. These ligaments were relatively fixed and prevented the cardia from passing up through the hiatus during inspiration. He concluded that, as the diaphragm contracts during inspiration, it constricts the esophagus, and thus supported the "pinchcock" theory advocated by Jackson in 1922.² Mosher, on the basis of his dissections and x-ray analysis, supported this theory as well, but he called it the "reversed phenomenon," i.e., ". . . the esophagus is momentarily closed when the diaphragm starts downward. This is due to the pressure on the esophagus of the expanded lung tips."³ He concluded that, not only the diaphragm, but the surrounding lungs contribute to the sphincteric action in

¹Peters, op. cit., p. 27.

²Ibid.

³Mosher, op. cit., p. 59.

the lower esophagus by occluding its lumen.

The evidence of an internal inferior sphincter was more difficult to discover. Peters suggested that this type of sphincteric mechanism is present because, in his dissections of two thousand cadavers, he observed a prevailing thickening of the lower esophagus.¹ This is similar to the findings of Laimer, as reported by Lerche, who found a general narrowing of the esophagus circa 2 cm. above the hiatus, extending about 2-3 cm. in axial length.² This constriction was also noted in dissections done by von Hacker, as reported by Lerche, at the level of the diaphragm.³ Lerche indicated a great deal of variability in the thickness of the esophageal walls in the eighty specimens he examined. He stated that the thickness depends on the state of contraction of what he termed the "inferior esophageal sphincter."⁴ He advocated rather strongly that ". . . the inferior esophageal sphincter represents the closing-mechanism between the esophagus and the G-E [gastro-esophageal] vestibule. Normally, it is always closed in tonic contraction. As the constrictor cardiae

¹Peters, op. cit., p. 34.

²Lerche, op. cit., p. 53, citing Laimer, op. cit.

³Lerche, loc. cit., citing von Hacker, op. cit.

⁴Lerche, op. cit., p. 54.

ordinarily is not contracted when the stomach is empty, the inferior esophageal sphincter then constitutes the only closure between the negative pressure in the esophagus and the positive pressure in the stomach."¹

Additional support for an intrinsic inferior esophageal sphincter comes from recent intraluminal pressure studies. Fyke et al., in 1956, performed intraluminal pressure readings on nineteen subjects, using a swallowed single transducer, referred to in their prior study. During rest no single pressure measurement could be obtained in the esophagus or stomach because of changes that were constantly occurring during respiration. However, during deglutition a high pressure zone running from 1 cm. below to 3 cm. above the hiatus was demonstrated. The pressure in this zone fell during the act of swallowing, and then returned to its former level at the completion of deglutition.² The authors concluded that there definitely is a "gastroesophageal sphincter because of this high pressure zone and that this area behaves as a sphincter by its ability to contract in coordination with deglutition."³ They described this lower sphincter as weak, with a high

¹Ibid.

²F. E. Fyke, Jr., C. E. Code, and J. F. Schlegel, "The gastroesophageal sphincter in healthy human beings," Gastroenterologia, LXXXVI, 1956, pp. 144-145.

³Ibid., p. 148.

pressure of only 10 cm. of water at most greater than the stomach, but adequate enough to prevent reflux under normal conditions.¹

Nagler and Spiro also performed intraluminal pressure tests of this area, using simultaneous recordings from three sites. These authors reported a high pressure zone interposed between the fundus of the stomach and the esophagus which lies from 1 cm. below to 2 cm. above the hiatus. They described its action during deglutition: ". . . the pressure decreases in this zone to indicate relaxation of the sphincter. When the peristaltic wave passes, pressure in the lower esophagus rises beyond its resting state; this indicates that contraction has taken place."²

The third sphincteric mechanism mentioned by Peters is that of a valvular action. Reportedly this action presents two parts. The first is the fact that the esophagus inserts into the stomach at an oblique angle, and the second is that the terminal esophagus turns to the left and partially twists immediately below the diaphragm.³ This anatomical orientation is similar to the description given by Mosher, who stated that the lower end of the

¹Ibid., pp. 148-149.

²Nagler and Spiro, op. cit., p. 2.

³Peters, op. cit., p. 36.

esophagus has a vertical and horizontal arm, and where the two meet they twist and turn to the left.¹ It is this angulation that has been purported to be another mechanism that prevents reflux. Peters concluded that all three mechanisms work together to prevent regurgitation.²

Ingelfinger has summarized these findings with reference to the lower esophageal sphincter: It is ". . . a mechanism not ascribable to either pinching by diaphragmatic crura or the gastroesophageal pressure gradient."³ Also, ". . . the high pressures characteristic of the resting state appear independent of diaphragmatic action and are not adequately explained by passive valvular mechanisms. The response of the vestibular high pressure zone to swallowing or esophageal distention also suggests an intrinsic mechanism which undergoes sequential relaxation and contraction in response to the peristaltic impulse."⁴

Peristalsis

The normal function of the esophagus is to convey food from the hypopharynx to the stomach and, as such, is part of the process of deglutition. In his efforts to use

¹Mosher, op. cit., p. 58.

²Peters, op. cit., p. 36.

³Ingelfinger, op. cit., p. 574.

⁴Ibid., p. 567.

this organ as a pseudoglottis and air reservoir, the laryngectomy must alter this normal process, so that the air introduced into his esophagus during his speech attempts is not carried off, via peristalsis, to the stomach, but is directed rostrally. A short discussion of the normal process of deglutition, including peristalsis, is therefore in order, so that the laryngectomy's use of the esophagus will be better understood.

Negus described two stages of deglutition: the buccal stage when the food is inserted between the lips and masticated in the oral cavity; and the second when food is propelled from the pharynx into the mouth of the esophagus.¹ It is the second stage that is of primary interest to this investigation.

Two theories have been advanced to explain the manner in which a bolus enters the esophagus. One is that the bolus is sucked into the esophagus because of the negative pressures present in the esophagus. During swallowing, according to Negus, the upper esophageal sphincter relaxes to open the mouth of the esophagus. Since there is reduced pressure in the esophagus during inspiration, when the esophagus does open, there is some sucking action of the bolus into the esophagus, but he contended that this action alone cannot override the second theory--the pumping action

¹Negus, "The mechanism of swallowing," p. 148.

of the pharyngeal constrictors.¹ In this theory it is advocated that the pumping action of the pharyngeal constrictor muscles propels the bolus toward the esophagus.

Fyke and Code investigated these two theories. Their research design used fifteen normal subjects who swallowed a tube containing a small transducer at one end and a free end that was attached to a recording system, consisting of a galvanometer and photokymograph. The subjects were tested in the performance of dry swallows. The results indicated that in the upper and middle portion of the pharynx there was first ". . . a large positive deflection of short duration followed by a small negative deflection. The mean pressure developed by the positive wave was 99 cm. of water."² In the upper esophageal sphincter, at the start of the act of swallowing, there was a positive deflection, with a mean of 41 cm. of water, which dropped quickly to -12 cm. of water, then re-established itself at a higher pressure, with a mean of 19 cm. of water. This pressure profile indicated the relaxation of the upper sphincter, at the initiation of the swallowing act, which allowed material to enter the esophagus.³ The upper esophagus revealed an initial

¹V. E. Negus, "The second stage of swallowing," Acta Oto-laryng. Suppl., LXXVIII, 1948, p. 81.

²Fyke and Code, op.cit., p. 29.

³Ibid., pp. 27-28.

negative deflection, which was followed by a large positive one, whose mean was 59 cm. of water.¹ Their study gives evidence to indicate that it is the large, almost pumping action of the pharynx that propels the bolus or material into the esophagus and not the sucking action of the negative pressure in the esophagus.² They reported that during deglutition ". . . our studies have shown, however, that pressure in both the lower part of the pharynx and upper part of the esophagus is reduced to a value considerably below resting esophageal pressure. This negative pressure does not bear any relation to any phase of the respiratory cycle, and it, therefore, cannot be ascribed to a decreased thoracic pressure." The authors theorized that the negative pressure in the esophagus may be the result of the lengthening of this organ during respiration.²

Zaino et al. studied the changes that occurred in the esophagus during respiration using spot x-ray plates of fifty patients with tuberculosis. During inspiration the esophagus gets thinner and stretches, which they concluded was the result of the anchoring devices at the level of the hiatus.³ They wrote: ". . . while the esophagus is

¹Ibid., p. 27.

²Ibid., p. 31.

³C. Zaino, M. H. Poppel, and C. F. Blazik, "Roentgenologic study of the abdominal segment of the esophagus in the presence of pneumoperitoneum," Am. J. Digest. Dis., XXII, 1955, p. 124.

anchored down at the esophageal hiatus, the supporting phrenoesophageal membrane is also overstretched, allowing for considerable excursion of the lower esophagus above or below the diaphragm depending on the abdominal air pressure fluctuations due to changes in position, reshuffling of abdominal organs and respiratory action."¹

The action of the esophagus during deglutition has been studied by several researchers. Nagler and Spiro found that, as the esophagus contracted to produce the primary peristaltic wave, there was a forceful, monophasic, bell-shaped rise in pressure that was recorded, which passed progressively down the length of the esophagus in wave-like fashion.² Secondly, Butin et al., using twelve normal subjects, studied the peristaltic wave. Their subjects swallowed an electric transducer attached at the end of a rubber tube, whose output was recorded on a photokymograph. This was similar to the equipment used by Fyke and Code.³ Butin's subjects were asked to produce a dry swallow, drink water, and eat half a cookie, while pressures were measured in the upper, middle, and lower thirds of the esophagus.⁴ They described a "normal swallow

¹Ibid., p. 125.

²Nagler and Spiro, op. cit., p. 2.

³Fyke and Code, op. cit., p. 24.

⁴J. W. Butin, A. M. Olsen, H. J. Moersch, and C. E. Code, "A study of esophageal pressures in normal persons and patients with cardiospasm," Gastroenterology, XXIII, 1953, p. 279.

complex" as an initial wave of negative pressure in the esophagus, followed by three waves of positive pressure. The first wave observed was greatest in the upper esophagus, and occurred in 0.5 seconds in the upper esophagus; 0.8 seconds in the mid-esophagus, and 1.5 seconds in the lower esophagus.¹ The second wave occurred most frequently in the distal portion of the esophagus, with the times ranging from 1.5 seconds, 2.7 seconds, and 4.4 seconds in the respective portions of the esophagus. The third wave occurred at 2.1 seconds, 5.1 seconds, and 7.9 seconds in the same three sections of the esophagus.² They arrived at the conclusion that the first wave indicated the buccopharyngeal pressures, because of the time factor involved. The second wave reflected the coordinated muscle contractions necessary for peristalsis, while the third wave was often absent in the distal portions because the cardia opened and dispersed the pressure.³

Earlier the stretching of the esophagus was mentioned as a cause of the negative pressure found in this organ during inspiration. In Ingelfinger's review, he has written that ". . . depending to some extent upon the competency of the esophageal sphincters, and upon the nature and amount of the esophageal content at the moment of swallowing, pressure in the esophagus might well fall as

¹Ibid., p. 281. ²Ibid., p. 283. ³Ibid., p. 289.

the organ is extended longitudinally. Such a mechanism, moreover, would account for the higher incidence of the wave at the ends as opposed to the middle of the esophagus."¹ This concurs with and summarizes the findings of Fyke and Code, Nagler and Spiro, and Butin et al. that have just been cited. Butin et al. theorized that the initial negative wave noted at the beginning of deglutition was due to the "respiration of swallowing" that is the stretching of the esophagus during swallowing.²

Ingelfinger summarized the mechanism of deglutition as follows:³

Several mechanisms participate in moving material through the esophagus; the esophageal contribution is the peristaltic wave, a lumen-obliterating contraction, about 4-8 centimeters in length, moving aborally at 2-4 centimeters per second. This contraction follows a swallow (primary peristalsis), or may be elicited by local esophageal stimuli (secondary peristalsis). Once elicited, both types of peristalsis appear similar and travel down the esophagus whether or not a bolus is being transported. . . . Unlike the buccopharyngeal response to swallowing, the esophageal is neither invariable nor all-or-none: swallowing or esophageal stimulation usually elicits a peristaltic response, but this is not consistent with respect to incidence, force, or extent of propagation.

¹Ingelfinger, op. cit., p. 544.

²Butin, op. cit., p. 288.

³Ingelfinger, op. cit., p. 559.

The Laryngectomized Individual

Esophageal Anatomy in Laryngectomees: Operative Procedures

In the laryngectomee the normal anatomical relationships previously discussed have been altered. The degree of tissue removed varies in each patient, depending on the surgeon involved and the needs of the situation. Saunders stated that in a total laryngectomy the following are removed: ". . . the hyoid bone, thyroid cartilage and contents, the strap muscles, epiglottis, cricoid cartilage, and the upper two or three rings of the trachea."¹ Pressman and Bailey reported that a total laryngectomy includes removal of the true and false cords, the ventricles, the arytenoid and cricoid cartilages, and the epiglottis. Sometimes the hyoid bone and/or supra-hyoid and strap muscles are included.² Finkbeiner, in her study which compared speech ability and type of laryngectomy performed, observed variations in the components of surgery performed even in total laryngectomies. She based her information on patients' medical reports obtained from their surgeons. Seventeen subjects described by her had

¹W. H. Saunders, The Larynx, reprint from Clinical Symposia (Summit, N.J.: CIBA Corporation, 1964), p. 97.

²J. J. Pressman and B. J. Bailey, "The surgery of cancer of the larynx with special reference to subtotal laryngectomy" in Speech Rehabilitation of the Laryngectomized, ed. by R. West (Springfield, Ill.: Charles C. Thomas, 1968), p. 26.

a ". . . narrow field laryngectomy in which the thyrohyoid and sternothyroid muscles are usually preserved."¹ She also defined a wide-field laryngectomy operation as one in which the strap muscles are removed.² A modified narrow-field operation involved ". . . essentially resection of the middle section of the hyoid bone and tapering of the pharynx downward."³ It is not always possible to ascertain the amount of cricopharyngeus muscle that was preserved in each case, simply from the operative reports. Hunt, another surgeon, reported that a total laryngectomy consists of removal of the larynx, strap muscles, while leaving the hyoid bone, epiglottis, and cricoid cartilage intact.⁴

Along with a total laryngectomy (whose definitions may vary from surgeon to surgeon), a radical neck dissection may also be performed. According to Pressman and Bailey, this procedure necessitates removal of, not only the larynx and ribbon muscles, but the ". . . sternocleidomastoid and omohyoid muscles, the muscles of the floor of the mouth together with the stylohyoid and

¹E. R. Finkbeiner, "Surgery and speech, the pseudo-glottis, and respiration in total standard laryngectomy," in Speech Rehabilitation of the Laryngectomized, p. 64.

²Ibid., p. 65.

³Ibid.

⁴R. B. Hunt, "Rehabilitation of the laryngectomee," Laryngoscope, LXXIV, 1964, p. 382.

digastric muscles, the submaxillary gland, sometimes the ipsilateral half of the thyroid gland, and the parathyroid glands of that side, the fat pad of the posterior triangle of the neck, the internal jugular vein and some of its branches, the external carotid artery and some of its branches, and the deep cervical chain of lymph nodes together with their lymphatic channels."¹

Since the common denominator of these operations is the excising of the larynx, it is necessary that it be severed from the trachea. Pressman and Bailey stated that the trachea is then brought to the surface of the skin at the lower section of the neck and sutured to a small round opening that has been prepared, thus creating a "breathing hole," which is called the "tracheal stoma." Air passes directly through the stoma to the lungs, bypassing the upper respiratory tract of the pharynx and nose. The hole existing in the lower pharynx, representing the area of the removed larynx, is sewn together to allow once again for the continuity of the connection between the oral cavity, pharynx, and upper esophagus.² Figure 4, taken from Pressman and Bailey, shows the relationship of the normal anatomy to that of the laryngectomee.³ In Figure 4, the

¹Pressman and Bailey, op. cit., p. 26.

²Ibid., p. 31.

³Ibid., p. 28.

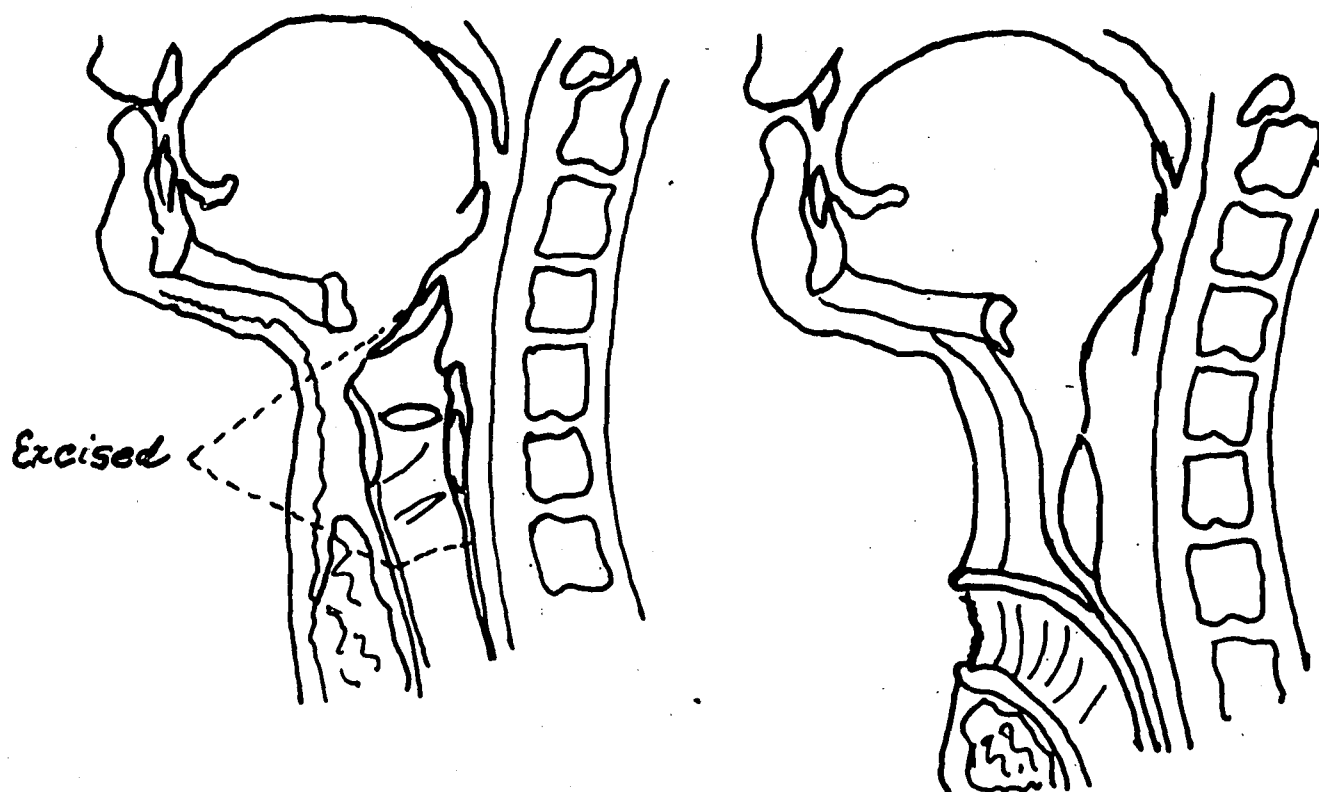


Fig. 4.--Total laryngectomy. Half section of the head and neck demonstrating the normal arrangement of the mouth, pharynx, and larynx preoperatively. On the right is the change in arrangement after removal of the larynx. The severed end of the trachea has been brought forward and sutured to a hole in the skin of the neck. The hiatus created in the pharynx by removal of the larynx is being closed with sutures (from Pressman and Bailey, "The surgery of cancer of the larynx with special reference to subtotal laryngectomy" in Speech Rehabilitation of the Laryngectomized).

laryngectomee can no longer use his lungs as a source of energy or bellows to produce speech. Also lacking are his vocal folds, so that normal phonation is not possible for him. His articulators and, for the most part, his resonators, are reasonably intact, so that he can use these once he develops his ability to phonate.

Modes of Alaryngeal Speech

The opportunities for communication available to the laryngectomee are the use of nonverbal means (writing and gesturing), artificial larynges, or esophageal speech. The manner in which he develops the latter will be discussed later in this chapter.

Diedrich and Youngstrom reported that at least one-third of the laryngectomee population do not use esophageal speech.¹ One alternative for this segment of the laryngectomees is the use of an artificial larynx. Diedrich and Youngstrom list the several models available, which fall into two basic categories: the pneumatic larynx and the electronic larynx.² The pneumatic larynx is a device placed against the stoma and, as the pulmonary air is expelled, it passes a vibratory reed, which serves as the sound source. The vibrations of the reed are transmitted to the oral cavity by means of an external tube, manually

¹Diedrich and Youngstrom, op. cit., p. 138.

²Ibid., p. 143.

held there by the laryngectomee. He then articulates speech in the normal manner.¹

The second category of artificial larynges is the electronic device. These instruments are described by Snidecor as being of two styles: the neck-type and the mouth-type.² The mouth-type artificial larynx presents the sound-producing vibrations within the oral cavity. They are set in motion by a battery-operated, transistorized oscillator. One model requires the laryngectomee to hold the tube in the mouth in order to articulate. There are, however, other mouth-type larynges. For example, there is one that contains a vibrating diaphragm located in the mouth, connected to an artificial dental plate. A small wire running out of the corner of the mouth to an external battery-operated audio-oscillator switch is operated by the laryngectomee to produce sound in various pitches.³

The neck-type vibrator, as described by Snidecor, is ". . . a pulsating disc [that] sets the tissues of the throat vibrating."⁴ The laryngectomee must manually hold the vibrating diaphragm against his neck, and control the

¹Ibid., p. 145.

²J. C. Snidecor, "The artificial larynx," in Speech Rehabilitation of the Laryngectomized, p. 202.

³Ibid., pp. 202-204.

⁴Ibid., p. 204.

vibrations with a manual on-off switch located directly on the device.

Seeman, as translated by DiCarlo et al., listed the disadvantages of the artificial larynx as: 1) merely a prothesis and reminding the patient that he is not well; 2) wearing and using them are embarrassing; 3) they are unreliable; 4) the voice produced by them is monotonous.¹ Other disadvantages pointed out by Snidecor are:²

1. The instrument is at best a crude vibrator. . . .
2. Without support from pulmonary air, the consonants must be made in large part with buccal air.
3. The larynx must be placed for optimum loudness. The location will vary from one subject to another.
4. Phrasing must be learned, that is, the larynx must be switched off at the end of phrases so that reasonably natural speech results.

Diedrich and Youngstrom conceded that some laryngectomees cannot use an artificial larynx for various reasons. Some of these are: dysfunctions of the lungs that would hamper the use of pulmonary air from the stoma; excessive scar tissue on the neck due to the surgery performed; absorption of the sound waves before they reach

¹L. M. DiCarlo, W. Amster, and G. R. Herer, Speech After Laryngectomy (Syracuse, N.Y.: Syracuse University Press, 1955), p. 2, citing M. Seeman, "Phoniatische bemerkungen zur laryngektomie," Archiv. fur Klinische Chirurgie, CXL, 1926, pp. 285-298.

²Snidecor, op. cit., p. 208.

the oral cavity due to the thickness of the neck, or edema or post-radiation fibrosis of the tissues.¹ In spite of the disadvantages of the artificial larynx, these authors advocated its use while the patient is learning esophageal speech. Its use can help to offset the psychological trauma of being unable to communicate orally immediately following the laryngectomy operation and in the training period that ensues, which may last from six to twelve months.²

To aid the laryngectomee in developing speech using pulmonary air, as in normal individuals, several attempts are being made to anatomically re-establish a patent airway between the lungs and the articulators in the oral cavity. One such attempt was made by Dr. John Conley et al. in 1958. He created a mucosal tube, using a section of remaining esophageal mucosa. The free end of the tube was sutured to the posterior end of the trachea or to the skin, just above the tracheostoma. The fixed end opens directly in the pharynx, and the laryngectomee is then able to pull the tracheal air into the pharynx without inflating his esophagus.³

¹Diedrich and Youngstrom, op. cit., p. 146.

²Ibid., p. 140.

³J. J. Conley, F. Deamesti, and M. K. Pierce, "A new surgical technique for the vocal rehabilitation of the laryngectomized patient," Ann. Otol., LXVII, 1958, p. 664.

Another recent surgical procedure appears to be successful, especially in Japan where it was developed. It is known as the Asai method and has been reported by Miller, a plastic surgeon, who visited Dr. Asai and discussed his methods. Miller stated that of the first six of nine patients seen, the resulting voice quality was better than the average esophageal voice after laryngectomy. (He gives no criteria for making this judgment, however.)¹ This type of operation, as reported by Miller, is performed in three separate stages. First, the tracheal stoma is created 1 or 2 cm. higher than usual. A lower stoma is then made through the fourth or fifth tracheal ring.² In the second stage a fistula is produced which opens into the pharynx just below the base of the tongue. In the final stage, he reported, a tube of skin is placed so that ". . . its lower opening [is] the upper tracheal stoma and its upper opening being the fistula into the pharynx."³ In order to speak, the lower tracheal stoma, the one used for breathing, ". . . was closed with the patient's finger, air could then be expired up the dermal tube and into the pharyngeal cavity with sound produced there and transformed into speech. The voices of these patients had an excellent

¹A. H. Miller, "First experiences with the Asai technique for vocal rehabilitation after total laryngectomy" in Speech Rehabilitation of the Laryngectomized, p. 50.

²Ibid.

³Ibid., p. 51.

quality and a wide range of pitch. They could sing, whistle with ease, and speak sentences of average length with normal pauses for inspiration."¹ Miller mentioned some difficulties in using this method, including the fact that one hand must be used to occlude the lower stoma when speaking and the upper stoma has to be occluded manually when swallowing saliva or liquids.²

Snidecor, a Speech Pathologist, evaluated seventy of Dr. Asai's patients and described other problems which may arise, including hair growing within the dermal tube from the skin transplant. The use of an external valve instead of use of digital pressure has been developed but needs a great deal of adjustment to be used correctly. From his own personal experience he reported that ". . . detailed voice studies support the observations made by Dr. Miller."³ Comparison of five Asai speakers and five normal speakers with the results obtained in a previous study conducted by Snidecor on esophageal speakers revealed the following phenomena:⁴

1. Higher pitches than the esophageal speakers.
2. The same loudness levels as normal speakers.

¹Ibid., p. 50.

²Ibid.

³Ibid., p. 57.

⁴J. C. Snidecor, "Asai speech: A special case of phonation after total laryngectomy and laryngoplasty," in Speech Rehabilitation of the Laryngectomized, p. 136.

3. The same amount of words/minute as normal speakers.
4. The same amount of air volume used as normal individuals.
5. The same duration of phonation as normal subjects.

The speakers were rated by three sophisticated judges on a 1-5 scale.

Other means of communication are available to the laryngectomee. However, since the subjects used in the present investigation were using or were learning esophageal speech, the following discussion is necessary to understand how the laryngectomee has adapted various organs to the function of alaryngeal speech.

The Esophagus as an Air Reservoir

Since the laryngectomee no longer has a patent airway between his lungs and oral cavity, in order to develop some form of alaryngeal speech, he must learn to develop an adequate air reservoir in some other fashion. Early workers in the field, using limited technical equipment, reported incorrect information as to the anatomy and physiology of alaryngeal speech. One area which proved difficult to study effectively was the site of the actual air reservoir used.

Stern, in 1926, proposed the stomach as the air reservoir, since in his x-ray studies he noted enlargement of the stomach in laryngectomees. He did, however, observe

that in some individuals this was not true, and often the hypopharynx and esophagus assumed the role. He further pointed out that, during the course of therapy, there appeared to be a shift in the position of the air chamber from the stomach to the esophagus or from the lower esophagus to the upper one-third.¹ DiCarlo et al., discussing Seeman's translated study, reported that Seeman postulated the esophagus as the air chamber, based on the analysis of laryngectomee subjects who swallowed barium and were then x-rayed as they spoke. The barium remained in the esophagus, and Seeman stated that his experiments ". . . revealed that the esophagus expands during inspiration and contracts during expiration."² Kallen, following Stern's technique using x-ray studies of laryngectomees, also postulated the stomach as the vicarious air chamber.³ However, Kallen qualified this by suggesting the site of the air chamber might depend on the teaching method used, i.e., Stern taught his patients to swallow air and Seeman taught them to aspirate the air into the esophagus.⁴

¹Morrison, op. cit., p. 425, citing H. Stern, "Der mechanismus der sprechund stimmbildung bei laryngektomierten, und die derartigen fallen angewandte uebungstherapie," in Denker and Kahler, Handbuch der Hals-Nasen-u. Ohrenheilkunde (Berlin: Julius Springer, 1926, vol. 5), p. 494.

²DiCarlo et al., op. cit., p. 11, quoting Seeman, op. cit.

³L. A. Kallen, "Vicarious vocal mechanisms," Arch. Otol., XX, 1934, p. 470.

⁴Ibid., p. 473.

Modern techniques, such as cinefluorography, have enabled researchers to better understand the location and nature of the vicarious air chamber. The area under question can now be photographed externally using x-ray motion pictures, in addition to still plates. Using these methods, recent researchers, including Diedrich and Youngstrom, Moolinaar-Bijl, and Vrticka and Svoboda, have presented convincing evidence that the esophagus is the vicarious air chamber used by the esophageal speaker.¹

The esophagus meets all the criteria set forth by Morrison for such a chamber:²

- (a) It must be large enough to contain more than a few cubic centimeters of air.
- (b) It must be capable of being filled with air at a reasonably quick rate, voluntarily.
- (c) The contained air must be expelled again under the control of the will.
- (d) The current of air so expelled must be such that it will be set into vibration as it passes the pseudo-glottis; this is a very important requirement, from which it seems obvious that the air chamber must lie below, i.e., caudal, to the pseudo-glottis.

The possible sites for this air chamber are:
 . . . the mouth, the pharynx, particularly the hypopharynx, the esophagus as a whole, more especially its upper thoracic and cervical portions, and the cardiac end of the stomach.

¹Diedrich and Youngstrom, op. cit., p. 62; A. Moolinaar-Bijl, "Some data on speech without larynx," Folia Phoniatica, VII-IX, 1951, p. 20; K. Vrticka and M. Svoboda, "A clinical and x-ray study of 100 laryngectomized speakers," Folia Phoniatica, XIII, 1961, p. 183.

²Morrison, op. cit., p. 418.

That the esophagus has a capacity of more than a few cubic centimeters of air was demonstrated by van den Berg, who reported that this organ has a potential air capacity of eighty milliliters (as opposed to the three thousand milliliters of the lungs).¹ Snidecor and Curry reported that the air in the esophagus can be expelled under voluntary control and, in studying six esophageal speakers, rated by three sophisticated listeners on a 1-5 scale, observed that the three superior speakers were capable of utilizing an air flow for 1.5 seconds, in which time the speaker articulated 2.8-6.3 words.² While this rate is not as rapid as the normal speaker (air flow for normal individuals was found to be circa 4.19 seconds, during which time the normal speaker can repeat 12.5 words), it nevertheless appeared rapid enough to fulfill criteria (b) and (c) as listed by Morrison.³

Since it is now generally accepted that the esophagus acts as the vicarious air chamber, the next factor to be considered is the relative portion of the esophagus used during esophageal speech. Vrticka and Svoboda examined one hundred laryngectomized patients fluoroscopically and

¹Van den Berg and Moolinaar-Bijl, op. cit., p. 305.

²J. C. Snidecor and E. T. Curry, "Temporal and pitch aspects of superior esophageal speech," Ann Otol., LXVIII, 1959, p. 631.

³Ibid., p. 629.

rated them on a scale with seven steps in speech proficiency ranging from automatic speech to no speech. Their conclusions indicated that the better the speaker, the more of the esophagus he filled with air. The best speakers filled the complete esophagus down to the lower sphincter, while the poorer ones often showed only the proximal portion of the esophagus to be filled with air that was not used for phonatory purposes. If the air in this latter group reached the distal end of the esophagus, it continued into the stomach. During phonation the expulsion of air began in the lower portion of the esophagus and continued into the upper portion by gradual retrograde contraction of the esophageal walls.¹ Vrticka and Svoboda do not report the physiology of the esophageal maneuver--whether this was the mechanism of reverse peristalsis or a different phenomenon.

Robe et al., in studying the coordination of esophageal speech with respiration in twenty-three laryngectomees, noted that the air reservoir was not limited to the upper third of the esophagus, but that the entire esophagus was dilated in good speakers.²

¹Vrticka and Svoboda, op. cit., pp. 181-182.

²E. Y. Robe, P. Moore, A. H. Andrew, Jr., and P. H. Hollinger, "A study of the role of certain factors in the development of speech after laryngectomy: 3. Coordination of speech with respiration," Laryngoscope, LXVI, 1956, p. 498.

Diedrich and Youngstrom, in discussing this particular aspect, reported that several German authors concur with the studies just cited. They stated that "Vandor found that the medial and lower one-third [of the esophagus] was filled with air. . . . Siroky concluded that the quantity of air capable of being trapped in the esophagus increased with speech proficiency especially in the supra-bifurcate portion. . . . Schlosshauer and Mockel found that poor speakers did not completely fill the esophagus."¹ They concluded that ". . . there appears to be (a) an association between better speakers and a larger available air supply indicated by dilation of the entire esophagus. (b) Poorer speakers have a smaller air supply which does not fill the entire esophagus."²

Hodson and Oswald, using cinefluorography and still x-ray analysis of a series of laryngectomized subjects (the exact number of subjects used was not revealed, nor was the speech proficiency of the subjects noted), observed that the air in the esophagus never reached the diaphragm, and that about two or three inches of the lower esophagus

¹Diedrich and Youngstrom, op. cit., pp. 103-104, citing F. Vandor, "Roentgenuntersuchung der pseudoglottis von laryngektomierten," Fortschr. Roentgenstr., LXXXII, 1955, pp. 618-625; J. Siroky, "Ergebnisse der reedukation der stimme nach der laryngektomie," Z. Laryng. Rhinol. Otol., XXXIX, 1960, pp. 504-512; B. Schlosshauer and G. Mockel, "Answertung der rontgentonfilm aufnahmen von speiserohren-sprechern," Folia Phoniatica, X, 1958, pp. 154-166.

