

LIBRARY

NAV1.950601.001b

SMKL-U

MEDICAL RESEARCH LABORATORY MEDICAL RESEARCH LABORATORY REPORT NO. 96

ACCESSION

MEDICAL RESEARCH DEPARTMENT



**U. S. Submarine Base
New London**

Vol. 5, No. 13

AEROTITIS MEDIA IN SUBMARINERS

Interval Report No. 1
on
Bureau of Medicine and Surgery
Research Division Project
X-434 (Sub No. 90)

Lt. (jg) Henry L. Haines, (MCS), USNR
Lt. (jg) J. Donald Harris, H(S), USNR

18 February 1946

APPROVED: Captain C. W. Shilling, (MC), USN
Medical Officer in Charge

LIBRARY

MEDICAL RESEARCH LABORATORY

ACCESSION

AEROTITIS MEDIA IN SUBMARINERS

Interval Report No. 1
Bureau of Medicine and Surgery
Research Division Project
X-434 (Sub No. 90)
"Aerotitis Media Among Submariners -
Prevention and Treatment", Section A

Prepared by

Lt. (jg) Henry L. Haines, (MCS), USNR
Lt. (jg) J. Donald Harris, H(S), USNR

18 February 1946

APPROVED: Captain C. W. Shilling, (MC), USN
Medical Officer in Charge
Medical Research Department
U. S. Submarine Base
New London, Connecticut

Aerotitis Media in Submariners *

Table of Contents

	<u>Page</u>
Summary and Conclusions	1
Definition of Aerotitis Media	4
History of the Problem	5
Purpose of the Experiment	6
Anatomy	7
The Effect of Pressure on the Normal Functioning of the Eustachian Tube	9
Etiology and Symptomatology	11
Experimental Design	14
1. Summary	14
2. Subjects	14
3. Prepressure examination	15
4. Conditions of Administration of Pressure	22
5. Postpressure examination	23
6. Control and Experimental Groups	23
a. psychological	23
b. symptomatic	24
c. x-ray	24
d. radium	24
Results	25
1. Volume of Work	25
2. The Effect of Weather	27
3. The Effect of Intelligence ...	33
4. Prediction	35

* This article in substantially its present form is shortly to appear in the ANNALS OF OTOLGY, RHINOLOGY, AND LARINGOLOGY.

	<u>Page</u>
a. objective cold	35
b. size of adenoids	36
c. appearance of Eustachian tube	39
d. ability in Valsalva	42
e. previous experience with pressure	44
f. discussion and conclusions of prediction experiments	45
 5. Therapy	 49
a. dental	49
b. radium	49
c. x-ray	52
d. topical	52
e. psychological	54
f. discussion and conclusions	55
 6. Effect on Absolute Threshold	 56
a. history	56
b. the factor of pain	59
c. the effect of rupturing the eardrum	62
d. the factor of grade of damage	62
e. the No. 5 category of damage	64
f. discussion and conclusions on acuity	67
 References	 72

Figures

	<u>Page</u>
1. The Nasopharyngoscope.	16
2. The Nasopharyngoscope in Use.	17
3. Normal Opening of Eustachian Tube seen through the Nasopharyngoscope.	18
4. Submarine Escape Training Tank.	19
5. Radium-containing Applicator.	20
6. Applicator in Place against Eustachian Tube: Seen through the Nasopharyngoscope.	21
7. Subject with Radium Applicators in Place.	26
8. Incidence of Pressure Failures and of Aerotitis Media.	28
9. Showing Lack of Correspondence between Temperature, Pressure, and Incidence of Aerotitis Media.	29
10. Day-by-day Percentage of Pressure Failures for January 1945.	31
11. Day-by-day Percentage of Pressure Failures for July 1945.	32
12. Relation of Intelligence to Ability to Pass Pressure Test.	34
13. Ear Damage as Related to Size of Adenoids.	37
14. Showing Lack of Precise Relationship between Size of Adenoids and Severity of Aerotitis Media.	38

	<u>Page</u>
15. Ear Damage as Related to Condition of Eustachian Tube.	40
16. Showing Lack of Precise Relationship between Appearance of Eustachian Tube and Severity of Aerotitis Media.	41
17. Effect of Radium Therapy on Incidence of Aerotitis Media.	46
18. Frequency Distributions of Ear Damage following Successive Radium Treatments.	51
19. Ear Damage as Related to Number of Radium Treatments.	53
20. Acuity Loss for Subjects Reporting Pain.	60
21. Distribution of Audiogram Changes of 154 Men with no Pain.	61
22. Distribution of Audiogram Changes of 29 Men Reporting Pain.	63
23. Composite Postpressure Audiogram for No. 4 Ears.	65
24. Showing Improvement in Acuity for a No. 4 Ear.	66
25. Comparing Difference Audiograms for No. 4 and No. 5 Ears.	68
26. Sample Case of Severe Loss for No. 5 Ear.	69

Summary and Conclusions.

1. Aerotitis media is the name given to a syndrome characterized by otopathology, particularly vascular rupture and separating of tissue layers, caused by a differential barometric pressure across the eardrum. A description of aerotitis media is given, together with a discussion of anatomy and etiology.

2. An experiment was performed in an attempt to discover the causes and effects of the disorder, and to find the best means of prediction, prevention, and treatment. In the course of this experiment 6,149 submariners were subjected to 50# positive pressure in a dry recompression chamber. They were examined minutely both before and after pressure by means of the otoscope, the nasopharyngoscope, and the pure tone audiometer, and all pertinent data was recorded.

3. A large group of men not contracting aerotitis media in the pressure chamber was required to undergo a second pressure test. Another group which did contract aerotitis media was likewise required to undergo a second pressure test after their otopathology had subsided; this group received no treatment whatever. These two groups served as control for 5 experimental groups given different types of treatment as follows: psychological, topical, x-ray, radium, and dental. The types of treatment were all based on some rationale designed to assist the men in successfully taking pressure in the future.

4. Psychological treatment included additional motivation and encouragement, the use of chewing gum, and the use of music. None of these things reduced the incidence of aerotitis media on subsequent pressure tests.

5. Topical treatment consisted of 1/4% neosynephrine in normal saline, applied locally for several hours before pressure. No effect was noted.

6. X-ray therapy was discontinued for administrative reasons and our results are inconclusive.

7. Radium therapy consisted in the application of a monel metal cylinder 2 cm long, outside diameter 2.3 mm, with walls .3 mm thick, containing 50 mg of radium salt, to the pharyngeal orifice of the Eustachian tube for 8-10 minutes. This dose is effective, after 3-6 treatments separated by a month, in reducing excessive hyperplastic lymphoid tissue around the opening of the tube, thus permitting many men formerly unable voluntarily to open the tube now to do so, and consequently to become able to sustain pressure without contracting aerotitis media. The treatment, where indicated, is effective in well over 90% of cases.

8. Dental therapy was investigated in several score of cases where improper jaw motion was suspected of hindering normal operation of the Eustachian tube. Very good success in these cases was achieved by Dr. William J. Kelly, (DC), USNR, who has reported his findings elsewhere.

9. No very efficient method was found to predict whether a man would contract aerotitis media. Positive correlations were indeed obtained with appearance of Eustachian tubes, whether open, flat, closed, or covered, and with size of adenoids; but the magnitude of the relationship did not permit of good prediction in individual cases.

10. It was found that pain is not a good indicator either of grade of damage to the ear or of the loss of auditory acuity.

11. Rupturing the eardrum was found to produce a loss in acuity of 5-10 db.

12. Almost no effect on acuity could be found as a result of aerotitis media unless the middle ear was filled with free blood. Deafness among submariners is thus seen to be caused more by damping of the ossicles than by otopathology.

13. Discussion is given throughout on the differences of pressure conditions and results of aerotitis media between the Submarine Service and the Air Forces.

Aerotitis Media in Submariners*

Definition.

Aerotitis media is the name given to a syndrome characterized by pathological changes in the middle ear as a result of failure to equalize differential pressure across the eardrum. There may be discomfort or even pain, bleeding, tinnitus, vertigo, and deafness. All grades of severity exist, from slight congestion to extensive rupture of tissue. The syndrome has an acute and in some individuals a chronic aspect. Various names have been given to it, aerotitis, otitic barotrauma, salpingotympanitis, and aviator's ear among others. We prefer the term aerotitis media since it indicates at once the etiology, nature, and locus of the disorder.

* The outline of this study was conceived largely by Captain C. W. Shilling, (MC), USN, to whom we are indebted for many suggestions and for providing all necessary facilities.

History.

Before World War I, only sporadic accounts of ear damage under conditions of changing pressure appeared. There are antique accounts of disorders in pearl divers of the Orient, and of ballooners even before the Wrights. Beaven(2) and Campbell(4) have given much of this early history, mentioning a case of aerotitis media described by Pilatre de Rozier in 1783 after descent from a balloon journey, and giving Glarsher and Coxwell's description of the symptoms in 1862.

Shilling and Everley(18) have recounted the history of aerotitis media particularly as seen in divers, salvage workers, caisson workers, and submariners. Requarth(15) contributed to the literature on pressure effects on caisson workers, particularly the treatment of caisson disease with helium and oxygen mixtures.

Accelerated research on aerotitis media has kept pace with its growing seriousness as a result of the great increase in high altitude flight during World War II. In 1941 Poppin(13) considered aerotitis media as seen in flying personnel. The use of radon in treatment of aerotitis media began with Fowler(8) who treated successfully many cases in the RAF by the Crowe and Burnam technique. The U. S. Army Air Forces soon thereafter launched a major attack on the problem, of which a report will shortly appear.

The work of the present paper stems from the investigations of Shilling and Everley(18) who saw that the air forces would experience difficulty with aerotitis media, and from the later investigations of Teed(20) who discussed the factors producing obstruction of the Eustachian tubes in submariners.

Preliminary accounts of our work have already appeared(9, 10).

Purpose of the Experiment.

In the past few years the problem of aerotitis media has assumed serious proportions, with the increase of high-altitude flying and of diving and salvage operations, and the large expansion of the Submarine Service, the men engaging in these activities being subjected routinely to extreme pressure changes. In the case of submariners, exposure to pressure changes comes only upon the use of the escape apparatus, and in the training tank by which the men are instructed in the proper use of the escape hatch. Aerotitis media is now a recognized occupational injury, both in and out of the Armed Forces. A number of centers both here and abroad have been active in studying the condition with a view to its prevention and cure. Our own activity was selected by the Bureau of Medicine and Surgery, U. S. Navy, as the Navy center best suited to do this particular research. In the first place, Captain C. W. Shilling, (MC), USN, the Officer-in-Charge of the Medical Research Laboratory, was one of the Navy's authorities on the physiology of pressure. We had a well-equipped Sound Laboratory staffed with an otologist, a psychologist trained in audition, with technical and statistical assistants, and we had access to several hundred men a month who were required to undergo a severe pressure test. Moreover, any of these men could be held for observation and treatment as long as seemed necessary.

