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B. THE EFFECT OF A VELOPHARYNGEAL SHUNT UPON VOCAL TRACT DAMPING TIMES: AN ANALOG STUDY

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Abstract

Vocal fold vibration can be arrested by blocking air flow so that the transglottal pressure differential is diminished. In this study, the effect of a shunt on vocal tract damping times was studied. Very small shunts had little effect on laryngeal damping, but shunts in excess of 2 mm diameter had profound effects and vocal fold vibration was not arrested.

The internal behavior of a healthy larynx is fairly predictable from the standpoint of well established aerodynamic principals. Vocal fold vibration is dependent upon two rather easily satisfiable conditions. The vocal folds must first be adducted or at least nearly so (medial compression). If the glottal chink is narrowed to about 3 mm, a very minimal amount of air flow between the folds will set them into sustained vibration. The second condition, then, which must be met is an adequate transglottal pressure differential. Previous research by von Leden(1) and by Öhman and Lindqvist(2) has shown that a pressure drop across the vocal folds of as little as 10-20 mm of water is sufficient to maintain vocal fold vibration, although subglottal or transglottal pressure values of 8-12 cm of water(2) are commonly produced during speech production. If, during speech, certain articulation gestures such as an unvoiced bilabial or lingua-alveolar stop cause air to be impounded in the oral cavity, supraglottal air pressure will quickly reach values approximating subglottal pressure. Thus, the transglottal pressure differential is diminished and vocal fold vibration is arrested.

In previous reports(3, 4, 5) this arrest of vocal fold vibration by means of closing an air flow gate has been referred to as vocal tract damping, although from the standpoint of acoustics this is not altogether an appropriate term. The time interval between gate closure and vocal fold arrest has been called vocal tract damping time. The mechanism, of course, is not the same as arrest of vocal fold vibration produced by air flow stoppage due to the checking action(6) of the respiratory

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musculature. In this latter instance the rebound of the elastic thoracic wall and lung tissues is checked by contraction of the muscles of inhalation. In vocal tract damping, then, arrest of vocal fold vibration is due to a diminution of transglottal pressure differential, while in checking action, arrest of vocal fold vibration is the consequence of a diminution of subglottal air pressure.

A number of factors can influence the magnitude of vocal tract damping times. They include the overall dimensions of the vocal tract and compressibility of the vocal tract walls. Bulging of the pharyngeal walls and cheeks, for example, will increase damping time. However, the effectiveness of vocal tract damping is dependent upon the integrity of both the articulatory and the velopharyngeal mechanisms. An air flow shunt through a velopharyngeal port, for example, will reduce the effectiveness of vocal tract damping and vocal fold vibrations will continue for longer periods of time than they would were the velopharyngeal seal a tight one.

Vocal tract damping times have been shown to correlate very highly with perceived nasality in speech. In a population of children for example, Johnston(5) obtained a correlation of .90 between judgements of nasality and vocal tract damping times as measured by a system developed by Zemlin.

The system, shown schematically in Fig. I-B-1, is quite simple in principal and in many respects is not unlike that used by Öhman and Lindqvist(2). It consists of a valve fitted with a mouthpiece into which the subject phonates a sustained /i/ vowel at conversational pitch and effort level. Air flow and indirectly vocal intensity level, is controlled by visually monitoring an air flow meter. Laryngeal vibrations are detected at the level of the thyroid cartilage by a piezoelectric throat microphone held in place by a spring band. The microphone output, in this system, is coupled through a preamplifier to one input of a dual trace-oscilloscope which has been placed in a single 500 msec sweep mode. When, during phonation, proper vocal intensity and air flow conditions are met, the experimenter depresses the cable release on an oscilloscope camera, with a shutter speed set to 1 sec. This maneuver sinultaneously triggers the oscilloscope sweep and breaks the current to an electromagnet. This in turn releases a ball type check valve. A