²Ibid.

remained unfilled.¹ DiCarlo et al. performed cinefluorographic analysis of ten esophageal speakers. Five of these had been rated intelligible and five poor speakers. The rating scale was based on articulatory errors made by the laryngectomees during the reading of single words and sentences. These errors were evaluated by two groups of auditors--speech majors and non-speech majors--who listened to recordings by the laryngectomees. Rhythm patterns were also evaluated by sophisticated listeners, who rated the patterns as "normal," "non-rhythmic," or "abnormal." As a result of the cinefluorographic analysis, the authors concluded that ". . . the five laryngectomized speakers (high in intelligibility) did not appear to employ swallowing behavior but, instead, the intake of air was limited to the proximal portion of the esophagus. For the five laryngectomized speakers judged to be low in intelligibility, the film views illustrated decided swallowing behavior which propelled the air into the medial or lower two-thirds of the esophagus with some escape into the stomach."²

Researchers, then, are in general agreement that the esophagus acts as the vicarious air chamber in the esophageal speaker. However, some question remains as to the

¹C. J. Hodson and M. V. Oswald, Speech Recovery after Total Laryngectomy (Edinburgh and London: E. and S. Livingstone, Ltd., 1958), p. 4.

²DiCarlo, op. cit., p. 160.

exact amount of the esophagus used by these speakers, and whether a relationship exists between this and the proficiency of the speaker.

The Nature of the Pseudoglottis

No aspect of esophageal speech has received as much attention as the vicarious phonating mechanism used by the laryngectomized individual. This mechanism must approximate, in function, the normal phonating mechanism. Damste stated that "the pseudoglottis is defined as the most cranial narrowing in the lumen of the oesophagus or the pharynx over which the contrast medium is seen vibrating."¹ Morrison has outlined the necessary requirements for a pseudoglottis:

- a. It must consist of some portions of the organ concerned that can be set into vibration by the air current passing out of the chamber below; hence, it must lie above, i.e., cephalad to the air chamber.
- b. It must be a place that is, or that can be, constricted until the frequency of the vibrations of the passing air current is such that it will yield an audible sound.
- c. It must be under the control of the will in some degree.
- d. If the tension of the part or parts that vibrate can be changed at will, the pitch of the resultant sounds will be capable of modulation. . . .

¹Damste, op. cit., p. 40.

Morrison, translating from the German, gave the following sites of the pseudoglottis as listed by Stern (1926):¹

1. between base of tongue and posterior wall of the pharynx;
2. between the back of the tongue and the tightly stretched velum;
3. between the strongly contracted posterior palatine arches of the two sides;
4. between contracted portions of the inferior constrictor muscle of the pharynx;
5. between the epiglottis and two folds formed laterally from the musculature of the pharynx;
6. at the hiatus of the esophagus, the esophageal mouth of Killian, between folds formed by the cricopharyngeus muscle;
7. in some cases, there seems to be no real pseudoglottis, the patient merely employing the sound produced by the eructation of swallowed air for phonation.

At the time he wrote, it was difficult for Stern and other researchers to determine the exact site and nature of the pseudoglottis, because of the anatomic inaccessibility of the area. Stetson, as translated by DiCarlo et al., challenged Stern's statement relative to the pseudoglottic site:²

In any form of oesophageal speech the opening of the oesophagus constitutes the substitute glottis. Stern's series of possible locations of the substitute glottis is a physiological phantasy; he loses sight of the necessary use of the tongue and velum in consonant articulation when he places a substitute larynx between

¹Morrison, op. cit., p. 418, quoting Stern, op. cit.

²DiCarlo, op. cit., p. 12, quoting R. H. Stetson, "Oesophageal speech: methods of instruction after laryngectomy," Arch. Neerlandaises de Phonetique Experimentale, XII, 1937, p. 99.

the tongue and velum or the tongue and the posterior wall of the pharynx; and a constriction of the muscles of the pharynx to produce a glottis must interfere with the formation of both vowels and consonants.

As research techniques improved, it was possible to locate the pseudoglottis by using such investigative approaches as fluoroscopy, still x-ray, and cinefluorography. In 1922, Seeman (translated by Vrticka and Svoboda) identified the upper esophageal orifice as the vicarious glottis.¹ Research has revealed definite evidence of an upper esophageal sphincter in normal individuals. Lindsay et al., using fluoroscopic examinations, found this upper sphincter to be present in laryngectomized patients as well as in normal subjects. They concluded that the upper esophageal sphincter in laryngectomized patients ". . . opens with flash-like suddenness, allowing air to pass into the upper end of the esophagus accompanied in the less proficient by a slight sound."²

Dey and Kirchner studied the upper esophageal sphincter and attempted to correlate its function with speech ability in the laryngectomee. Fifteen normal and twenty laryngectomized subjects were studied via simultaneous intraluminal pressure measurements of the upper esophagus, upper esophageal sphincter, and lower pharynx.

¹Vrticka and Svoboda, op. cit., p. 174.

²Lindsay et al., op. cit., p. 63.

The subjects swallowed a polyethylene tube, consisting of three fused smaller tubes, whose free end was attached to recording devices. The upper esophageal sphincter was measured during rest and, in normal subjects, they recorded a pressure in this area of 10 mm. or more of mercury above intraesophageal pressure. This was not found in the laryngectomee population studied. They hypothesized that ". . . the normal sphincter closure of the upper end of the esophagus is usually absent after laryngectomy. In spite of this there is no difficulty in swallowing nor is air sucked into the esophagus on ordinary or even deep inspiration. The prevention of esophageal respiration is not an important function of the upper sphincter mechanism."¹ This was in direct opposition to the position of Negus, who has stated that the function of the upper esophageal sphincter in normal individuals is to prevent esophageal respiration so that as air is sucked into the thorax, it would not easily enter the esophagus as well.² Dey and Kirchner did not give the rating scale used to test the speech proficiency of their laryngectomized subjects, but simply stated the speech abilities of the subjects ranged from good to excellent.³

¹F. L. Dey and J. A. Kirchner, "The upper esophageal sphincter after laryngectomy," Laryngoscope, LXXI, 1961, p. 114.

²Negus, "The second stage of swallowing," p. 81.

³Dey and Kirchner, op. cit., p. 100.

Diedrich and Youngstrom examined the pseudoglottis of twenty laryngectomized subjects using cinefluoroscopy. Each subject was asked to record a reading of the "Grandfather" paragraph, and his speech ability was then rated by unsophisticated listeners. These judges were asked to compare and give a numerical rating to the subject's reading, based on an initial speech sample which had been given a rating of "100." The results of these ratings were compared to the physical findings relative to the pseudoglottis and hypopharynx. The authors concluded that the pseudoglottis was most often located at the level of cervical vertebrae 5, 5-6, or 6.¹ These results concur with the findings by other investigators. DiCarlo et al. noted that the pseudoglottis was located at the level of cervical vertebrae 5 or 6.² Damste compared eight "good" esophageal speakers and eight "less good" speakers and also located the pseudoglottis at approximately C5 and C6.³ The ratings cited here relative to the Damste study were based on a scale of three steps: "(1) esophageal speech insufficient for practical purposes; (2) serviceable speech; and (3) good or excellent speech."⁴ The speakers were judged

¹Diedrich and Youngstrom, op. cit., p. 58.

²DiCarlo, op. cit., p. 160.

³Damste, op. cit., p. 41.

⁴Ibid., p. 12.

by two trained speech therapists, who listened to a series of tape recordings containing speech samples of the subjects vocalizing single words, sentences, pitch changes, and conversational speech. Damste also observed that in poor speakers, the pseudoglottic prominence was lower than C5 or C6.¹ This finding was challenged by Vrticka and Svoboda in their x-ray study of laryngectomees. They stated that ". . . contrary to Damste, we have never observed any relation between the level of the pseudoglottis and the quality of speech."²

Researchers tend to agree that the pseudoglottis in laryngectomees is located at the upper end of the esophagus, at approximately C5 or C6. There is some question as to whether the location of the pseudoglottis is influenced by the speech ability of the laryngectomee.

Muscular Composition of the Pseudoglottis

As discussed earlier in this chapter, the muscle components of the upper esophageal sphincter in normal individuals and, therefore, the pseudoglottis in laryngectomees are still being analyzed. Some investigators consider the cricopharyngeus muscle to be an important contributor to this sphincter. This position is held by Lindsay et al.

¹Ibid., p. 41.

²Vrticka and Svoboda, op. cit., p. 178.

who, on the basis of their fluoroscopic study of laryngectomees, concluded that the better esophageal speakers had better control of the cricopharyngeus muscle during phonation and swallow.¹ Hoople and Brewer studied forty-five laryngectomees, using kymographic analysis. They theorized that the "cricopharyngeus sphincter control was the deciding factor as to where and when the air was trapped."² Van den Berg and Moolinaar-Bijl also concurred with these statements; in an article based on the research conducted by them and Damste, they contended that the best speech is achieved when the cricopharyngeus muscle is used as the pseudoglottis.³

If, as the above investigators contend, the cricopharyngeus muscle is the only muscle used by the laryngectomee as his pseudoglottis, there appears to be a discrepancy between this viewpoint and the results of anatomical and recent pressure studies of this area. Batson has reported the longitudinal length of the cricopharyngeus muscle to be 10-12 mm., while Ingelfinger's review revealed the esophageal spincter in normal individuals extending from 10 to 30 mm. in its resting stage.⁴ In the

¹Lindsay et al., op. cit., p. 62.

²Hoople and Brewer, op. cit., p. 650.

³Van den Berg and Moolinaar-Bijl, op. cit., p. 299. .

⁴Batson, op. cit., p. 50; Ingelfinger, op. cit., p. 534.

previously described study by Dey and Kirchner of normal subjects, a high pressure zone (indicating the upper sphincter) was demonstrated whose longitudinal dimensions were 30-40 mm. during the resting phase.¹ These reports, as Diedrich and Youngstrom stated, indicated that sphincteric constriction of the pharyngoesophageal junction "extended over an axial distance greater than that comprised solely from cricopharyngeus muscle fiber."² Dey and Kirchner suggested that fibers from the upper esophagus, as well as those from the lower pharynx, comprised the upper esophageal junction.³ Diedrich and Youngstrom found the average cephalo-caudal length of the pseudoglottis was 29 mm., the means ranging from 18 to 23 mm., depending on which phonemes were being vocalized.⁴

Whatever muscle or muscles comprise the upper esophageal sphincter, there appears to be a change in the tension of this area as a result of the laryngectomy operation. Since this surgery does significantly alter certain anatomical relationships and functions, surgeons have recommended careful reconstruction of the upper esophageal sphincter in general and of the cricopharyngeus muscle in particular,

¹Dey and Kirchner, op. cit., p. 112.

²Diedrich and Youngstrom, op. cit., p. 28.

³Dey and Kirchner, op. cit., p. 113.

⁴Diedrich and Youngstrom, op. cit., p. 59.

believing that a well-reconstructed sphincter will promote a better voice. This is the position held by van den Berg and Moolinaar-Bijl, Kallen, and Robe et al.¹

In their study, Robe et al. examined seventeen laryngectomees to evaluate the relationship between the type of surgery and subsequent speech proficiency in laryngectomees. According to this study, good speech is not dependent on preservation of the strap muscles, the thyrohyoid or sternohyoid muscles. However, they could draw no conclusions with reference to the cricopharyngeus muscle.²

Dey and Kirchner, using intraluminal pressure measurements, delineated a high pressure zone in normal individuals at the upper esophageal sphincter. This pressure was considerably reduced in the laryngectomees they studied, allowing them to conclude that laryngectomees have less tension associated with this sphincter.³ Hodson and Oswald concurred with this statement, noting that a tense sphincter in laryngectomees would not allow the air to enter the esophagus.⁴ Damste felt that the tension of the cricopharyngeus

¹Van den Berg and Moolinaar-Bijl, op. cit., p. 299; Kallen, op. cit., p. 481; E. Y. Robe, P. Moore, A. H. Andrews, and P. H. Hollinger, "A study of the role of certain factors in the development of speech after laryngectomy, Part I. Type of operation," Laryngoscope, LXVI, 1956, p. 184.

²Robe et al., op. cit.

³Dey and Kirchner, loc. cit.

⁴Hodson and Oswald, op. cit., p. 15.

muscle was a barrier to be crossed by the laryngectomee before he could learn esophageal speech.¹

From the above discussion it appears that the pseudoglottis is comprised of not only the cricopharyngeus muscle but surrounding tissue as well, and that a tight reconstruction of the upper esophageal sphincter may be detrimental to an esophageal speaker by actually preventing easy access of air into the esophagus. However, it would also seem that functionally it is important for the laryngectomee to have anatomical and physiological elements available from which "pseudo vocal folds" may evolve.

Methods of Air Intake

The laryngectomee has an altered breathing mechanism and can no longer depend on pulmonary air for phonation. He must learn to inflate the esophagus, so that the air contained in the esophagus can be used for phonation. To achieve this, the air is introduced into the esophagus via the oral cavity and, even though the organs used are the same as in the mechanism of deglutition, researchers have demonstrated that the pattern of movements varies.

In normal individuals the bolus introduced into the esophagus is directed to the stomach by peristaltic waves. If the laryngectomee were to use this normal swallowing

¹Damste, op. cit., p. 32.

pattern, the air entering the esophagus would be propelled to the stomach also by peristalsis. Instead, he is able to maintain the air briefly in the esophagus, then directing it rostrally when phonating. Van den Berg and Moolenaar-Bijl, discussing one laryngectomee studied, observed no peristaltic waves following the injection of air into the esophagus, except during heavy vocal efforts.¹

The dissimilar patterns between deglutition and air intake in laryngectomees were further demonstrated by Diedrich and Youngstrom. In their cinefluorographic studies they compared twenty-six laryngectomized subjects and seven normal subjects during deglutition. Their results indicated that ". . . in general, the [soft] palate in the laryngectomees did not elevate as high during swallowing as compared to air injection or phonation. . . . Slightly over one-third of the laryngectomees in this study appeared to have a deviant swallowing pattern in terms of delayed palatal elevation and filling of the hypopharynx with barium before the tongue retrudes and completes its stripping action."² While swallowing patterns tended to be the same for normal and laryngectomized subjects, Diedrich and Youngstrom noted that during air intake using the glosso-pharyngeal press method, the laryngectomee's tongue contacted the posterior

¹Van den Berg and Moolenaar-Bijl, op. cit., p. 310.

²Diedrich and Youngstrom, op. cit., p. 65.

pharyngeal wall for one or two frames of the cinefluoroscopic record, as opposed to the action of the tongue during swallowing, when it contacted the pharyngeal wall for ten or eleven frames. The laryngectomee using the glossal press never made any contact between the tongue and the pharyngeal wall.¹ These methods will be discussed in detail later.

Another difference suggested by Damste between the patterns of movement used in swallowing and in air intake is relative to the amount of pressure noted in the hypopharynx in the prephonation period and the period just prior to deglutition. He studied the pressures in this area in twenty-four laryngectomees by inserting a polyethylene catheter through the nose and suspending it in the pharynx. The external end of the tube was attached to recording devices. He noted that in the prephonation period, pressures in the pharynx measured from 30 to 40 cm. of water, which he stated is about ". . . twice as high as the highest pressure found in swallowing."² It is assumed he was comparing the swallowing pressures of laryngectomees with their air intake pressures, although this was not clearly stated. Normal pressure measurements taken of fifteen normal subjects, who had swallowed a single catheter

¹Ibid., p. 64.

²Damste, op. cit., p. 22.

containing a transducer, were made by Fyke and Code. In this situation "the mean positive pressure developed in the pharynx was 99 cm. of water."¹ It appears that the laryngectomee does not build up high pharyngeal pressures during air intake, perhaps because he does not need them to overcome the tension of the upper esophageal sphincter.

Research indicates that generally the laryngectomee uses a unique method to introduce air into the esophagus and establish his transitory air reservoir. One of the methods used by the laryngectomee is called the "injection" method. As described by van den Berg and Moolinaar-Bijl, this physiological procedure requires that pharyngeal air is compressed and some of it forced into the esophagus. They stated that ". . . the air in the pharyngeal cavity, which is still under pressure, is then used for the pronunciation of the plosive and the injected esophageal air is used for the subsequent vowel."² In the opinion of Moolinaar-Bijl, the injection method is smoother and results in a more continuous flow of speech than other methods, because air can be brought into the esophagus unobtrusively and quickly, requiring little energy output, and can be used for phonation in a relatively short period

¹Fyke and Code, op. cit., p. 29.

²Van den Berg and Moolinaar-Bijl, op. cit., p. 308.

of time.¹

Diedrich and Youngstrom have divided the injection method into two types, based on the analysis of their cine-fluorographic films of laryngectomees. The first method was the glossal press in which the tip of the tongue is in contact with the alveolar ridge, with occasional contact between the tongue and hard and soft palates. The tongue does not make contact with the posterior pharyngeal wall. In the glossopharyngeal press, the second type, the tongue was in contact with the alveolar ridge, the hard and soft palates, and the posterior portion of the tongue would contact the pharyngeal wall. Frequently the hypopharyngeal cavity was obliterated as the tongue moved back.²

Another method used by laryngectomees to introduce air into the esophagus is called the "inhalation" or "aspiration" method. Diedrich and Youngstrom defined this method as one in which ". . . the tongue never occludes the oral cavity and little dorsal movement of the posterior tongue is visible. The lips are open and the velopharyngeal port is usually closed. A completely patent airway exists between the lips and pharyngo-esophageal junction."³

¹A. Moolinaar-Bijl, "The importance of certain consonants in esophageal voice after laryngectomy," Ann.Otol., LXII, 1953, p. 983.

²Diedrich and Youngstrom, op. cit., p. 37.

³Ibid.

Criticisms of this latter method have been mentioned by Diedrich and Youngstrom, who stated that, on the basis of their observation, laryngectomees using inhalation tend to produce stomal noises both on inhalation and exhalation during phonation.¹ Basing his findings on four subjects who used the inhalation method, Damste concluded that ". . . the intake of air by means of suction takes much more time than with the aid of injection."²

In rehabilitating the laryngectomee, certain phonemes appeared to facilitate the learning of alaryngeal speech. Kallen advocated exercises that used the repetition of a non-vocal [p], [t], and [k] and then vocalizing a series of vowels preceded by these plosives, saying each syllable on a single breath. The final step was to pronounce several syllables on one breath. He did not, however, connect injection of air into the esophagus with the voiceless plosives.³ Stetson also observed the connection between esophageal speech and air intake and summarized his findings in a paper in 1937. After studying air pressure changes in the mouth and trachea during esophageal speech, he reported that the plosives [p] and [t] were capable of injecting air

¹Ibid., p. 103.

²Damste, op. cit., p. 19.

³Kallen, op. cit., pp. 496-497.

into the esophagus.¹ Morrison also noted that the use of the [k] sound was being advocated by two Germans teaching esophageal speech--Gutzmann, Jr. and Stern.² He advocated the use of the [k] sound to help develop the pseudoglottis.³ These writers were proposing the use of the injection method through the use of certain phonemes, but did not label it as such.

Diedrich and Youngstrom reported the use of the term "injection" first appearing in a speech by G. Paul Moore, who suggested two alternative means of teaching speech to the laryngectomees. The first was an injection procedure utilizing the [d] sound to start and the second, the inhalation method.⁴

In advocating the use of the injection method, the Dutch investigators advanced the use of certain phonemes to facilitate esophageal speech. Moolinaar-Bijl stated that the plosives [p], [t], and [k] help to force air into the esophagus.⁵ Damste stated the plosives are ". . . making use of the high pressure built up in the pharynx before

¹R. H. Stetson, "Esophageal speech for any laryngectomized patient," Arch. Otol., XXVI, 1937, p. 1.

²Morrison, op. cit., p. 428.

³Ibid., p. 426.

⁴Diedrich and Youngstrom, op. cit., p. 79.

⁵A. Moolinaar-Bijl, "Some data on speech without larynx," Folia Phoniatica, VII-IX, 1951, p. 22.

pronouncing voiceless plosives."¹ The analysis of one excellent speaker led van den Berg and Moolinaar-Bijl to summarize the advantages of using plosives as ". . . the refilling of the oesophagus before each plosive so that the oesophagus remains filled all the time without the necessity of a separate intake of air; . . . the use of the plosives for an unobtrusive and regular intake of air."² These investigators noted that voiceless plosives then increase the air in the esophagus, while sounds such as "ma" and "la" deplete the esophageal air reserve.³

Diedrich and Youngstrom, as a result of their cine-fluorographic study, reached the conclusion that, while plosive sounds may aid in learning to inject air into the esophagus, the movements of the tongue, palate, mandible, pharynx, and P-E (pharyngo-esophageal) junction (pseudo-glottis) were essentially the same whether the air intake was followed by a vowel, plosive, nasal, or glide.⁴ The subjects in their study were compared as to method of air intake and speech skills. Their results indicated no relationship between these two factors.⁵

¹Damste, op. cit., p. 32.

²Van den Berg and Moolinaar-Bijl, op. cit., p. 310.

³Ibid., pp. 309-310.

⁴Diedrich and Youngstrom, op. cit., p. 45.

⁵Ibid., p. 41.

In discussing a pilot study presented at an ASHA convention, Diedrich and Youngstrom reported having used six subjects (laryngectomees) vocalizing one sentence with many plosive sounds and one sentence with non-plosive sounds. Cinefluorographic analysis revealed fewer air intakes for the plosive sentence and phonation time between air intakes was longer for the plosive sentence than the non-plosive sentence. As a result of this study, they purport that while the plosives were useful in sustaining phonation, they were not responsible for filling the esophagus.¹ In their later study, however, they discussed a phenomenon that they found in one subject. In this subject there was an overlap of air intake and phonation for the production of the sound [s] as revealed in the cinefluorographic analysis, whereas in the analysis of the plosive air injection, there was a sequence of first air injection and then explosion of the consonant.²

In conclusion, the laryngectomee is potentially capable of introducing air into the esophagus and using it for phonation. While the initial movements needed for air intake appear similar to movement patterns used in swallowing, there are subtle changes that the laryngectomee learns. His method of air intake can be of two types--the injection

¹Diedrich and Youngstrom, op. cit., p. 84.

²Ibid., p. 85.

method or the aspiration method, the former apparently being facilitated by the use of voiceless plosive sounds.

Pulmonary vs. Esophageal Air

There is an intimate relationship between the esophagus and the thoracic cavity in general, and the diaphragm in particular. In the normal individual the diaphragm descends during inspiration, and, because the esophagus is attached to the diaphragm, it, too, descends. During expiration or phonation, the diaphragm ascends, pushing the esophagus upward as it does so. The inspiratory phase of respiration results in decreased intrathoracic pressure, as well as decreased intra-esophageal pressure, as noted by Diedrich and Youngstrom.¹ This interaction is supported by Ingelfinger, who stated the pressure gradient in the esophagus "is determined by the intrathoracic pressure at the time of sphincteric opening and the stretch to which the esophagus is subject just before or at the time this happens."²

If the laryngectomee were to synchronize his respiratory movements and his speech attempts as the normal individual does, there remains the question as to how one might influence the other. Ingelfinger reported that in normal individuals the respiratory effects on intra-esophageal

¹Ibid., p. 98.

²Ingelfinger, op. cit., p. 536.

pressure are dampened in the upper esophagus.¹ This would indicate that if the laryngectomee were to use pre-operative movements, diaphragmatic shifts may not aid in the expulsion of air.

This theory is proposed by Damste, who felt that the contraction of the diaphragm at the lower end of the esophagus could not be the means of air expulsion. He contended that there were two mechanisms that can merge or act independently, which aid in expelling the air from the esophagus during alaryngeal speech. These mechanisms are the tonus and elasticity of the esophageal wall, and the alveolar pressure present during expiration. In discussing the first mechanism, he stated that the injected air in the esophagus, which is under pressure, maintained this pressure for a short period of time, due to the muscle tonus and elasticity of the esophageal walls. After a brief time period, this air is carried off to the stomach via peristalsis, so that ". . . the air then left behind in the oesophagus is no longer under working-pressure. If this air is also used for speaking, another mechanism must start to function."²

In this second mechanism, Damste theorized on the function of alveolar pressure in expelling air from the

¹Ibid., p. 543.

²Damste, op. cit., p. 56.

esophagus. He stated:¹

During a rapid expiration pressure is exerted on the walls of the bronchioli; in addition the great air-velocity results in a diminished pressure from inside (Bernoulli phenomenon). The bronchi will be narrowed and the resistance, which is high anyway at this great velocity, is increased still more. Thus by rapid expiration a high alveolar pressure is built up.

In addition there is the phenomenon that the air-filled oesophagus presses against the dorsal wall of the trachea, where, owing to the absence of cartilagenous protection, it starts bulging during the increase of the intrathoracic pressure. The trachea is narrowed, which causes the air-resistance to increase, etc.

The separation of the act of air expulsion from the esophagus and expiration was demonstrated by x-ray films in a study by Vrticka and Svoboda. During phonation, fair esophageal speakers began expulsion of air in the lower portion of the esophagus, and continued to expel air into the upper portion by gradual retrograd contractions of the esophageal walls.² This contraction, or change in the tonus of esophageal walls, was also observed by Hodson and Oswald. In their cinefluorographic study of laryngectomees, they described anti-peristaltic movements or wave-like contractions commencing at the lower esophagus and passing upward to the upper portions of the esophagus.³

¹Ibid., pp. 56-57.

²Vrticka and Svoboda, op. cit., p. 182.

³Hodson and Oswald, op. cit., p. 5.

Some evidence exists indicating that the esophagus expels air during alaryngeal speech independent of expulsion of pulmonary air during expiration. However, the location of the esophagus in the thoracic cavity must be taken into consideration. The esophagus lies in contact with the mediastinum of the lungs and, as Mosher has stated, ". . . from the bifurcation of the trachea to the tip of the diaphragmatic cone the lungs are in close relationship with the esophagus."¹ From this description, it appears that, not only will the esophagus be stretched longitudinally during respiration because of its attachments to the lungs and diaphragmatic hiatus, but may be stretched horizontally as the lungs expand.

The relationship of respiration and esophageal speech is discussed by Diedrich and Youngstrom, who theorized:²

In a position of rest the esophagus is under slightly negative pressure, or equal atmospheric pressure if the P-E junction is open. The inhalation of pulmonary air increases the negative pressure in the esophagus. If there is no spasm of the P-E junction, the injection of air into the esophagus is accomplished with comparative ease because the air streams into a partial vacuum. During phonation, the esophagus is under constant pressure from the thoracic cavity and abdominal muscles; consequently, there is a certain amount of positive pressure present in the esophagus while the

¹Mosher, op. cit., p. 72.

²Diedrich and Youngstrom, op. cit., pp. 98-99.

patient says, for example, a series of [p] sounds. At the end of the first [p] sound a quantity of air remains in the esophagus and the patient compresses (on the next [p] sound) some additional air from his oral and pharyngeal cavities into the esophagus. . . .

Because some amount of air is available within the esophagus during an intraphrase interval, it is conjectured that the quantity of air intake at this moment is not as large as the air intake which occurs from rest or during an interphrase pause.

Even with the evidence of the anatomical relationships of the esophagus and the thoracic cavity, some researchers have advocated a trained dyssynchrony between respiratory movements and movement of intraluminal air during esophageal speech to prevent stomal noises. This procedure would be in contrast to the synchronous pattern used by normal individuals. Kallen felt that the laryngectomee should be trained to produce a dyssynchronization of his breathing pattern and his phonatory attempts to prevent rapid fatigue, presumably due to excessive breaths taken during the initial stages of learning alaryngeal speech.¹ Stern, as translated by DiCarlo, on the basis of x-ray studies he performed on ninety-eight laryngectomees, also advocated a disassociation of respiration and esophageal air in these individuals. He theorized that the noise escaping from the stoma during expiration would mask the

¹Kallen, op. cit., p. 496.

laryngectomy's speech and severe coughing would result.¹

Evidence indicates that the laryngectomy should generally maintain the normal relationship of thoracic movements and alaryngeal speech attempts. DiCarlo et al. performed kymographic and cinefluorographic analysis on laryngectomees. The better speakers studied exhibited a synchrony of pulmonary and esophageal air, while the poorer speakers showed dyssynchronization of the two functions.² Hoople and Brewer, in administering kymographs to forty-five laryngectomees, not only found synchronization, but that speech proficiency was related to it. They reported that the better speakers demonstrated synchronization, while the poorer speakers did not.³ Hodson and Oswald observed the intake of air in laryngectomees coinciding with a downward movement of the diaphragm in their cinefluorographic study. From their data they concluded that poor esophageal speech is due to failure by the patient to coordinate sphincteric action and diaphragmatic breathing.⁴

¹DiCarlo et al., op. cit., p. 7, citing H. Stern, "Grundprizipien der sprache und staimmausbildung bei laryngektomieren nebst neuen geitrag zum mechanismus der sprache und stimme derartig operierter," Wien Klin., Wschnschr., XXXIII, 1920.

²Ibid., p. 166.

³Hoople and Brewer, op. cit., p. 645.

⁴Hodson and Oswald, op. cit., p. 15.

Robe et al. tested synchrony by placing a tissue bib over the stoma of the laryngectomees in their study. They perceived the blowing up of the bib to coincide with esophageal speech attempts.¹ Hodson and Oswald demonstrated this same phenomenon by the use of a feather placed over the stoma. They saw the feather move in synchrony with alaryngeal speech only in the better speakers.²

An interesting sidelight was recorded by Snidecor and Isshiki in their pneumographic study of six esophageal speakers. These speakers were all rated as good to excellent as a result of listening to their recordings of "The Rainbow" passage. They hypothesized that synchronization appears to be related to the method of air intake. The laryngectomee who inhaled air into the esophagus maintained synchronization of pulmonary air and esophageal speech attempts, while the laryngectomee who used the injection method showed dyssynchronization.³

Mounting evidence appears to favor the encouraging of the synchrony of pulmonary air and alaryngeal speech. The manner in which one affects the other is still not precisely known. Research has also indicated a tendency for

¹Robe et al., op. cit., p. 498.

²Hodson and Oswald, op. cit., p. 5.

³J. C. Snidecor and N. Isshiki, "Air volume and air flow relationships of six male esophageal speakers," JSHD, XXX, 1965, p. 212.

synchronization to occur only in the better esophageal speakers, and possibly connected to the method of air intake used by the laryngectomee.

Summary

Normal esophageal functioning indicates that there is a relaxation of the upper esophageal sphincter prior to the entrance of the bolus into the esophagus, followed by the bolus being propelled down the esophagus via peristalsis. While there is some mechanism in the lower esophagus that functions as a sphincter, to prevent reflux of material into the esophagus, its precise nature is still under investigation.

The laryngectomee, while using the remaining organs in his oral cavity for articulation, has adapted the act of deglutition to aid the intake of air into his esophagus to produce esophageal speech. Review of the literature on studies pertaining to alaryngeal speech have concentrated on the nature and functioning of the pseudoglottis and upper esophagus during esophageal speech. The few investigations focusing on intraluminal esophageal air pressure patterns have not attempted to examine the patterns of esophageal motility during esophageal speech and its relationship to speech proficiency.

The functional impact of the plosives' contribution to esophageal speech can also be studied further by

examining pressure variation in the esophagus. Few detailed studies have been attempted in this area to date.

Studies examining the synchronization of pulmonary and esophageal air flow during esophageal speech have indicated synchrony on a gross level, but there is some indication that other factors, such as speech ability and method of air intake, might affect the relationship.

CHAPTER III

EXPERIMENTAL DESIGN AND PROCEDURES

The object of this study is to investigate the nature of esophageal motility in laryngectomized individuals. It has been hypothesized by the author that laryngectomees whose speech is superior will show intraluminal pressure patterns that differ from the laryngectomee whose speech is inferior. It has further been hypothesized that certain consonants facilitate the learning of esophageal speech. In relation to the synchronization of pulmonary and esophageal air during alaryngeal speech, it is hypothesized that a synchrony of respiratory movements and esophageal speech exists, similar to the synchrony found in normal individuals.

Since this study is designed to investigate physiological aspects of alaryngeal speech, certain psychological problems that might have been present in the subject were not studied. For example, apparent emotional problems were noted by the author as a result of gathering background material on each subject. These included: poor adjustments to family life, either by the laryngectomee or the wife/husband; withdrawal from social activities post-operatively; and the impact of lack of communicative opportunities (found in the older subjects).

Another area not controlled in this study was the amount of tissue excised during the subject's laryngectomy operation. Even though all the subjects were from the New York City area, surgery was done by a number of different surgeons, and, as has been noted in the previous chapter, different surgeons define "total" laryngectomy surgery in various ways.

Subjects

There were twenty-one subjects initially in this study; however, three subjects had to be eliminated. One individual made no speech attempts during the testing procedures, while the records of two subjects were subsequently unavailable. Eighteen subjects remained in the project for complete analysis.

All subjects were laryngectomized individuals who had volunteered for the research project. Eleven of them are members of the Bergen County Laryngectomy Association located in Hackensack, New Jersey; five were found through the efforts of the Speech Rehabilitation Institute in New York City; and two were patients of Dr. Henry Rosin, Head and Neck Surgeon. There were three women and fifteen men in the study.

In organizing the experimental group, there were only three criteria established for the subjects:

1. The subject was required to be a laryngectomee.

2. The subject was required to have at least one month of speech training.
3. The subject was required to have normal or near normal hearing.

Since the object of the study was to investigate the esophagus during alaryngeal speech, it was deemed necessary that the subject have a working knowledge of producing speech in this manner, even though attempts produced little or no sound. Thus, the rationale for the second criterion was established.

The third criterion was stipulated because hearing difficulties might have an impact upon the subject's speech ability. What might be classified as a poor alaryngeal speaker might be a person unable to hear directions clearly, and monitor speech attempts effectively. Diedrich and Youngstrom found that the greater the hearing loss, the poorer the speech. They also stated that "no significant relationship was found between speech skill and auditory discrimination scores."¹

Some selected data of the individual subjects are summarized in Table 1. From this table it can be seen that none of the three female subjects were placed in Group 1, which represents the better speakers in the study. One female subject was in Speech Group 5 (representing no

¹Diedrich and Youngstrom, op. cit., p. 61.

Sub- ject No.	Sex	Speech Group	Chronological Age (Years)	Post-operative Interval (Months)	Extent of Speech Training (Months)
1	F	2	59	15	5
2	M	1	62	60	5
3	M	2	78	36	24
4	M	1	65	27	unknown
5	M	1	62	73	5
6	M	3	49	18	6
7	F	4	58	17	unknown
8	M	3	63	3	1
9	M	4	77	2	1
10	M	2	51	39	1
11	M	5	48	6	1
12	M	1	47	18	5
13	M	5	67	39	3
14	M	5	78	41	3
15	M	1	40	24	unknown
16	F	2	53	17	5
17	M	1	60	87	3
18	M	3	62	10	3
Range		40-78 years		2-87 months	1-24 months
Mean		59.9 years		29.2 months	5.2 months

Table 1
Selected Data on Individual Subjects

speech heard) and the other two were in Group 2. The chronological ages of the subjects were within the age group that one would expect in a laryngectomy population. The chronological ages ranged from 40 to 78 years, with a mean of 59.9 years.