In view of the incomplete and often confusing statements which have been made on various aspects of the syndrome, there was felt a necessity for especial care in experimental design and in the application of control procedures. Merely another clinical study would not meet the need. Because of our favorable position we were able to meet rigorous

research criteria. However, in our desire to satisfy exacting scientific demands, we did not wish to lose sight of the practical importance of the work. Specifically, it was hoped that the relatively high incidence of aerotitis media among submariners could be reduced considerably by means of better methods of selecting personnel, and by better techniques of administering pressure; and that the cases of aerotitis media which did occur could be alleviated and cured more quickly by improved therapy. It was hoped furthermore that some treatment could be developed the results of which would be of a permanent nature so that an individual could repeatedly sustain pressure without difficulty in the future.

Since we had a rich source of clinical material, and since every condition necessary for rigid experimental control was made available, we felt it possible to provide a fairly definitive study on the causes, effects, prediction, and treatment of the disorder. The present report describes aerotitis media as it appears in submariners, and recounts the experiments by which we attempted to understand it and to mitigate its effects.

Anatomy.*

Inasmuch as it is an abnormal functioning of the Eustachian tube which is the inciting cause of aerotitis media, its anatomy should be described. The tube consists of a bony and a cartilaginous part. The bony part is roughly a flattened funnel in shape, is about 12 mm long, and arises from the upper part of the anterior wall of the tympanic cavity. Its mucous membrane, which lies close to the bone, is covered with ciliated epithelium. The bony part passes downward, forward, and medially, and joins the cartilaginous part without a definite line of demarcation. The juncture is known as the isthmus, and is the narrowest part of the tube.

* For much of the anatomy and for many helpful suggestions throughout we are indebted to Dr. Stacy Guild, Johns Hopkins Medical School.

The cartilaginous portion is about 24 mm long from the isthmus to its opening high up on the lateral wall of the nasopharynx. Its size increases as the pharynx is approached, but normally its walls are apposed and it remains a vertical slit-like potential tube unless opened by action of voluntary muscles or forced open by positive pressure in the middle ear. It is lined with columnar ciliated epithelium on a loose stroma containing mucous glands and diffuse lymphoid tissue (7). The cilia create a current toward the nasopharynx, thus helping to drain the middle ear. The lymphoid tissue near the mouth of the tube is known as the tubal, or Gerlach's, tonsil. This should not be confounded with the lymphoid tissue in the fossa of Rosenmueller, the part of the nasopharynx behind the torus tubarius of the pharyngeal opening of the Eustachian tube.

The end of the tube, the pharyngeal ostium, acts as a flutter valve in that as a result of its contour it opens easily to allow the escape of air under pressure in the middle ear, and yet unless opened voluntarily it prevents passage of air into the middle ear.

Of the muscles near the Eustachian tube, the tensor veli palatini is the most important in opening the lumen (16).

The Effect of Change of Pressure on the Normal Functioning of the Eustachian Tube.

An individual is subjected to a change of ambient air pressure whenever he goes from a more dense to a less dense atmosphere, or



Fig. **A**. Eustachian tube in relation to the nasopharynx.
 (1) eustachian tube, (2) adenoidal tissue, (3) nasopharynx.

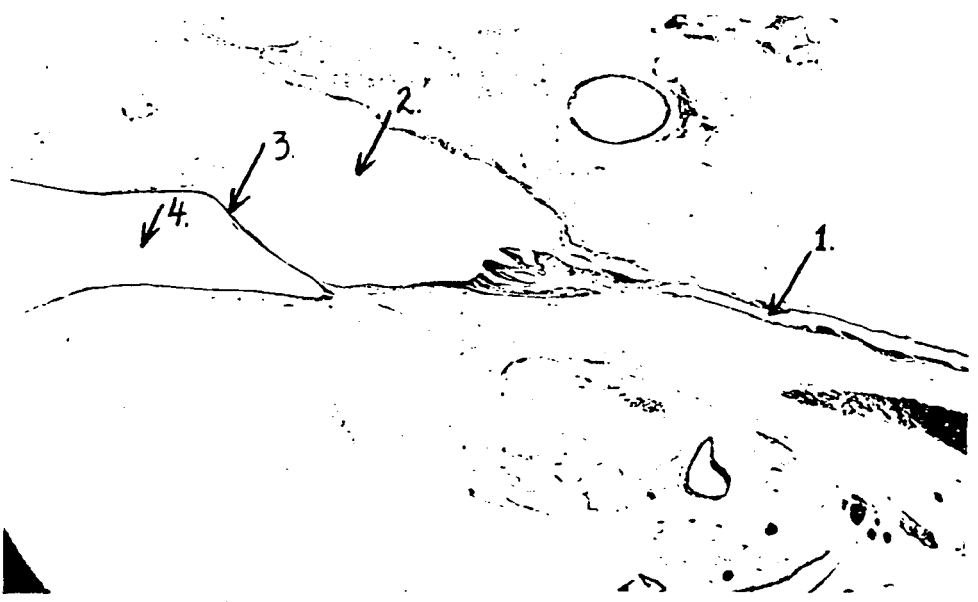


Fig. **B**. Eustachian tube in relation to the middle ear.
 (1) eustachian tube, (2) middle ear, (3) tympanic membrane,
 (4) external ear.

(Pictures courtesy U. S. Army Medical Museum No. 82362 & 82637)

conversely from a less to a more dense atmosphere. Since the Eustachian tube is normally closed, entrapping the air in the middle ear, it follows that with a change in ambient air pressure there results a pressure difference across the eardrum.

If the ambient air pressure is decreasing, the relative pressure of the entrapped air in the middle ear builds up until it is about 15 mm of Hg. (see footnote) greater than that of the air in the nasopharynx, at which time the Eustachian tube is forced open and enough air escapes from the tympanum to equalize the pressure across the eardrum. As the ambient air pressure continues to decrease, the relative pressure in the tympanum again increases to 15 mm whereupon more air escapes; and so on. We have found it rare for an individual to experience difficulty with this automatic process.

On the other hand, if the ambient air pressure is increasing, the mechanical effect of the differential pressure is not exerted to open the Eustachian tube--rather it is exerted to keep the tube closed. If pressure is to be equalized, the Eustachian tube must be opened by action of its muscles. If the tube is not opened by some means, a rather definite series of events will occur. Under increasing ambient air pressure a sense of fullness develops in the ears at a pressure of 3-5 mm. Discomfort is noted if the pressure is allowed to increase to 15-30 mm. Here there

Footnote: This figure is for sea level air density. All pressure readings in mm must take density into account. We have seen an electric fan, running rapidly at sea level, almost stop as a result of the extra load when the air pressure was raised to 3.4 Atmospheres.

is diminished hearing as a result of retraction of the eardrum and consequent telescoping of the ossicles. Above 30 mm pressure there may be pain, tinnitus, bleeding, and even vertigo and nausea. Pressures of 80-90 mm give great pain, and the severity of all symptoms increases.

At any time during the increase up to 80-90 mm, the Eustachian tube can be opened by any of a wide variety of actions--swallowing, yawning, sneezing, screaming, contracting the throat, or forced expiration while holding the nose (the Valsalva maneuver). Most experienced divers and flyers have learned favorite ways of "clearing" their ears. If this is done from time to time while the pressure is increasing, no symptomatology need appear and the subject will be able to sustain great amounts of pressure without contracting aerotitis media. It is only when something goes wrong with the intermittent equalization process that the typical syndrome appears.

A relative pressure of 80-90 mm acting against the pharyngeal opening of the Eustachian tube is, however, usually above that which the tubal muscles can overcome, whereupon with any increase in pressure the tube becomes "locked"--the walls are pressed so tightly that the muscular reflexes which normally open the tube are unable to exert their usual effect, and the pressure must be reduced before equalization can occur. When the pressure difference reaches 150-540 mm, rupture of the eardrum will result.

Etiology and Symptomatology.

Most persons are able to inflate the middle ear at will. Many persons, however, are not able to do so voluntarily, usually because of some obstruction of the Eustachian tube. There

may be colds, with infection of the lymphoid tissue underlying the epithelium so that the lumen is entirely closed, or there may be sufficient excess tissue to block the tube even with no infection. There may be other types of congestion, or there may be paralysis or atypical functioning of the tubal dilator muscles.

But even with subjects who can ordinarily inflate the middle ear voluntarily, there may be occasions when it becomes impossible, as during periods of sleep (babies in airplanes are particularly susceptible) or of unconsciousness, or during the condition of "locked" tube as described above. The element of rate of pressure change must also be considered--that is to say, a subject may be able to maintain equal pressure across the eardrum at one rate of change, but be unable to accomplish this if the rate is increased.

With an individual unable to inflate the tympanum, or unable to do so with sufficient speed, a series of pathological events may occur in the tissues of the middle ear whenever pressure is administered. These events are characterized by vascular rupture and by the pulling apart or separating of tissue layers.

The immediate cause of the otopathology appears to lie in a pressure differential between the entrapped air in the tympanum, and a component of ambient air pressure transmitted to and expressed in the tissues involved. When this occurs, so that for example within a capillary or arteriole the pressure is greater than in the surrounding air, the vessel will expand and may rupture, allowing free blood and serum to escape. The same "suction" effect may cause the outer layer or layers of certain tissues to be pulled loose. The eardrum layers may for example become separated in this manner.

We have followed Teed(20) in describing and grading the symptomatology of aerotitis media. A perfectly normal ear is described as No. 0. An ear showing some congestion in Shrapnell's membrane and along the handle of the malleus is described No. 1. Retraction and an extensive and fiery red congestion of the entire drum and tympanum characterizes a No. 2 ear. A No. 3 ear exhibits the same symptoms as No. 2 but in addition there is evidence of ruptured vessels in the drum. A No. 4 ear is characterized by extensive vascular rupture, with bleeding in the middle ear and from the Eustachian tube. There may be dissecting hemorrhages in the layers of the eardrum. The eardrum may actually be ruptured or there may be bleb formation in the canal. The whole middle ear may become filled with blood mixed with air, or filled with blood alone, in which case the drum appears purple or black. These last cases we have termed No. 5 ears because of a differential effect on acuity.