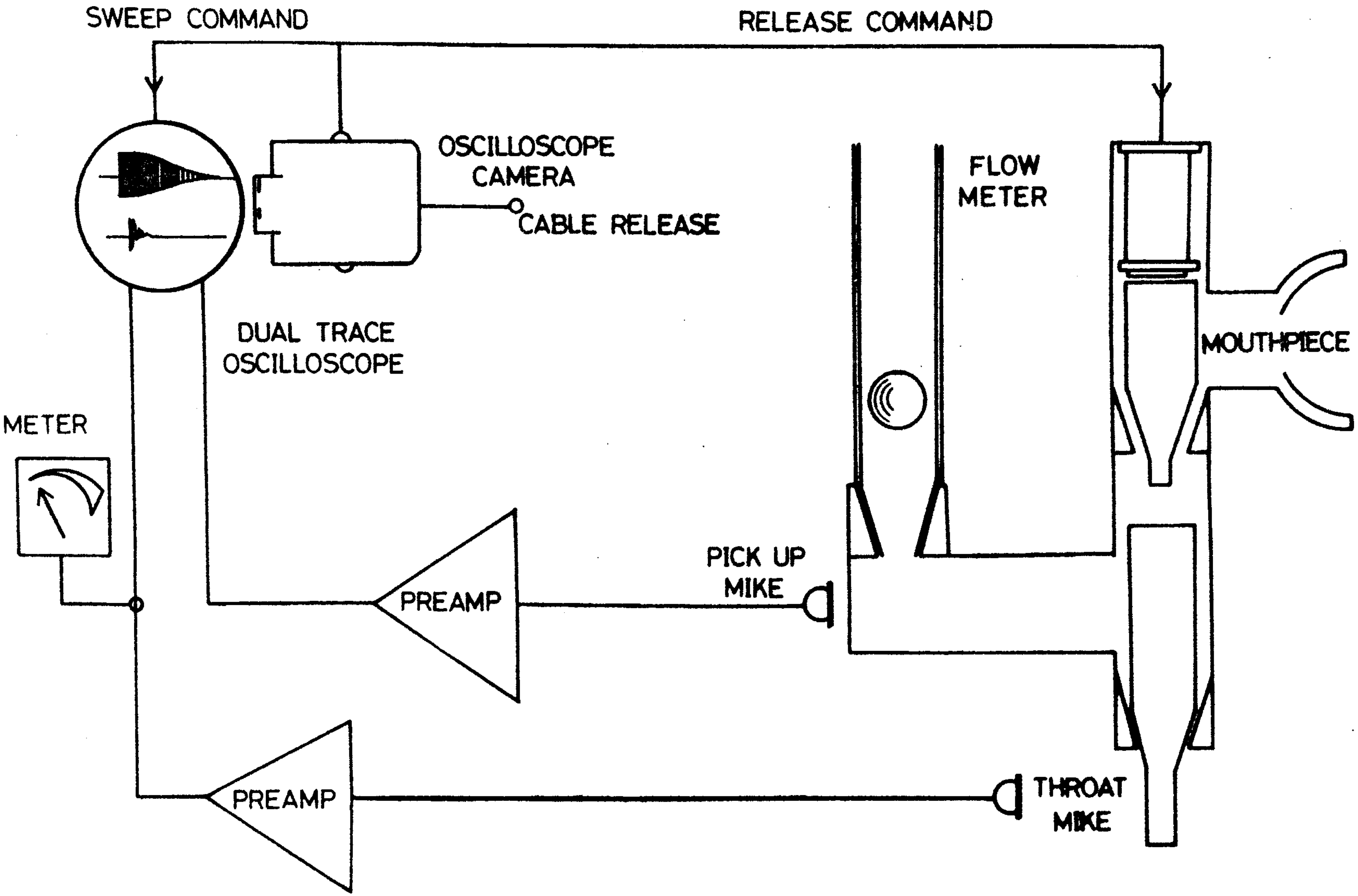


Fig. I-B-1. From University of Illinois Patent Disclosure by W.R. Zemlin.

pickup microphone, placed against the main valve body senses the mechanical contact between the ball check and the valve seat. The output of this microphone is coupled through a preamplifier to the other channel of the oscilloscope. The instant the ball check is seated, supraglottal air pressure begins to rise and within a few glottac periods (100-150 msec) approximates subglottal pressure, and vocal fold vibration is arrested. The time interval between valve closure and laryngeal arrest is taken as an index of the integrity of the velopharyngeal mechanism.