There was a wide range in the amount of post-operative time that had elapsed at the time of the study. The range here was from 2 to 87 months, with a mean of 29.2 months. Only four subjects had post-operative intervals under a year, while the rest were over a year. The last column in this table shows that some of the subjects could not estimate the amount of speech training they had received. But, even considering this, there is a marked difference in the amount of training each subject has had. Each of the four subjects (Numbers 8, 9, 10, and 11) who had only one month of training was placed in a different speech group, indicating different speaking abilities and demonstrating that time alone for training was not a decisive factor. Three of these subjects, Numbers 8, 9, and 11, had short post-operative intervals, yet still exhibited different speech abilities. The range of speech training of all subjects was from 1 to 24 months, with the mean being 5.2 months.

The above information for grouped subjects relative to their speech abilities can be examined in Table 2.

	Group 1	Group 2	Group 3	Group 4	Group 5
N	6	4	3	2	3
Subject Numbers	2, 4, 5 12,15,17	1, 3 10,16	6, 8 18	7, 9	11, 13 14
Sex					
Male	6	2	3	1	3
Female	0	2	0	1	0
Chronological Age (Years)					
Range	40-60	51-78	49-63	58-77	48-78
Mean	56.0	60.3	58.0	67.5	64.3
Post-operative Interval (Mos.)					
Range	18-87	15-39	3-18	2-17	6-41
Mean	48.2	28.8	10.3	6.3	28.7
Period of Speech Training (Months)					
Range	3-6	1-24	1-9	unknown	unknown
Mean	4.7	8.7	5.3	unknown	unknown

Table 2
Selected Data for Grouped Subjects

In Table 2 the majority of the subjects in this study were classified as better esophageal speakers, falling into either Group 1 or Group 2. It will also be noted that Group 1 (the best speakers) tended to have the longest post-operative interval of any group, while Group 4 (poor speakers) had the shortest interval. Interestingly, Group 2 (better speakers) and Group 5 (poorest speakers) had the same amount of post-operative interval. None of the female speakers fell into Group 1, although two of them did indicate speech abilities which placed them in Group 2.

In the present investigation the chronological age of the subjects does not appear to vary greatly, with Group 1 subjects having the youngest subject and a mean age of 56 years. The means of the poor speakers (Groups 4 and 5) appear to be slightly higher when comparing them to the better speakers; however, both Groups 2 and 5 have an elderly subject of 78 years. An examination and discussion of the period of speech training cannot be valid, since some subjects in Groups 4 and 5 could not remember the length of time they had received speech therapy; therefore, this column could not be completed for them. Of the three remaining groups, the best speakers, Group 1, did tend to have the shortest training time, with a mean of 4.7 months, and Group 2 (good speakers) had the longest period of speech training, with a mean of 8.7 months.

Audiological Evaluations

Since one of the criteria for selecting subjects was an adequate hearing level, audiological evaluations were administered by the author prior to any intraluminal pressure testing. The author discussed procedural techniques with Dr. B. V. Sheets, and it was decided to allow the author to perform these audiological tests because of her clinical experience in this area. Mrs. Nancy Lehrer, audiologist, was consulted as to proper testing techniques, and any difficulties in testing were checked with Dr. John Duffy or his staff audiologists at the out-patient Hearing and Speech Center of Kings County Hospital Center in Brooklyn, New York, where the majority of the subjects were given their audiological evaluations. Because some of the subjects resided in New Jersey, they were tested in the office of Dr. Joel Lehrer in Teaneck, New Jersey. No subject had to be eliminated because of hearing difficulties.

The facilities used in the two test situations were essentially similar. Testing was administered in a two-room sound-treated testing suite, employing a Beltone 15C Clinical Audiometer. In performing the audiological tests, the author followed the procedures and recommendations suggested by Newby and Harris.¹ Initial audiometry

¹H. Y. Newby, Audiology (New York: Appleton-Century-Crofts, Inc., 1958), pp. 71-85; J. Donald Harris, "Speech Audiometry" in Audiometry: Principles and Practices, ed. by Glorig (Baltimore: Williams and Wilkins Co., 1965), pp. 154-167.

consisted of pure-tone air conduction testing. This was administered to each ear separately at 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz. The subject was given the following instructions, as recommended by Newby:¹

We are now going to test your hearing. You will hear some sounds in only one ear at a time. The point of the examination is to locate the point where you can just barely hear the sounds. When you hear a sound, no matter how soft it is, raise your hand to indicate to me that you hear it. Are there any questions?

The headphones were then placed on the subject's ears, with testing performed initially on the right ear and then the left. The testing began by administering the 1,000 Hz tone, as suggested by Newby.² The intensity was increased until the subject's threshold was reached. It was then increased beyond this point, then attenuated until it was no longer heard by the subject. Again the tone was increased in 5dB steps until it was again heard by the subject. This point of minimal audibility was accepted as his threshold.

The same procedure was repeated for all the frequencies listed above. After completing the array of frequencies, the author returned to 1,000 Hz and re-established the threshold to check reliability of the tester, as suggested by Newby.³ The same testing procedures were followed

¹Newby, op. cit., p. 74.

²Ibid., p. 75.

³Ibid., p. 77.

for the left ear of the subject.

After pure-tone air conduction testing was completed, pure-tone bone conduction testing was administered. The headphones were removed, and the bone oscillator was placed on the subject's mastoid bone. This is the method of bone conduction testing that is used at the Kings County Center as well as by Dr. Maurice H. Miller under whom the author trained. The same instructions were administered to the subject and the same procedures were followed, as outlined by Newby.¹ After completing the testing in the right ear, the bone oscillator was removed and placed on the subject's left mastoid bone and the testing of the left ear was performed.

Speech audiometry conformed to established procedures and was performed as the next step in the audiological testing of the subjects. Even though Diedrich and Youngstrom, in their evaluations, found no significant relationship between speech skill in the laryngectomee and their auditory discrimination scores, it was felt necessary by the author and Dr. Sheets that a complete audiological evaluation, including speech audiometry, be performed.²

The same audiometer and two-room testing suite was employed in obtaining the subject's Speech Reception

¹Ibid., p. 84.

²Diedrich and Youngstrom, op. cit., p. 61.

Threshold and Discrimination Scores as had been used for the pure-tone tests. The material chosen for the SRT Test was the CID Auditory Test W-1, Lists A, B, C, and D.¹ These are standardized lists of two syllable (spondee) words widely used in audiometric evaluations.

The author chose to employ monitored live-voice testing as opposed to the use of previously recorded material. Harris stated that "every audiologist will encounter a large number of patients who cannot follow a rather fast-paced test in general American dialect. Here the monitored live voice has certain advantages. . . . For such cases the monitored live voice definitely should be available. . . ."² The laryngectomized subjects in this study fell into this category, since some of them could not respond fast enough orally, and some could not write their responses in English.

The SRT Test was administered by the author following the suggestions outlined by J. Donald Harris. The author also used Harris' instructions to the subjects:³

You will hear a list of words through your earphones. These will consist of two-syllable words such as baseball, armchair, etc., with the accent on both syllables. First I will make the words loud enough for you to hear

¹Newby, op. cit., pp. 315-316.

²Harris, op. cit., pp. 156-157.

³Ibid., p. 165.

them easily, then the loudness will gradually get weaker. You must repeat into the microphone every word just as you hear it. If you are not sure, guess. The words will finally become so weak that no one could hear them all, so do not worry if toward the end of the test you cannot repeat some words. Do you have any questions?

If the subject could not speak, the instructions were altered to enable him to write his responses.

The headphones were placed on the subject's ears, and the spondee words were administered in the right ear first, then the left, and finally binaurally. As Harris suggested, each word presented was preceded by the carrier phrase "You will say . . ." and the VU Meter was watched carefully to see that it peaked at "0."¹ The attenuator was set at a level loud enough for the subject to hear the words comfortably. Then it was decreased by 10dB, and several more words were presented to the subject. This attenuation was continued until the subject began to miss words, and ceased when the level was reached at which the subject responded to only 50 per cent of the words presented.² This level was his Speech Reception Threshold.

The final phase of the audiological evaluations was the determination of the subject's speech discrimination scores. Again, live voice was used to present the test

¹Ibid., p. 166.

²Ibid.

stimuli, which were standardized lists of phonetically balanced words, the CID Auditory Test W-22, Lists 1A, 2A, and 3A.¹ The instructions followed were taken from Harris:²

You are going to hear a list of 50 one-syllable words with which everybody is familiar. You are to repeat (or write) each word into the microphone as best you can. If you are not sure, guess.

Initially the subject's right ear was tested, then his left, and then both ears simultaneously. The PB (phonetically balanced) words were administered at a level of 40 dB above the subject's SRT, and the percentage of words correctly repeated was recorded. These figures became his discrimination score.

There was only one exception to the above procedure, which involved one subject who wore a behind-the-ear hearing aid. In his case, at the suggestion of Dr. Duffy, his unaided air and bone conduction, SRT and discrimination scores were determined in the manner described above, and then he was retested wearing his aid, in a free-field situation. The results were shown to Dr. Duffy, who agreed that the subject was able to hear adequately with the help of his hearing aid.

The results of the audiological evaluation revealed that, in most cases, the hearing level on pure-tone testing

¹Newby, op. cit., pp. 317-318.

²Harris, op. cit., p. 167.

fell within normal limits, with normal discrimination ability noted. (See Appendix B for the raw data.) In two cases the hearing was in the mildly impaired range, but both of these individuals had excellent speech discrimination abilities and were not hampered by their mild loss. The one subject who wore the behind-the-ear aid was one of the better speakers. With this type of amplification, it was thought that the subject could be legitimately included as a subject. One other subject showed poor speech discrimination ability binaurally. However, since he was beginning to learn esophageal speech, he was not excluded from the study. In no instance, then, did hearing difficulties significantly affect the subject's ability to learn esophageal speech.

Questionnaire

Each subject was asked to complete a questionnaire so that pertinent background data might be obtained. (See Appendix C for the complete questionnaire.) As suggested by Dr. Sheets, the questions, for the most part, were of the nature of forced-choice, with five or six possible alternate answers for each question. This was done to quantify the subject's response and thereby facilitate the analysis of the data. Often the subject could not remember certain facts (such as the length of each speech lesson or the total amount of lessons), and he was asked to make an

estimate using the choices available.

The questionnaire was not standardized but, rather, reflected the professional experience of the author, who considered the questions to be relevant to the study, and had encountered similar questions in studies done by Diedrich and Youngstrom, and DiCarlo.¹ The nature of the questions dealt mostly with speech therapy, including such information as to the amount and type of speech training received, method taught, type of therapist, and length of each lesson. There were some questions dealing with personal and social adjustments of the subject in various situations.

The author did not evaluate all the responses to be found on this questionnaire but, rather, chose those that revolved around the subject's speech. Some of the questions were of a psychological nature, which were felt to be beyond the scope of this study.

The Speech Rating Scale

In order to compare the speech abilities of the laryngectomees in this study, it was necessary to analyze the speech proficiency of each subject. The review of the literature in the previous chapter indicated that several types of rating scales had been used by previous authors.

¹Diedrich and Youngstrom, op. cit., pp. 65-78; DiCarlo et al., op. cit., pp. 174-177.

Damste used a three-step scale, which was considered by the author to be too generalized.¹ DiCarlo et al. employed a scale measuring mainly articulation and resulting in a numerical percentage for each subject's speech ability.² This approach was similar to that of Diedrich and Youngstrom, who also gave a numerical rating to the subject's speech output, based on a comparison with an initial speech sample.³ Because of the small number of subjects, the author felt that a numerical ranking would not be the best method of rating the subjects in this study.

The subjects were evaluated on a practical scale that would in some way indicate the ability of each individual to communicate. A similar scale was used by Finkbeiner, where the subjects were rated on a seven-point scale as follows:⁴

1. no sounds produced
2. partial control; single sounds under fair control
3. simple words produced
4. combines 2-3 words
5. some sentences used
6. sentences consistently used
7. fluent, nonhesitant speech.

This type of scale would certainly demonstrate the practical ability of the laryngectomee to communicate, but,

¹Damste, op. cit., p. 12.

²DiCarlo et al., op. cit., pp. 25-26.

³Diedrich and Youngstrom, op. cit., pp. 151-154.

⁴Finkbeiner, op. cit., p. 64.

that the seven-point scale would spread the subjects over too wide a range to make statistical analysis feasible. It was then decided to adopt a modified version of the Wepman Scale that had been employed by Kroll in his study of laryngectomees. Kroll reduced the seven-point scale to five points whose classifications were:¹

Level 1. ability to use esophageal speech with continuity in an automatic manner;

Level 2. ability to produce word groupings;

Level 3. ability to produce single words;

Level 4. ability to produce any recognizable sounds;

Level 5. inability to produce any recognizable sounds or words in an esophageal manner.

The author felt that since this scale represented a practical measure of the laryngectomee's ability to communicate orally, and it had been employed in a previous study, it would be useful to use this rating scale for the present study.

After discussion with Dr. Sheets, it was decided that the author, who has had considerable clinical experience in teaching alaryngeal speech, would be the sole judge of the speech ability of the subjects. Judgments were made by

¹A. Kroll, "A study of two psychological variables in the study of esophageal speech," unpublished Master's Thesis, Brooklyn College, 1968, p. 21.

listening to tape recordings completed by each subject prior to the intraluminal pressure tests. All recordings were made on a Norelco four-track tape recorder (model number EL 3549), using Scotch brand magnetic tape running at a speed of seven and one-half inches per second.

Each subject was asked to read the "Grandfather" paragraph (see Appendix A for text).¹ This paragraph was chosen because it has been used extensively as a test for articulation by Van Riper and many other Speech Pathologists, and was employed by Diedrich and Youngstrom in rating the speech proficiency of their subjects. Prior to his oral reading, the subject was allowed to read the paragraph silently for familiarization purposes. His oral reading was then recorded. In one case the subject was illiterate so the material was read to him orally, phrase by phrase, and he was asked to repeat it as the recording was made.

The author rated the subjects on two separate occasions, each a week apart. The previously described five-point scale was used on both ratings. As a result of the analysis, the eighteen subjects in this study were divided into five speaking groups. Table 2, which was discussed previously, indicates the number of subjects in each group, as well as other selected data for each group. More than

¹C. Van Riper, Speech Correction: Principles and Methods (4th ed.; Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1963), p. 484.

half of the subjects fell within the first two groups, indicating that there were ten good to excellent speakers in this study.

A vital part of esophageal pressure testing requires the subject to swallow a specially constructed polyvinyl catheter bundle (to be discussed in detail later in the chapter) that entered the esophagus but remained protruding at one end from the mouth. Since this catheter was introduced orally, it was felt that perhaps it would interfere with the subject's speech proficiency once it was in place. To investigate this, the subject was asked to re-read the "Grandfather" paragraph orally after the catheter had been introduced in the subject's esophagus, and this reading was recorded. The speech proficiency of the subject was again rated in a manner similar to the first rating (without the catheter) and they were placed in the appropriate groupings, using the same five-point rating scale.

Because all subjects exhibited visible difficulty reading the conversational material with the pressure catheters inserted (there was much gagging noted), they were asked to complete only the first sentence. In practice it was found that the single sentence provided an ample basis upon which to rate individual speech production. Apparently, the catheter impeded the speech of all subjects to the degree that all were placed in a group one step lower than their speech rating under normal conditions; i.e., all of the

speakers initially placed in Group 1 were now placed in Group 2. Similarly, all of Group 2 speakers were now in Group 3. There seemed to be little doubt that the catheters used for the intraluminal tests were detrimental to the subject's speech ability, and the effect was uniformly felt by all subjects.

Speech Material

In order to perform the intraluminal pressure studies on the subjects, a set of speech stimuli were evolved. The speech tasks chosen were based on the procedures administered by Diedrich and Youngstrom:¹

1. [i] [a] [u]
2. [pa] [ta] [ka] [sa]
3. [ma] [na] [ra]
4. upward intonation of [a]
5. downward intonation of [a]
6. counting from one to ten
7. blowing on the oral manometer
8. producing the modified Valsalva maneuver

These authors do not discuss why they placed the above lists of tasks in this sequence. They stated that they were mainly interested in observing the hypopharynx, pseudo-glottis, and upper esophagus under various physiological

¹Diedrich and Youngstrom, op. cit., pp. 10-11.

conditions with a variety of phonemes.¹ They reported that when the subjects were asked to phonate the [a], many produced the [ʌ] or [ɔ]. They further note that [sa] was added after the study began.² A reported complication arose in their study during the counting procedures. Although the subjects were asked to count in a natural manner, and not to impose any artificial moments of air intake, they often counted one number at a time, taking in air before each number.³

Since one of the goals of the present study was to observe esophageal motility under the influence of different consonants, the speech tasks employed were a modified version of the Diedrich and Youngstrom list. The repetition of three different vowels was eliminated because the aim was not to evaluate various vowels, but consonants. Therefore, it was felt that the use of one vowel would eliminate the variable of vowel influence on the production of the preceding consonant while the pressure measurements were being taken. The labial sound [p] and the nasal sound [m] were eliminated because the subjects had the catheter introduced into their mouths, and protruding from their lips. It was felt that the catheter would not permit complete bi-labial closure. The remaining consonants were felt to reflect a representative sound from each consonant grouping, i.e.,

¹Ibid., p. 10. ²Ibid. ³Ibid., p. 11.

plosive, fricative, nasal, and glide. Two plosives were used because of the controversy in therapy concerning the use of these sounds in facilitating esophageal speech.

The sequence of the sounds for the present study was arbitrary, since the subjects were asked to repeat the syllables upon cue from the investigator, and this was from a position of rest. Because the sequence of sounds seemed not to influence the collection of data significantly, the author chose to follow the Diedrich and Youngstrom sequencing.

Instructing the subject to count from one to ten was included in the present study with certain modifications vis-a-vis previous investigations. It was felt that two types of counting should be included. The first counting task involved individual numbers spoken slowly with air intake before each number. This, the author felt, would give the investigation a sample of familiar speech, rather than the imposed nonsense syllables. In this manner, some later comparison could then be made between the consonants in the syllables and the consonants followed by different vowel sounds. The second counting task was serial counting by the subject, from one to ten. He was asked to start at one and count as far as he could on one air intake. In this way it was anticipated that some analysis could be made between the subject's rapid speech (serial counting) and his individual speech attempts (syllables and single numbers).

The serial counting task proved to be a poor one, insofar as a study of intraluminal pressures is concerned because the resulting tracings on the written record were too close together and did not lend themselves to analysis.

Tasks four and five in the Diedrich and Youngstrom study represented changes in pitch. These procedures were eliminated since pitch factors were not a part of the present investigation. The research design also did not include the morphological changes occurring in the oral and pharyngeal cavities, the pseudoglottis, and esophagus under different physiological states.

As a result of the modifications and eliminations, the following were the speech tasks each subject was asked to repeat during the intraluminal pressure tests and cine-fluorography:

1. [tɑ] [kɑ] [sɑ] [nɑ] [rɑ]
2. Counting slowly from one to ten; air intake between each number
3. Serial counting on one air intake

Intraluminal Pressure Equipment

Various types of pressure measuring devices have been employed to evaluate the pressure variations in the esophagus, its sphincters, and the stomach, to facilitate the understanding of the mechanisms that occur in these organs.

The force of esophageal contraction was tested by Schreiber, as translated by Lerche, by having the subject

swallow an artificial bolus, either a water-filled condom or a piece of sausage attached to a silk thread. The thread was marked off in centimeters, and run smoothly over a pulley apparatus, and finally attached to a recording apparatus. Any movement either downward or upward of the bolus would be recorded and the end result would be a rough graph, in wave form, indicating the various pressures in these organs and at approximately what level the pressure variations occur.¹

This crude type of apparatus was subsequently replaced by more efficient and precise equipment, similar to that which is used in the present study. The studies by Fyke and Code, cited in Chapter II, utilized a single water-filled rubber tube with a small transducer attached to the swallowed end. The subject swallowed the tube to the required depth. Externally, the tube was calibrated in centimeters, and its external tip attached to a recording system consisting of a galvanometer and photokymograph. Pneumographic tubes were fastened to the lower thorax to record respiratory movements. This type of intraluminal pressure testing allowed only one site to be tested at any given moment.

¹Lerche, op. cit., pp. 162-163, citing J. Schreiber, "Ueber die normalen Vorgänge beim Schlucken und die Schluckkraft," Arch. f. Verdauungskrankheiten, XVII, 1911, pp. 647-676.

Nagler and Spiro modified the test equipment to allow simultaneous pressure measurements to be obtained at three different sites. Their equipment consisted of:¹

Three polyethylene catheters, each with an internal diameter of approximately one and a half mm., are fastened together and sealed at the tips. A lateral hole in each at 5 cm. intervals permits simultaneous recording of pressure changes from multiple sites within the esophagus. These catheters are water filled so that pressure changes developing within the esophagus may be transmitted to three Sanborn electromanometers and the changes then recorded on a four channel Sanborn direct writing recorder. Swallowing is signaled by recording the action potential of the accessory muscles of deglutition. A pneumographic belt around the chest indicates respiratory movements.

This equipment, as described above, is similar to apparatus used by Dey and Kirchner in their study cited in Chapter II. It is also similar to the type of equipment utilized in the present study.

The intraluminal pressure equipment in this study was located at the Gastro-intestinal Laboratory of Kings County Hospital, where this phase of the study was administered. The laboratory consists of two rooms: an office-laboratory and the larger technical room. The photographs presented on the following pages (Figures 5 through 10) indicate the type of equipment found in this laboratory.

¹Nagler and Spiro, op. cit., p. 1.

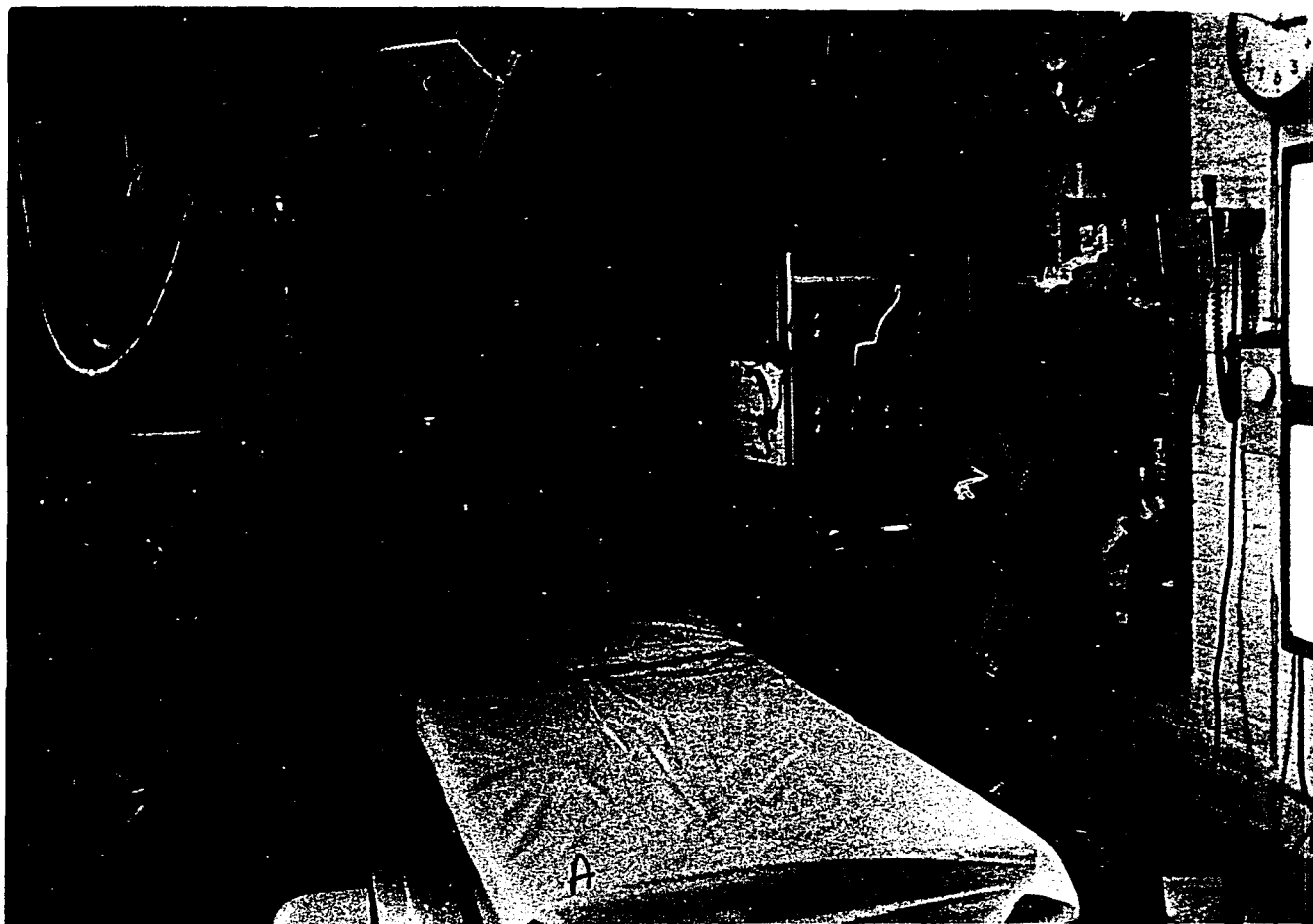


Fig. 5.--Photograph of intraluminal testing instrumentation with the exception of the television monitor. A: x-ray table; B: polyvinyl tubes; C: external transducers; D: overhead suspended projection containing 16 mm. cinefluorographic camera; E: monometer; F: location of subject's head; G: Sanborn Carrier Preamplifier; H: oscilloscope.

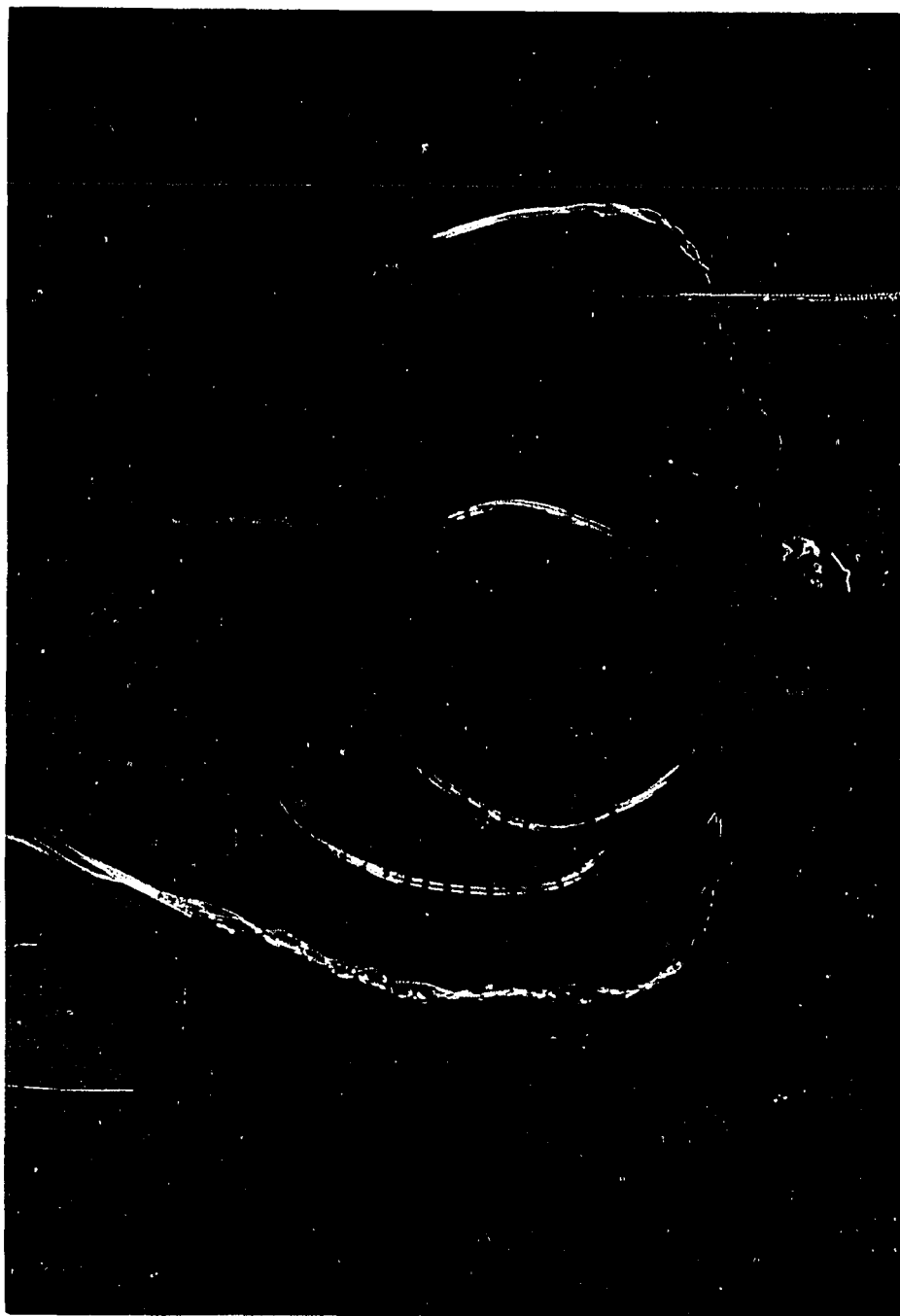


Fig. 6.--Photograph of the specially constructed polyvinyl catheter bundle. A: small mercury bag; B: free end of the catheter bundle.

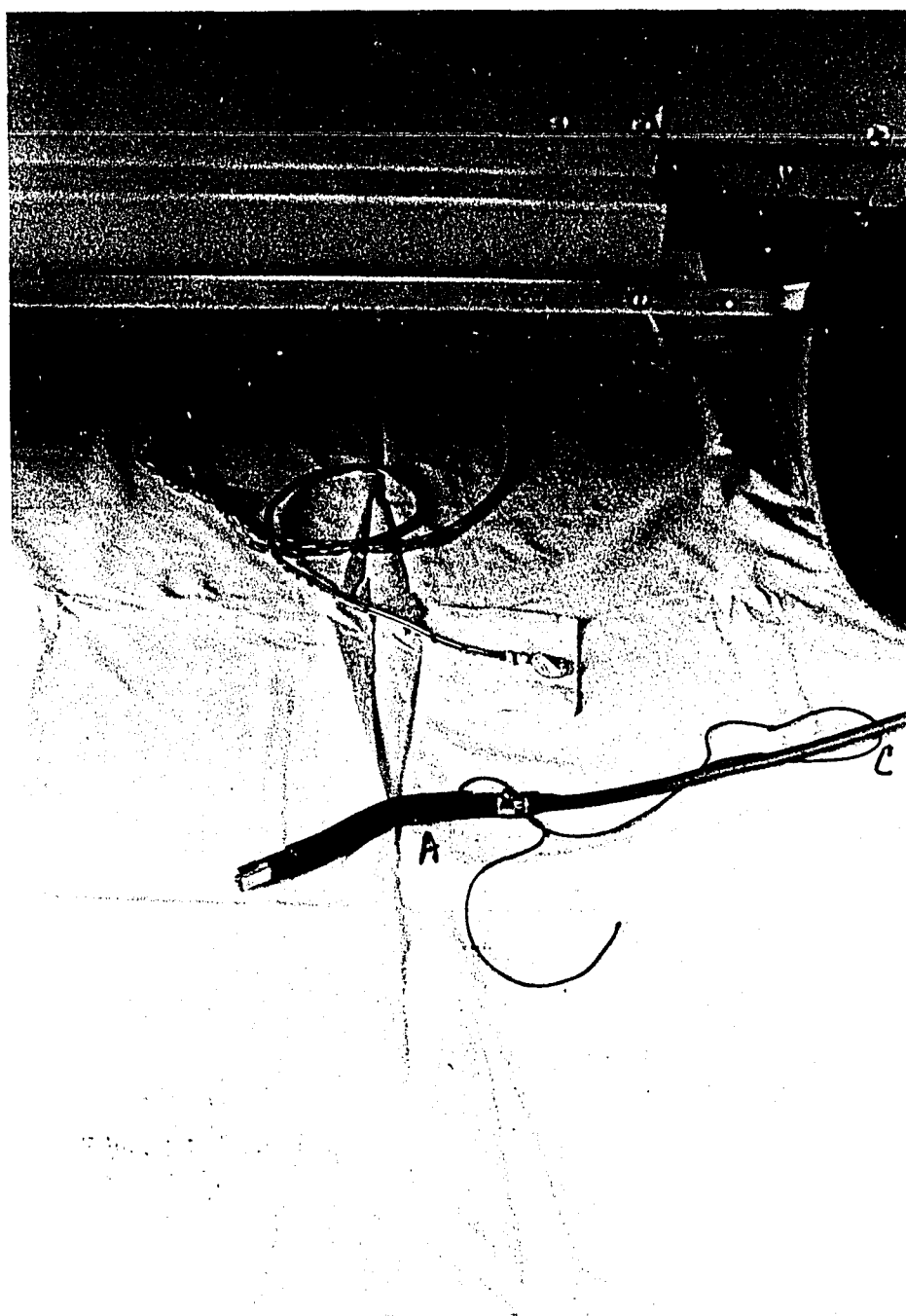


Fig. 7.--Photograph of the specially constructed catheter and pneumograph tubes. A: air-filled tube placed at lower thorax; B: air-filled tube placed on subject's neck; C: sections of tubes leading to pre-amplifier connections.