In addition to the objective description with the use of the otoscope and nasopharyngoscope, a number of other observations are of importance. A few patients develop vertigo and nausea. Commonly, pain occurs radiating down the side of the face to the throat, or it may be deep-seated in the ear. Sometimes it is rather mild, and a ruptured drum may occur before the patient feels more than a transitory needle-like pain. Often there is tinnitus, usually a roaring noise. Stiffness and "dullness" of the ears is common--many patients state that it seems they were talking "with their head in a bucket." Many complain of reduced auditory acuity, though we have found their subjective feeling of deafness is not always to be trusted.

These subjective symptoms may be found in varying degrees in all grades of damage according to the graded scale. However, no very close correlation can be drawn between, for example, pain and grade of damage. It has proved to us much more satisfactory to rely upon the objective data we were able to obtain.

Experimental Design.

1. Summary.

Over six thousand men were exposed to 50 lbs. positive air pressure. Their whole auditory systems were carefully examined before and after pressure. Those who contracted aerotitis media were selected for special observation and treatment. A study was made of mechanical and pathological factors possibly contributing to the appearance of the disorder. The effect of aerotitis media upon acuity was determined. Finally, the effectiveness was investigated of 5 different types of treatment, dental, by x-ray, by radium, topical, and psychological. For each type of treatment one or more control groups was studied simultaneously with the experimental group.

2. Subjects.

All men used in this study were young, healthy males, averaging in the early twenties, with an IQ of 95 or higher. Very few had any previous experience in taking pressure, although in this report both experienced and inexperienced men are included. All had passed on the preceding day a rigorous physical and psychiatric examination for entrance to the Submarine Service, the most highly selected group of enlisted men in the country.

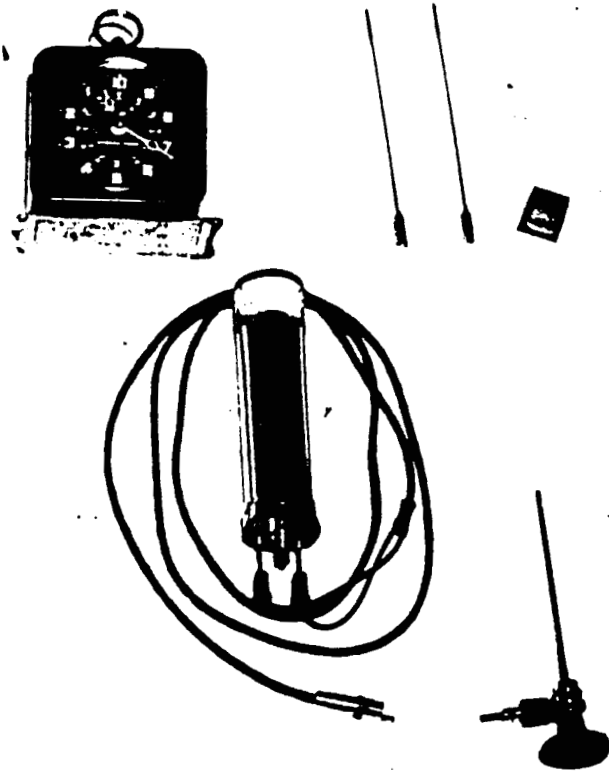
A relatively high state of motivation exists generally; they are 100% volunteers. A number of inducements are offered to prospective candidates: the men receive 50% extra base pay, they are indoctrinated as to the importance of submarine warfare, living conditions are excellent with respect to food, officer-enlisted man relations, and shipboard morale; lastly, it is known that the pressure test must be passed before entrance to the Submarine Service.

3. Prepressure Examination.

On the day before pressure, each man received a pure tone audiogram at the 6 octaves 256-8192 c.p.s. This was administered by a well-trained audiometrician using a Western Electric 6B machine in a soundproof anechoic chamber. Attenuation of outside noise in this chamber is over 90 db.

Each man received a careful examination with an otoscope, the condition of his ears being made a matter of detailed record. In addition, each man received an examination with the nasopharyngoscope (see Fig. 1).* This instrument provides a view of the entire nasopharynx. We have found that it may be inserted along the floor of the nose without, in the vast majority of cases, any preliminary anesthesia or astringent. Fig. 2 shows the instrument in use. Fig. 6 shows the tip of the nasopharyngoscope in place against the nasopharynx, while Fig. 3 shows a normal Eustachian tube opening as seen through the instrument. Figs. 3 and 6 were taken by a camera specially fitted to a nasopharyngoscope.

* For Figs. 1, 3, and 6 we are indebted to Captain John Hendricks, MC, AUS, Westover Field, Massachusetts.



Shows Nasopharyngoscope with Appliances

Fig. 1

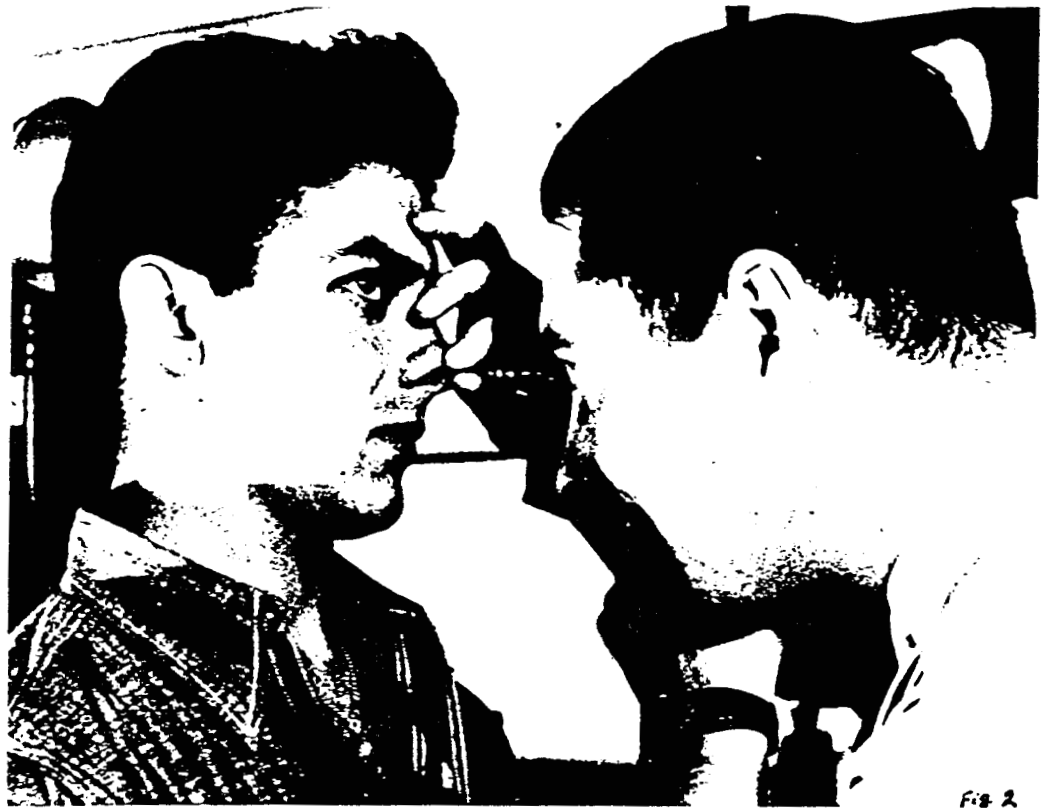
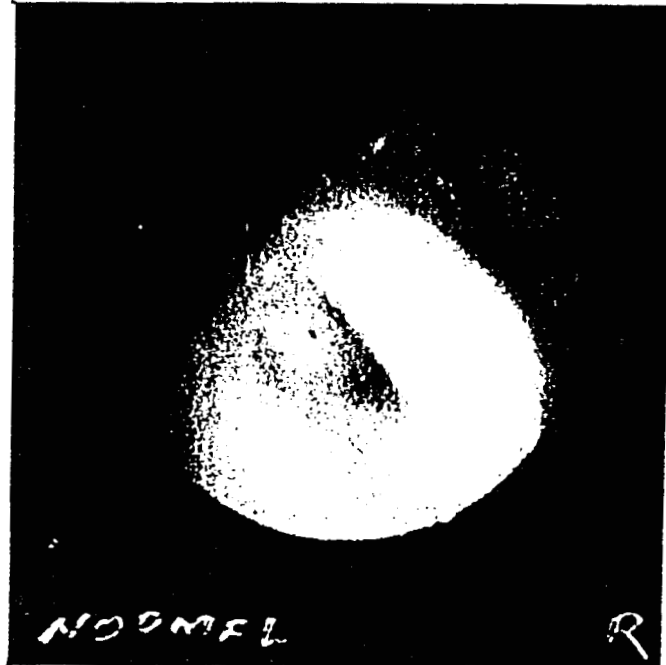