The Experiment:

The purpose of the present experiment is to introduce an artificial shunt of variable dimensions into a normal speech mechanism and to determine the effects of the shunt on vocal tract damping times and on the vibratory characteristics of the vocal folds. As shown in Fig. I-B-2, the valve was modified so that a shunt of variable dimensions could be inserted into the main body of the system. The effect of such a shunt, assuming no great differences in air flow characteristics, is the same as a palatal fistula or a small hole through the side of the cheek. The effects will also be the same as leakage through a velopharyngeal port. In the present system a shunt was variable in size from a hole 1.1 mm in diameter (.949 mm^2) to a hole 3.5 mm in diameter (9.61 mm^2). The electronics were also modified so the laryngeal vibrations from the throat microphone could be recorded on magnetic tape, along with a timing pulse which signifies closure of the check valve. A block diagram of the modified system is shown in Fig. I-B-2 and examples of damped laryngeal vibrations with a superimposed timing pulse are shown in Fig. I-B-3.

A current swith supplied energy to the valve magnet. It is operated by a remote switch which is closed by the experimenter when air flow and other conditions have been met. Closing the switch breaks current flow to the magnet for about 1 sec. At the same time a short duration pulse is delivered to both the mixer and to the lamp switch. The pulse is mixed with the audio output from the microphone preamplifier and fed into a voltage amplifier, the output of which can be fed directly into either a mingograph or any conventional AM magnetic

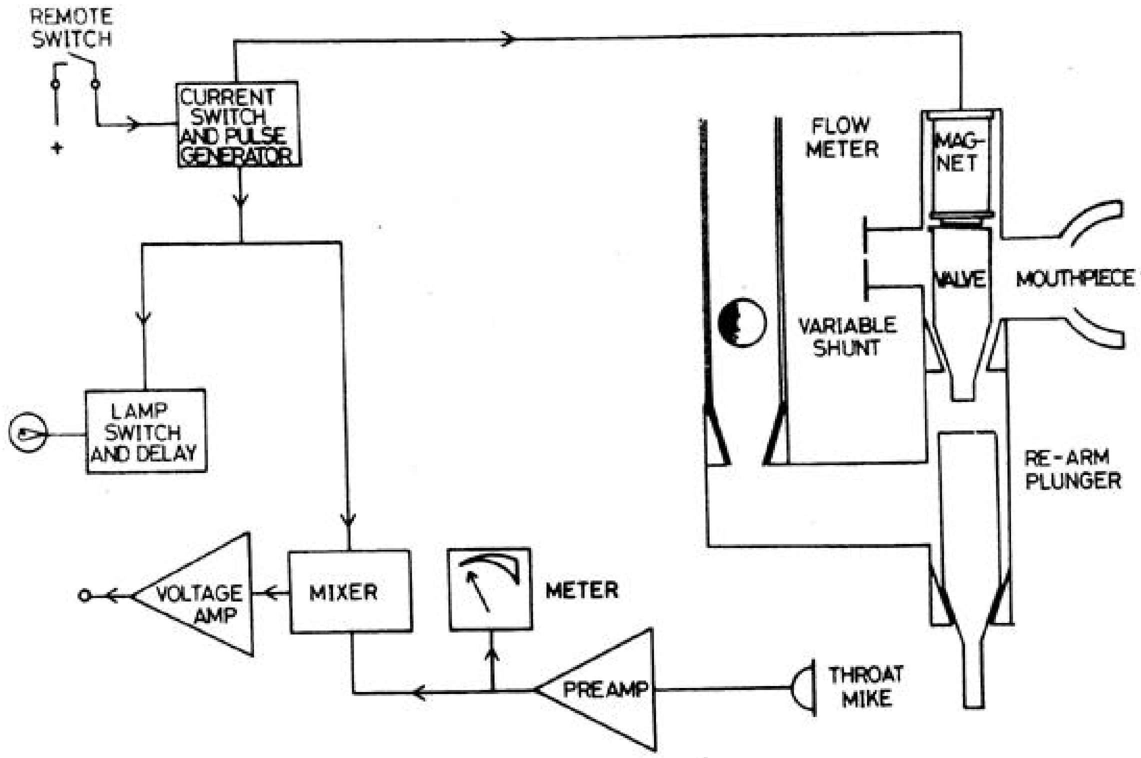
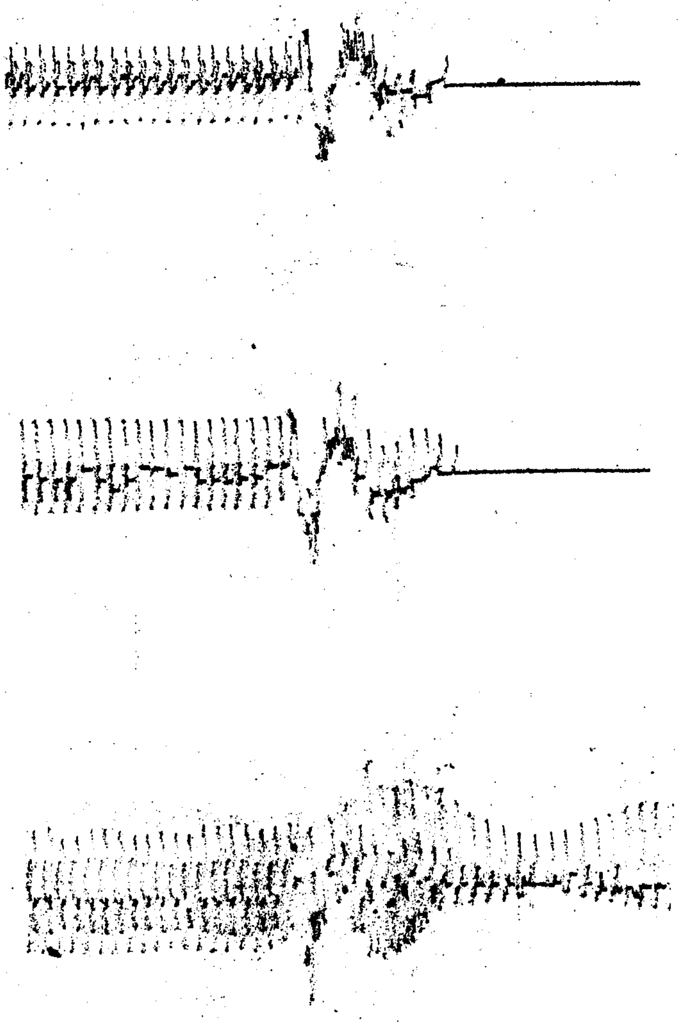