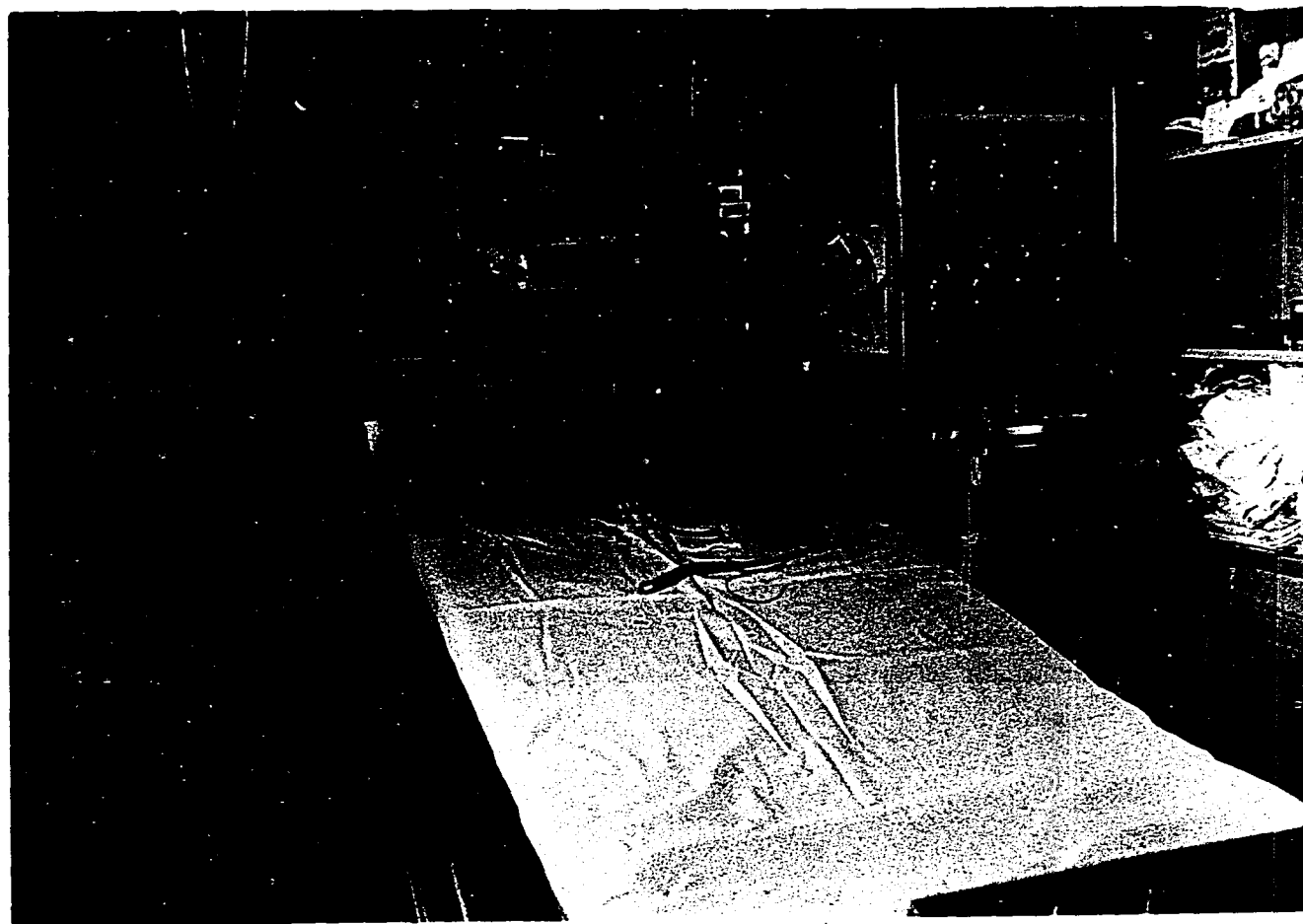


Fig. 8.--Photograph of intraluminal pressure testing instrumentation indicating 16 mm. cinefluorographic camera suspended over the x-ray table.

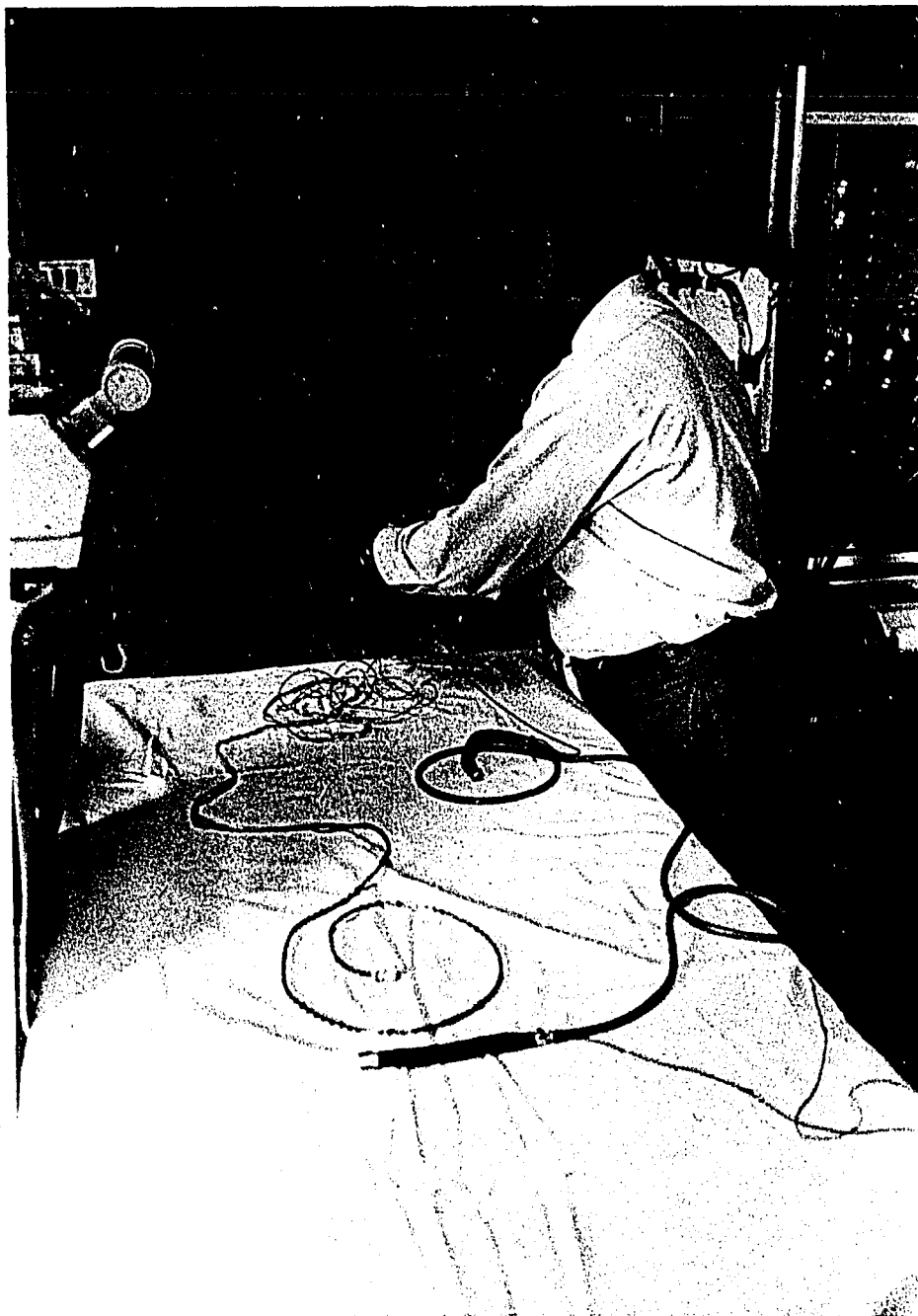


Fig. 9.--Photograph of free end of the catheter bundle being attached to the external transducers.

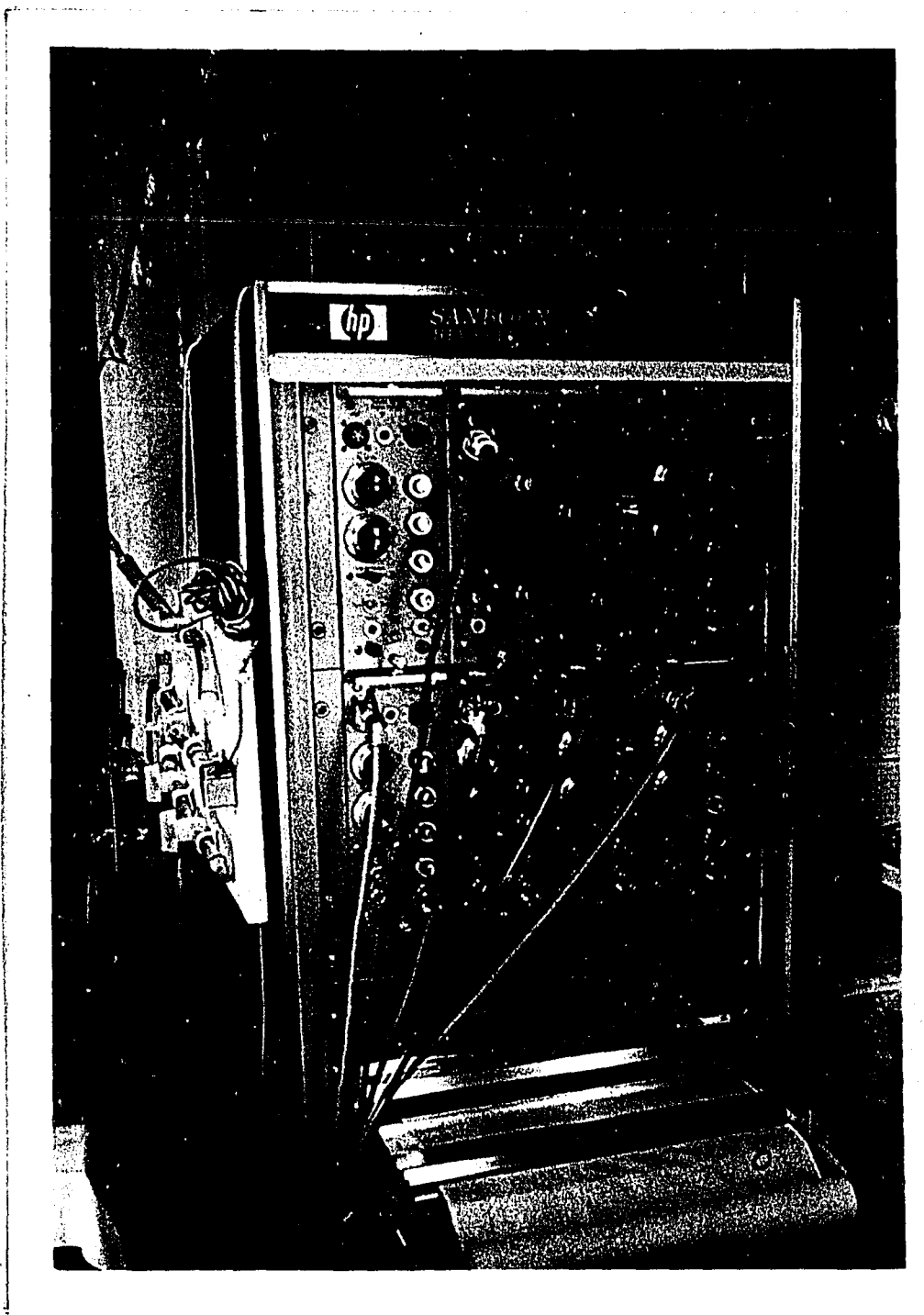


Fig. 10.--Close-up photograph showing details of the Sanborn Carrier Preamplifier and multi-channel Sanborn Direct Writing Recording System. K: recording styli; M: connections of the five tubes to the amplifier; N: Sanborn Direct Writing Recording System; O: recording graph paper; P: speed regulators of the motor-driven drum.

Figure 5 illustrates all the intraluminal test equipment, with the exception of a television screen, which was used to monitor fluoroscopic examinations of the subjects.

Before beginning the intraluminal studies, the subject was dressed in a hospital gown and his pharynx was sprayed with 0.5 per cent solution Dyclone (a brand of Dyclonine Hydrochloride), to inhibit his gag reflex. One of the physician co-investigators performed this procedure. After the pharynx felt sufficiently numb, the patient was asked to swallow the specially constructed multi-component polyvinyl tubes, heat welded into a single unit.

This tube or catheter can be seen in Figures 6 and 7. It consists of three small tubes, each with an internal diameter of 1.4 mm., fused together to form one tube, whose external diameter is .5 cm. In Figure 6 the small bag of mercury (A) can be seen. This bag was attached to the swallowed end of the catheter to aid the subject in swallowing. Each tube, as in the Nagler and Spiro study, contains a lateral orifice whose openings are 5 cm. apart, so that three pressure readings from three different sites can be obtained simultaneously over a 10 cm. range. These orifices are not clearly indicated on the photographs. The opening close to the external end of the tube is known as the proximal tip; the middle opening is the medial tip, and the opening that is most internal is the distal tip.

The dark lines indicated in Figure 6 have been placed on the external surface of the catheter bundle. These markings are 1 cm. apart and are numbered from one to one hundred. They are used to locate the level being tested. As the subject swallows, the tube part will remain externally protruding through the mouth. The investigator notes the centimeter at this point, counts the number of centimeters remaining internally and, since the level at which each orifice is located is known, by subtraction, can determine the exact number of internal centimeters or at what level the subject's lower sphincter or upper sphincter is located and what level is being tested. The measurements taken of pressure changes are determined as the person performs his tasks and familiar wave patterns appear on the written record. The free or protruding end of the catheter bundle (6B) is attached to the external transducers.

After the catheter bundle was introduced into the esophagus, the subject was placed in a supine position on the x-ray table at the end of the table (5A). The photograph shows the Monarch 90 x-ray table with fluoride image intensifier. The x-ray table is capable of rotating from 180 degrees to 90 degrees (in relation to the floor) and contains the Roentgen tubes. Working in conjunction with the x-ray table is the overhead suspended projection (Figure 5D), containing the 16 mm. cinefluorographic camera

and nine-inch image intensifier. This equipment array provides for spot x-ray films, cinefluoroscopy (motion picture x-ray films), and simple fluoroscopic examinations. The image intensifier permits greater light during filming without increasing the exposure of the patient to increased radiation. The camera is capable of rotating with the table to any desired degree, as well as being suspended over the table when in use, as in Figure 8, or slid out of the way, as in Figure 5. The equipment also provides for television presentation of the image to the television monitor suspended from the ceiling just to the right of Figure 5 (cannot be seen in the photograph) and to another monitor located in the office next door. Closed-circuit video tape studies are likewise possible with this equipment.

After placing the subject in a supine position on the x-ray table (with his head at location F in Figure 5), the free ends of the catheter bundle, appropriately labeled "proximal," "medial," and "distal," were attached to the external transducers (Figure 5C). It is accomplished by inserting a needle adapter into a stop-cock mechanism. This procedure is being performed in Figure 9. A manometer placed above the transducers was used to fill the individual tubes with water (Figure 5E). When the tubes were completely filled with water, the stop-cock was closed, permitting no more water to enter the system, thus each

catheter became a closed system. Any change in pressure in the intraluminal sites under test was reflected by liquid displacement at the orifice and recorded as such on the Sanborn recorder.

It was necessary to maintain the orifice at the same horizontal level as the transducers, but, since the subject maintained a horizontal position throughout the testing, this did not present any problems once the initial leveling procedure was done. Any change in water pressure at the test site was registered by the transducers, altered into electrical impulses, and fed into the amplifier-recorder. Here a visual record of the pressure changes was produced as a permanent paper read-out. If, for some reason, the intraluminal pressure changes appeared to be dampened, the stop-cock was opened during testing and the tube filled with water again.

In Figures 5 and 7, two other pieces of equipment are shown--two air-filled rubber tubes, capable of expanding and contracting, used for pneumographic purposes. The lowermost tube (Figure 7A) was placed at the lower thorax, while the other tube (Figure 7B) was secured on the patient's neck. The latter tube registered gross muscular movements during swallow. The free ends of the tube fed into the recorder and two of the available recording channels. In Figure 7 the tubes labeled "C" are the sections leading to and connecting with the preamplifier.

The three leads from each of the external transducers, and the two leads from the pneumograph around the thorax and around the neck, were fed into the Sanborn Carrier Preamplifier, Model 350-1100B, which is part of a multi-channel Sanborn Direct Writing Recording System. This device can be seen in Figure 5G and in more detail in Figure 10. Figure 5 shows how the investigator is able to control the preamplifier and recording material while still maintaining close observation of the subject and transducers. In Figure 10, "M" indicates the connection of five of the tubes to the amplifier.

The Sanborn Carrier Preamplifier is a plug-in amplifier designed to measure physical variables, such as pressure (as in this study), strain, force, and flow. The preamplifier operates in conjunction with an external device, already described, the transducer. The preamplifier supplies an excitation voltage to the transducer, and, when the load to be measured is zero, the transducer returns zero voltage to the preamplifier. When there is a load present, the transducer returns a signal to the preamplifier, whose amplitude represents that of the physical variable being measured, and whose phasing indicates the sense of the physical variable, such as pressure versus vacuum. Figure 11 shows this relationship in block diagram.

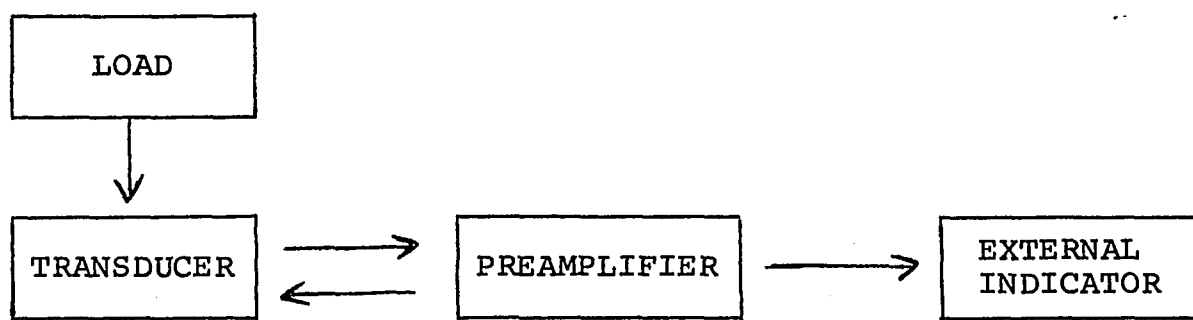


Fig. 11.--Block diagram of the Sanborn Carrier Preamplifier.

When a load (in the case of the present study, a variation in pressure) is fed into the transducer, it upsets the static relationship between the transducer and amplifier. This signal passed to the amplifier for interpretation and then recorded on the external indicator, in the case of this study, presents a written record. The Sanborn Preamplifier is capable of recording information several ways. The results may be displayed in the form of a meter or an oscilloscope; the latter can be seen in Figure 5H. Neither of these was used for the present study because they would not leave a permanent record that could be studied and analyzed.

In this study the results of the intraluminal pressures--and directly related phenomena--were available in the form of a direct, continuous recording read-out on a Sanborn Direct Writing Recorder (Figures 5N and 10N). This is a multi-channel recorder, capable of responding to six different inputs simultaneously. The physical relationship

of the preamplifier and direct writing recorder is indicated clearly in Figure 10. As the information is received into the preamplifier, it is converted to wave form on the recording graph paper (Figure 10-0). The paper is driven by a synchronous motor, past the recording styli (Figure 10K --not clearly seen in the photographs), which are heat sensitive. Deflections of the pens are inscribed on the pressure sensitive paper.

The speed of the motor-driven paper is variable. Thus, the paper can move past the styli at speeds of .25 mm./sec., .5 mm./sec., 1.0 mm./sec., 2.5 mm./sec., 5.0 mm./sec., 10 mm./sec., 25 mm./sec., 50 mm./sec., and 100 mm./sec. In the present study, the recorder was run at a speed of 10 mm./sec. when intraluminal pressures were being recorded during periods of vocalization. At all other times, the recorder was run at a speed of 2.5 mm./sec. The faster speed was considered more advantageous in analyzing the data, since the resultant wave patterns were extended along the horizontal plane and more easily discernible.

An example of the resulting graph can be seen in Figure 12. The Sanborn Direct-Writing Recorder is calibrated with the preamplifier, so that one volt of preamplifier output corresponds to one nominal centimeter, or to ten divisions of the recording chart. The preamplifier in this study was calibrated so that the pressures of one millimeter of mercury would cause a deflection of one

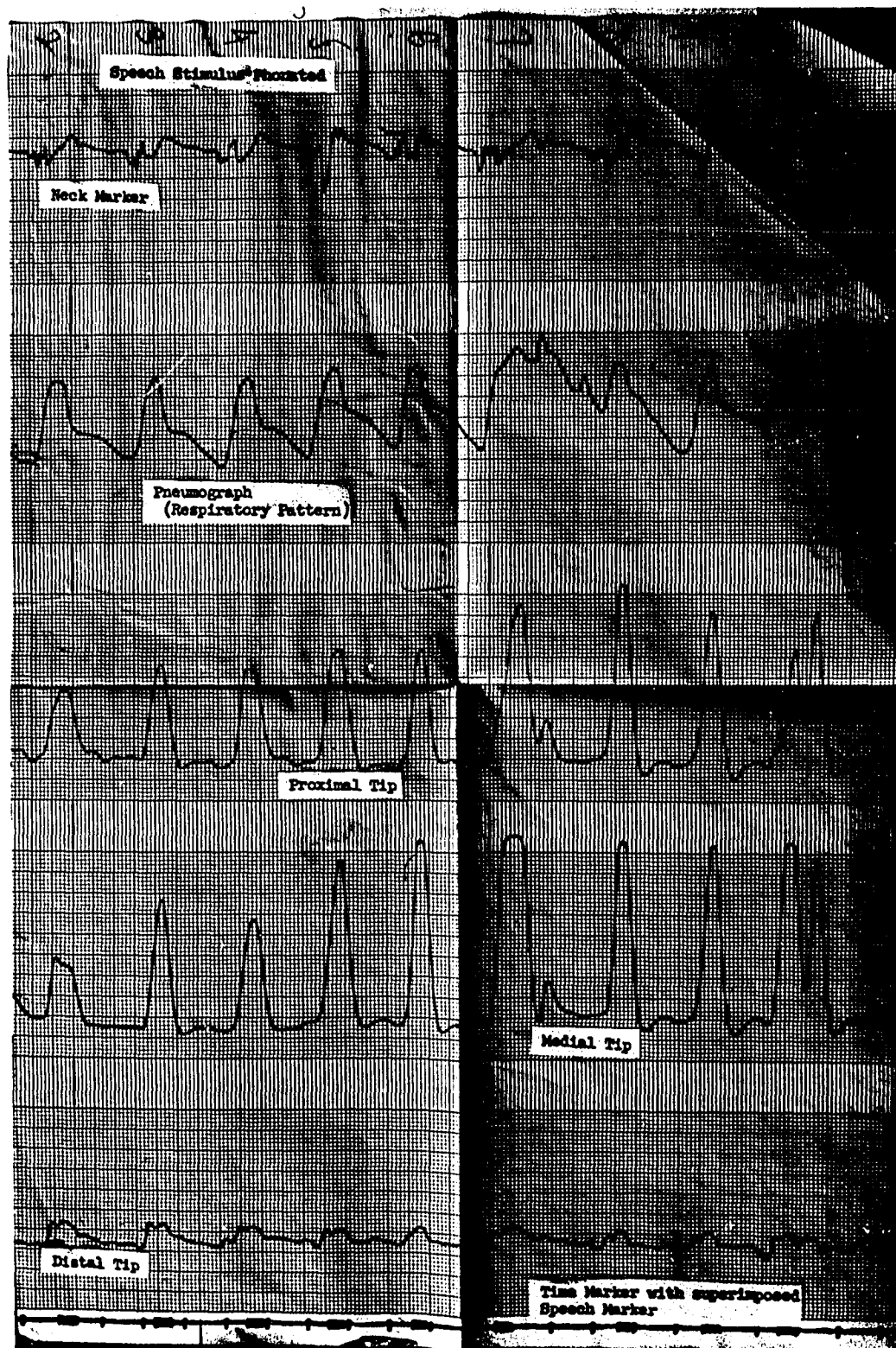


Fig. 12.--Photograph of a sample of recording pressure-sensitive paper with examples of tracings of the intraluminal pressure wave patterns.

millimeter on the recording chart. For the purposes of this study the 10 mm. line for each channel recording was the base line used in calibrating the equipment.

In Figure 12 the wave patterns from the various measurements taken have been labeled. The three bottom graphs (labeled "proximal," "medial," and "distal") refer to the intraluminal tips and recorded the results of the internal pressure changes. An increase in pressure is indicated on the recording chart as a positive (upward) deflection of a specific number of millimeters of mercury. These positive changes are the sharp-peaked waves that can be seen in the sample recording. A drop in pressure, as measured against the 10 mm. base line, would be indicated by a negative (downward) deflection.

The pneumograph recorded the external movements of the thoracic cavity, indicating inspiration (a trough in the wave) and expiration (a crest). The uppermost recording channel is labeled "neck marker" and reflects external neck movements by the subject in swallowing or intake of air during esophageal speech attempts. The sharp negative deflections are indications that the swallowing act has been accomplished.

Above the neck marker channel on the multiple read-out the speech stimuli which the subject was asked to phonate are manually recorded directly on the recording paper, as they were vocalized by the subject. At the lower

margin of the recording chart, time units were automatically imprinted. Each vertical line represents a fraction of a second, the exact amount of time depending on the speed of the paper. Superimposed on this time line are heavy, short horizontal lines. These indicate phonation attempts by the subjects. They were recorded by means of a foot-activated switch located on the floor where it could be easily activated by the investigator at the initiation of phonation by the subject. Any latency factor in activating the switch was not thought to be significant. The phonation switch was depressed during the length of vocalization so that the initiation and completion of the speech attempt could be analyzed in relation to related wave patterns. The phonation marker was pressed whether audible speech could be heard or the subject only attempted to speak.

A sixth channel, whose recordings are not shown on this graph, measured the flow of air from the stoma. This was accomplished by use of a thermo-couple unit, two wires manually held over the subject's stoma as he attempted speech. Because of lack of space on the recording graph, it was activated only during the recording of the final set of vocalizations during the intraluminal testing. The unit, sensitive to heat, theoretically would detect pulmonary air as it was expired because of the increase in heat, and would indicate thermal differentials as a positive deflection of the resultant wave on the recording

chart. This wave could then be compared to other wave patterns produced during speech indicating synchrony or dissynchrony between pulmonary and esophageal air. In practice the thermo-couple proved to be a poor device for testing synchronization of air flow. One of the reasons appeared to be that it was manually held at the stoma with resultant imprecision of distance and stability. Often it did not register any wave patterns, or if it did, they were unclear and could not be analyzed. The device also had a relatively long latency period and was not sensitive enough to minute changes in heat at the stoma. As a result, this portion of the testing procedure was eliminated in the final analysis of the data. However, the investigators feel that an accurate comparison of pulmonary air flow at the stoma and intraluminal pressures is a potentially significant procedure.

Summary

In summary, the equipment used in this study to test intraluminal pressure changes consisted of water-filled polyvinyl catheters (three small fused tubes) swallowed by the subject to any desired depth, which were then connected to external transducers. The transducers fed the appropriate changes in internal pressure to a preamplifier which recorded these changes in pressure in terms of millimeters per second on a direct writing recorder. Also, the external

movements used in respiration and swallowing were recorded through the preamplifier and indicated on the recording chart in the same form.

Experimental Procedures

Just prior to the commencing of the intraluminal pressure testing, the subject was given the following instructions:

You are going to be asked to swallow, to repeat certain nonsense syllables and to count with the tube in your mouth. You'll find that you will be able to speak, but, in the event that nothing comes out, don't make a second attempt unless asked to do so. When asked to swallow or speak, try to make one attempt only to do so. Try not to move around. If anything bothers you, one of the doctors can help. You'll be asked to repeat the series of words several times before the test is over.

During the course of the recording, one physician co-investigator monitored the preamplifier, while another held the polyvinyl tube close to the subject's lips, to prevent slippage during vocalization and to adjust the tube to the proper level desired. The tube was withdrawn from the esophagus centimeter by centimeter at specific intervals during the testing. At each centimeter the subject was asked to swallow. By examining the pressure readouts of the swallowing pattern, the investigator could locate the three openings in the catheter bundle. If desired, precise momentary location of the three pressure

orifices within the esophagus could be determined by fluoroscopy. The polyvinyl tube tips distal to the orifice were filled with mercury and thus provided a radio-opaque medium easily visible under the fluoroscope.

Three main intraluminal levels were tested and the subject was asked to repeat the speech tasks previously discussed at each of these levels. In Figure 13 the testing sequence is shown in a block diagram. The levels tested were:

<u>Level 1</u>	<u>Proximal Tip:</u>	in lower esophagus (1C)
	<u>Medial Tip:</u>	in lower esophageal sphincter (1B)
	<u>Distal Tip:</u>	in stomach (1A)
<u>Level 2</u>	<u>Proximal Tip:</u>	middle one-third of esophagus (2F)
	<u>Medial Tip:</u>	middle one-third of esophagus (2E)
	<u>Distal Tip:</u>	middle one-third of esophagus (2D)
<u>Level 3</u>	<u>Proximal Tip:</u>	in hypopharynx (3I)
	<u>Medial Tip:</u>	in upper esophageal sphincter (3H)
	<u>Distal Tip:</u>	in upper esophagus (3G)

In Figure 13, Points A, B, and C refer to the orifices in each of the three tubes separated by a distance of 5 cm. each. At Level 1 the tubal orifices are located respectively in the stomach, lower esophageal sphincter, and the lower esophagus. Points D, E, and F are Level 2, where all the tips are in the mid-esophagus, covering a 10 cm. range. Points G, H, and I refer to the placement of the orifices at Level 3 in the upper esophagus, upper esophageal sphincter, and hypopharynx, respectively.

At times, due to subject variability, a given patient may have been asked to repeat the speech tasks, with the

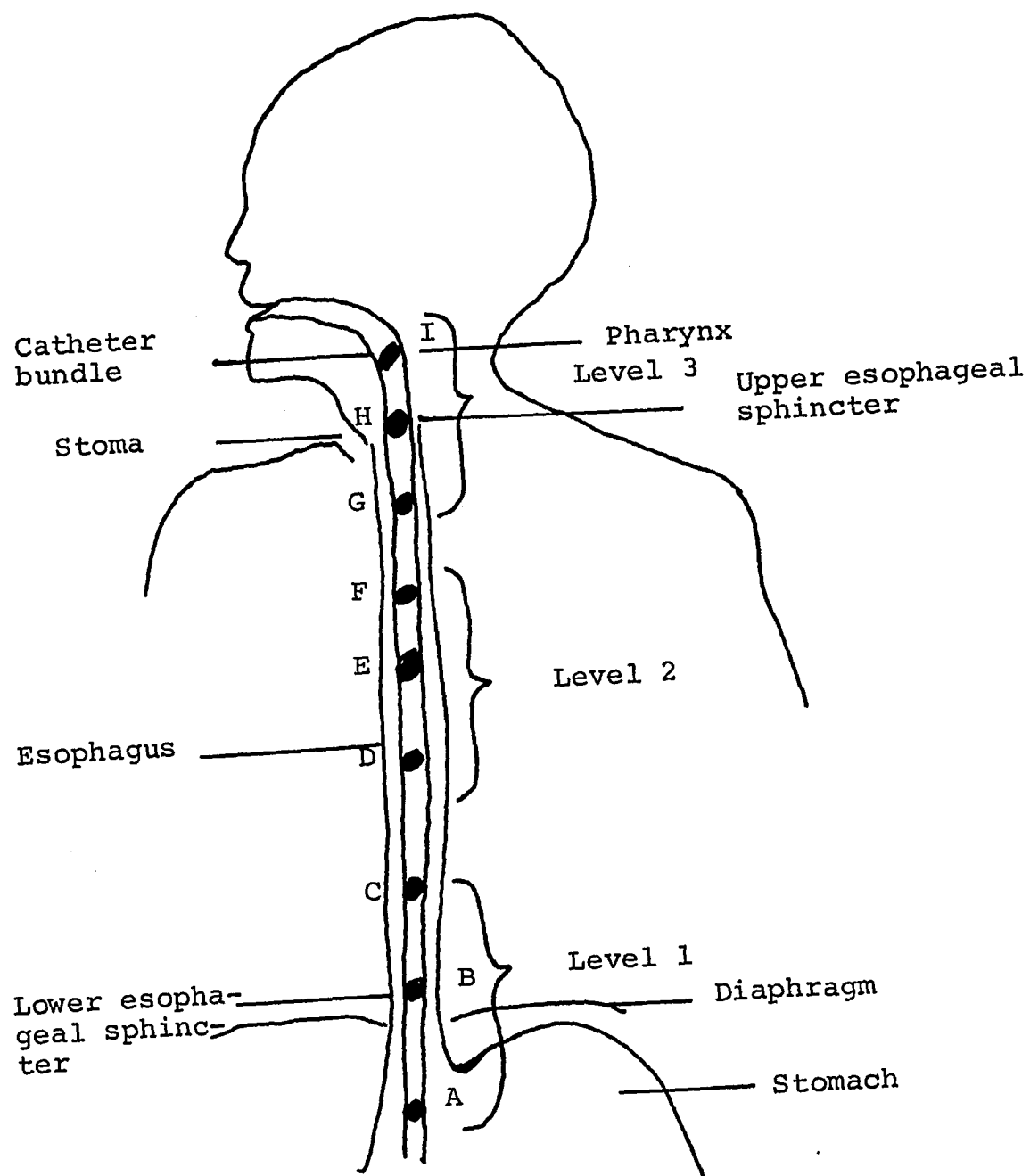


Fig. 13.--Block diagram of the positions of each opening of the catheter bundle and the levels tested.

pressure tips at other levels. For example, if there were difficulty locating the subject's lower sphincter, he might be tested at Level 1, then retested at a slightly higher level, when the distal tip was in the lower sphincter and the proximal and medial tips were in the esophagus. In this manner closer analysis of sphincter activity could be obtained, and it acted as a means of checking the results obtained during the initial test of that site. The same type of variability also occurred infrequently when testing the upper esophageal sphincter.

At Level 3 the thermo-couple unit was attached and activated. In Figure 12 there is little space available between the neck marker read-outs on the recording chart and the written speech stimuli. This space represented the area in which the thermo-couple recordings would be printed.

After the intraluminal testing was completed, the tubes were gently withdrawn, and the neck marker and pneumograph removed. The subject rested for several minutes while the room was prepared for cinefluoroscopy. This was done by rotating the x-ray table and cinefluorographic camera, until both units were perpendicular to the floor. The subject then stood between the camera and now upright x-ray table. He was given a barium solution to swallow and asked to repeat the same sequence of sounds and numbers used during the intraluminal pressure testing. No tape recording devices were used during either the cinefluoroscopy

or pressure testing, since articulatory quality was not being measured at these points in the investigative sequence. The x-ray motion picture films were made in the same order as the pressure testing, i.e., first the lower esophagus, lower esophageal sphincter, and stomach as Level 1; then the mid-esophagus as Level 2; finally the upper esophagus, upper sphincter, and hypopharynx as Level 3. A complete swallow of the barium solution was photographed as it progressed down the esophagus and entered the stomach.

Because no visual markings were placed on the cine-fluorographic film as it was being photographed, nor were auditory records in the form of synchronized tape recordings kept, it was later difficult to analyze the physiologic maneuvers clearly as they occurred during the filming. Also, some initial cinefluorographic records were not clearly filmed and these had to be disregarded completely because they could not be carefully analyzed. In view of these difficulties, it was felt by the author that this portion of the study should be eliminated in the final formal analysis of data.

This study is only part of a larger investigation being undertaken by the staff of the Gastro-intestinal Laboratory at Kings County Hospital, under the direction of Edmund F. McNally, M.D., Chief of Gastro-enterology, and Professor of Internal Medicine, Downstate Medical Center of

New York State University. Therefore, some added tests that were performed on the subjects were not included in this document but will be mentioned briefly.

While the subject was undergoing pressure testing at Level 2 (all tips in the esophagus), 50 cc. of air were injected into the esophagus. By using this procedure the other co-investigators wished to discover the nature of secondary peristalsis in the laryngectomee for later comparison with the same phenomenon in normal individuals.