Fig. 2

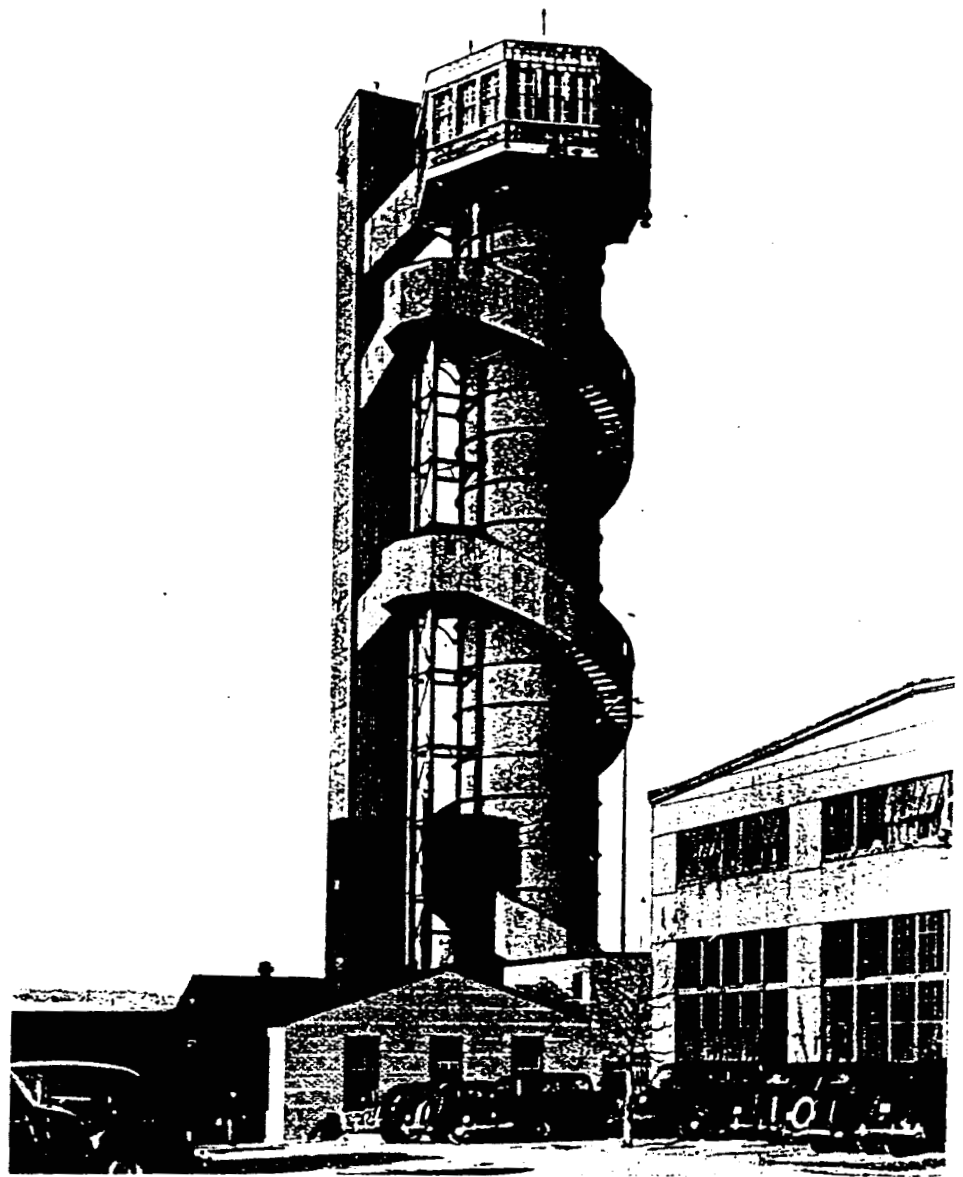
The Nasopharyngoscope in Use

Fig. 2



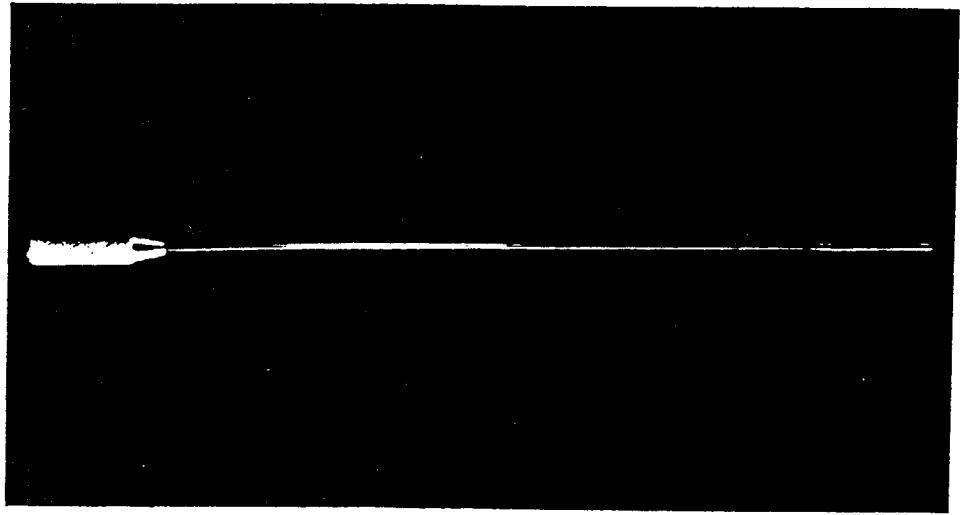
Opening of Normal Eustachian Tube
Seen through the Nasopharyngoscope

Fig. 3



The Submarine Escape Training Tank

Fig. 4



Radium-Containing Applicator

Fig. 5



Applicator in Place against Eustachian Tube:
Seen through the Nasopharyngoscope

Fig. 6

With the use of this instrument the Eustachian tubes were labelled "open", "flat", "closed", or "covered", and the adenoids were listed on a 5-point scale from "small" to "enormous". Any unusual conditions, such as congestion or plugs, were noted. In addition, the presence or absence of colds was ascertained by objective means. Those who had severe colds, or for some other reason it was thought they would be unable to take pressure, were excused from doing so until their trouble was corrected. There were, for example, a few men with psychological disturbances arising from the imminence of a pressure test. When all men had been thoroughly examined and selected, they were sent for a pressure test.

4. Conditions of Administration of Pressure.

The Submarine Escape Training Tank (see Fig. 4) is a tower containing a column of fresh, clear water 25 feet in diameter and 100 feet deep. Escape hatches are located at depths of 18, 50, and 100 feet. The hatches are constructed in a manner similar to the escape hatch of a submarine. Men are required to enter a hatch, submit to a pressure increase appropriate to the depth of the hatch, don a Submarine Escape Appliance, or "lung", pass from the hatch to the water, and ascend to the surface.

As a preliminary check on the ability of the men to undergo the pressures involved in these hatch escapes, they are first required to enter a dry recompression chamber where they are subjected to 50 lbs. (3.4 Atmospheres) pressure in from 8-10 minutes depending on the trouble experienced by individuals in any particular group. If a man is in such pain that he cannot continue, he is "locked" out of the chamber and excused from that day's pressure test. Fifty pounds pressure is as much as the men will need in the course of their

escape training, and it is with the dry recompression phase only that this experiment deals.

5. Postpressure Examination.

Immediately upon completion of the dry pressure test each man was examined carefully with the otoscope. Every ear was assigned a grade of damage according to the graded system. Several hundred men were given a postpressure audiogram. At the sign of any otopathology in a particular ear, that man was carefully examined with the nasopharyngoscope. A daily log was kept with descriptions of all ears suffering damage. These protocols could then be compared with those on the same men from the prepressure examination.

6. Control and Experimental Groups.

Of those not contracting aerotitis media, a group was required after the lapse of a week to take pressure a second time as a normal control procedure. In this as with all other groups, the percent of those failing to complete the test, the percent of those contracting aerotitis media, and the average grade of damage, were carefully noted and made the basis for group-to-group comparison.

Of those contracting aerotitis media, a control group was required after the lapse of a week to take pressure a second time, no therapy whatsoever having been given in the interim. Of the others exhibiting the syndrome, men were assigned at random to experimental groups for treatment as follows:

a. psychological

This sort of treatment consisted of personal assurance that in 10 days, or less, his ears would heal and he would experience no

difficulty a second time. He was subsequently instructed again in the Valsalva maneuver and given a second pressure test, the otologist usually present in the chamber for individual example and instruction.

For a period, alternate groups were presented with band music during pressure. It was supposed that the rhythm or the relaxation induced would be of benefit. Again, with certain groups half of the number were given chewing gum to masticate during pressure.

b. symptomatic

Every two hours for 6-8 hours before a second pressure test, individuals with symptoms of aerotitis media were instructed to apply drops of 1/4% neosynepine in normal saline to the nose.

c. x-ray

A random sample of those exhibiting severe otopathology were to be exposed to an appropriate dose of x-rays in an attempt to shrink certain tissues. As described below, it became impossible to make more than a start with this type of therapy.

d. radium

A random sample was selected from those men with otopathology who had exhibited excessive lymphoid tissue in and about the orifice of the Eustachian tube and in the fossa of Rosenmuller. With a small monel metal applicator, radium was applied to the orifice of the Eustachian tube according to Crowe's and Burnam's technique, but without anesthetic(6). Fifty milligrams of radium salt were applied once a month for 8-10 minutes to each side of the nasopharynx.

Fig. 5 shows a radium applicator. It is a hollow monel metal chamber 2 cm long containing the radium. It has an outside diameter of 2.3 mm, and an inside diameter of 1.7 mm. The walls are .3 mm thick. This cylinder is brazed to a wire by which it is handled. With the patient on his back, the applicator is passed slowly along the floor of the nose following the same pathway as the nasopharyngoscope, until the middle of the radium chamber touches the orifice of the Eustachian tube. (The correct depth can be determined by inserting a nasopharyngoscope in one side and a dummy applicator in the other). A similar radium applicator is then placed in contact with the orifice of the other tube, and a clamp is placed over the handles of the applicators in such a way that the inner tips are forced outward against the tissues it is desired to shrink. Fig. 7 shows a subject with the two applicators in place.

Successive radium treatments were given to individuals at intervals of about a month. One group was required to take a pressure test after every treatment, others were required to wait until a course of 3 or 4 treatments was completed.

Results:

1. Volume of work.

Since the official date of the start of this project, August 9, 1944, a total of 6,149 men have been examined before and after the 50# dry pressure test. This includes otoscopy in all cases, and nasopharyngoscopy and audiometry in all but a few cases.