REMOTE SWITCH
+
CURRENT SWITCH AND PULSE GENERATOR
LAMP SWITCH AND DELAY
VOLTAGE AMP
MIXER
METER
PREAMP
THROAT MIKE
FLOW METER
VARIABLE SHUNT
MAG-NET
VALVE
MOUTHPIECE
RE-ARM PLUNGER

Fig. I-B-2.



NO SHUNT CONDITION

DAMPING TIME 60 MILLISECONDS

1.5 mm SHUNT CONDITION

DAMPING TIME 80 MILLISECONDS

2.0 mm SHUNT CONDITION

INCOMPLETE DAMPING

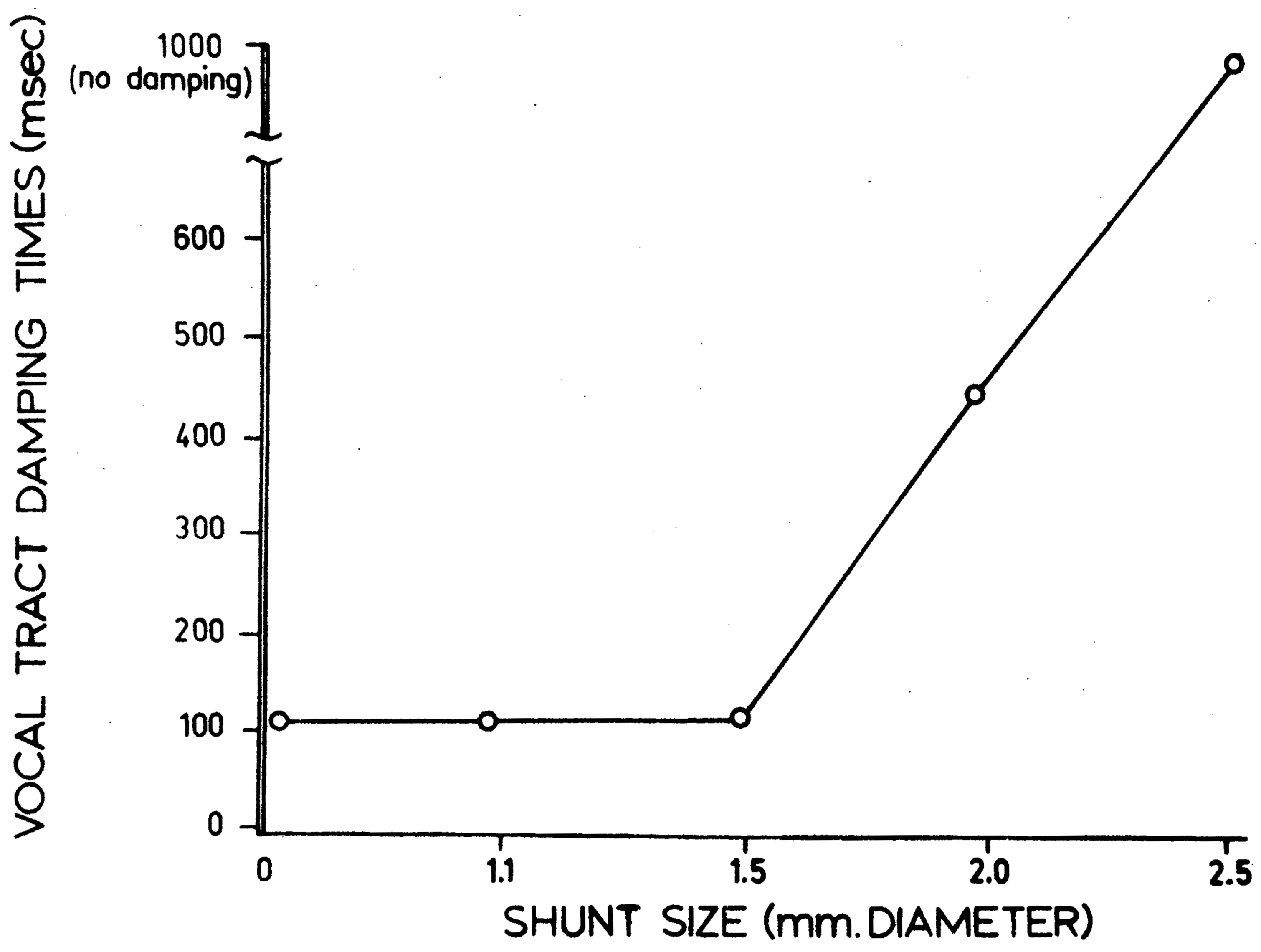
Fig. I-B-3. Examples of damped laryngeal vibrations with superimposed timing pulse.