During the cinefluoroscopy of the subjects, they were asked to swallow a barium-coated marshmallow in one gulp. Here the aim of the researchers was to investigate the tension of the upper esophageal sphincter in laryngectomee individuals and compare their performances with a normal population.

Plan of Analysis of the Data

Each subject's intraluminal testing resulted in forty-five responses to be analyzed. Breaking this number down, there were three main anatomical levels tested, with three pressure tip positions at each level (Figure 13). For each of these positions fifteen sound stimuli were administered, each of which required analysis. In analyzing the particular recorded read-outs that were the result of the changes in intraluminal pressure, time was held to be the constant factor for all channels.

Little work has been done in analyzing motility studies for statistical analysis, but conferences with the medical co-investigators reached the conclusion that the logical approach to the wave analysis was from the point of time versus amplitude, since these were the two variables recorded synchronously on the graph as the subject spoke. In examining the raw data of the wave patterns, Dr. Iyer, one of the medical co-investigators, and the author selected five major points to be measured for each subject, at each position, for each speech task performed. These points are shown in Figure 14.

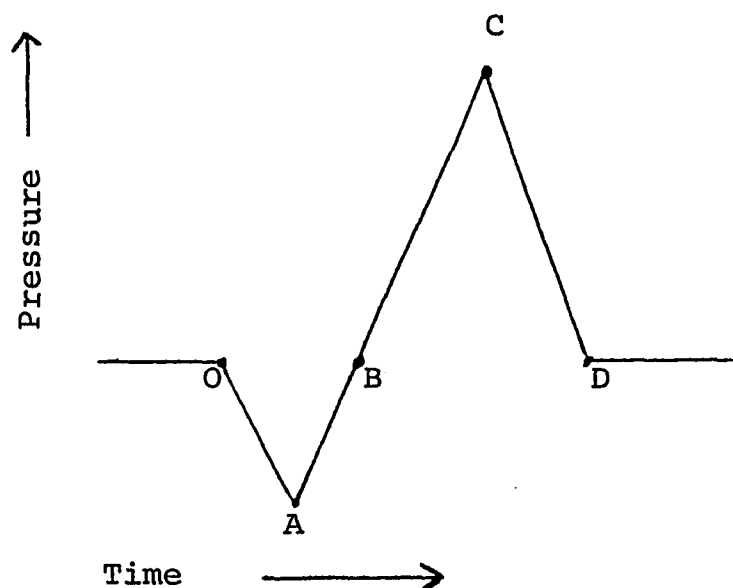


Fig. 14.--A schematic diagram of a resultant read-out of intraluminal pressure changes. Point O: onset of the wave; Point A: change in the base line; Point B: return to the base line; Point C: amplitude of wave during speech; Point D: cessation of speech.

Point O represents the onset of the wave and was located at the base line. This base line may vary with the individual person and/or sound uttered, and was not necessarily the base line at which the instrumentation was calibrated. Point A represents a change in the base line at the onset of the speech attempt. It did not necessarily have to be a negative deflection or a rise in the wave, but may have been a continuation of Point O. The variations of the waves and their meanings will be discussed later. Point B represents the return of the wave to the base line O. Again, Point O may have been equal to Point B, or Points O, A, and B may have been one and the same. Point C was the amplitude of the wave during speech itself, and Point D represents the end of the wave for this particular utterance. From Point O to Point B was the time of the prephonation period and Point B to Point D was the time of the speech utterance.

To determine the amplitude of the pressure, first Point O was determined, by examining the line of the graph just prior to the utterance, and this was then the base line for that wave. Each of the three waves analyzed (the waves for the proximal, medial, and distal tips) had different base lines. The numerical equivalents of Points A, C, and D were then determined by counting the millimeters in amplitude and/or negative deflection that occurred from the base line and noting them in terms of so many

millimeters of mercury.

Time was the constant factor in analyzing the waves at a particular level. As cited earlier, the foot-actuated length-of-utterance switch left a dark line superimposed over the time marker at the bottom of the recording paper. This line was used to determine where speech began and ended, and what part of the wave constituted the pre-phonation period. In the analysis of the earlier subjects, the length-of-utterance indication was not used, so it was necessary to examine the neck marker and pneumographic tracings to determine the pre-phonation and speech periods. During the speech tasks, the paper moved past the recording pens at a speed of 10 mm./sec., and each vertical line on the recording graph represented .1 second. In this manner the amount of time of each utterance could be determined.

Statistical Treatment of the Data

Conferences were held between the author and Dr. Harry Levitt, Professor at the City University of New York. After studying the data, he suggested the method of statistical analysis which was implemented with his constant supervision. Computer analysis was applied to all statistical data which had been collected.¹ Initially, the

¹All computer analyses utilized in the study were programmed by Dr. Levitt.

data on each subject were analyzed, using an analysis of variance to investigate the interaction of the different variables in the test situation (the specific syllables, the three levels, and the nine positions of the open-tip catheter). This general analysis, as explained by Dr. Levitt, could help isolate those interactions that might be significantly affecting speech proficiency.

The above described analysis of the data was over the whole range of structures tested. When the analysis was done on Point A, for example, all the initial points of the wave were included--those in the stomach, sphincters, esophagus, and hypopharynx. A similar approach was employed in analyzing Points B, C, and D, as well as the relationships of the interactions. Therefore, it was felt that the above general type of analysis should be broken down by examining the various levels tested on each subject, because the action of the stomach, for example, is not equivalent to the action of the esophagus in the esophageal speaker. And, even though the same analysis was performed on all the speakers, and the same factors investigated for each, the exact relationship of the syllables (a prime investigation of this study) and total esophageal motility cannot be examined closely using this type of analysis.

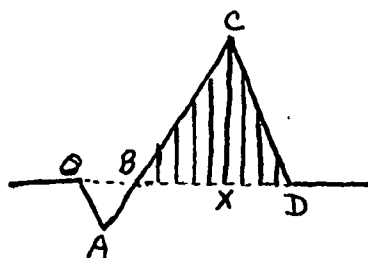
The next approach was to perform an analysis of variance to obtain the interaction relationships, more specifically the relationship of the syllables to Level 2

(where all tips are in the esophagus), and to test the significance of these relationships. In this second analysis, the effect of the syllable on the different points of the esophageal wave form could be investigated. If this mid-portion of the esophagus did not reveal any significant data or conflicting data, then examination of the upper esophagus, as measured in Level 3, and the lower esophagus, as measured in Level 1, could be included in the analysis of data. By using this method of analysis, it could be seen whether there were any significant pressure changes in the esophagus by the esophageal speaker with varying degrees of proficiency.

Similar analyses were obtained to indicate the relationship of the syllables to the different locations of the open tips. These included: the interaction of the syllables with the pressure changes that occurred in the stomach; the interaction of the syllables with changes exhibited in the lower esophageal sphincter; the interaction of the syllables with the pressure changes demonstrated in the upper esophageal sphincter; and the interaction of the syllables with the pressure changes registered in the hypopharynx. In all of the above instances the interaction of the syllables with the site indicated would reveal significant differences, if any, in the structures cited, due to the different phonemes uttered, and if these differences were significant between the different groups of

esophageal speakers.

A final approach to the analysis of the raw data was to investigate the approximate energy expended by the speaker in his esophagus during syllable phonation. The energy at Level 2, where all the tips are in the esophagus, was determined by examining each part of the wave. The wave was divided into sections as follows:



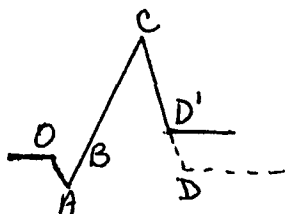
The height of each section of the wave was determined using the following formula:

$$\text{Energy} = \frac{\epsilon}{2} h^2$$

The heights of each wave section were then added together and combined with the heights of the two other waves produced by the two other tips during the utterance of the same syllable, to arrive at the average of the approximate energy expended for each utterance.

There were two assumptions that had to be made in determining the energy. The first was that the time elements were equal, i.e., $BX = XD$. In other words, Point C was the peak of the wave that occurred directly in the middle of the phonation period. The second was a problem

that arose for certain individuals, and that was that the pressure was maintained in the esophagus at the end of the phonation period so that the wave pattern produced appeared like this:



In this case it was then necessary to stop the analysis of the energy at Point D' so that the energy output determined in these cases was not completely accurate. This tendency of the speakers did not occur too often, and in no subject did it occur all of the time. But for the two reasons just stated, it is necessary to refer to the amount of energy expended as "approximate" energy.

All of the above statistics were submitted to "t" tests in determining the significance of the findings.

Summary

Eighteen laryngectomized subjects, whose speech ability had been rated, were asked to swallow a specially constructed three-in-one polyvinyl tube, in order to perform intraluminal pressure tests of their stomach, esophagus, upper and lower esophageal sphincters, and hypopharynx.

They were asked to repeat nonsense syllables and to count, as the changes in pressure in the various structures were recorded on a direct writing recorder. Analysis of the resultant wave form was subjected to, first, a general type of analysis of variance, and then more specific interactions were examined. Finally, the approximate energy expended by the esophagus during the phonation of the speech stimuli was calculated. The significance of all the statistical data was then determined and reported on in the next chapter.

CHAPTER IV

RESULTS AND DISCUSSION

For purposes of this study the intraluminal esophageal pressure wave was analyzed by examining five selected points of the total wave pattern. They have been designated as follows:

- O = the base line prior to speech;
- A = the onset of the speech attempt (pre-phonation period);
- B = the return of the wave to the base line;
- C = the maximum excursion of the wave during phonation;
- D = the cessation of the speech attempt.

Two time elements were also investigated, although the factor of time per se was not a specific consideration of this investigation. The period of pre-phonation (Points O-B) and the actual time encompassed in the speech attempt (Points B-D) were recorded. The recording paper is in graph form (see Figure 12). Since the paper moved at a speed of 10 mm./sec., each vertical line during the speech tasks represented .1 second. As the subject vocalized, a foot-actuated length-of-utterance switch left a dark line, superimposed over a time marker at the bottom of the recording paper. This time marker resulted in short vertical lines indicating one-second intervals, so that the

speed of the revolving drum and paper could be determined at all times. The length of time of each intraluminal wave pattern was arrived at by counting the number of vertical lines it encompassed as a whole or in any of its parts, as just described.

Statistical Analysis

Mean Squares

Initial statistical analysis investigated the subjects' variability of performance. This analysis attempted to isolate those factors that might be affecting speech production, so that more detailed investigation might be performed.¹

The raw data indicated three main factors to be analyzed: forty-five speech utterances; three levels of the polyvinyl tube; and nine positions in which the open tips were placed during the test situation. A previously devised program for the computer employed an analysis of variance to examine those three factors and their interactions. Each subject's intraluminal pressure responses during vocalization of specific consonants were fed into the computer and analyzed. Dr. Levitt suggested that by scanning the resultant mean squares of three separate points of the intraluminal pressure wave pattern (Points A,

¹These analyses were performed at the suggestion of Dr. Harry Levitt.

C, and D), subject variability could be detected and any gross differences between grouped subjects noted for further investigation.¹

Tables 3 through 6 present the summary of the mean squares of all subjects. The tables were arranged so that the better speakers (Groups 1 and 2) are listed at the top, and the poorer speakers (Groups 4 and 5) listed last. The columns represent the analysis and interactions of the various factors as they relate to points in the intra-luminal wave pattern.

Analysis 1 (Table 3) refers to Point A of the wave form, i.e., the period of pre-phonation; Analysis 2 (Table 4) represents the elements of Point C in the wave form, i.e., the excursion of the wave during phonation; Analysis 3 (Table 5) is of Point D--the cessation of speech; and Analysis 4 (Table 6) describes the pre-phonation time period.

In Table 3 there are seven columns headed by Roman numerals. Each of these columns represents some interaction between Point A (pre-phonation period) of the pressure wave and another factor. Column I indicates the mean squares for all nine positions of the open-tips at Point A.

¹The residual mean squares is used as an index of variability. It is equal to the sum of the experimental error variance and the highest order interactions.

Group	S#	I	II	III	IV	V	VI	VII
1	2	138	49	6	857	203	73	7
1	4	324	152	19	255	224	173	25
1	6	157	42	9	115	158	41	16
1	13	38	49	8	226	48	45	12
1	16	272	201	57	1,024	420	135	52
1	17	345	668	35	1,536	90	221	14
1	18	863	61	17	434	250	47	15
1	1	126	29	19	868	752	29	18
1	3	3,264	73	13	2,034	1,856	59	14
1	11	45	104	8	731	69	97	9
5	8	54	10	2	3	13	5	3
5	10	29	32	7	74	172	22	8
5	12	53	20	5	230	93	21	6
5	14	93	28	10	216	158	22	12
5	15	216	9	8	293	136	21	13

Table 3

Summary of Mean Squares of Analysis of
Variance of Point A (Pre-phonation Period)

Note: All data in terms of (mm./mercury)²

For example, Subject 2 has a mean square of 138 (mm./mercury)² for the pre-phonation period when all nine positions of the open-tips are analyzed. Column II represents the factor of the speech utterances in reference to Point A on the wave pattern, and for the same subject there is a resultant mean square of 49 (mm./mercury)². In Column III these two factors have been combined, and this column represents the interaction of the factors of the nine positions of the open tip and the forty-five speech utterances for this subject; 6 (mm./mercury)² is the resultant mean square. The next column, Column IV, refers to the analysis of the factor of the three levels at which the subject was tested. Subject 2 here indicates a mean square of 857 (mm./mercury)². The interaction of the factors of the nine positions and the three levels are analyzed in Column V, where this subject indicates a result of 203 (mm./mercury)². Column VI represents the interaction of the factors of the speech utterances and the three levels that were employed in the test situation. This subject has a resultant mean square of 73 (mm./mercury)². The interaction of all three pertinent factors--the speech utterances, the nine open-tip positions, and the three levels. For this final analysis Subject 2 demonstrates a mean square of 7 (mm./mercury)² for Point A or the pre-phonation period of the pressure wave.

For the purposes of analysis Groups 1 and 2 were combined and investigated as one group representing the

better speakers, and Groups 4 and 5 were combined and examined as representative of the poorer speakers.

From the tables it appears that Group 1 shows greater variability than Group 5. This can be demonstrated in examining the analysis of Column I (open-tip positions) of this table. The range for the mean squares of the better speakers is from 30 to 3,264 (mm./mercury)², while for the poorer speakers the range is from 29 to 216 (mm./mercury)². This pattern recurred for the factor of speech utterances (Column II), where the range of the better speakers is from 29 to 668 (mm./mercury)², and that of the poorer speakers is from 9 to 32 (mm./mercury)². The variability is detected again in the pattern in Column IV, the analysis of the factor of the three levels, where the better speakers range 115-2,034 (mm./mercury)², while the poorer ones range 3-293 (mm./mercury)². In examining the differences in Column VII (the interaction of the factors of speech utterances and positions of the open-tips and the three levels), the better speakers again demonstrate greater variability, with a range from 7 to 52 (mm./mercury)², while the poorer speakers range from 3 to 13 (mm./mercury)². The most extensive difference between these two groups occurs in Column VI (the interaction of the factors of speech utterances and levels). Here, the better speakers range 41-221 (mm./mercury)², while the poorer speakers range 5-22 (mm./mercury)², with four of the

five subjects in this latter group demonstrating closely similar patterns. There is little apparent difference that can be observed in the mean squares of the two groups with relation to the interaction of the factors of open-tips position and speech utterances (Column III). The same pattern holds true in the interaction of factors relating to the position of the open-tips and the levels tested (Column V).

The analysis and examination of the mean squares in this study are used only as a rough indication of areas to be investigated further. Therefore, the above results, as well as the results to be discussed in Tables 4, 5, and 6, were not subjected to tests of statistical significance.¹ Further statistical testing was performed in those areas where the resultant mean squares might prove to be of interest for further research.

The second point of the pressure wave to be analyzed in a similar manner is Point C--the excursion during phonation. The mean squares for Point C have been summarized in Table 4. A similar division of the results was performed for this point of the wave form as for Point A (Table 3). Column I represents the mean squares for all nine positions of the open-tip catheter during the entire speech test sequence, with reference to Point C of the wave pattern.

¹Personal communication with Dr. Levitt.

Group	S#	I	II	III	IV	V	VI	VII
1	1	543	23	17	1,437	492	42	24
1	2	18	48	7	398	391	32	12
1	3	277	28	17	546	694	29	17
1	4	1,782	202	56	6,059	773	78	66
1	6	70	124	22	3,308	350	100	25
1	13	373	34	8	374	91	38	13
1	16	341	170	54	2,242	177	96	82
1	17	320	168	36	1,123	258	153	32
1	18	1,621	25	6	725	467	14	8
1	11	471	34	21	300	241	58	23
5	8	1,636	58	36	158	74	46	47
5	10	544	57	84	4,399	1,562	68	82
5	12	2,488	30	12	1,620	954	25	27
5	14	3,794	124	81	3,701	1,597	129	75
5	15	1,141	213	78	1,699	2,014	219	84

Table 4

Summary of Mean Squares of Analysis of
Variance of Point C (Phonation Period)

Note: All data in terms of (mm./mercury)²

Subject 1, for example, has a mean square for this factor of $543 \text{ (mm./mercury)}^2$, while Subject 8 indicates a mean square of $1,636 \text{ (mm./mercury)}^2$ for this same factor. Column II again represents the factor of the speech utterances with reference to this point in the pressure wave. Subject 1 has a mean square of $23 \text{ (mm./mercury)}^2$, and Subject 8 has one of $58 \text{ (mm./mercury)}^2$ in Column II. The interrelationship of these two factors (the nine open tips and the speech utterances) is shown in the analysis represented in Column III. Here Subject 1 has a mean square of $17 \text{ (mm./mercury)}^2$, while Subject 8 shows a mean square of $36 \text{ (mm./mercury)}^2$. Column IV in Table 4 represents the analysis of the factor of the three levels tested relative to Point C in the wave pattern. For this factor the mean square for Subject 1 is $1,437 \text{ (mm./mercury)}^2$, and for Subject 8 it is $158 \text{ (mm./mercury)}^2$. Column V indicates the interaction of the factors of the nine positions of the open-tipped catheter and the three levels tested as it refers to Point C. In this area Subject 1 has a mean square of $492 \text{ (mm./mercury)}^2$ and Subject 8, $74 \text{ (mm./mercury)}^2$. Column VI represents the interaction of the factors of the speech utterances and the three levels tested. For this interaction, at Point C, Subject 1 resulted in a mean square of $42 \text{ (mm./mercury)}^2$, while Subject 8 recorded a mean square of $46 \text{ (mm./mercury)}^2$. Column VII represents the analysis of the interaction between all three pertinent

factors examined--the speech utterances, the nine positions of the open tips, and the three levels tested. For this analysis, Subject 1 indicates a mean square of $24 \text{ (mm./mercury)}^2$, while Subject 8 has a mean square of $47 \text{ (mm./mercury)}^2$.

Visual inspection of Table 4 demonstrates the factor of a diminished quantity difference between the better speakers (Group 1) and the poorer speakers (Group 5). There are small differences in the mean squares of the speech utterances (Column II), with the better speakers ranging $23\text{--}202 \text{ (mm./mercury)}^2$ and the poorer ones ranging $30\text{--}213 \text{ (mm./mercury)}^2$. Column II, the interactions of the open-tips position and the speech utterances, reveals this same lack of difference between the speaking groups. The better speakers range $6\text{--}56 \text{ (mm./mercury)}^2$ and the poorer range $12\text{--}84 \text{ (mm./mercury)}^2$. This same pattern is repeated in Column VI, the analysis of the interaction of the speech utterances and levels. Here the range of mean squares for the better speakers is $14\text{--}153 \text{ (mm./mercury)}^2$, while the poorer speakers' mean squares range $25\text{--}219 \text{ (mm./mercury)}^2$. Column VII, representing the analysis of the interaction of all three factors (speech utterances, open-tips positions, and levels), indicates the same pattern. The better speakers range $8\text{--}82 \text{ (mm./mercury)}^2$ and the poorer ones, $27\text{--}84 \text{ (mm./mercury)}^2$.

Visual inspection reveals only two factors in this table that distinguish between the better and poorer esophageal speakers. The first is the factor of open-tips position (Column I), where the better speakers range 18-1,782 (mm./mercury)²--a difference of 1,764 (mm./mercury)²--and the poorer ones range 544-3,794 (mm./mercury)²--a difference of 3,250 (mm./mercury)². The range of the latter group is almost twice that of the former. The second factor indicating a visual difference between speaking groups is in Column V (the interaction of open-tips positions and esophageal levels tested). Here the better speakers range 91-773 (mm./mercury)² and the poorer ones, 74-2,014 (mm./mercury)². The former group has a range of 682 (mm./mercury)², while the latter ranges 1,940 (mm./mercury)². These range differentials again visually demonstrate that the better esophageal speakers tend to show more variability in the factors analyzed than the poorer esophageal speakers.

The last point of the pressure wave analyzed in the above manner is Point D (the cessation of phonation) and the summary of its mean squares is listed in Table 6. The organization of this table is similar to the organization of the two previously discussed tables. In Table 5 there are less differences between the better speakers and the poorer esophageal speakers. For example, in Column III (representing the interaction of the open-tips positions

Group	S#	I	II	III	IV	V	VI	VII
1	1	36	13	6	8	38	24	6
1	2	3	22	10	2	22	26	7
1	3	76	29	8	105	98	14	8
1	4	14	65	10	66	40	58	16
1	6	377	41	23	376	139	38	19
1	11	113	39	12	23	34	24	11
1	16	131	39	16	114	87	39	20
1	13	1	10	6	84	48	15	6
1	17	62	35	8	121	52	34	8
1	18	241	3	3	494	270	6	3
5	8	61	53	45	79	27	43	50
5	10	4	43	9	193	87	34	13
5	12	204	21	10	41	67	24	13
5	14	838	32	15	289	347	15	16
5	15	98	68	17	544	38	28	11

Table 5

Summary of Mean Squares of Analysis of Variance
of Point D (Cessation of Phonation)

Note: All data in terms of (mm./mercury)²

and the speech utterances), the better speakers (Group 1) reveal a range of 3-23 (mm./mercury)² and the poorer speakers, a range of mean squares of 9-45 (mm./mercury)². This same pattern can be observed in Column IV (the analysis of the levels relative to the cessation of the pressure wave--Point D), where the range of mean squares for the better speakers is 2-494 (mm./mercury)² and 41-544 (mm./mercury)² for the poorer speakers. In Column VI (the interaction of speech utterances and levels), the better speakers are shown to have a range of 6-58 (mm./mercury)² and the poorer ones have a range of 15-43 (mm./mercury)².

More extensive differences between the speaking groups were evident upon inspection of the factor of the position of the tips in relation to the cessation of phonation (Point D in the wave). In this analysis, as indicated in Column I, the better speakers range 1-377 (mm./mercury)² and the poorer speakers' mean squares range 4-838 (mm./mercury)². A repetition of this pattern appears in Column V (the interaction of speech utterances and esophageal levels), where the better speakers range 22-2,270 (mm./mercury)² and the poorer ones, 27-347 (mm./mercury)². A similar pattern is evident in visual inspection of the mean squares in Column VII (the interaction of the speech utterances and the levels), where the better speakers range 3-20 (mm./mercury)² and the poorer ones, 11-50 (mm./mercury)².

The data described above were used merely to indicate areas that might reflect intergroup differences when examining the individual performances, so they were not submitted to tests of statistical significance, but merely inspected visually. The range array noted in Table 5 appears to indicate a reversal of the trend reported in the two previous tables. After examining Table 3 (the analysis of the pre-phonation period) and Table 4 (the excursion during phonation), the information revealed that better speakers tended to indicate more variability in performance. The discussion of Table 5 (the cessation of phonation) indicates the reversal. The poorer speakers exhibit more variability than the better ones at the end of the phonatory period.

As indicated earlier, time was not a criterion in the present study, but since it was the common factor employed in the analysis of the wave pattern, some analysis of its role was considered pertinent. Table 6 is a summary of the time of the intraluminal wave pattern during phonation. For purposes of analysis of the element of phonatory time, a separation into the pre-phonation and phonation periods has been made. The subjects are again listed individually by speech group. For each section--pre-phonation and phonation--there are only three columns listed instead of six as in the previous tables. Only two of the three factors are necessary for this analysis of variance relative

Group	S#	Pre-phonation Period			Phonation Period		
		I	II	III	I	II	III
1	1	.10	.10	.06	.02	.01	.02
1	2	.05	.01	.05	.03	.02	.01
1	3	.20	.20	.27	.17	.87	.12
1	4	.07	.45	.07	.02	.37	.01
1	6	.01	.42	.02	.04	.90	.03
1	11	.04	.09	.04	.05	.20	.03
1	13	.05	.01	.03	.02	.04	.04
1	16	.01	.03	.01	.04	.33	.03
1	17	.03	.01	.02	.02	.10	.01
1	18	.07	.13	.06	.01	.50	.03
5	8	.31	.48	.18	.26	.26	.39
5	10	.07	.02	.12	.05	.02	.04
5	12	.06	.05	.12	.07	.30	.04
5	14	.05	.45	.12	.03	.10	.03
5	15	.02	.28	.03	.02	.67	.01

Table 6

Summary of Mean Squares of Analysis of
Variance of the Time Factors

Note: All data in terms of (seconds)²

to time.¹ These two factors are speech utterances and levels tested. Eliminating the factor of the open-tips position, Column I represents the factor of speech utterances relative to the time element. In the pre-phonation period Subject 1 has a mean square of .1 (seconds)², and in the phonation period a mean square of .02 (seconds)². Column II is the factor of the three levels tested. Here Subject 1 shows a pre-phonation mean square of .1 (seconds)² with his phonation time as .01 (seconds)². Column III represents the analysis of the interaction of these two factors. The mean square of Subject 1 in the pre-phonation period is .0 (seconds)² and in the phonation period it is .02 (seconds)².

Visual inspection of this table does not reveal sufficient intergroup differences to validate further investigations. In Column I (speech utterances) the better speakers in the pre-phonation period range .01-.2 (seconds)² and the mean squares for the poorer speakers range .02-.3 (seconds)². In this same period the better speakers show a mean square range from .01 to .45 (seconds)² in Column II (levels), while the poorer speakers range .02-.48 (seconds)². Visual examination of the phonation period repeats this same pattern evident in the first two columns. In Column I (speech utterances) the mean squares of the better speakers

¹Personal communication with Dr. Levitt.

range .01-.17(seconds)², and those of the poorer speakers range .02-.26 (seconds)². In Column II (the factor of the levels tested relative to time), the mean squares of the better speakers range .01-.9 (seconds)², while those of the poorer speakers range .02-.67 (seconds)². The single element that might signify differences between the two groups of speakers is the interaction of the speech utterances and the levels (Column III) in the phonation period. In this instance, the mean squares of the better speakers range .01-.12 (seconds)², while the poorer speakers range .01-.39 (seconds)². These data indicate that the poorer speakers attempted to phonate for longer periods of time than the better speakers. But, since this factor of time was not a prime investigatory area, these data were not tested further for statistical significance.

Summary. Visual inspection of the mean squares of the initial analysis of variance detected certain factors that distinguish the better esophageal speaker from the poorer speaker. These factors warrant further investigation. In examining Tables 3-6, the better speakers appear to demonstrate more variability in performance in the pre-phonation period (Table 3, Point A) and in the excursion of the wave during phonation (Table 4, Point C). In the analysis of the cessation of phonation (Table 5, Point D), visual inspection of the data reveals the poorer speakers to have a wider range of mean squares and, therefore, greater

variability in their performance. To a lesser degree the poorer speakers indicate more variability in the lengths of time during the pre-phonation and phonatory periods of vocalization.

In the design of this study this initial analysis was to be utilized to indicate areas for further study. One unique aspect of visual inspection of Tables 3-6 is demonstration of which section of the wave pattern can reveal intergroup differences. At the beginning of phonation (Point A, Table 3), five factors out of a possible seven were found reflecting intergroup differences. In Table 3 the better speakers showed more variability of performance relative to the factors of open-tips positions (Column I), speech utterances (Column II), the three levels (Column IV), the interaction of the factors of speech utterances and levels (Column VI), and the interaction of all three factors (Column VII). Progressing to the next portion of the wave pattern, the excursion of the wave during phonation (Table 4, Point C), there are only two factors observed that could possibly distinguish between the better and poorer esophageal speakers. These are the factors of the open-tips positions (Column I) and the interaction of the open-tips positions and the levels (Column V). Finally, visual inspection of Point D (Table 5--the cessation of phonation) reveals no strong differences between the speakers in the two groups. This

might indicate that the pre-phonation period of the intraluminal pressure wave is more important in distinguishing differences, and examination of the cessation of phonation is less revealing.

Interaction Means

The above analysis of variance included the entire range of the internal structures tested (stomach, esophagus, and its upper and lower sphincters, and the hypopharynx). Therefore, the initial analysis considered all the values resulting from read-outs of the nine open tips positions of the catheter at various points in the wave. For example, in Table 3 the discussion of Point A (the pre-phonation period) included the analysis of the pressure recorded from the stomach, esophagus, the upper and lower esophageal sphincters, and the hypopharynx at this moment in time. Similar treatment of the data was done for Point C (Table 4--the excursion during phonation) and Point D (Table 5--the cessation of phonation). This treatment of the data yielded a general overall view of subject variability, but did not allow for investigation of the motility of isolated structures in relation to the speech stimuli. However, this factor is of prime concern to this study.

Data analysis could be more relevant in this research paper if the action of individual structures could be examined as the esophageal speaker is phonating, in

order to reveal differences, if any, between the better and poorer esophageal speakers. Of particular interest, then, is the analysis of variance relating to the interaction between the selected phonemes and esophageal motility.

An analysis of variance was performed on the data which allowed for an investigation of the separate structures involved in esophageal speech. Tables 7 and 8 present summaries of the interaction means of the speech utterances at Level 2. This level was chosen for examination because at this point all pressure-sensing tips are in the esophagus. It would appear that esophageal motility, as it relates to selected phonemes, would be a productive area for closer study and examination.

Therefore, the resultant pressure wave was divided into its sections to allow for closer examination. Table 7 summarizes the interaction means of Point A (the pre-phonation period) as it relates to Level 2 and the selected phonemes. Once again the groups of speakers have been combined, so that Group 1 on the table refers to the original Groups 1 and 2 (better speakers), while Group 5 corresponds to the original Groups 4 and 5 (poorer speakers). The "S" refers to the number of the subject, and the speech utterances are listed across the top of the table. Subject 1 (in Group 1) has an interaction mean of -6 (mm./mercury)² for the utterance [t Δ], while Subject 8 (in Group 5)

Group	S#	[ta]	[ka]	[sa]	[na]	[ra]	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten
1	1	-6	-5	-2	0	-11	-7	-7	-8	-7	-7	-8	-10	-4	-2	-8
1	2	-1	-14	-13	-4	-7	-3	-7	-3	-2	5	7	5	5	2	5
1	3	0	0	0	16	19	13	5	5	4	5	2	0	0	0	0
1	4	0	0	0	0	0	0	0	0	31	0	0	0	0	0	0
1	6	-5	-7	-1	-3	-7	0	-3	-5	-8	-5	-10	-1	-6	-4	-9
1	11	2	-4	-2	-5	-5	-2	-10	-7	-6	-3	-4	-6	-7	-4	-3
1	13	10	0	-2	0	11	2	-2	3	7	0	6	9	0	9	5
1	16	-6	-3	-4	-9	-5	-5	-6	-9	-8	-8	-4	-4	-6	-6	-1
1	17	-7	-5	-3	-5	-7	-4	-10	-7	-7	-5	-2	-1	25	25	-2
1	18	5	0	2	6	5	4	5	9	15	7	12	8	7	9	8
5	8	0	5	-1	-1	-1	0	0	0	-5	-3	0	0	0	0	0
5	10	-6	-5	-5	-12	-14	-5	0	-6	-3	-1	-5	3	-4	-4	0
5	12	-2	-1	-1	-6	-3	-2	-3	-2	0	-2	0	1	-1	-3	-1
5	14	-4	-1	-2	-5	-1	-3	-5	-3	-2	-3	5	-2	3	-2	-1
5	15	-4	-6	-9	-9	-5	-3	-4	-6	-4	-6	-4	-5	-3	-5	-8

Table 7

Summary of Interaction Means of Level 2 for Point A (Pre-phonation Period)

Note: All data in terms of (mm./mercury)²
 Negative sign indicates negative pressure

indicates an interaction mean of 0 (mm./mercury)² for the same utterance. Progressing horizontally to the utterance [ra], Subject 1 has an interaction mean of -11 (mm./mercury)² and Subject 8, an interaction mean of -1 (mm./mercury)². The last column, labeled "Ten," indicates that, for this speech utterance, Subject 1 has an interaction mean of -8, while Subject 8 has one of 0 (mm./mercury)².

In Table 7 a tendency for the majority of the subjects to exhibit negative pressures in the esophagus in the pre-phonation period is revealed. Only three subjects--3, 4, and 18--did not indicate any negative pressures, while the other subjects showed negative pressures in all or some utterances. The significance of these data will be explored in greater detail in the discussion of methods of air intake utilized by the laryngectomee.

Table 7 reveals that overall differences can be discerned between the better esophageal speakers and the poorer ones. A similarity exists between the mean squares and the interaction means of Point A (the phonation period), in that the better speakers individually indicated more variability in general performance when using alaryngeal speech. This same pattern is repeated in the examination of these speakers relative to the motility of the esophagus during phonation. In addition, the material in this table listed in the column marked [ta] reveals the fact that the better speakers show interaction means that range from

-7 (mm./mercury)² to 10 (mm./mercury)², while the poorer speakers, for the same utterance, range from -6 to 0 (mm./mercury)². For the production of the utterance [sa], the interaction means of the better speakers range from -13 to 2 (mm./mercury)², from -9 to 1 (mm./mercury)² for the poorer speakers. Once more, this pattern of greater variability is repeated in examining the interaction means of the utterance [na], where the interaction means for the better speakers range from -9 to 16 (mm./mercury)² and for the poorer speakers it ranges from -12 to -1 (mm./mercury)². The identical pattern continues for all the utterances with the exception of [ka]. The statistical significance of these data, as well as the other data pertinent to this table, will be discussed later in this chapter.

Another point of divergence between the good and poor esophageal speaker appears to emerge from visual inspection of this table. The better speakers not only show more negative deflections, but these deflections are deeper than those of the poorer speakers. In examining Table 7, it can be noted that in Group 5, the interaction mean of Subject 10 is as low as -12 (mm./mercury)² in the prephonation period prior to the speech utterance [na], and -14 (mm./mercury)² prior to the utterance of [ra]. None of the other speakers in this group went below an interaction mean of -9 (mm./mercury)². But visual examination of the performance of the better speakers reveals that,

although one subject--Number 2--went as low as -13 (mm./mercury)² in the utterance of [sɑ] and -14 (mm./mercury)² in the utterance of [kɑ], there are five speakers (Subjects 1, 6, 11, 16, and 17) who indicated interaction means for various utterances that ranged from -9 to -8 (mm./mercury)². Visual examination of this table did not reveal any consistent differences between the various phonemes uttered by the two groups of speakers relative to the pre-phonation period in the intraluminal pressure wave.