Subject with Radium Applicators in Place

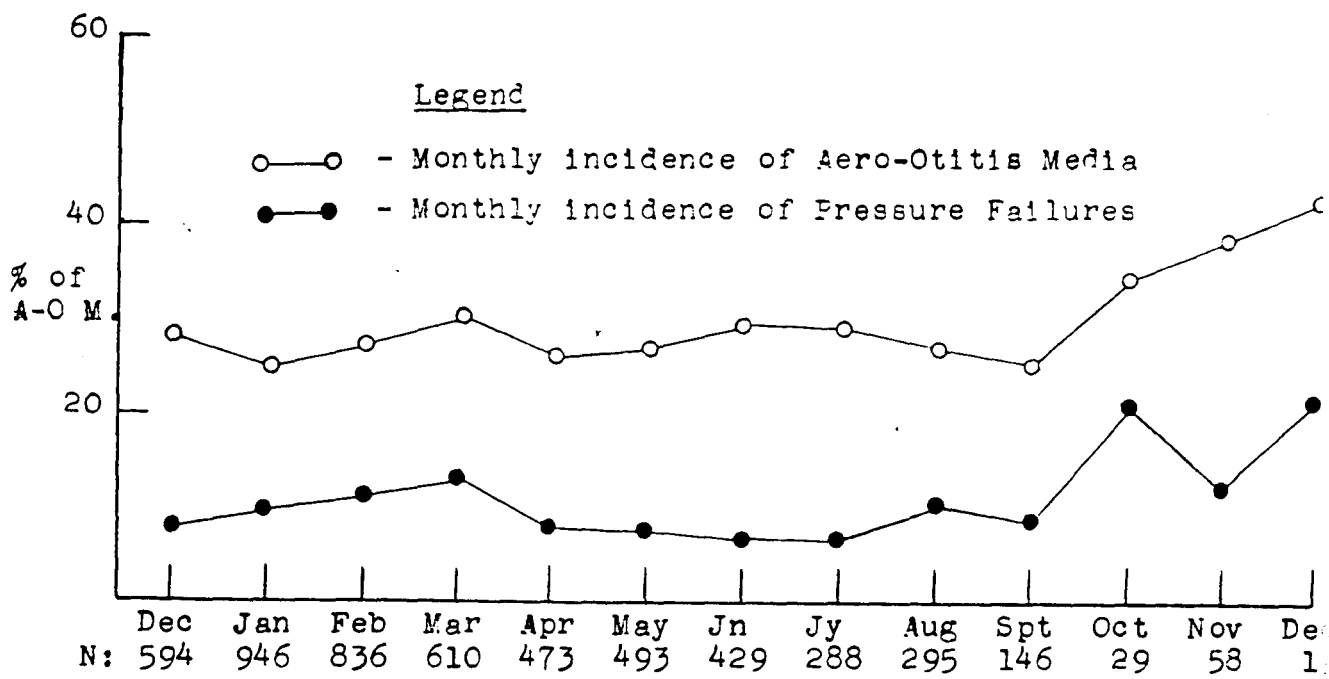
Fig. 7

Of these, a total of 1,659 men, or 26.9%, contracted more or less severe aerotitis media. A total of 732 of these cases of aerotitis media were treated with radium therapy. An attempt was made to administer radium at least 4 times in each case; in some cases as many as 8 treatments were needed. It was sometimes impossible to complete a series of 4 treatments when, for example, a man was unexpectedly transferred. But for the most part, therapy was completed and the man again admitted to the pressure chamber.

The routine volume of our work for the past year is shown in Fig. 8, where below the month is printed the number of men examined during that month.

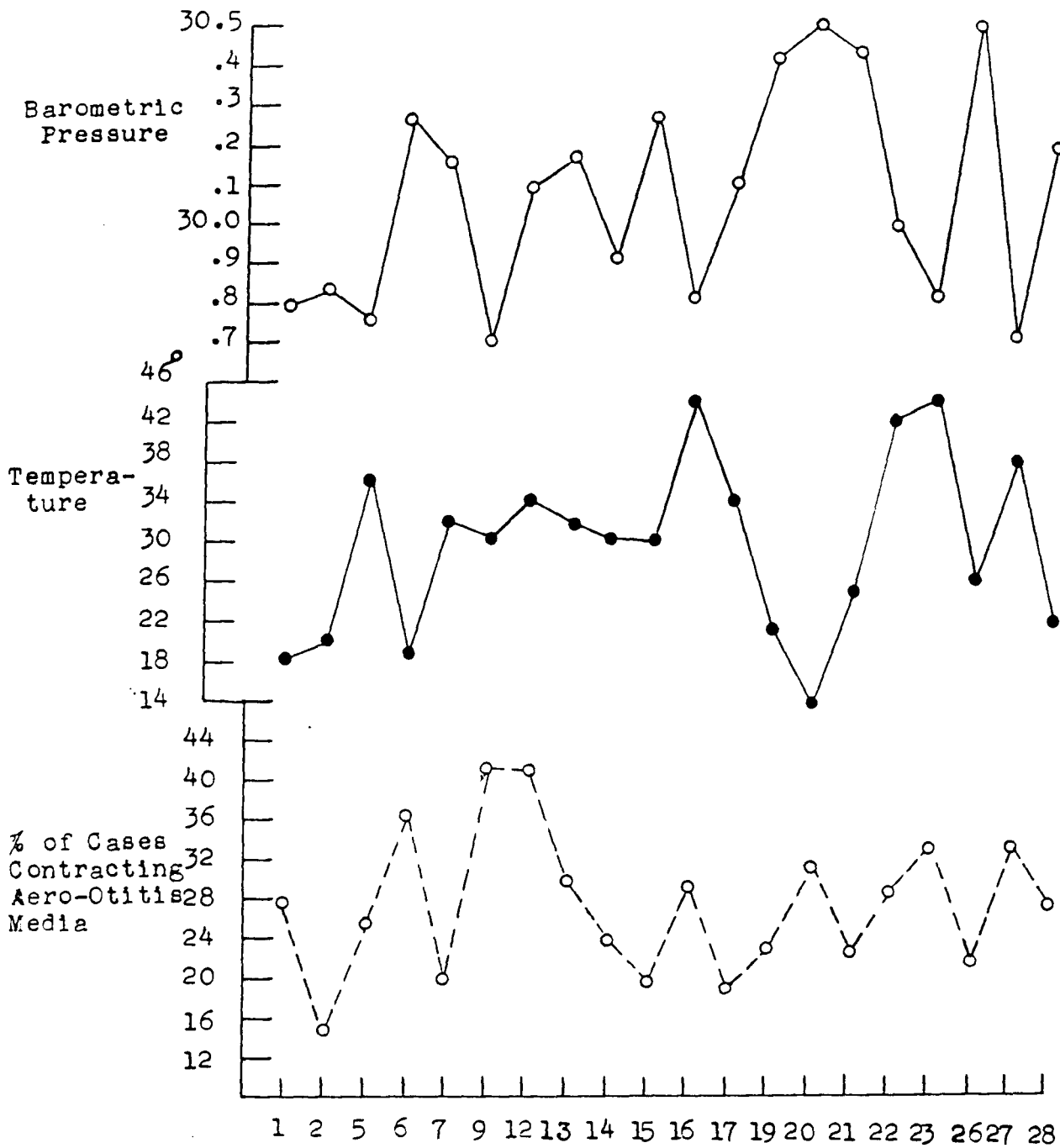
2. The Effect of Weather.

It has often been supposed that weather conditions appear to influence the onset of aerotitis media, but we conclude from our studies that where meteorological conditions appear to influence the onset of aerotitis media, the connection is indirect. We do not see any tendency for the disease to be associated in any way with temperature or barometric pressure. Figure 9 presents day-by-day charts for a typical winter month. The lower line gives the daily percentage of men contracting aerotitis media, the middle line gives the temperature in Fahrenheit, and the top line gives the pressure in mm of Hg. Observations were taken at 0600 every morning just before each group was given pressure. The pressure and temperature curves are rough mirror images, but for every interval where these seem related to the lower line, another interval in the month can be found where the opposite tendency is the rule.



Incidence of Pressure Failures
and of Aero-Otitis Media

Fig. 8



Day-by-Day Record for Feb., '45
 N of Daily Groups from 20 - 66

Shows Lack of Correspondence between
 Temperature, Pressure, and Incidence
 of Aero-Otitis Media

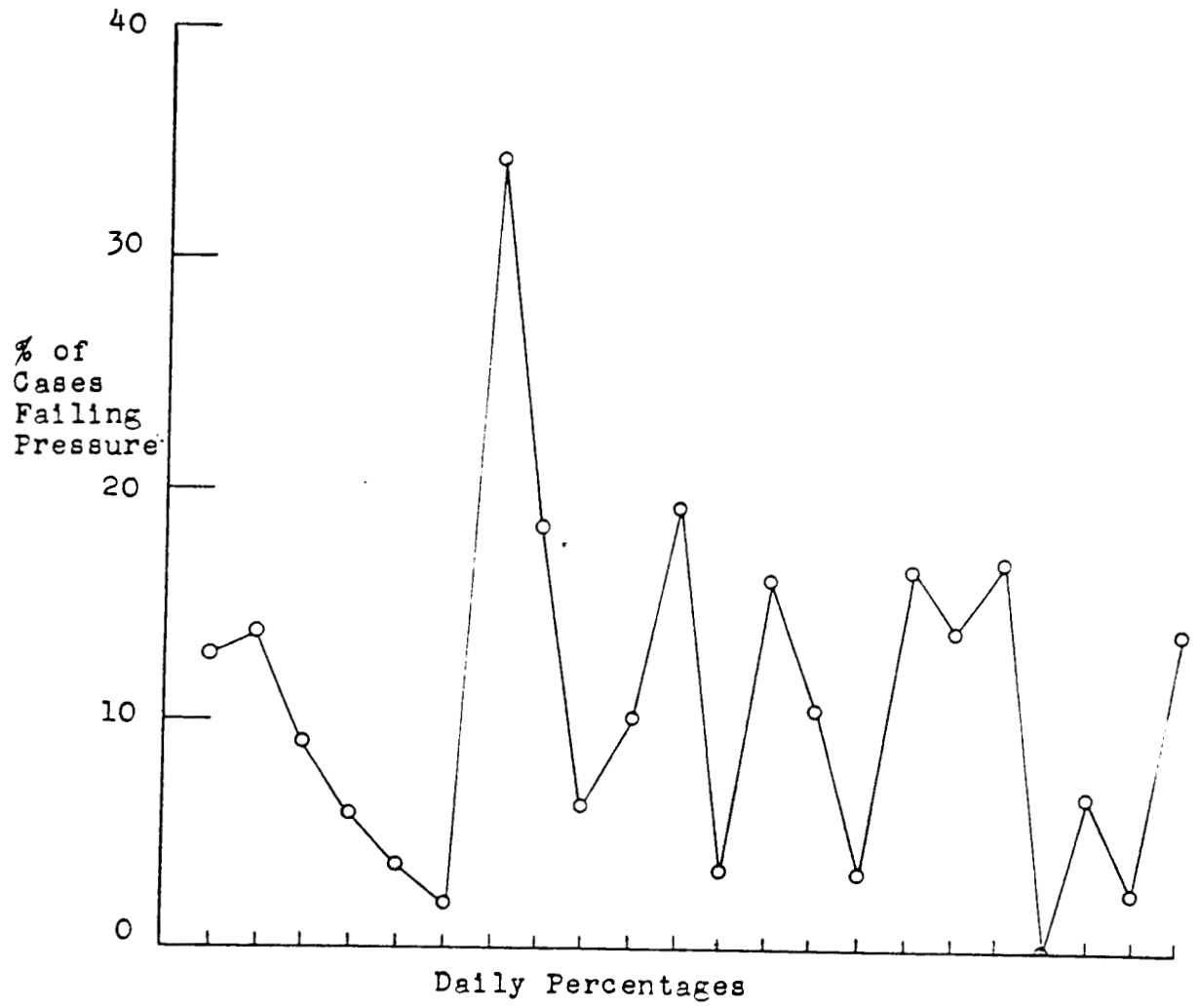
Fig. 9

A slight seasonal effect is apparent, there being slightly more disturbance in the winter months. Fig. 8 demonstrates that both the incidence of aerotitis media and the number of men failing pressure on the first trial are at a peak during March.