tape recorder. The pulse which is delivered to the lamp switch also activates a timing circuit and after a delay of about 1 sec, switches off an indicator lamp as a signal to the subject to cease phonating. In actual test conditions the subject is instructed to phonate as long as the indicator lamp is lit. The lamp remains off for about 5 sec, and is automatically switched on again, only to be turned off by the arrival of an impulse from the current switch and pulse generator when the remote switch is closed by the experimenter.

The subjects for this experiment were five adults that had been judged to be free from any speech, voice, or hearing problems. They ranged in age from 29 to 43 years. Vocal tract damping times were obtained for 9 conditions, one of which was a no shunt condition. Eight additional conditions, with shunts ranging from a hole 1.1 mm in diameter to a hole 3.5 mm in diameter were also tested. The length of the shunt was about 1 mm. Order of presentation was randomized to minimize any order effect, and all conditions were presented twice. In all then, 18 measures of vocal tract damping times were obtained for each subject.

Damping time values ranged from 40 msec in the no shunt condition to an upper limit of 1000 msec, and as can be seen in Fig. I-B-4, they remained rather unaffected by the very small shunts. When the shunt size larger than 1.5 mm is placed into the system, however, damping times increase considerably, and shunts larger than 2 mm in diameter have a profound influence on the aerodynamics of the airway, to the extent the vocal tract fails to damp completely. Assuming similar air flow characteristics in the case of a small palatal fistula, compensatory laryngeal articulation would be required in order to produce unvoiced plosive sounds.

The technique of assessing the integrity of the velopharyngeal mechanism by measuring vocal tract damping times seems to have utility, especially in the clinical setting. Damping times correlate highly with judgements of nasality[5]. In this experiment it was shown that damping times also correlate with the size of a vocal tract shunt. The results, therefore, seem to have at least two implications. First, in the case of excessive nasality, vocal tract damping times may be an index of the



VOCAL TRACT DAMPING TIMES (msec)
1000
(no damping)
600
500
400
300
200
100
0
0
1.1
1.5
2.0
2.5
SHUNT SIZE (mm.DIAMETER)

Fig. I-B-4

physical dimensions of a velopharyngeal shunt, or leak, and second, damping times may prove to have predictive value in uncovering velopharyngeal incompetence which might otherwise be unmasked by surgical removal of adenoid tissue. An experiment which relates to these clinical problems is presently being conducted and will be included in a later report.

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