Table 8 is a summary of the analysis of the interaction of speech utterances and Level 2 (all open-tips in the esophagus) for Point C (the excursion of the intraluminal pressure wave). The speaking groups have been combined into two groups--Group 1 representing the better speakers and Group 5, the poorer ones. This analysis permits an examination of the motility of the esophagus during phonation (Point C) with reference to the selected phonemes. Subject 18, in Group 1, reveals an interaction mean of 13 (mm./mercury)² for the utterance [tɑ], while Subject 15, in Group 5, has an interaction mean of 19 (mm./mercury)² for the same utterance. For the utterance "Two" Subject 18 has an interaction mean of 10 (mm./mercury)² and Subject 15 an interaction mean of 30 (mm./mercury)² for the same utterance. In the column marked "Ten," Subject 18 shows an interaction mean of 9 (mm./mercury)², while Subject 15 has one of 36 (mm./mercury)² for the same

Group	S#	[tA]	[kA]	[sA]	[nA]	[rA]	One	Two	Three	Four	Five	Six	Seven	Eight	Nine	Ten
1	1	6	10	16	22	16	15	15	17	14	18	17	16	18	21	23
1	2	11	3	2	10	17	14	10	14	15	9	14	7	17	15	11
1	3	15	16	15	14	23	9	9	16	15	14	20	19	20	14	17
1	4	4	27	28	15	41	28	40	44	38	26	33	26	38	30	38
1	6	3	13	17	15	0	7	11	10	12	14	18	19	17	13	7
1	11	10	13	6	14	16	12	10	16	14	12	15	11	4	12	13
1	13	8	10	5	11	18	13	9	4	5	8	3	12	12	8	7
1	16	17	27	26	24	29	22	25	19	19	20	22	21	18	15	23
1	17	20	16	16	21	17	25	16	28	22	19	16	25	20	16	19
1	18	13	9	10	10	11	13	10	10	16	6	9	11	12	11	9
5	8	10	21	12	11	10	17	17	1	13	0	7	5	4	4	2
5	10	33	35	29	39	33	23	21	23	32	30	27	32	25	29	27
5	12	10	15	14	12	11	11	4	14	15	13	13	8	17	16	16
5	14	39	28	32	33	24	15	13	14	19	21	20	18	27	28	25
5	15	19	21	18	19	28	24	30	29	24	21	32	37	37	32	36

Table 8

Summary of Interaction Means of Level 2 for Point C
of the Pressure Wave (Height of the Wave)

Note: All data in terms of (mm./mercury)²

utterance.

This table reveals material to demonstrate that the poorer speakers produce more consistent responses than the better speakers. This is the same overall pattern that was disclosed in the inspection of the mean squares of Point C in the previous section. The poorer speakers showed a range of interaction means which extended from a low range of 11 to 24 (mm./mercury)² for the utterance "One" to a high range of 2 to 36 (mm./mercury)² for the utterance "Ten." The better speakers' interaction means ranged from a low of 10 to 24 (mm./mercury)² for the utterance [nɑ], to a high range of 0 to 41 (mm./mercury)² for the utterance [rɑ]. In general, the poorer speakers showed a range of interaction means that fell within the 20-29 (mm./mercury)², while the better speakers showed a range that fell between 14 and 40 (mm./mercury)². The statistical significance of these data will be discussed later in the chapter. Subject 4 in Group 1 showed extremely high pressures in the esophagus during phonation, with his responses for the utterance [rɑ], "Two" and "Three" being 41, 40, and 44 (mm./mercury)², respectively, while Subject 13 in this group showed an overall yield of low esophageal pressures when compared with the other speakers in Group 1. Even discounting these two extremes of variability, visual comparison of the interaction means of the pressure wave during phonation indicates that the better speakers exhibit

lower esophageal pressures but greater variability than the poorer esophageal speakers.

Tables 7 and 8 indicate that certain sounds produce different esophageal performances, but there is no consistency observed in sound classifications. The greatest intergroup difference is disclosed in the utterance of the syllable [rɑ] in Table 8. The interaction means of the better speakers range from 0-41 (mm./mercury)², while those for the poorer ones have a range of 10-33 (mm./mercury)².

Continued inspection of the syllables that begin with plosives indicates no consistent pattern of performance. The syllable [tɑ] for the better speakers shows a range of interaction means from 6 to 24 (mm./mercury)², and for the poorer speakers it ranges from 10 to 39 (mm./mercury)². The interaction means for the syllable [kɑ], for the better speakers, range from 3 to 27 (mm./mercury)², and for the poorer speakers the range is from 15 to 35 (mm./mercury)². The number "Two" uttered by the better speakers ranges from 9 to 40 (mm./mercury)² and from 4 to 30 (mm./mercury)² for the poorer speakers. The utterance "Ten" had a range of 7-38 (mm./mercury)² for the better speakers, and 3-36 (mm./mercury)² for the poorer speakers.

Gross examination of the interaction means during phonation (Point C) of selected phonemes indicates

excessive variability in esophageal motility, so that no generalizations about the use of any consonant to promote esophageal speech can be advanced. This factor was submitted to statistical significance testing and is reported in Table 9.

Gross comparison of the plosives with the other phoneme classifications appears to indicate the same wide range of esophageal pressures demonstrated in the utterance of all phonemes. In order to indicate whether the plosives and/or other phonemes contribute in a significant manner to esophageal motility, certain syllables were selected and submitted to significance testing. Table 9 summarizes the means and results of the tests of significance of these means.

Group 1, the better speakers, reveals a mean of 13.7 (mm./mercury)² for the utterance [t~~ɑ~~], as compared to a mean of 22.2 (mm./mercury)² for the same utterance by the poorer speakers, Group 5. Because of the small sampling used in this investigation, the "t" test for significance was employed, using the 5 per cent level of confidence.¹ Intergroup comparison relative to the utterance [t~~ɑ~~] reveals a "t" value of 1.4, which does not reach the level of 2.0, which is necessary for this value to be statistically

¹Personal communication with Dr. Levitt.

	[t ~~a~~]	[k ~~a~~]	[s ~~a~~]	[n ~~a~~]	[r ~~a~~]	Two	Six	Nine	Ten
Group 1 means	13.7	14.4	14.1	15.6	18.8	15.5	16.7	15.5	16.7
Group 5 means	22.2	24.0	21.0	22.8	21.2	17.0	19.8	21.8	21.2
"t" value achieved	1.4	2.3	1.4	1.2	0.4	0.3	0.6	1.1	0.7
df	4.7	8.1	7.8	4.7	8.5	8.3	6.5	5.1	6.3
t _{.05}	2.0	1.9	1.9	2.0	1.9	1.9	1.9	1.8	1.9

Table 9

Means of Interaction Means of Selected
Words at Point C (Phonation Period)

Note: All data in terms of (mm./mercury)²

significant.¹ In examining the other syllables which contain the [t] phoneme, the same result is achieved, so that in the case of the word "Two" the mean of Group 1 is 15.5 (mm./mercury)² and 17.0 (mm./mercury)² for Group 5. For the third word containing the [t] phoneme ("Ten"), the mean for Group 1 is 16.7 (mm./mercury)² and 21.2 (mm./mercury)² for Group 5. In neither case does the "t" value surpass the value needed at the 5 per cent level of significance, so that there is no statistical difference in the use of this phoneme between a group of good esophageal speakers and a group of poor esophageal speakers. Therefore, for the present study the phoneme [t] does not significantly alter the performance of the better speakers when compared to the poorer speakers. Only the phoneme [k] on this table indicates a statistically significant difference in its use by the two groups of speakers. For the better speakers the mean is 14.4 (mm./mercury)² for [ka] and 24.0 (mm./mercury)² for this utterance by the poorer speakers. The "t" value achieved is 2.3, which goes beyond the value necessary for statistical significance at the .05 level of confidence. Therefore, the plosive [k] in this investigation does indicate a significant difference between the esophageal performances of the two groups of

¹G. A. Ferguson, Statistical Analysis in Psychology and Education (New York: McGraw-Hill, 1966), Table B, "Critical Values of 't,'" p. 406. All values of "t" in this study were taken from this table.

speakers. However, the direction of the difference is inconsistent with what might be expected since it is the poorer speakers that show a higher mean esophageal pressure with the phonation of [ka] than the better speakers.

Approximate Energy

Another means of examining esophageal motility in the laryngectomized subject is to document the amount of energy expended in the esophagus during phonation of each speech utterance. To accomplish this, the energy at Level II, where all three open tips are in the esophagus, was determined as described in Chapter III. In applying the formula for this analysis, two assumptions had to be made and only an approximate estimate of energy could be obtained. The first assumption is that Point C of the wave pattern (the height of the wave during phonation) occurred directly in the middle of the phonation period. The second assumption is based on the fact that some individuals maintained high esophageal pressures at Point D (cessation of phonation) and the pressure wave did not return to the base line. It was necessary to stop the analysis of energy expended at this elevated level.

The means of the energy expended in the esophagus by the subjects in the present study during the speech utterances and their statistical significance are summarized

in Table 10.¹ Again, only selected syllables were employed in order to discern any differences that might occur between words containing plosives and other phonemes. The plosives [t] and [k] could be examined in the utterances [tɑ], [kɑ], "Two," and "Ten," while the other phonemes could be examined in the words [sɑ], "Six" and [nɑ], "Nine" and [rɑ].

Examination of intergroup means reveals overall performances in which the better speakers (Group 1) show mean values that remain under circa 100 energy units except for the utterances "Ten" and [rɑ], where they are 102.6 energy units and 128.6 energy units, respectively. The means of the poorer speakers (Group 5) range from 139.6 energy units for the utterance "Two" to 388.8 energy units for the utterance [kɑ]. Submitting the data to the "t" test of significance, using the 5 per cent level of confidence, reveals no differences in the amount of energy expended by the different speakers. Even though the utterance [kɑ], in Table 9, showed significant intergroup differences relative to esophageal pressure, the present table does not. In Table 10, the mean of Group 1 is 81.9 energy units and 388.8 energy units for Group 5. The "t" value achieved

¹Dr. Levitt devised the formula for testing significance based on approximate df in testing unequal samples involving unequal variances following the methods outlined in K. A. Brownlee, Statistical Theory and Methodology in Science and Engineering, 2nd ed. (New York: Wiley and Sons, 1965).

Speech Utterance	Group 1	Group 5	df	"t" Value Achieved	t _{.05}
[tA]	59.1	237.4	4.4	1.8	2.1
[kA]	81.9	388.8	4.3	1.9	2.1
[sA]	81.2	166.6	7.5	1.6	1.9
[nA]	72.7	251.2	4.2	1.9	2.1
[rA]	128.6	210.4	8.0	1.0	1.9
Two	88.8	139.6	8.6	0.8	1.8
Six	93.7	160.2	6.3	1.2	1.9
Nine	72.2	146.8	5.2	1.1	2.0
Ten	102.6	193.2	7.2	1.2	1.9

Table 10

Energy Expended in the Phonation of
Selected Speech Utterances

Note: All means in terms of energy units

in this instance is 1.9, which does not reach the necessary value of 2.1 at the 5 per cent level of confidence in order for this difference of energy expenditure to be of statistical significance.

Raw data examination appears to indicate more energy expended in the esophagus of poor speakers than of better speakers. Intragroup analysis does not appear to indicate any consistent differences in energy units expended between the various phonemes uttered. This may be seen in Table 10, reflecting the fact that, for the better speakers, there is only a difference of .7 energy units between the utterance [kʌ] and [sʌ]. Examination of the utterances containing the [t] phoneme, all three--[tʌ], "Two," and "Ten"--indicate wide differences without any consistent pattern demonstrated. However, a stable pattern of energy output is observed in the utterance of the nasal [n] in [nʌ] and "Nine." Here the energy expended indicates a difference of only .5 energy units between the grouped speakers.

The poorer speakers, as a group, do not show any consistent pattern in their use of phonemes, not even for the utterances containing the nasal sounds. Intragroup analysis here reveals more variability in the amount of energy expended, with a range of mean values from circa 140-390 energy units. The better speakers show more consistency in the amount of energy used, with their

mean values ranging from approximately 59-120 energy units.

Upper and Lower Esophageal Motility

The results indicated in Tables 9 and 10 yield data for esophageal motility as a physiological entity. It is also possible to examine the data relative to the functioning of the upper and lower portions of the esophagus. By isolating the interaction means obtained from Level 1, Position C (see Figure 13) and Level 3, Position G, of the open tips, data on these two portions of the esophagus can be isolated. Table 11 is a summary of the interaction means of each subject's upper and lower esophagus at Point A (pre-phonation period), Point C (excursion of wave during phonation), and Point D (cessation of phonation) of the intraluminal pressure wave. Examination of this table yields significant and pertinent material.

Intergroup examination of Point A of the pressure wave in the lower esophagus reveals eight negative deflections, with five negative deflections in the upper esophagus. In studying the intergroup performance at Point C of the pressure wave, indications are that the better speakers (Group 1) tend to respond with similar patterns of pressure variation at the upper and lower portions of the esophagus. The pressures of these speakers range from approximately 7 to 27 (mm./mercury)² in the upper esophagus and from approximately 2 to 28 (mm./mercury)² in the lower

S#	Group	(Pre-phonation Period) Point A		(Phonation Period) Point C		(Cessation of Phonation) Point D	
		Lower Esophagus	Upper Esophagus	Lower Esophagus	Upper Esophagus	Lower Esophagus	Upper Esophagus
2	1	-2.4	1.7	13.6	11.0	0.2	0.3
4	1	6.9	2.2	28.8	21.1	0.0	0.3
6	1	-2.5	-8.2	17.8	27.0	0.3	0.1
13	1	0.9	4.4	2.4	7.2	0.1	0.1
16	1	2.0	1.2	24.0	10.2	0.6	0.2
17	1	3.8	4.2	15.2	14.1	0.1	0.2
18	1	4.8	4.8	10.2	8.8	0.5	0.2
1	1	-7.4	-3.8	11.9	12.2	0.4	0.3
3	1	2.5	0.1	10.2	13.7	0.2	0.8
11	1	-0.3	1.8	11.6	14.4	0.2	0.3
8	5	0.1	-2.3	1.6	12.3	-0.1	0.9
10	5	-5.9	-6.6	21.4	24.8	0.7	0.4
12	5	-2.7	0.1	18.4	7.2	-0.1	0.5
14	5	-4.8	1.4	35.8	21.6	-0.1	0.1
15	5	-7.2	-0.7	21.0	16.4	0.5	0.0

Table 11

Interaction Means of Upper and Lower Esophagus
at Three Points of the Pressure Wave

Note: All data in terms of (mm./mercury)²

esophagus. This represents a mean difference of 20 (mm./mercury)² in the upper esophagus and 26 (mm./mercury)² in the lower esophagus.

Group 5 responds with wider fluctuations of pressure changes in these portions of the esophagus. In the upper esophagus the poorer speakers demonstrate a range of interaction means from 7 to 24 (mm./mercury)² and in the lower esophagus from approximately 2 to 35 (mm./mercury)², representing a difference of 17 (mm./mercury)² in the upper esophagus and 33 (mm./mercury)² in the lower portion. This evidence appears to indicate more variable responses in lower esophageal pressures of the poorer speakers in this study than of the better speakers.

When Table 11 is examined at Point D (cessation of phonation), the pressure wave indicates small differences between groups. Similar findings were noted relative to the mean squares, which indicated no gross differences between subject responses at Point D of the pressure wave.

The means of these interaction means were submitted to tests of significance summarized in Table 12. At Point A (pre-phonation period) the better speakers (Group 1) show a mean of .8 in the upper esophagus and Group 5 (poorer speakers), a mean of -1.6. The "t" value achieved here is 1.3, which does not reach the significance level of 1.8 at the 5 per cent level of confidence. No statistical difference exists between the performance of the

	Pre-phonation Period Point A		Phonation Period Point C		Cessation of Phonation Point D	
	Upper Esophagus	Lower Esophagus	Upper Esophagus	Lower Esophagus	Upper Esophagus	Lower Esophagus
Group 1 mean	0.8	0.8	14.0	14.5	0.3	0.3
Group 5 mean	-1.6	-4.1	16.5	19.6	0.4	0.2
"t" value	1.3	2.7	0.7	0.9	0.6	0.4
df	10.4	11.3	7.0	5.5	5.3	5.0
t _{.05}	1.8	1.8	1.9	2.0	2.0	2.0

Table 12

Comparison of Upper and Lower Esophagus at
Various Points on the Pressure Wave

Note: Means in terms of (mm./mercury)²

upper and lower esophagus of the good and poor esophageal speakers in this study. A similar response pattern is repeated for both the upper and lower esophagus at Points C and D. During phonation, in general, inter-group tests of significance revealed no difference between the resultant wave pattern in the lower esophagus with the one formed in the upper esophagus. The only significant difference occurred at the pre-phonation period (Point A), where better speakers demonstrate a mean of .8 (mm./mercury)² in the lower esophagus and the poorer speakers, a mean of -4.1 (mm./mercury)². The "t" value achieved here is 2.7, which exceeds the necessary value of 1.8 at the .05 level of confidence. The poorer speakers show significantly deeper negative deflections in this portion of the esophagus than the better speakers. A similar trend was noted in the analysis of the raw data in Table 11.

Sphincteric Activity

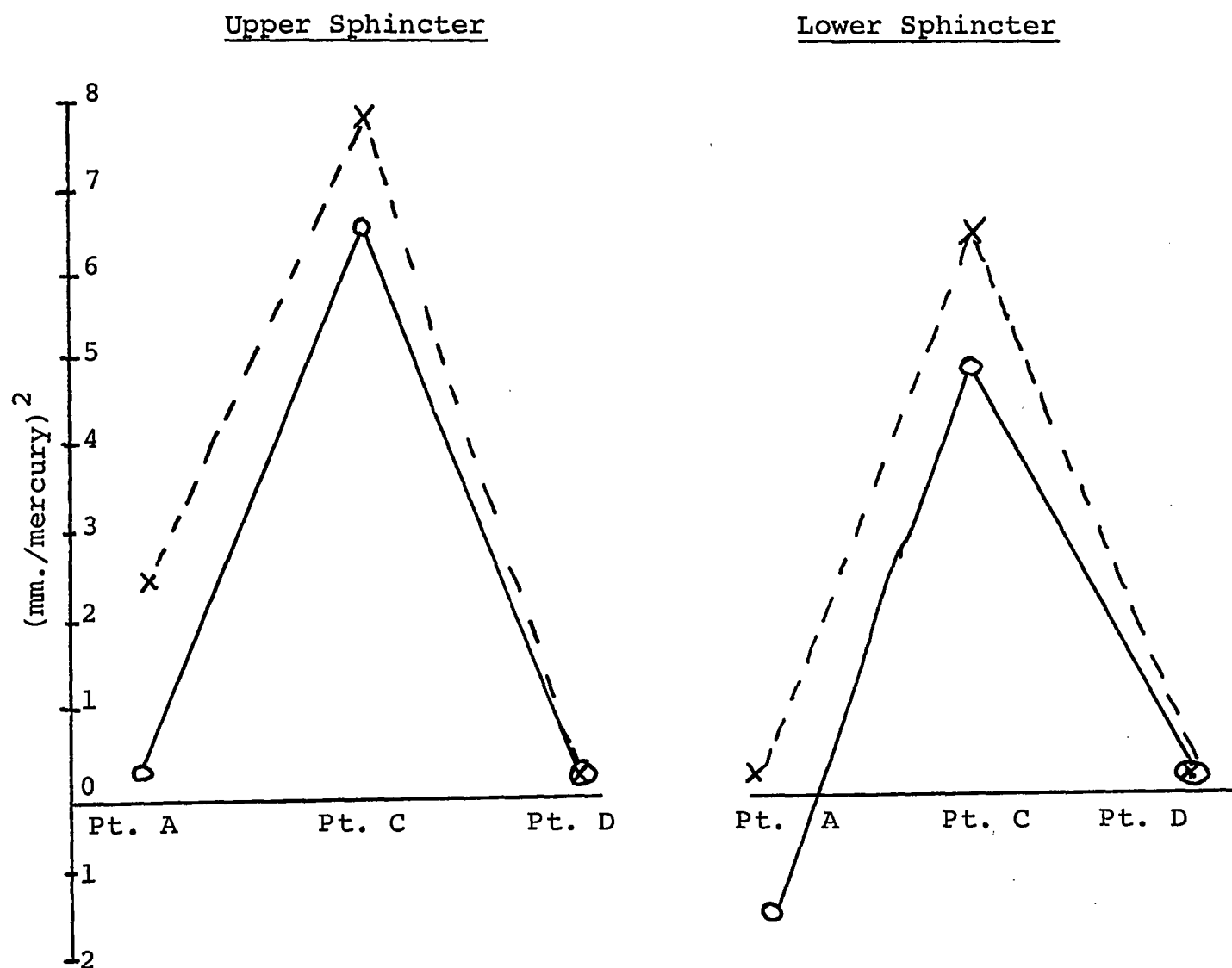
The study of esophageal sphincteric action of the laryngectomee involved a determination of the resting pressures of the upper and lower sphincters. For the better speakers, the upper esophageal sphincter yielded a mean resting pressure of 5.7 mm./mercury, while the poorer speakers showed a mean of 2.4 mm./mercury. In the lower sphincter the mean for the better speakers was

7.9 mm./mercury and for the poorer speakers, 6.4 mm./mercury.

The activity of the esophageal sphincters was compared for the two speaking groups during the speech utterances. This method isolated the value of the interaction means of the pressure waves at Level 1, Position B (see Figure 13), for the lower esophageal sphincter action, and Level 3, Position H, for the upper esophageal sphincter action.

Figure 15 is a graph of the schematicized wave form derived by using the mean values of the interaction means for the three points of the pressure wave. Both the upper and lower sphincters are indicated, as well as the two speaking groups.

In these graphs the two groups of speakers demonstrate a similar configuration of the pressure wave. The upper esophageal sphincter indicates relatively low pressures during the pre-phonation period (Point A), with a high pressure zone during phonation (Point C), and then a return to the low pressure level at the cessation of phonation (Point D). Even though the pressure at Point A is slightly higher for the better speakers than for the poorer ones, when these data were submitted to the "t" test, they did not reveal any significant intergroup difference in the activity of the upper esophageal sphincter during phonation (see Table 13). In Table 13 the mean of Point A for



Legend: Group 1: x Pt. A: pre-phonation period
 Group 5: o Pt. C: phonation period
 Pt. D: cessation of phonation

Fig. 15.--Graph comparing the activity of the upper and lower esophageal sphincters in grouped subjects.

the better speakers (Group 1) is $2.6 \text{ (mm./mercury)}^2$ and $.4 \text{ (mm./mercury)}^2$ for Group 5. The "t" value achieved is 1.0, which does not reach the level of 1.8, the value needed for these data to be significant at the .05 level of confidence. A similar pattern can be noted in the performance of the upper sphincter at Points C and D.

The motility of the lower esophageal sphincter also indicates similar wave patterns for the two groups during phonation. In Figure 15, there is an initial low pressure during the pre-phonation period (Point A), a rise in pressure during phonation (Point C), and then a decrease of pressure to almost the initial pressure levels at the cessation of phonation (Point D). The pressure for the poorer speakers' lower sphincter is slightly below that for the better speakers. Table 14 is a summary of the performance of the lower sphincter by the two speaking groups. The mean of Group 1 for Point A of the pressure wave is $-.1 \text{ (mm./mercury)}^2$ and for Group 5 it is $-1.5 \text{ (mm./mercury)}^2$. The "t" value achieved is 1.8, which does not surpass the value of 1.8 at the 5 per cent level of confidence although it approaches it. For the other points, C and D, no significant difference was found in the performance of these two groups at the 5 per cent level of confidence. Therefore, in the present study, there is no evidence of statistical difference between the activity of the lower sphincter of the good and bad esophageal speaker during phonation.

Point	Group 1 Mean	Group 5 Mean	"t" value	df	t _{.05}
A	2.6	0.4	1.0	9.5	1.8
C	7.7	6.6	0.3	11.0	1.8
D	0.1	0.1	0.0	12.8	1.8

Table 13

Tests of Significance of Performance
of Upper Sphincter*

Point	Group 1 Mean	Group 5 Mean	"t" value	df	t _{.05}
A	-0.1	-1.5	1.8	11.6	1.8
C	6.5	4.9	0.6	6.9	1.9
D	0.1	0.1	0.2	4.2	2.1

Table 14

Tests of Significance of Performance
of Lower Sphincter*

Point	Group 1 Mean	Group 5 Mean	"t" value	df	t _{.05}
A	13.5	1.9	3.5	10.9	1.8
C	8.4	3.5	1.1	12.8	1.8
D	-0.1	0.1	5.6	1.6	1.9

Table 15

Tests of Significance of Performance of Hypopharynx*

*All means in terms of (mm./mercury)².

Hypopharynx

The action of the hypopharynx was more difficult to analyze than the pressure waves in the esophagus, especially within the criterion of time established for the wave form analysis. Since any action in this area--usually a build-up of pressure--occurred prior to esophageal air intake and eventual phonation, the time factor constant was not synchronous with other dynamics. Physically, any build-up of hypopharyngeal pressure occurred prior to relaxation of the upper esophageal sphincter and the registration of pressure in the esophagus.

The raw data yields evidence of differences between better and poorer esophageal speakers relative to the hypopharynx. All of the better speakers exhibited high initial hypopharyngeal pressures which then dropped to the base line as the pressures increased in the esophagus. This phenomenon can be demonstrated by examining the pressure tracings at Level 3 of Subject 2, who is in Group 1 (Figure 16A). The lowest pressure read-out is of the upper esophagus, the medial read-out is in the upper sphincter, and the read-out third from the bottom, in the hypopharynx. Sharp peaks of pressure occur in the hypopharynx prior to the rise of the pressure peak in the upper esophagus. These increases in pressure are high in comparison to the increases to be noted in this area for a poorer speaker.

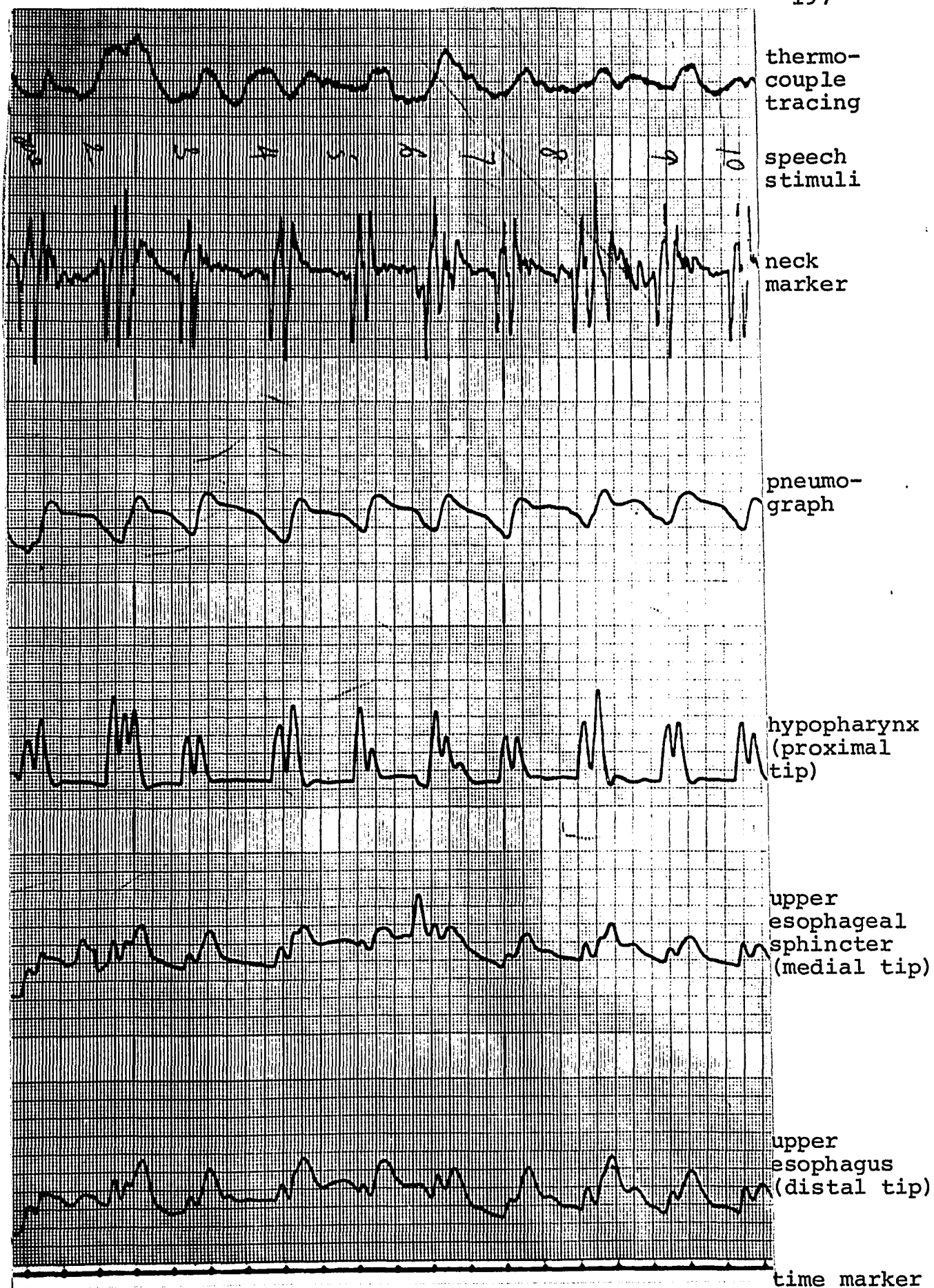


Fig. 16A.--Intraluminal pressure tracings of Subject 2, a good speaker, at Level 3.

Figure 16B is a sample of the pressure tracing at Level 3 of Subject 14, who is a poor speaker, unable to produce any esophageal sounds. Generally, the hypopharyngeal pressures for this subject are lower than for the better speakers. These two records also reflect on the variability of performance as discussed in the section on mean squares. Visual comparison reveals that the poorer speaker has a read-out that is clearer to analyze with the wave patterns exhibiting more consistent responses. The movements in the upper esophagus show a generally consistent pattern of pressure increases which are easily discernible and, therefore, easily analyzed. Conversely, the better speaker responds with much more variety and fluctuation in his intraluminal pressure record, especially in the upper esophagus and upper esophageal sphincter. In another area of comparison, the poorer speaker indicates an increase in pressure and return to the base line after each utterance, while the better speaker's pressure pattern reflects a continuous elevation which fails to return to the base line until the completion of all the speech utterances.

Intragroup analysis of the poorer speakers discloses that, as a group, they exhibit low pressures in the hypopharyngeal area. They demonstrated more consistency relative to their mode of air intake, while the better speakers showed variety by employing a combination of methods. This aspect will be discussed in greater depth in the following

section.

The performance of the good and the poor speakers relative to the hypopharynx is of significance because of the unexpected responses. The better speaker, Subject 2, not only had higher pressure waves in the hypopharynx, but the waves in this area exhibited a consistent pattern. There were definite rises in pressure, usually in the form of bimodal peaks, and then a return to the base line. The poorer speaker, Subject 14, showed some rise in pressure, never as high as the better speaker, and with inconsistent wave patterns noted.

The following graphs represent the schematicized waves in the hypopharynx of the two groups of speakers--good and bad (Figure 17). The mean values of the three points of the pressure wave (Point A--pre-phonation; Point C--phonation; Point D--cessation of phonation) are indicated for both groups. In Figure 17, better speakers exhibit a high pressure peak in the pre-phonation period (Point A), with a mean of $13.5 \text{ (mm./mercury)}^2$ and a drop during phonation (Point C) to $8.4 \text{ (mm./mercury)}^2$. The poorer speakers do not reveal this same tendency of performance relative to the hypopharynx. Their mean pressure for Point A is $1.9 \text{ (mm./mercury)}^2$, with a small rise in pressure to $3.5 \text{ (mm./mercury)}^2$ at Point C. The poorer speakers tend to yield a wave pattern in the hypopharynx similar to the pattern found in their esophagus during phonation. The

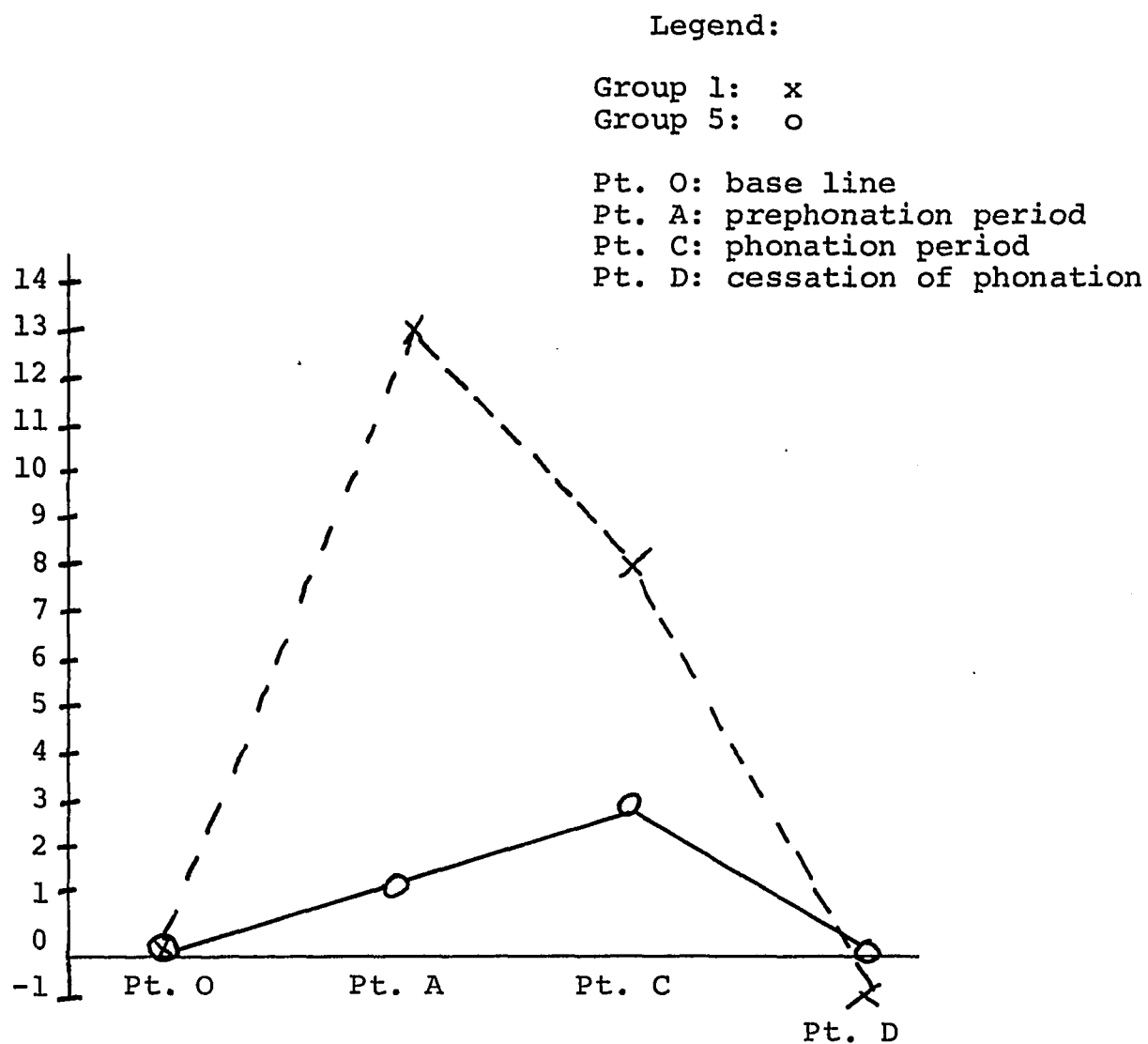


Fig. 17.--Graph comparing the pressures in the hypopharyngeal area of grouped subjects.

better speakers show the initial build-up of pressure in the pre-phonation period and a drop in pressure at Point C, which does not conform to the wave pattern found in their esophagus during phonation.