(It should be said here that the rise in both these variables during October, November, and December of 1945, is not explained as a seasonal phenomenon, but probably arises from a different factor altogether. Before V-J day the men were examined by the otologist and sent through pressure on the next day; shortly after V-J day the scheduling of the men was so changed that in many cases several days or even weeks elapsed between the examination and the taking of pressure. During this time the men had ample opportunity to contract upper respiratory infections which may have affected their ability to undergo pressure).

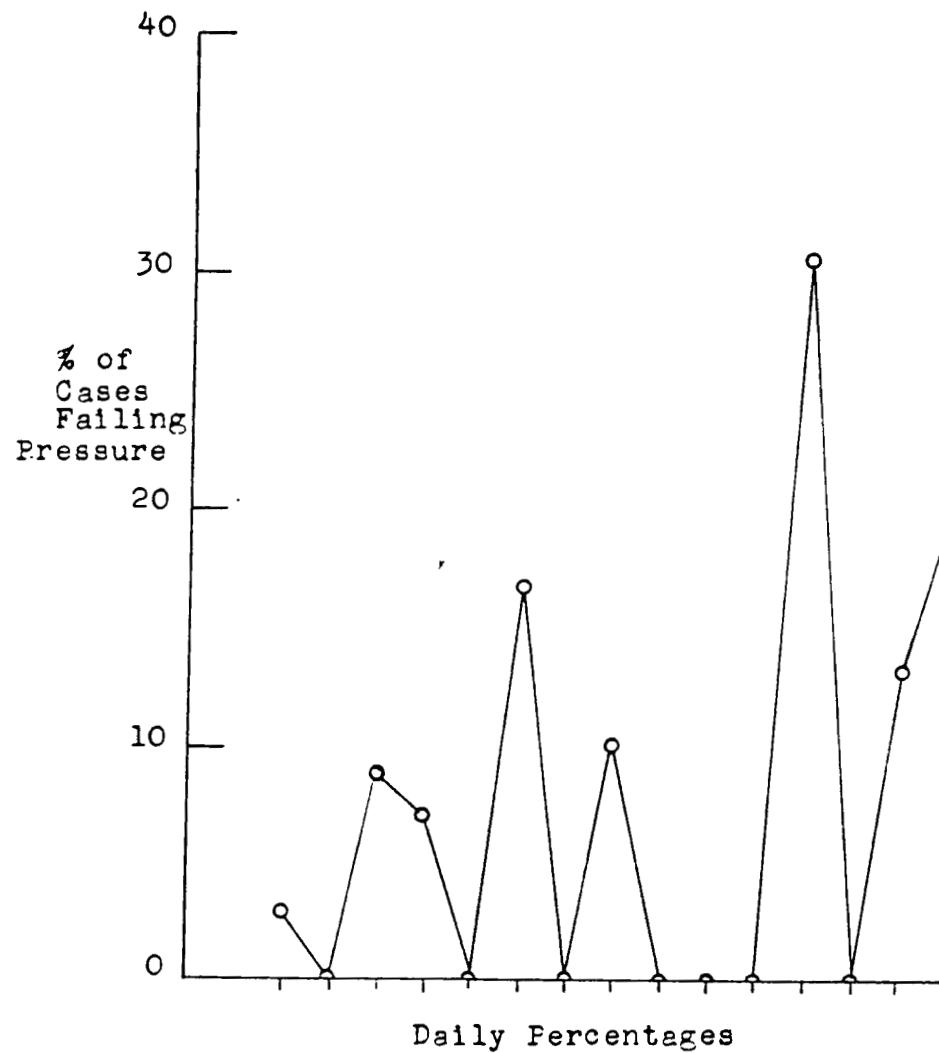
The possibility of a slight seasonal difference is brought out by a comparison of the day-by-day records for a typical winter and a typical summer month (Figs. 10 and 11). It is seen that the figures for January (Fig. 10) are somewhat higher. The average percentage of failures for the whole month of January was 9.93, that for July only 6.25. The difference of 3.68% is 3.4 times its own standard error, indicating that there is less than 1 chance in 1,000 that the difference is due to the presence of chance factors.

The reader will carefully note that in the preceding paragraph we have been speaking not of the incidence of aerotitis media, but of pressure failures. The two are by no means the same thing. In this connection, we point out that the comparison of pressure failures for January and July is not corroborated by the comparative incidence of barotrauma, since indeed there the percentage is higher for July than for January.



Day-by-Day Percentage of Pressure Failures for January, 1945

Fig. 10



Day-by-Day Percentage of Pressure Failures for July, 1945

Fig. 11

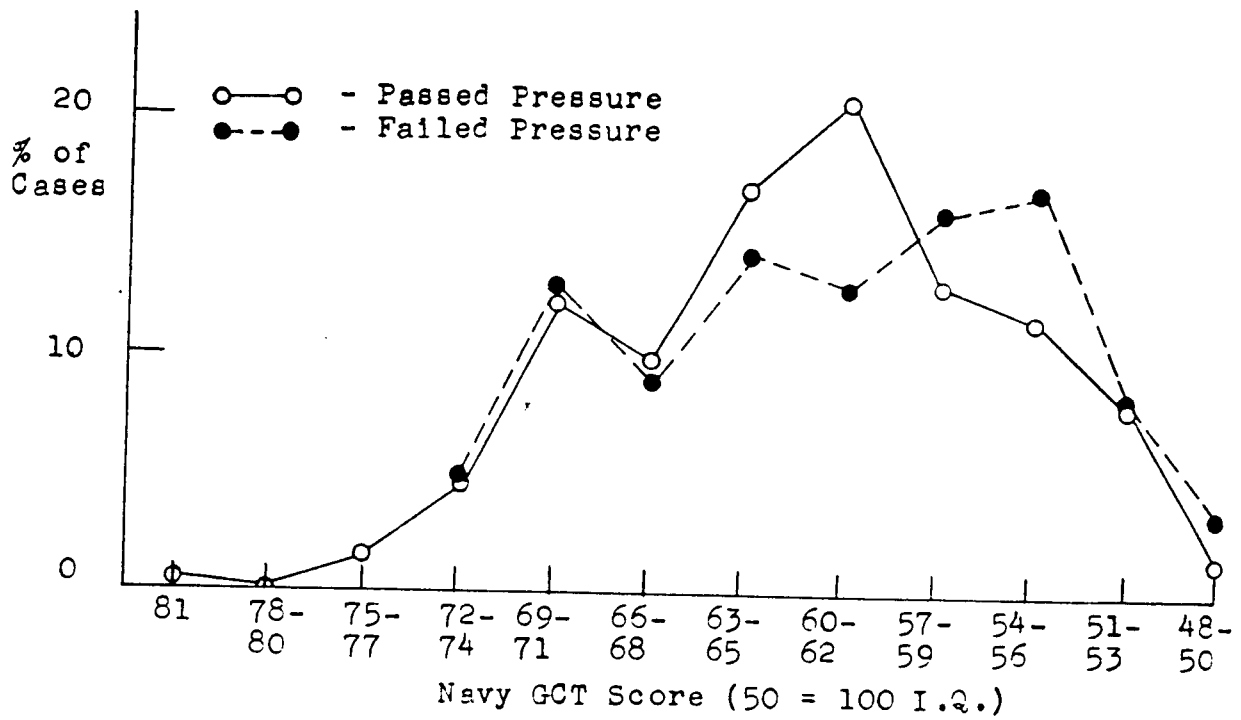
The greater number of failures during January, while significant, does not of course necessarily mean that the difference is due to seasonal changes. At least as good a hypothesis is the possibility that in some indirect manner the untoward events of the war both in Europe and in the Pacific affected the readiness of some men to undergo pain and thus complete their pressure test satisfactorily. It was, for example, about this time that the Navy announced the loss of three submarines in one week.

What we must explain, therefore, is not the reliability of the difference between January and July, but why the difference is so slight. The explanation probably lies in our selection methods, by which all men with acute colds were excused from pressure. The result is that although the amount of upper respiratory infections in January is greater than in July, the number of men with colds actually taking pressure is about the same from month to month.

Although as we shall show, the presence of colds is of far less significance in aerotitis media than is usually claimed, we are forced to conclude with regard to weather, that in our data no day-by-day or truly seasonal meteorological effects can be discerned.

3. The Effect of Intelligence.

Fig. 12 presents distributions of intelligence for a group of 200 men who passed pressure, and a group of 200 who failed. A tendency can be detected for the curve of those who failed to be shifted to the right hand or "low" side of the intelligence continuum. However, the difference between the means is slight (.99) and is statistically insignificant.



Relation of Intelligence to Ability to Pass Pressure Test

Fig. 12

It would be the part of caution not to assume that intelligence is unrelated to the problem. Note that our men are very highly selected for intelligence, only a rare one or two per hundred falling below an I.Q. of 100. We can make no statement concerning the behavior under pressure of the lower levels of intelligence, but it is possible that with a wider range the factor of intelligence would take on added significance.

4. Prediction of Aerotitis Media.

- a. objective cold and allergic upper respiratory manifestations.
- b. size of adenoids.
- c. appearance of Eustachian tube.
- d. ability in Valsalva.
- e. previous experience with pressure.
- f. discussion and conclusions

a. Objective cold and allergic upper respiratory manifestations.

Because of the prevalent opinion that the presence of upper respiratory infection contributes heavily to the onset of aerotitis media, it was decided to see whether most of the patients gave a history of cold at the time of the pressure test. Of a group of 232 men with aerotitis media, a total of 38, or 16.3% were listed by the otologist as having had mild cold symptoms.

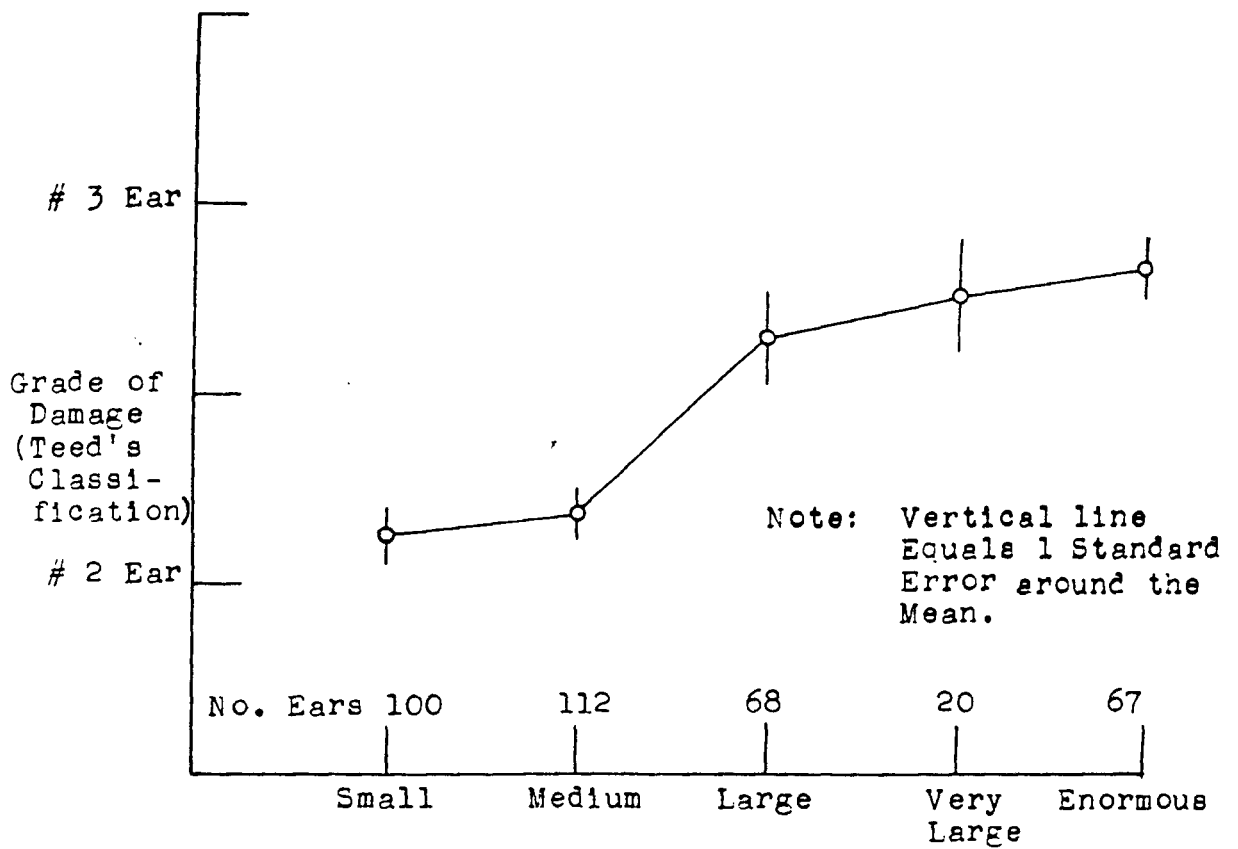
Evidently within the limits of our data the relation of mild colds to aerotitis media is not very pronounced. It is true that those with severe colds were excused from the pressure test; but on the other hand, we find 83.7% of our patients had no colds whatsoever, and we conclude that colds are by no means always an accompaniment of aerotitis media.

b. Size of adenoids.

In view of the close approximation of the adenoids to the opening of the Eustachian tube and their effect on the behavior of the latter, it has seemed logical to expect that with larger and larger adenoids, more aerotitis media would occur. That this is in general true is concluded from the data of Fig.13, where the average damage (according to the Teed classification) resulting from a first pressure test is related to size of adenoids. There is a strong and reliable tendency for the damage to increase in severity as the size of adenoids increases.

A sharp rise in the curve of Fig.13 is obvious as the size increases from "medium" to "large". Almost certainly the explanation for this rise lies in the fact that the "large" category includes those cases with lymphoid tissue in the fossa of Rosenmuller, while the "medium" category does not. It seems that the fossa of Rosenmuller occupies a strategic position with regard to its effect on the patency of the Eustachian tube.

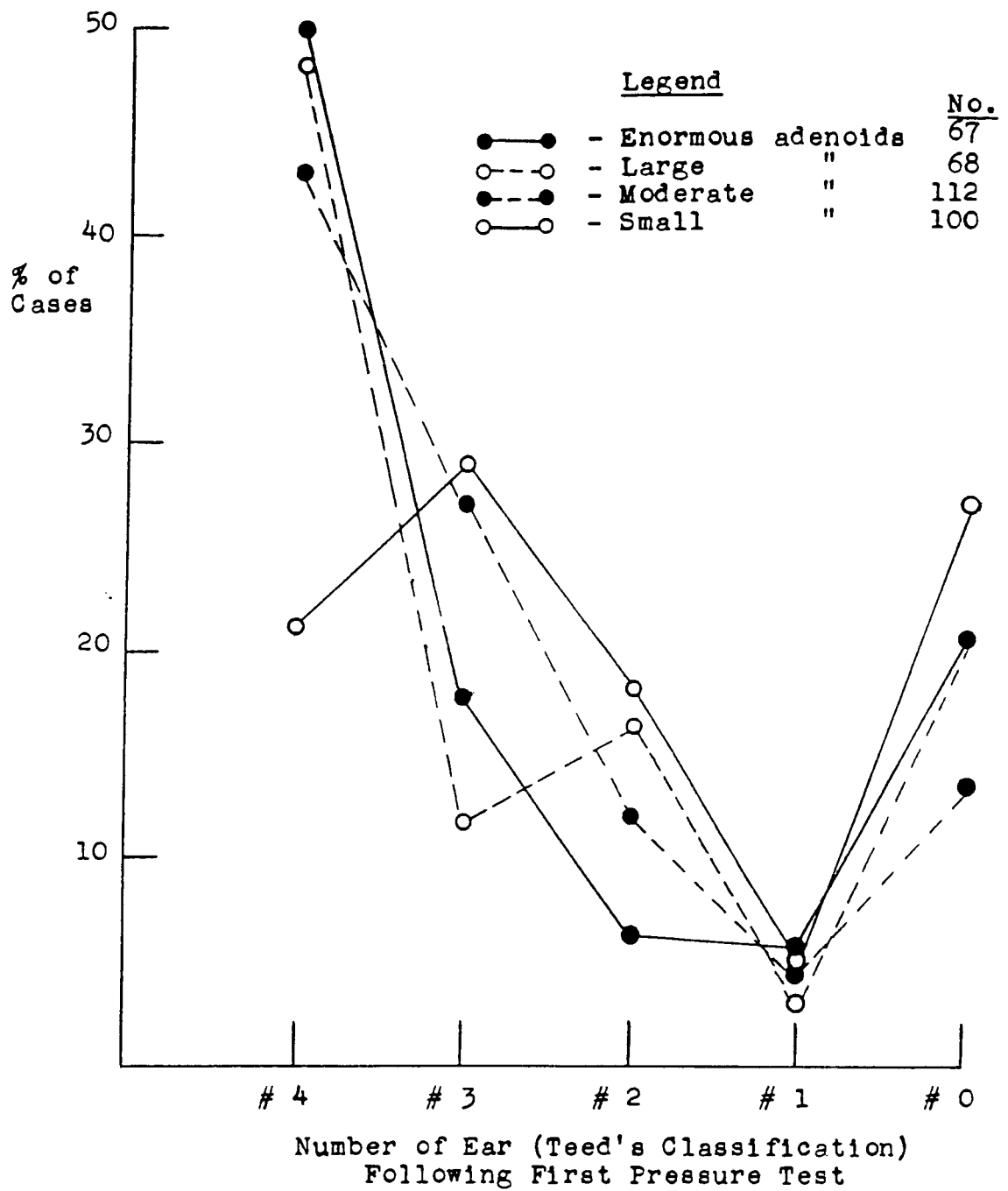
A caution must be raised in interpreting Fig.13, in that the relationship between size of adenoids and severity of aerotitis media is not nearly so precise as appears from the single curve of the figure. A great deal of overlap occurs such that many patients with enormous adenoids have no trouble with pressure whatsoever, while on the other hand many with small or no adenoids sustain severe damage. This argument is carried by Fig.14, where a frequency distribution is presented for each of four groups, those with small, medium, large, and enormous adenoids. When the curve for the "small" group is compared with that for the "enormous" group, it is seen that whereas 50% of the "enormous" group contract #4 ears, still, over 20% of the "small"



Ear Damage as Related to Size of Adenoids

Routine Nasopharyngoscopic Examinations
for a Two-Month Interval

Fig. 13



Shows Lack of Precise Relationship between Size of Adenoids and Severity of Aero-Otitis Media