The summary of the tests of significance of hypopharyngeal performance has been presented in Table 15. In Point A, Group 1 (the better speakers) indicates a mean of 13.5 (mm./mercury)² and Group 5 (the poorer speakers), a mean of 1.9 (mm./mercury)². Using the "t," at the 5 per cent level of confidence, the results indicate a statistical difference between the two groups in the pre-phonation period. During the phonation period (Point C), Group 1 indicates a mean of 8.4 (mm./mercury)² and Group 5, 3.5 (mm./mercury)². These data do not reach the level of significance at the 5 per cent level of confidence. In the performance of the hypopharynx relative to the cessation of phonation (Point D), Group 1 has a mean of -.1 (mm./mercury)² and Group 5, .1 (mm./mercury)². This achieves a "t" value of 5.6, which exceeds the value necessary at the 5 per cent level of confidence (1.9). In studying the hypopharyngeal motility, there are significant differences between the two speaking groups. At Point A, the better speakers use a significantly higher amount of pressure than the poorer speakers, while at Point D they show a significant decrease in pressure as compared to the poorer speakers. During the phonation period, Point C, no

difference of consequence was shown to exist in the performance of the two groups, although the analysis approaches statistical significance.

Stomach Pressures

Intergroup comparison of the pressure evoked in the stomach during phonation provided some meaningful data. The mean of the interaction means for the stomach pressures is summarized in Table 16. The mean for the better speakers at Point C (the height of the wave during phonation) is 12.9 (mm./mercury)², while for the poorer speakers it is 26.2 (mm./mercury)². These data were found to indicate a significant difference in the pressure patterns of gastric origin for the two groups of speakers, with the poorer speakers indicating higher stomach pressures than the better speakers.

Figure 18A is a pressure tracing of Level 1 of Subject 18, who is in Group 1, while Figure 18B is a tracing of Level 1 of Subject 15, who is in Group 5. The lowest recording (distal pressure tip) was taken with the open tip in the stomach. The difference in the performance of the two subjects is striking. What appears to be excessively high pressures are evident in the record of Subject 15. These pressures were, in fact, too elevated to be recorded on the graph paper, and the result is a "square" wave.

	Group	Mean	"t" value	df	t _{.05}
Stomach pressure	1	12.9 ^a	146.7	35.5	1.7
	5	26.2			
Approximate energy	1	71.2 ^b	2.2	5.4	2.0
	5	235.6			

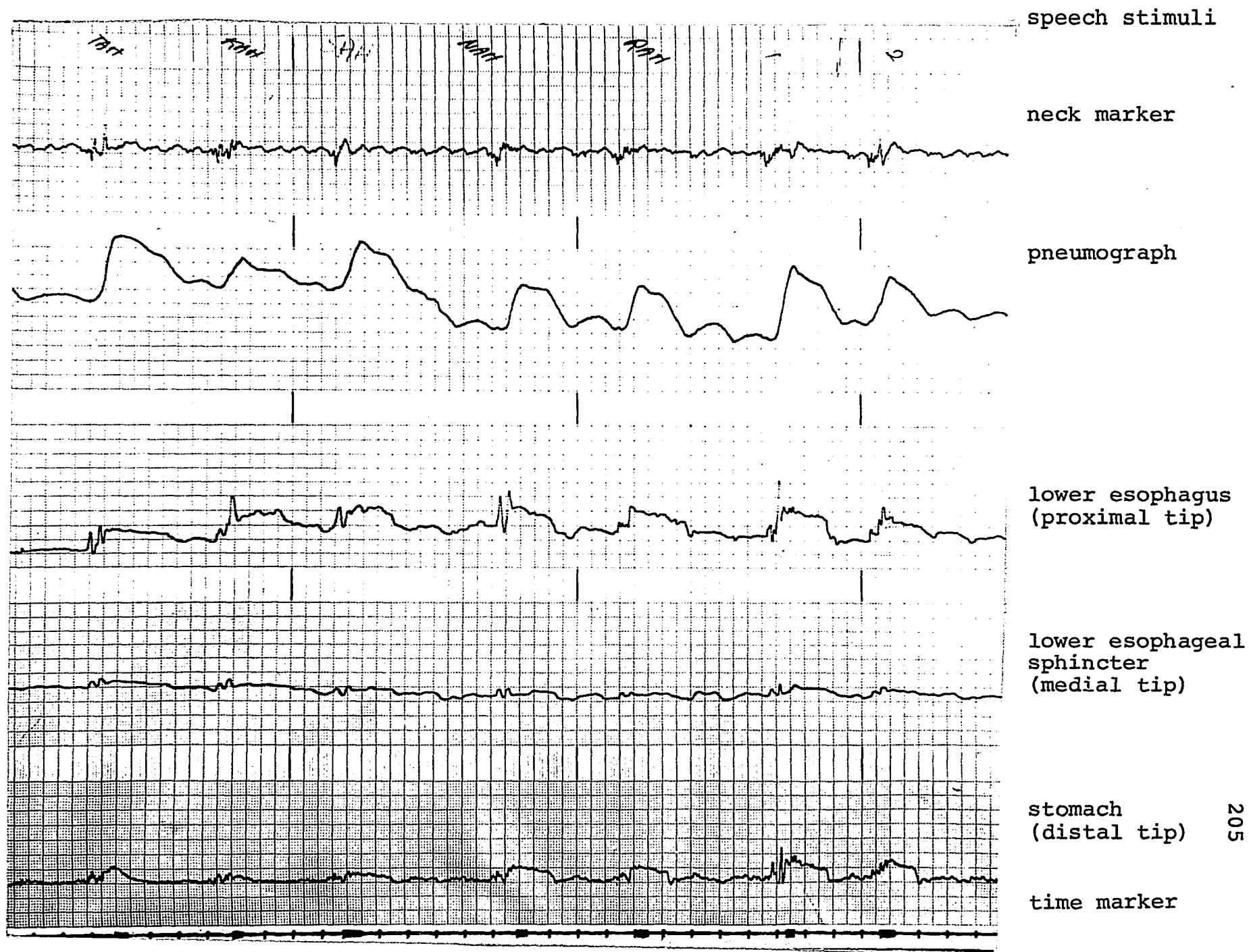
^aMeans of stomach pressures are in terms of (mm./mercury)².

^bMeans of approximate energy are in energy units.

Table 16

Stomach Pressures at Point C (Phonation Period)
and Energy Expended in Stomach

Fig. 18A.--Intraluminal pressure tracings of Subject 18, a good speaker, at Level 1.



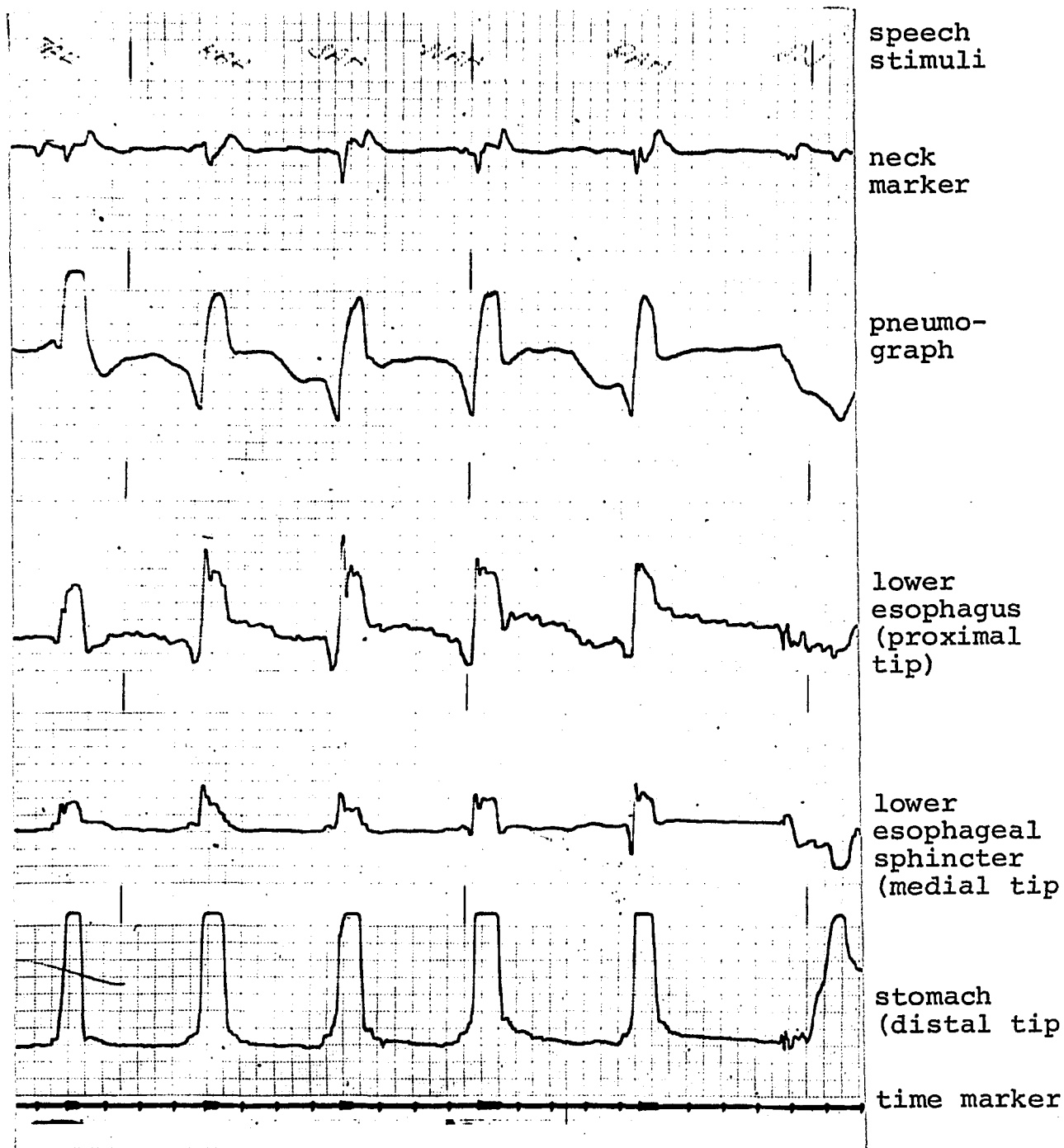


Fig. 18B.--Intraluminal pressure tracings of Subject 15, a poor speaker, at Level 1.

In comparison, the record of Subject 18 (good speaker) reveals an almost constant level of gastric pressure. There are relatively few pressure peaks during phonation to the degree that if it were not for the time marker and the peaks at the other two recording sites, analysis would be difficult to achieve.

In summary, the poorer speaker (Subject 15) shows well-defined peaks of pressure, not only in the stomach, but in the other two test sites as well. Contrasting with this, the better speaker demonstrates irregular wave patterns in his other two pressure tracings that make analysis difficult.

By examining the approximate energy expended in the stomach of these two groups of speakers, an apparent physiological difference can again be demonstrated. Table 16 discloses that Group 1 indicates a mean of 71.2 energy units, and the mean expended by Group 5 is 235.6 energy units. This difference between means is significant at the 5 per cent level of confidence, indicating the poorer speakers in this study expend more energy in the stomach than the better speakers.

Pulmonary and Esophageal Air Flow

The thermo-couple unit devised for this study and designed to produce a wave pattern of stomal pulmonary air flow simultaneously with esophageal air flow during

phonation, performed poorly during the test situation. The resultant wave patterns were not synchronized with the rapid rise and fall of the pressure changes as they occurred in the esophagus. As a result, a definitive analysis of pulmonary and esophageal air flow could not be accomplished.

However, the pneumographic tracings provide a gross measure of air flow from the stoma. The pneumograph, an air-filled tube, was attached around the lower portion of the thoracic cavity and gross external movements of the cavity were recorded simultaneously with internal pressure changes. The resultant tracings were then examined for any synchrony of air flow. In almost all cases, study of the record tracings revealed synchronization of expiration with the phonation period of speech. However, it does not necessarily follow that these subjects used aspiration as their means of air intake.

In the sample pressure tracings (Figures 18A, 16B, and 18B), patterns of synchrony are demonstrated. In Figure 16B, the pressure wave patterns are not clearly discernible for the three open tips; nevertheless the pneumographic wave (second tracing from the top) exhibits a definite pattern. The wave for the speech utterance "Two," for example, shows an initial trough in the pneumographic wave, followed by an increase in pressure. By locating the foot marker indication at the bottom of the tracings (dark

line), the crest in the wave pattern is synchronized with the phonation period. This same pattern is clearly repeated in the tracings for the speech utterances "One" and "Three" through "Ten."

Figure 18B demonstrates the relationship between pulmonary and esophageal air flow with even more clarity. This subject, a poor speaker, shows a sharp negative deflection of his pneumographic wave followed by a sharp rise in amplitude above the initial base line. Glancing down at the intraluminal pressure tracings from the proximal, medial, and distal tips, the sharp negative deflection is reflected simultaneously in the proximal tip (lower esophagus), somewhat in the medial tip (lower sphincter), but not in the distal tip (stomach). The recording segment represents inspiration during the pre-phonation period. Also demonstrated is a sharp rise in the pressure of the lower esophagus coinciding with exhalation, as indicated on the pneumograph.

The synchrony between pulmonary and esophageal air flow is clearly demonstrated in examining the tracings in Figure 16B. This subject, a poor speaker, shows large excursions of his pneumographic wave patterns. Comparing these excursions with the pressure changes recorded at the distal tip (bottom tracing, representing the upper esophagus), there are no initial negative deflections recorded simultaneously in the esophagus to coincide with the

negative deflections denoting inspiration. However, there are definite increases in pressure during phonation that coincide with expiration, as noted on the pneumograph. The pulmonary air flow and air flow for esophageal speech appear to indicate a gross synchrony, as produced by all subjects in this study.

Method of Air Intake

In examining the pressure waves produced by the laryngectomized speakers in the present study, the author, in consultation with Dr. Iyer, a medical co-investigator, found that there were apparently two main types of wave patterns in the esophagus. The first type of wave, appearing in Figure 19, indicates the use of the aspiration method of air intake.

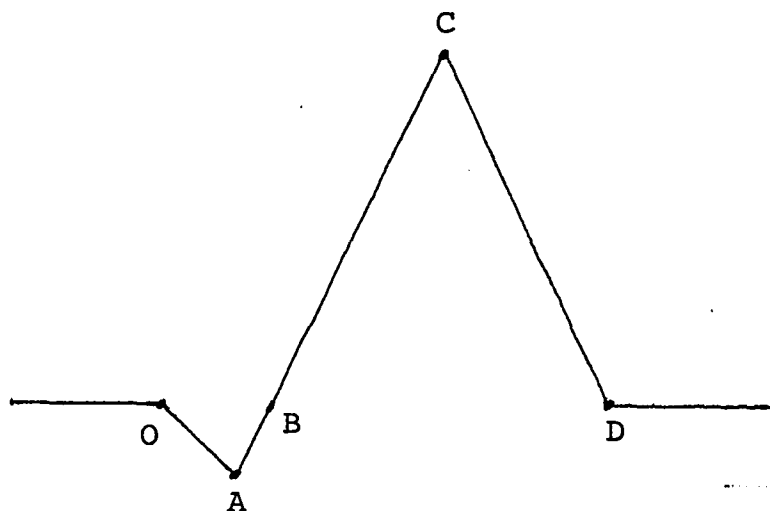


Fig. 19.--Schematic drawing of one type of pressure wave pattern representing the use of the aspiration method of air intake. A: pre-phonation period; B: return to the base line; C: height of the wave during phonation; D: cessation of phonation; O: base line.

Point A in Figure 19 indicates a negative pressure, or negative deflection, in the wave pattern. Point C indicates a sharp rise in amplitude, demonstrating positive pressures in the esophagus during the phonatory period. Point D is the cessation of phonation and a return of pressures to the base line (initially labeled "O").

As demonstrated in Chapter II, the esophagus is in close anatomical proximity to the structures involved in respiration (the lungs, via the mediastinum, and diaphragm, via the phreno-elastic ligaments). Therefore, as these structures expand and descend during inspiration, they will cause similar movement of the esophagus, usually stretching it and causing a negative pressure. A simple negative pressure in the esophagus at the initiation of the speech utterance need not be interpreted as related precisely to the air intake method utilized by the subject.

Examination of Point C of the wave pattern would be necessary to determine whether the subject were using the aspiration method or not. If there is a sharp rise in amplitude during phonation, it would indicate positive pressure in the esophagus caused by the air entering the esophagus. Figure 20 demonstrates this method of air intake. The tracings are at Level 2 taken from the record of Subject 17, who is in Group 1. The wave patterns here are clearly discernible. There are initial sharp, well-defined negative deflections in all three open tips as well as in the

again, applying it to a small sampling would not be practical in the statistical analysis of the data.

Another such scale was devised by Wepman et al. based on their clinical experiences. This was also a seven-point scale containing the following levels of achievement:¹

- Level 1. Automatic esophageal speech; no effort; rapid and automatic speech;
- Level 2. Esophageal sound produced at will with continuity; word grouping (short phrases, definite swallowing effort);
- Level 3. Esophageal sound produced at will; single word speech (voluntary speech but no continuity);
- Level 4. Voluntary sound production most of the time; vowel sounds differentiated, monosyllabic speech--short one-syllable words;
- Level 5. Voluntary sound production part of the time; no speech. Much effort and time needed to produce anything;
- Level 6. Involuntary esophageal sound production; no speech; indirect belches;
- Level 7. No esophageal sound production; no speech; no attempt at verbal communication.

The Wepman Scale was employed in another study, previously discussed, by Vrticka and Svoboda. Again, since the present study contained a small sample, it was felt

¹J. M. Wepman, J. A. McGahan, J. C. Rickard, and N. W. Shelton, "Objective measurement of progressive esophageal speech development," JSHD, XVIII, 1953, pp. 247-251.

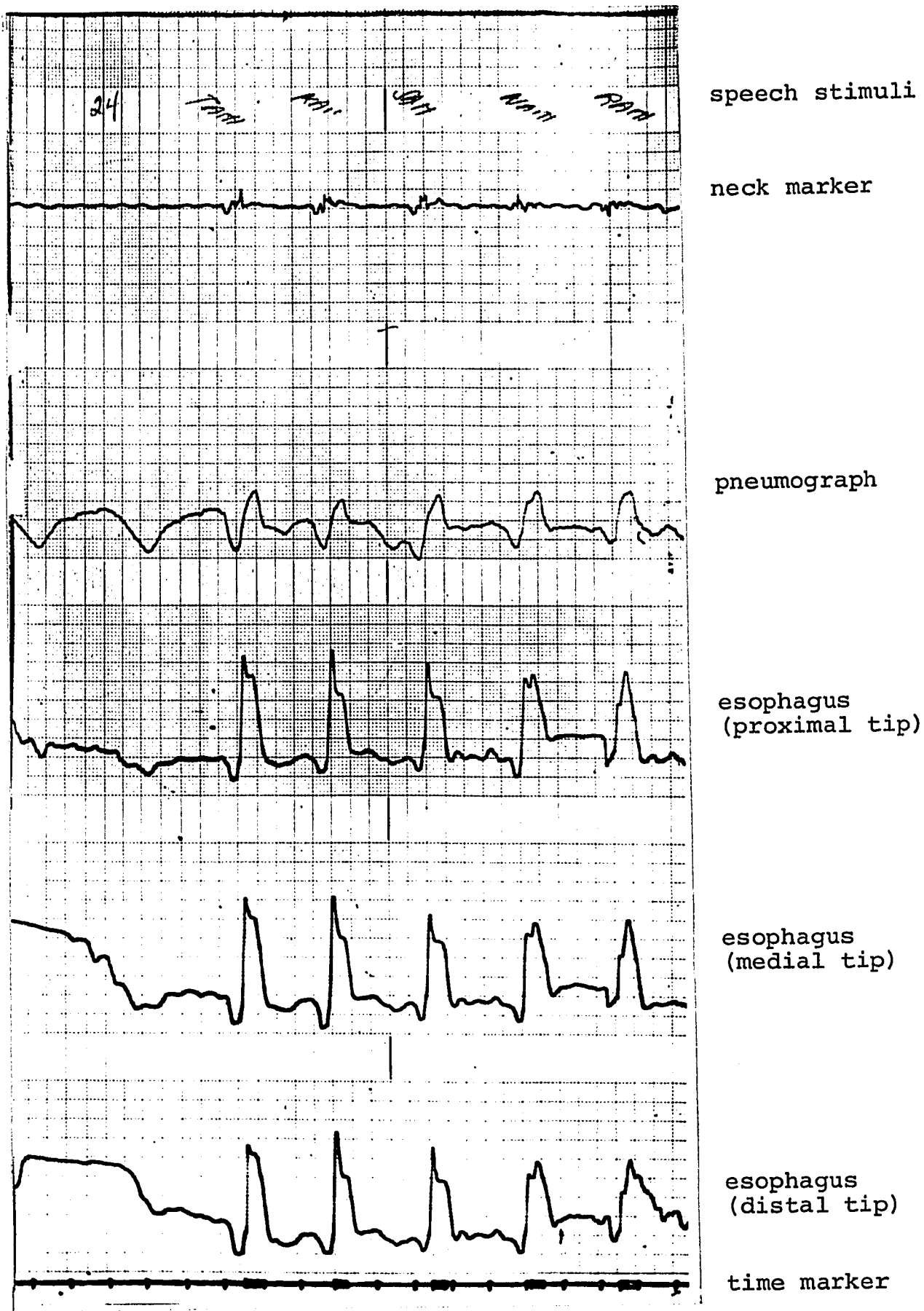


Fig. 20.--Intraluminal pressure tracings of Subject 17, a good speaker, at Level 2.

pneumographic tracings. These are followed by a sharp rise in amplitude, during phonation, indicating positive pressures in the esophagus during speech. Also, this tracing reveals the fact that, at the end of each speech utterance (Point D), the pressure pattern returns to the base line, except during the utterance of [n~~o~~]. In this case the pressure remains above the base line indicating apparently that air remains in the esophagus in preparation for the next utterance.

The same pattern of aspiration can be noted in Figure 18B, where the speaker was in Group 5 (poorer speaker). The proximal tip linked with this tracing (lower esophagus) illustrates sharp initial negative deflections, followed by an increase in positive pressure in the esophagus. However, the related vocal responses did not follow the pattern of the previous subject. This subject was unable to speak and utilize the air entering his esophagus.

Figure 21 presents a pressure read-out at Level 2 of Subject 2 (Group 1). While the wave patterns for this subject are not as well defined as in the other tracings just discussed, the pressure patterns indicate a similar configuration. There is a sharp negative deflection, followed by a sharp positive deflection, which occurs simultaneously with his respiratory movements.

A second type of wave pattern identified in the esophagus indicates the injection method of air intake.

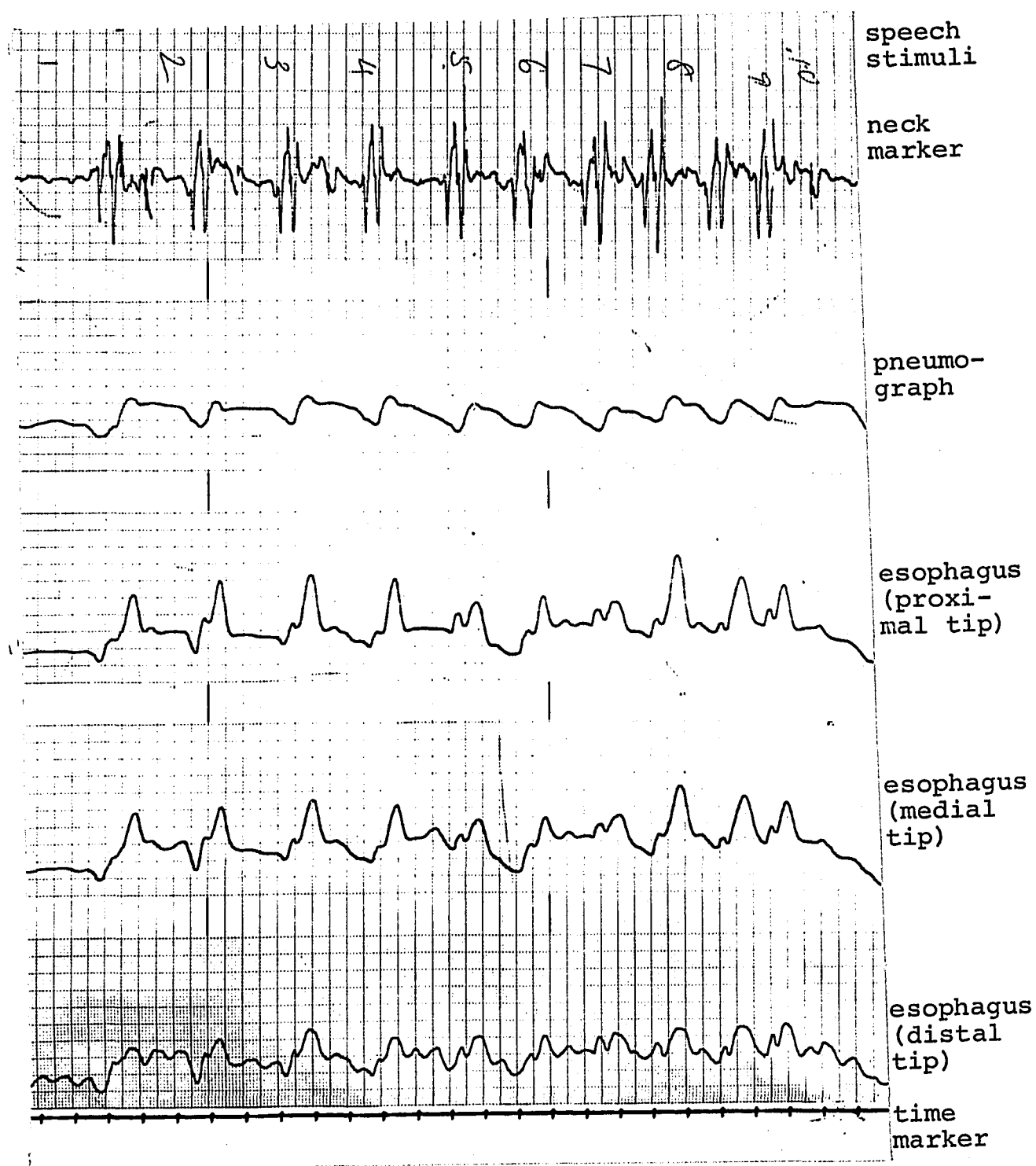


Fig. 21.--Intraluminal pressure tracings of Subject 2, a good speaker, at Level 2.

It is drawn in Figure 22.

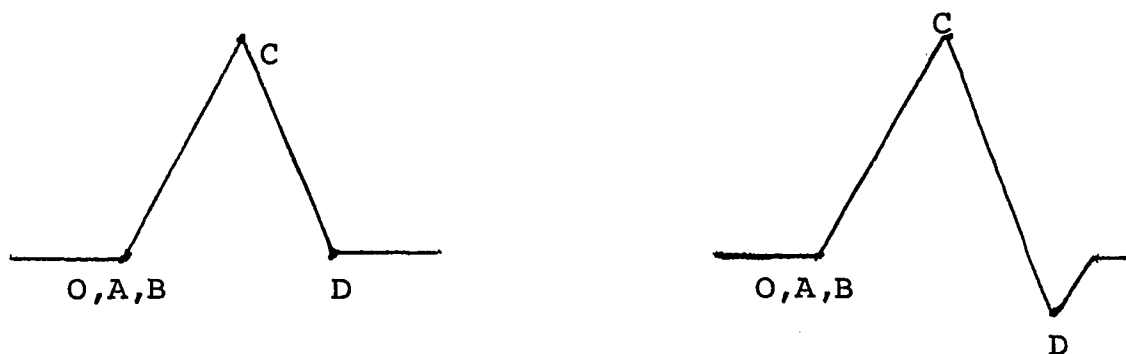


Fig. 22.--Drawings of pressure wave patterns representing the use of the injection method of air intake. O: base line; A: pre-phonation period; B: return to base line; C: height of wave during phonation; D: cessation of phonation.

These drawings illustrate that in these wave patterns, Points A, O, and B are located in the same place. This indicates no pressure changes in the esophagus during the pre-phonation period, so that the base line (Point O), the beginning of the pre-phonation period (Point A), and the return to the base line (Point B) are of the same value. From this type of wave pattern, it is difficult to determine the exact duration of the pre-phonation period.

Figure 23 demonstrates the injection type of air intake as just described. It is the tracing at Level 2 of Subject 4 (Group 1). There are essentially no initial negative deflections prior to the large increase in positive pressure that occurred during phonation. In the utterance of the number "Two," Subject 4 responded with a slight negative deflection prior to phonation, but in comparison

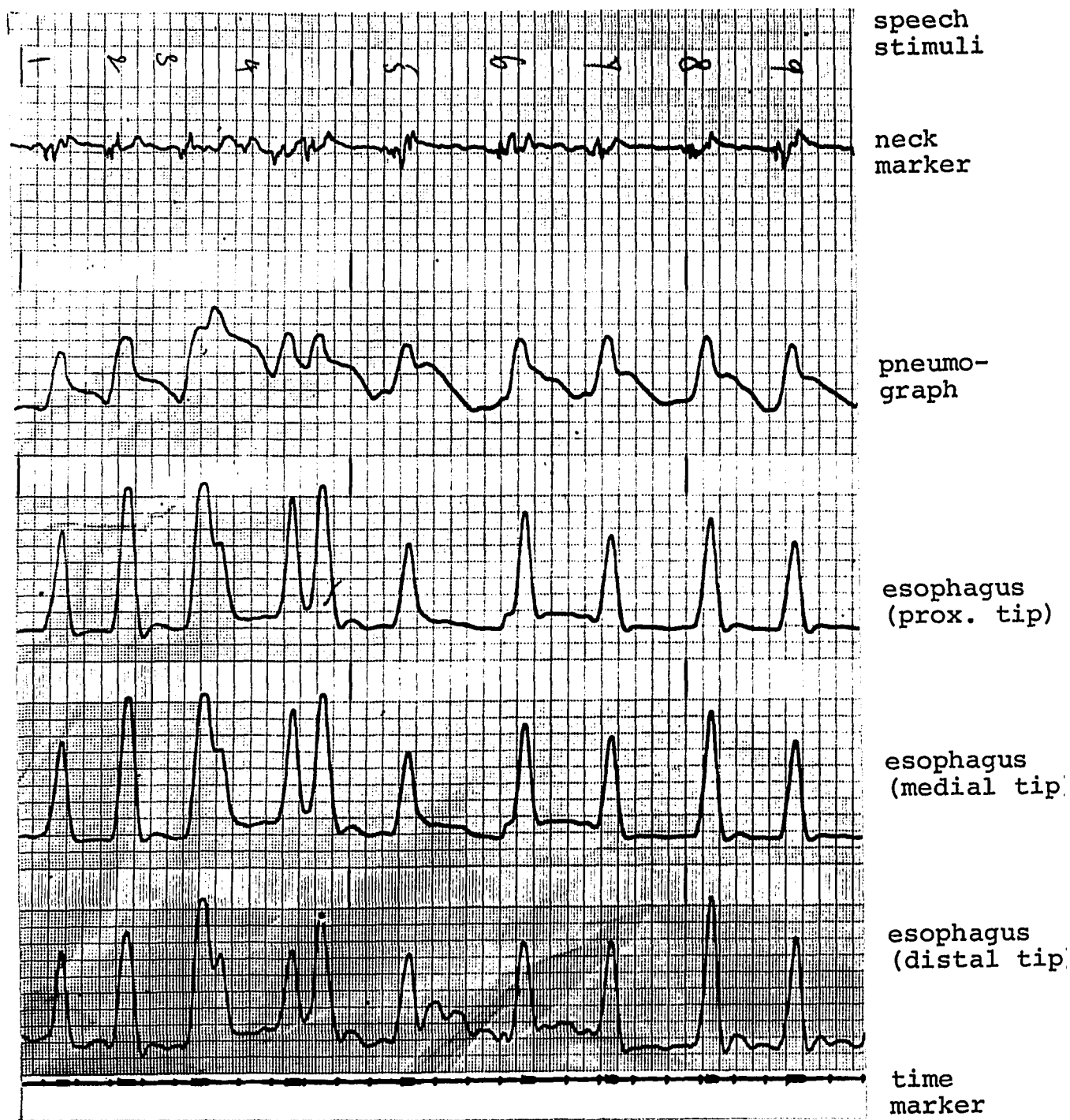


Fig. 23.--Intraluminal pressure tracings of Subject 4, a good speaker, at Level 2.

to the other tracings, this dip is slight and probably not associated with the aspiration of air into the esophagus. This subject did show high pressures in the hypopharynx just prior to phonation, as much as 20 mm./mercury, apparently indicating that for speech purposes he is using only the injection method to force air into the esophagus. Subject 4 illustrates a variation of the second type of wave form just discussed. In the above drawing the second wave indicates a slight negative deflection following the cessation of phonation (Point D). This pressure point can occur in some subjects who use the injection method of air intake. It indicates that the subject took a slight inspiration of air at the end of the speech utterance.¹ In Figure 23, this maneuver is illustrated in the subject's utterance of the numbers "Two," "Four," "Five," and "Eight," with the negative deflection most prominent in the proximal and distal tips.

Even though this subject does not appear to aspire air into the esophagus, he does show a synchrony of pulmonary and esophageal air flow during speech production.

This particular segment of intraluminal pressure read-out further illustrates a bimodal wave pattern produced by the subject during the phonation of the numbers "Three" and "Four." In the utterance "Three," the first large

¹Personal communication with Dr. Iyer.

excursion, or increase in pressure in the esophagus (Point C), is synchronized with the activation of the foot marker, indicating that the subject phonated or attempted to phonate the word. There is then a slight drop in pressure, with another slight increase immediately following. Dr. McNally interpreted this as indicating the subject's apparent effort to improve, or at least to repeat, his initial speech attempt. This point is clearly indicated in the phonation of the word "Four," where the pressure falls almost to the base line before rising even higher for the second speech trial of this word. The foot marker, however, indicates that the first speech attempt ended after the first wave's peak was reached.

Not all the wave patterns analyzed could be divided into the two classifications discussed. Often, as can be illustrated in Figures 16A, 16B, 18A, and 18B, all tracings were not easily discernible. Occasionally a bifid wave pattern resulted, as already noted in Figures 23 and 16A, which appeared to be closely linked to a second respiratory effort. Occasionally, no positive or negative pressures were found in a particular reporting site of the open tip within the esophagus. When any such irregularities in wave form occurred, the time marker or pneumographic wave pattern was used to determine the moment at which speech occurred.

Some speakers did not use one method of air intake exclusively. Speaker 4 (Figure 23), for instance, used the injection method exclusively, while Subject 17 (Figure 20) appeared to use the aspiration method to the exclusion of the other. However, Subject 2 seemed to use a combination of methods. In Figure 21 it was demonstrated that this subject used aspiration to aid in insufflating the esophagus, while in Figure 16A the excessive positive hypopharyngeal pressures indicate the build-up of pressure necessary for injecting the air into the esophagus prior to phonation.

Discussion

Esophageal Motility

Intraluminal pressure testing can potentially reveal some differences in esophageal behavior of good and poor esophageal speakers. However, as is reflected in some results of this study, the critical differences appear to be derived from two segments of one specific wave pattern--the pre-phonation period and the phonation period. No inferences can be made on the basis of the total wave pattern. However, when the elements of the wave pattern were divided arbitrarily, but uniformly, into the pre-phonation and phonation periods, certain differences in esophageal motility appear.

In the discussion of the mean squares, the two groups of speakers--better and poorer--appeared to be differentiated

in total performance. For example, Group 1 (better speakers) showed more variability than Group 5 (poorer speakers) in the pre-phonation period. The phonation period revealed fewer comparable differences between the groups. However, Group 5 showed more variability than Group 1 at the point of phonation cessation. These impressions of intraluminal pressure differences were studied statistically at a later point in the investigation.

Examinations of the intraluminal esophageal pressure patterns, vis-a-vis patterned phonatory maneuvers, revealed apparent pressure changes in the two portions of the wave that could reveal loci of intergroup differentiation. Related data further appear to indicate the method of air intake being employed by a given alaryngeal patient can be determined by studying the intraluminal pressure wave. The pre-phonation period showed negative intraluminal pressures for almost all subjects, with negative deflections of greater amplitude noted for the better speakers.

If there were no increase in intraluminal pressures immediately following the pattern of initial negative pressure, it could be assumed that no air entered the esophagus even though intraluminal esophageal pressures were decreased. This is, indeed, the situation during periods of rest. However, examination of the phonation period, as documented by the analogous air pressure read-out, revealed increases in pressure amplitudes following the negative

pre-phonation pressures. Here, again, the poorer speakers revealed a more consistent pattern of intraluminal pressures than the better speakers. Another distinguishing characteristic in the performance between the two groups was that the better speakers tended to yield lower esophageal pressures during phonation than the poorer speakers. This same tendency, although never reaching statistical significance, was noted in terms of expenditure of energy by the laryngectomee during phonation. The poorer speakers appeared to utilize more energy units than the better speakers.

The relatively excessive amount of esophageal pressure and energy expended during alaryngeal phonation by the poorer speakers would seem to have extended into other areas. Comparison of the performance of gastric pressures during speech utterances revealed that the poorer speakers yielded a significantly higher amount of intragastric pressure than the better speakers. This finding tends to support the findings of DiCarlo et al., whose cinefluorographic study revealed greater movement of the abdominal walls in the poorer speakers.¹

The present investigation confirms the studies of Vrticka and Svoboda. These researchers stated that the entire esophagus is utilized during esophageal speech.²

¹DiCarlo et al., op. cit., p. 160.

²Vrticka and Svoboda, op. cit., p. 182.

It would seem to simultaneously dispute the conclusions of such researchers as Damste and DiCarlo, who contend that only the upper portion of the esophagus is employed.¹

In the present study, examination of the upper and lower esophageal intraluminal pressure wave patterns for all subjects revealed an apparent global pattern of positive pressure that would substantiate the conclusion that essentially the entire esophagus is insufflated preparatory to phonation. The author hypothesizes that Damste and DiCarlo may have reached their conclusions because they seemed to have limited their investigations to the rostral portion of the esophagus.

In comparing the motility of the upper and lower esophagus in the present study, the better speakers revealed relatively more consistent patterns of intraluminal pressure in both sections, while the poorer speakers appeared to indicate broader and more irregular fluctuations from the base line. The better speakers seem to employ better control of the esophagus and air flow for the purpose of alaryngeal speech.

The pre-phonation period provided a potentially significant finding relative to the motility of the upper and lower esophagus. There were negative pressure deflections in the lower esophageal region of both speaking groups.

¹DiCarlo et al., op. cit., p. 160; Damste, op. cit., p. 55.

However, the deflectional amplitude was greater for the poorer speakers when taken as a group. It might be hypothesized from this finding that the poor speakers are employing more total esophageal energy and expanding esophageal structures more extensively during phonation, with an apparently lesser phonatory achievement for their efforts. The findings of negative intraluminal pressure patterns in both the upper and lower esophagus of the combined subjects in this study tend to confirm the anatomical descriptions discussed in Chapter II. The esophagus is apparently being stretched longitudinally during inspiration due to its attachment at the diaphragmatic hiatus by the phrenoesophageal ligaments, and perhaps horizontally as well, due to its attachment to the pleural mediastina.

The recording of negative pressure read-outs more consistently in the lower esophagus of laryngectomized patients tends to confirm Ingelfinger's contention that "respiratory effects on intra-esophageal pressure are most marked immediately above the diaphragm; in the cervical esophagus they are dampened."¹ However, he is commenting on the normal esophagus, but similar physiological patterns appear to obtain in the laryngectomee as well, except that the effects seem not to be completely dampened in the upper esophagus.

¹Ingelfinger, op. cit., p. 543.

Use of Selected Phonemes

One of the aims of the present study was to analyze the effect of selected phonemes on esophageal motility in general. Examination of the intraluminal pressure patterns evoked in the esophagus could be compared with the evocation of specific arrays of speech sounds. The Dutch investigators in an earlier study have advocated the use of the plosives in learning esophageal speech. A comparison of subject performance in the present investigation reflected no significant differences among speech sounds when examined in terms of the related intraluminal pressure patterns generated. This lack of differentiation is apparent among both the better and poorer speakers, and is in direct conflict with the findings of Damste, who noted continued insufflation of the esophagus upon repetition of the phoneme [p].¹ In this study the phoneme [p] had to be eliminated because of the tube extending past the subject's lips. In the analysis of the results only the syllable [kɑ] indicated any significant difference in the performance of the two groups. However, this difference was exactly opposite to the findings of authors who advocate the use of plosives in learning alaryngeal speech. In the present study, the poorer speakers generated higher esophageal pressures for the syllable [kɑ] than the better

¹Damste, op. cit., p. 27.

speakers. No synchronized recording of the audible speech was available in the present investigation so that it could not be precisely ascertained whether the subject uttered the syllable vocally or only attempted to do so. The swallowed tube did alter the subject's ability to speak to some predictable degree, but this tube presented an identical problem to each subject. Even if no vocalizations occurred, the subject still attempted to take in air, and, in general, employ the usual vegetative movements he would use under normal conditions.

One interpretation made from the findings of the present study is that the exclusive utilization of plosive sounds in initiating speech rehabilitation of the laryngectomee is now questionable. There appears to be little significant difference in the ability of any single sound category to facilitate air intake into the esophagus. Diedrich and Youngstrom, in their study, concluded that the [s] is a good air injector,¹ and it appears from the present findings that other phonemes might also be of use to the beginning alaryngeal speaker.

Pulmonary and Esophageal Air Flow

Some researchers have advocated a physiological independence between pulmonary and esophageal air flow in the laryngectomee, mainly because of the excessive stomal

¹Diedrich and Youngstrom, op. cit., p. 84.

noises that occur, presumably related to simultaneous pulmonary and esophageal exhalation. Recent studies, reviewed in Chapter II, tend to conclude that a synchrony of pulmonary and esophageal air flow exists in the laryngectomee, but it may be dependent on the method of air intake employed, or the degree of individual speech proficiency achieved.

In the present study, analysis of the recorded wave pattern tracings of the pneumograph and esophagus during phonation revealed a closely related synchrony between pulmonary and esophageal air flow in the laryngectomized subjects. These findings would tend to support researchers, such as Diedrich and Youngstrom, and Finkbeiner, who advocated teaching the laryngectomee to maintain his pre-operative respiratory speech relationship even though stomal noises result.¹ The author of the present study hypothesizes that these stomal noises may not be the result so much of the air flow synchrony as of the relatively excessive amount of intra-thoracic, intra-gastric force and energy expended by the poorer esophageal speaker.

Snidecor and Isshiki observed the synchronization of pulmonary and esophageal air flow mainly with those subjects employing the inhalation method of air intake, and

¹Ibid., p. 50; Finkbeiner, op. cit., p. 83.

they suggested that the occurrence of synchronization is dependent on the type of air intake method used by the laryngectomee.¹ The present study, however, found synchronization of pulmonary and esophageal air flow to occur in subjects regardless of the type of air intake method they employed. DiCarlo et al. suggested that coordinated air outflow is dependent on the quality of alaryngeal speech achieved by a given patient. Their conclusions seem to be negated by the findings of the present investigation inasmuch as synchrony was found to occur in all subjects, regardless of speech proficiency.²

In the present investigation the thermo-couple unit designed specifically to determine this relationship was ineffective. In Figures 16A and 16B, the tracing from the stomal thermo-couple unit can be seen as the uppermost wave form. The relatively slow response time to thermal changes at the stoma, compared to the sensitive response of the intraluminal pressure transducers, is evident, as is also the poor quality of the wave pattern. A more definitive analysis of pressure changes and pulmonary air flow could probably be accomplished through the use of a more precise instrumentation, such as a thermester.

¹Snidëcor and Isshiki, op. cit., p. 212.

²DiCarlo et al., op. cit., p. 160.

Sphincteric Activity

All the laryngectomized subjects studied in this project had relatively low intraluminal pressure read-outs in their upper and lower esophageal sphincters. These results were predictable based upon previous empirical findings. The mean resting pressures of 5.7 mm./mercury for the better speakers and 2.4 mm./mercury for the poorer speakers are low as compared to pressures found in normal individuals. Fyke and Code reported that in normal subjects, the resting pressure in the upper sphincter had a mean of 41 cm./water.¹ The present findings support the research by Dey and Kirchner, who claimed that the average laryngectomee has less tension in the upper esophageal sphincter than normal individuals.² From the results of this study intergroup analysis indicated slightly higher sphincteric pressures for the better speakers than the poorer speakers. Thus, if Damste's statement in this regard is correct--namely, that the tension of the upper esophageal sphincter is a barrier to be crossed by the laryngectomee--the poorer speakers in this investigation would have a slight advantage over the better speakers in learning esophageal speech.³

¹Fyke and Code, op. cit., p. 27.

²Dey and Kirchner, op. cit., p. 114.

³Damste, op. cit., p. 32.

However, data reflecting differences in sphincteric pressures did not reach statistical significance, thus there appears to be no meaningful difference in the functioning of the upper esophageal sphincter (or pseudoglottis) in the better and poorer speaker, even though they both exhibit decreased tension.

In their investigation of normal individuals, Fyke et al. observed a lower resting pressure registered in the lower esophageal sphincter than in the upper esophageal sphincter. They found that the lower esophageal sphincter maintains a mean resting pressure of 10 cm./water above the resting stomach pressure.¹ In the present study, resting stomach pressures were not obtained, but the resting pressures of the lower esophageal sphincter were slightly higher than those of the upper esophageal sphincter for both groups. This finding would seem to represent a reversal vis a vis Fyke's normative data. Evidence in this paper indicates that the better esophageal speaker generally does not relax his lower esophageal sphincter when he introduces air into his esophagus. This action appears to deter the propulsion of air into the stomach by peristaltic movements, the predictable pattern. The pressures exerted at the lower sphincter are evident in Figure 16A. The medial pressure-sensing tip (second from the bottom)

¹Fyke et al., op. cit., pp. 148-149.

reveals little change in its pressure pattern. This tracing can be compared to a speaker from Group 5, Figure 16B, whose lower sphincter can be shown to be active during phonation.

Ingelfinger, in translating Kronecker and Meltzer, may have touched upon the reason that the laryngectomee can suppress his peristaltic action and, therefore, eventually achieve a reduced pressure state at the lower esophageal sphincter. According to Ingelfinger, Kronecker and Meltzer believe that a period of inhibition exists following each swallow strong enough to temporarily prevent the peristaltic contraction that would ordinarily follow the preceding swallowing. He notes that "Kronecker and Meltzer, who discovered this phenomenon, stated that the maximum interval permissible between swallows, if peristalsis is to be postponed during repetitive swallowing, is 1.2 seconds in the upper, 3 seconds in the middle, and 5-6 seconds in the lower esophagus. The interval between the last swallow and the peristaltic contraction increased, they also maintained, with the number of antecedent swallows. No report of an attempt to check these correlations has been found."¹

¹Ingelfinger, op. cit., p. 555, quoting H. Kronecker and S. J. Meltzer, "Der schluckmechanismus seine erregung und seine hemmung," Arch. Anat. u. Physiol., Suppl., 1883, pp. 328-362.

When examining the time factor derived from the raw data, this investigator found no pre-phonation periods that reached one second in length, which would be equivalent to the swallowing maneuver described by Ingelfinger. The better speakers immediately eject this air for phonatory purposes and may reverse direction of esophageal air because of this inhibitory pattern which has been introduced. An hypothesis to explain this phenomenon would be that as the laryngectomee introduces more air into the esophagus, the interval between inhibitory patterns increases, allowing him to speak quickly, momentarily overriding the peristaltic reflex patterns. The poorer speakers apparently do not immediately eject this air and with the air remaining in the esophagus, the temporary inhibitory pattern is extinguished, moving the air into the stomach via peristalsis. Each time the laryngectomee inflates his esophagus there is apparently only a short inhibitory interval within which phonation must occur. From these deductions it would seem that each speech attempt for the poor speaker is a new act, a discrete and separate physiological behavior.

Method of Air Intake and the Hypopharynx

The amount of pressure in the hypopharyngeal area appears to be dependent on the method of air intake employed by the laryngectomee. If the individual depends

solely on aspiration to insufflate his esophagus, relatively diminished hypopharyngeal pressure patterns can be predicted. This phenomenon was demonstrated in one subject, who used only this method of air intake and demonstrated low hypopharyngeal pressures. Subject 4 (Figure 23) used the injection method exclusively, and his hypopharyngeal pressures were relatively high. Subject 2 (Figure 21) also exhibits high hypopharyngeal pressures, but these were combined with the initial negative deflections of the pressure wave in his esophagus, indicating a combination of methods was in use.

On the basis of subjective analysis, Damste noted that ". . . it strikes us that the pressures registered in the pharynx and the oesophagus are, on an average, a little higher in [Groups] II and I, which points to an oesophageal sphincter that is none too supple."¹ In this reference Damste was referring to the poorer speakers of his study, in comparison to Group III, his group of "better" speakers. The data generated in this investigation do not support Damste's findings of lower hypopharyngeal pressures among better speakers. Significantly higher pressures in the better speakers' hypopharyngeal areas were recorded in the pre-phonation period.

¹Damste, op. cit., p. 23.

From these findings, it would appear that the better speakers were using the injection method of introducing air into the esophagus. It can be postulated that it is the injection method per se and not the specific tensions of the pseudoglottis which is responsible for augmented hypopharyngeal pressures. If these better speakers also aspirated air, they could be considered to employ a combination of air intake methods, and would support the findings of Snidecor and Isshiki. These investigators reported that effective laryngectomee speakers used a combination of air intake methods and that ". . . the clinician who arbitrarily insists upon any one method of air intake should probably revise his methodology in the direction of eclecticism."¹ Examination of the raw data did indicate most subjects in the present study utilizing a combination of methods, either simultaneously or at different moments, whether a relatively good or poor speaker.

Summary

Intraluminal esophageal pressure testing can reveal differences between the better and poorer esophageal speakers. These differences are most noticeable in examining the motility of the entire esophagus during phonation,

¹Snidecor and Isshiki, op. cit., p. 215.

where the better speakers tend to use less pressure, but who also show more variability in performance than the poorer speakers. Hypopharyngeal action--as reflected in intraluminal pressures--reveals higher pressures among the better speakers during the phonation period. Sphincteric activity appears to support more recent findings of a reduced area of tension in the upper esophageal sphincter in all laryngectomees, with normal lower sphincter function present. It can also be concluded that the laryngectomee uses synchronous pulmonary and esophageal air flow, independent of method of air intake or speech proficiency. Intraluminal pressure testing can differentiate the method of air intake employed by the laryngectomee, using the pre-phonation period and its corresponding pressure wave pattern as the prediction medium. In the present study the subjects tended to use a combination of aspiration and injection insufflation techniques, either simultaneously or at different moments. Finally, indications from the present study are that the poorer speaker utilizes more energy and force in speech attempts, appearing to involve, not only esophageal motility, but pressures in the stomach and perhaps intra-thoracic pressures as well.

CHAPTER V

SUMMARY AND CONCLUSIONS

The present study was initiated to investigate some physical attributes of the laryngectomee, in order to learn more about the process of alaryngeal speech. Testing procedures were conducted with eighteen laryngectomee subjects to determine discrete intra-esophageal pressure patterns. A tri-luminal polyvinyl tube was introduced into the subject's esophagus. Each tube had a distal opening, spatially separated by 5 cm., and each was filled with water. Esophageal pressure fluctuations registered at the tubal orifices were carried by transducers to a Sanford recorder, where they were transcribed as wave patterns. Recordings from the upper stomach region, the inferior sphincter, points along the esophageal length, the superior sphincter, and the hypopharynx were consistently measured. The intraluminal pressures were recorded at rest, during swallow maneuvers, and during esophageal phonation patterns. Data obtained from the read-out of the intraluminal pressure patterns were treated statistically in terms of differences between "better" and "poorer" alaryngeal speakers.

Findings

Within the limitations of this investigation several findings have been reached.

Esophageal Motility

Intraluminal pressure readings revealed some differences in the esophageal motility between good and poor alaryngeal speakers. However, in analyzing these results, the wave pattern representing discrete points along the esophagus must be divided into two sections, the pre-phonation and phonation periods. Using this technique, one can fairly carefully isolate intergroup differences. The better speakers tended to show more variability in performance than the poorer speakers, especially in the pre-phonation period. During this pre-phonation period, negative pressure patterns were recorded for nearly all subjects, with the better speakers presenting deeper negative deflections.

During the phonatory maneuvers, differences appeared between the two groups of speakers. The responses of poorer speakers formed a more consistent pressure wave pattern than the better speakers. Also, the pressure amplitudes for the better speakers tended to be lower during phonation.

Comparison of the approximate energy expended by the two groups revealed the better speakers to demonstrate significantly lower mean esophageal pressures. It would, therefore, seem that high intraluminal esophageal pressures

alone do not necessarily reflect an effective use of esophageal air, or that air entering the esophagus is necessarily available in producing alaryngeal speech.

Gastric Region

In terms of epigastric pressures generated during phonation, the relatively high energy output levels of poorer speakers were found to be significant. This comparatively high energy level among poorer speakers was also noted in the performance of the two groups in regard to the esophagus. It has been hypothesized that this excess of energy exhibited in these structures is responsible for the stomal noises demonstrated in some esophageal speakers.

Sphincteric Activity

The hypothesis that there is no significant difference in the patterns of intraluminal pressure between the upper and lower esophageal sphincters was supported by the present study. However, the sphincteric pressure patterns for the two speaker groups both exhibited lower mean pressures than have been previously reported in normative studies.

A study of the raw data indicates that the better speakers do not relax the lower esophageal sphincter to allow the air to enter the stomach, but eject it rostrally for speech. The same pattern did not persist for the poorer speakers. It would appear that the esophageal

speaker has modified sphincteric motility regardless of his speech abilities.

Hypopharynx

The hypothesis that there is no significant difference between the functioning of the hypopharynx in good and poor esophageal speakers--as reflected by air pressure patterns--was not supported by this study. The data revealed statistically higher pre-phonatory hypopharyngeal pressures in the better speakers than the poorer ones. These data suggest that the better speakers were building up hypopharyngeal pressures and using the injection method of air intake during the pre-phonatory period.

Selected Phonemes

No significant differences in the intraluminal pressure waves were discerned between the two groups of speakers vis-a-vis the phonation of selected phonemes. Evidence suggests that, regardless of the phoneme vocalized, the better speakers can ordinarily fill the esophagus with air and utilize it to produce speech, while the poorer speakers cannot. The only sound in the series which indicated any significant intergroup differences was [kA]. In this maneuver, however, the poorer speakers registered higher esophageal pressures than the better speakers, just the reverse of what one might expect to find.

The arbitrary use of certain phonemes in therapy is not conducive to successful esophageal speech production, as demonstrated by the present study. The intake of air does not appear to be facilitated by the use of plosives. However, other factors, such as the tension of the esophagus and its control, may affect speech proficiency.

Air Flow Patterns

Synchrony of pulmonary air flow and tracheostomal air ejection during esophageal speech has been confirmed by this study. Examination of the raw data reveals a close relationship between wave patterns produced simultaneously by the pneumograph and intraluminal pressures. Subjects apparently synchronized their respiratory mechanism with their speech mechanism, just as they had done pre-operatively. This conclusion is relevant for both groups.

Implications of the Study

1. The poorer speakers, along with other dynamics, expend considerably more energy during esophageal speech, but it is to be largely dissipated. Evidence of this air wastage appears in the apparently higher pressures found in the stomach and esophagus of poorer speakers. One explanation for this is the possibility that the poorer speakers are under more general bodily tension than the better speakers. Excessive tension could be interpreted as resulting from frustration, if all the poor speakers in this

investigation belonged to a post-operative group of considerable duration. Background information revealed that they were not.

The higher energy output level of the poorer speakers might also bear a relationship to augmented stomal noises. Such a postulate would have implications for an earlier comment on synchrony between pulmonary and esophageal air flow. Encouragement should be given to the laryngectomee, not only to maintain his former method of synchronizing respiratory air and speech production, but to perform verbally in as relaxed an atmosphere as possible. The latter status is not always easy to achieve.

2. Both groups of speakers coordinated pulmonary air flow with esophageal speech attempts, as indicated by the negative deflections in the pre-phonation period of the pressure wave. This wave pattern indicates the expansion of the esophagus during inhalation coordinated with synchronous patterns of the pneumograph read-outs. These phenomena appear to support the thesis that the laryngectomee needs to maintain pre-operative synchrony of pulmonary and speech air flow.

3. The physiologic action of the upper and lower esophageal sphincters was similar in both better and poorer speakers as compared to the normal population. These similarities obtained for sphincteric activity as well as tension exerted at the sphincters. This study suggests

that the tension of the upper esophageal sphincter in the laryngectomee is not a critical factor in his learning esophageal speech.

4. A combination of air intake methods was utilized by the better speakers in this study rather than relying on a single one. This group exhibited deeper negative prephonation deflections of their intraluminal wave patterns, indicating deeper respiratory inhalations, as well as significantly higher positive pressures in the hypopharynx during this same period. Background information revealed that all the speakers were trained in the same manner ("injection" method of esophageal air intake), although the present study suggests that the better speakers employed both the injection and inhalation methods in producing alaryngeal speech. In terms of therapy for the laryngectomees, an eclectic approach to air intake is indicated, since one method may serve some persons well, but not all.

5. The uniformity of the pressure patterns in the esophagus of the poorer speakers as compared to the relative variability among better speakers appears to indicate the responses of the poorer speakers might reflect the external mediastinal pressures exerted on the esophagus during exhalation, whereas the better speakers controlled the esophageal musculatures. The better speaker was able either to counteract the pressures of the surrounding structures or to maintain a more relaxed condition. From

this evidence the external esophageal pressures were deemed not to be a critical factor in speech production. The therapeutic aim of providing a relaxed climate for laryngectomees was reinforced. Excessive pressure evident in the poorer speakers might relate to heightened stomal noises, rather than the synchrony of pulmonary and esophageal air flow alone.

6. Important to the rationale of alaryngeal speech therapy is the finding that the ability of the esophageal speaker does not appear to depend on the phoneme being vocalized at the time of air intake. This would indicate that therapy could begin with, and employ, any phoneme, as long as the individual was capable of learning the esophageal speech method.

Future Research

The most immediate limitation of the present study was the small population employed. Consideration might be given to implementing a similar research design but utilizing a larger population. In this manner, the original five categories of speech abilities could be compared in greater detail. Similarly, had there been more subjects, they could have been divided into various stages of rehabilitation vis-a-vis the post-operative period. Subjects who were novices to esophageal speech techniques and those who were more experienced could be

examined and compared separately.

It would also be highly advantageous to initiate a long-term study. By introducing the time factor the results of the pressure measurements obtained at the initiation of speech therapy would provide a base line with which to compare periodic repetitions of the intraluminal procedures. Esophageal activity might then be contrasted with the quality of alaryngeal speech being produced at various learning stages.

Computer programming of esophageal intraluminal pressure is a theoretically significant research direction. The complexity of esophageal and para-esophageal function strongly indicates computer analysis. This technique was successfully done by Misiewicz et al. in England.¹ Synchronized video analysis, in the form of cinefluorography and audio analysis, are factors for potential inclusion in a research design.

The failure of the thermo-couple unit in the present study indicates another possibility for future research. Since this unit did not respond to the rapid elevation of the wave pattern, another thermo-couple device, such as a thermister, might be adapted, for use in sensitively

¹J. J. Misiewicz, S. L. Waller, M. J. R. Healy, and E. A. Piper, "Computer analysis of intraluminal pressure records," Brit. Med. Assoc., Gut, IX (1968), 232-236.

responding to stomal outflow.

The above physical measurements could further be enhanced by initiating detailed psychological testing of the subject. In a long-term study this testing could be done periodically in order to investigate the psychological adjustment of the laryngectomee. It is especially significant as he learns to communicate again. However, an anticipated difficulty in such a design would be to obtain accurate pre-morbid psychological data.

Summary

Relative to the present study, the following conclusions were found:

1. The poorer esophageal speakers expend significantly more energy than the better speakers during esophageal speech, especially in the stomach and esophagus.

2. No matter the level of speech proficiency demonstrated by the laryngectomy speaker, he exhibits synchrony of pulmonary and esophageal air during esophageal speech.

3. Similar action of the upper and lower esophageal sphincters exists in the laryngectomized speaker, regardless of his speech proficiency.

4. The better esophageal speaker appears to use a combination of the inhalation and injection methods for air intake.

5. The better esophageal speaker reveals great variability of esophageal performance, while the poorer speaker indicates a uniformity of performance during esophageal speech attempts.

6. No particular phoneme, or classification of phonemes, was found to be beneficial in the learning of esophageal speech.

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APPENDIX A

THE "GRANDFATHER" PARAGRAPH

You wished to know all about my grandfather. Well, he is nearly 93 years old; he dresses himself in an ancient black frock coat, usually minus several buttons; yet he still thinks as swiftly as ever. A long, flowing beard clings to his chin, giving those who observe him a pronounced feeling of the utmost respect. When he speaks, his voice is just a bit cracked and quivers a trifle. Twice each day he plays skillfully and with zest upon our small organ. Except in the winter when the ooze or snow or ice prevents, he slowly takes a short walk in the open air each day. We have often urged him to walk more and smoke less, but he always answers, "Banana oil!" Grandfather likes to be modern in his language.

APPENDIX B
 AUDIOLOGICAL EVALUATIONS
 RAW DATA (in dB)

Subject No.	Average			SRT			Speech Discrimination		
	Rt.	Lt.	Both	Rt.	Lt.	Both	Rt.	Lt.	Both
1	20	20	20	15	20	15	100	100	100
2	25	28	27	5	0	5	88	82	88
3									
Aided	35	23	29	-	-	25*	-	-	100*
Unaided	52	33	43	-	-	45*	-	-	99*
4	17	17	17	20	25	25	94	88	86
5	27	30	29	30	25	30	100	100	100
6	25	13	19	25	10	15	100	96	98
7	12	5	9	5	5	10	100	100	100
8	42	40	41	45	50	50	94	98	100
9	23	42	32	30	60	40	24	20	26
10	18	13	15	40	40	40	98	100	98
11	13	25	19	10	15	15	96	96	100
12	7	3	5	10	10	15	100	94	100
13	58	37	48	70	45	50	98	96	94
14	34	24	29	30	35	30	76	90	58
15	10	5	8	15	10	15	98	98	98
16	15	12	14	10	15	15	98	94	94
17	7	12	6	20	25	20	100	100	94
18	26	33	29	20	20	20	90	92	86

*Free field.

APPENDIX C
QUESTIONNAIRE

- I. Name:
- II. Address: Telephone:
- III. Birth date:
- IV. What is/was your occupation?
- V. Name and address of your surgeon:
- VI. Date of your operation:
- VII. At what hospital were you operated?
- VIII. What is/was the name of your Speech Therapist?

Please circle the letter next to the correct answer in the following questions.

IX. Family history

1. Are you married? a. Yes b. No
2. How long have you been married?
 - a. 11-20 years c. 31-40 years
 - b. 21-30 years d. Other _____ (specify)
3. What is your current marital status?
 - a. Wife/husband is living
 - b. Wife/husband is deceased
 - c. Divorced d. Separated
4. How many children do you have?
 - a. 1 c. 3
 - b. 2 d. More than 3

X. Surgical history

1. How old were you at the time of your operation?
 - a. 31-40 years d. 61-70 years
 - b. 41-50 years e. 71-80 years
 - c. 51-60 years f. Other _____ (specify)
2. How long was it from the diagnosis of cancer to the operation?
 - a. Less than one month c. 3-6 months
 - b. 1-2 months d. More than 6 months
3. What other type of pre-operative treatment did you receive?
 - a. x-ray b. cobalt
4. How long were you in the hospital?
 - a. Less than 2 weeks c. 5-8 weeks
 - b. 2-4 weeks d. More than 8 weeks

XI. Speech training history

1. Did you receive any counseling before the operation?
 - a. Yes b. No
2. Did you know that you would be unable to speak after the operation?
 - a. Yes b. No
3. Did you receive any speech training before the operation?
 - a. Yes b. No
4. If you did, by whom?
 - a. Surgeon d. Speech therapist
 - b. Another M.D. e. Other _____ (specify)
 - c. Laryngectomee

5. How long after your operation was speech training begun?
- a. Within 2 weeks
 - b. From 2 to 5 weeks
 - c. From 5 to 8 weeks
 - d. More than 8 weeks
6. Where did the first lessons take place?
- a. In your hospital room
 - b. In a speech clinic
 - c. In your home
 - d. Other _____ (specify)
7. Who gave you speech therapy after your operation?
- a. Surgeon
 - b. Speech clinician
 - c. Laryngectomee
 - d. Other _____ (specify)
8. How many lessons per week were you scheduled for?
- a. 1
 - b. 2
 - c. 3
 - d. 4
 - e. 5
9. Did you attend class regularly?
- a. Yes
 - b. No
10. How long was each lesson?
- a. Less than 1/2 hour
 - b. Between 1/2 and 1 hour
 - c. More than 1 hour
11. What type of lesson did you receive?
- a. Individual
 - b. Group
 - c. Combination of a and b
12. What type of communication are you using today?
- a. esophageal speech
 - b. artificial larynx
 - c. Other _____ (specify)

13. How were you taught esophageal speech?
- a. Using your tongue to trap the air
 - b. Just breathing in the air
 - c. Swallowing the air
 - d. Other _____ (specify)
14. If you are using esophageal speech, how do you speak?
- a. Using your tongue to trap the air
 - b. Just breathing in the air
 - c. Swallowing the air
 - d. Other _____ (specify)
15. Are you receiving therapy now?
- a. Yes
 - b. No.
16. If yes, how many lessons per week do you receive?
- a. 1
 - b. 2
 - c. 3
 - d. 4
 - e. 5
17. If yes, how long is each lesson?
- a. Less than 1/2 hour
 - b. From 1/2 to 1 hour
 - c. More than 1 hour
18. If you are not receiving therapy now, how long did you receive lessons?
- a. Less than 6 months
 - b. 6-12 months
 - c. 13-24 months
 - d. More than 24 months
19. What method of communication did you use immediately following your operation?
- a. Writing
 - b. Whisper
 - c. Artificial larynx
 - d. Other _____ (specify)

20. How long was it before you could say your first words after the operation?
- a. Less than 1 month
 - b. 1-2 months
 - c. 3-4 months
 - d. 5-6 months
 - e. More than 6 months
21. How long was it before you were fluent in your speech?
- a. Less than 1 month
 - b. 1-2 months
 - c. 3-4 months
 - d. 5-6 months
 - e. More than 6 months
22. How long was it before you could be understood by listeners?
- a. Less than 1 month
 - b. 1-2 months
 - c. 3-4 months
 - d. 5-6 months
 - e. More than 6 months
23. Did you withdraw from social situations because of your speech problem?
- a. Yes
 - b. No
 - c. Occasionally
24. Do you still withdraw from social situations because of your speech?
- a. Yes
 - b. No
 - c. Occasionally
25. How do you rate your present ability to speak?
- a. Excellent
 - b. Good
 - c. Fair
 - d. Poor

26. What speech situations, if any, still give you difficulty?

- a. Talking on the telephone
- b. Talking in groups--social gatherings
- c. Talking with strangers
- d. Talking with family members
- e. Talking on the job
- f. Other _____ (specify)

27. Are any of the following areas of difficulty?

- a. Smell
- b. Taste
- c. Swallowing food
- d. Coughing
- e. Sneezing
- f. Lifting heavy objects
- g. Caring for the opening in your neck
- h. Other _____ (specify)