Fig. 14

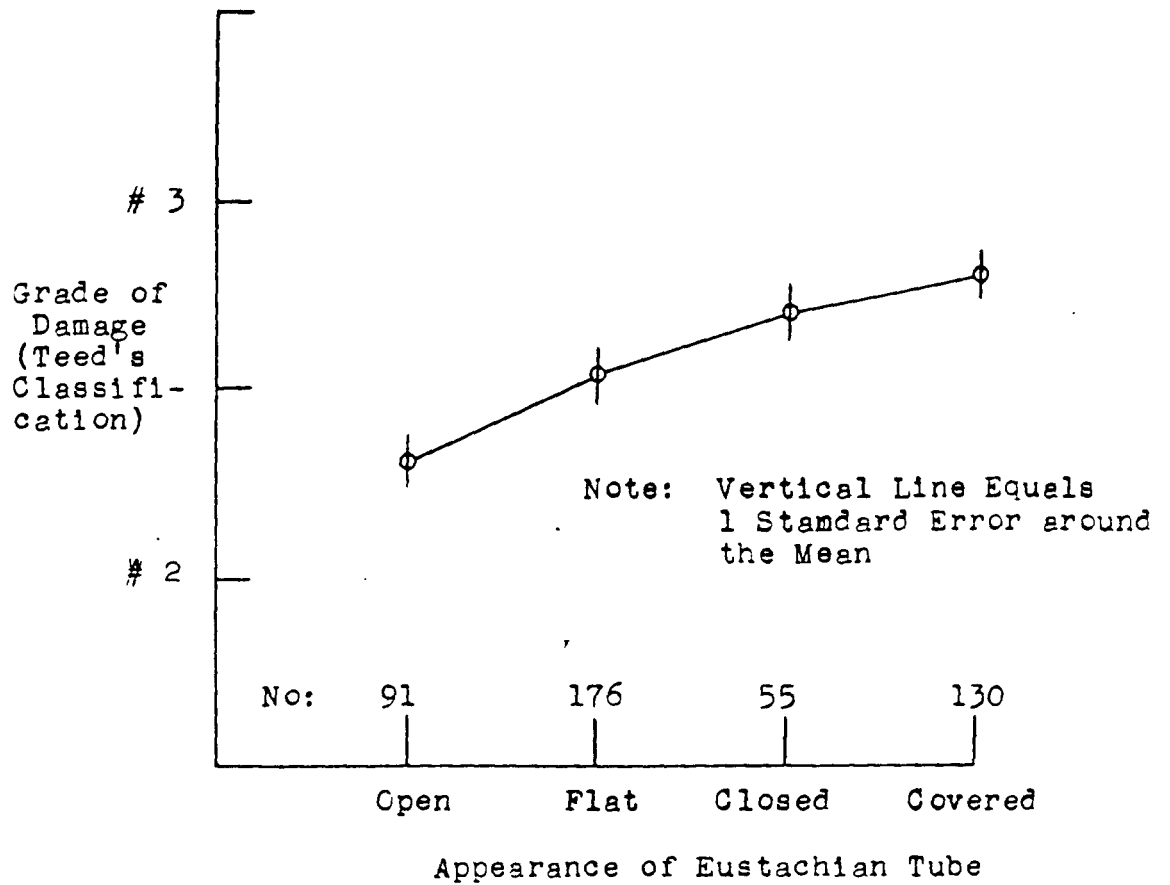
group contracts #4 ears also--a sizable proportion. Also, it will be noted that about 20% of the "enormous" group maintain perfectly normal ears.

c. Appearance of Eustachian Tube.

In our attempt at prediction, the condition of the Eustachian tube as seen on nasopharyngoscopy was considered. Tubes were labelled open, flat, closed, or covered. The men were then followed through pressure and the severity of damage, if any, noted. Fig.15 shows the relation of appearance of the tube to the grade of damage on the graded scale. A regular increase in severity occurs as the Eustachian tube becomes more and more occluded.

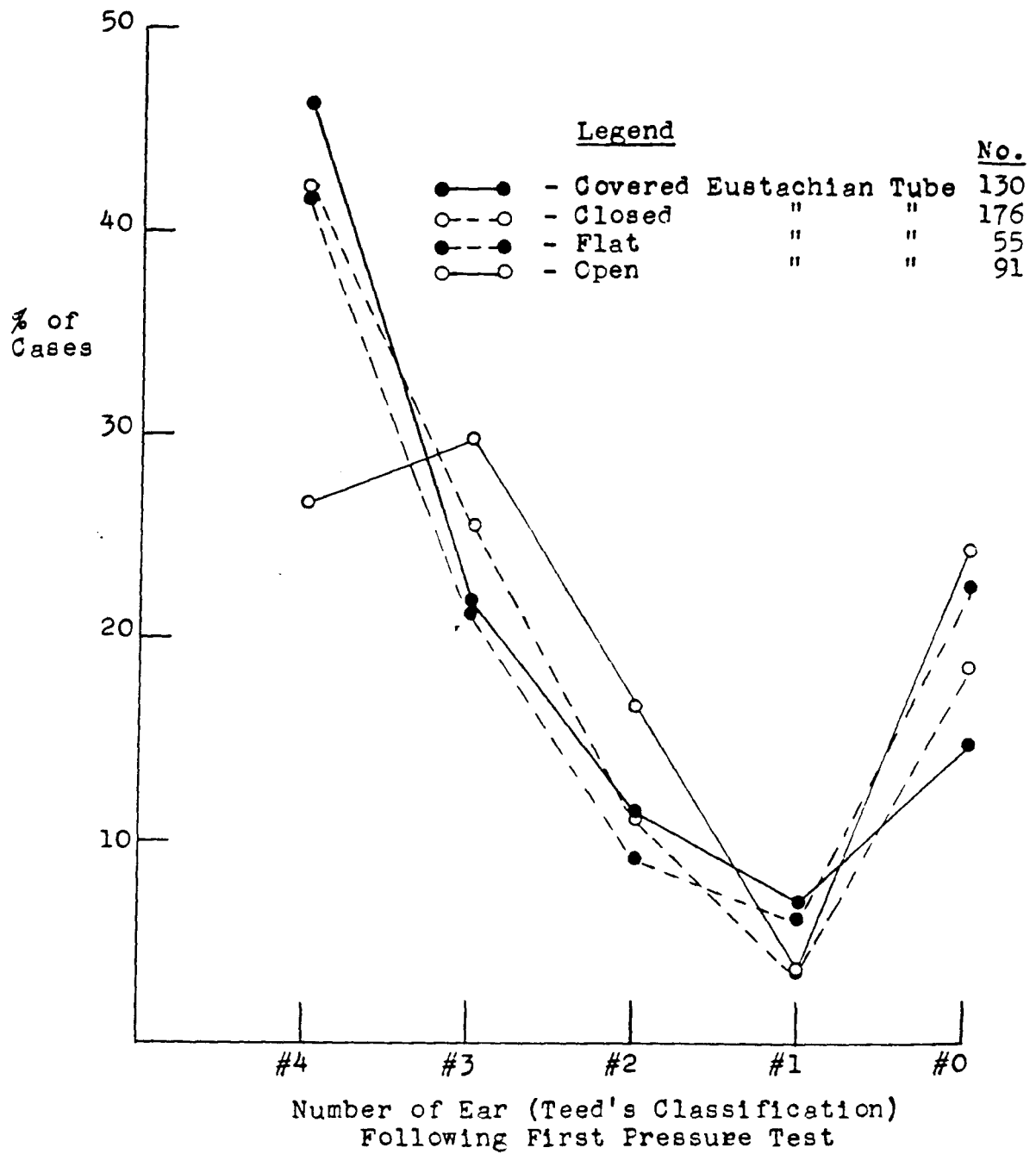
Again, the smoothness of Fig.15 although regular and reliable is deceptive--inspection of the raw data reveals that too much overlap occurs for prediction in individual cases to be very successful. Fig.16 puts the situation in graphic form. Here is presented a frequency distribution for each group, the open, flat, closed, and covered. Although Fig.15 showed the mean differences between these groups to be reliable from a statistical point of view, it is clear from Fig.16 that the severer grades of damage are by no means confined to those cases with covered or closed Eustachian tubes--in fact more than 25% of cases with perfectly open tubes suffered #4 ears. Moreover, of those cases with covered tubes, about 15% had no trouble whatsoever in taking pressure.

We conclude that a definite relation exists between appearance of Eustachian tube and ability to take pressure, but that the individual variation is too great to allow accurate prediction of just which men will contract aerotitis media.



Ear Damage as Related to Condition of Eustachian Tube

Fig. 15



Shows Lack of Precise Relationship between Appearance of Eustachian Tube and Severity of Aero-Otitis Media

Fig. 16

d. Ability in Valsalva.

In addition to studying the static appearance of the system we wished to obtain an idea of the functional properties as well in the form of the Valsalva maneuver. Before the pressure test a long series of men was checked on how well they could voluntarily inflate the middle ear. The records of 139 men who subsequently contracted aerotitis media were studied. It was found that over half, or 56%, had apparently had no difficulty with inflation beforehand. Thirty-one percent were listed as having had some difficulty beforehand, while the remaining 13% were in a poor category. It is evident from these figures that the ability to perform the Valsalva during a preliminary examination is no certain guarantee that during actual pressure the maneuver will always be successful. Nevertheless, as we shall show, we have in the Valsalva the best predictive measure of aerotitis media.

A total of 588 men who did not contract aerotitis media was drawn from the same weekly intervals as the 139 men of the preceding paragraph. The results from the two groups are compared in Table I.

Table I

Ability at Valsalva

	<u>Good</u>	<u>Poor</u>	<u>Doubtful</u>	<u>Total</u>
Contract. AOM-N:139	56.2	12.9	30.9	100.0
Not Contract. AOM-N:588	78.2	.5	21.3	100.0

Percent of cases

Compares Ability at Valsalva of those Contracting aerotitis media with those not Contracting.

When the absolute figures are treated according to the Chi-square technique, it appears that the difference between the control group and the aerotitis media group is significant at the 1% level for all three categories of ability in Valsalva.

For practical purposes we can say that a somewhat greater probability exists for a man to have passed a preliminary Valsalva if he does not contract aerotitis media, and that if he does contract it, the chances are nearly 1 in 2 that he had some trouble with the Valsalva.

In order to make our statements more precise the data must be treated in another way. We may specifically inquire what the chances are of a man contracting aerotitis media if he is labelled by the otologist Good, Doubtful, or Poor on ability at Valsalva. Table II gives an answer. The raw data are the same as in Table I, but the percentages are computed from the totals in the vertical columns rather than by rows.

Table II

		<u>Ability at Valsalva</u>		
		<u>Good</u>	<u>Poor</u>	<u>Doubtful</u>
		<u>N: 538</u>	<u>N: 21</u>	<u>N: 168</u>
Contract. AOM		14.5	85.7	25.5
Not Contract. AOM		85.5	14.3	74.5
Total:		100.0	100.0	100.0

Percent of cases

Shows successful prediction of aerotitis media by ability at the Valsalva maneuver.

Table II shows the prediction of which a preliminary Valsalva is capable. Of those labelled "Good", only 14.5% contracted aerotitis media, while 85.5% did not. This result at first looks very satisfactory until it is noticed that of those labelled "Doubtful", 74.5% did not contract aerotitis media while only 25.5% did so. There are too few cases labelled "doubtful" to make any final statement concerning that category; but it is certainly significant that so many as 18 of 21 "Poor" cases did contract aerotitis media.

The figures of 14.5% and 25.5% contracting aerotitis media for those men labelled "Good" and "Doubtful" respectively, are reliable at a satisfactory level of confidence (2% level), but it is clear that since about 3 out of 4 of those labelled "Doubtful" do not contract aerotitis media, it is impractical to prevent these cases from attempting the pressure test. Furthermore, if all such cases were eliminated, the prevention of aerotitis media would still not be complete since about 15% of those labelled "Good" would experience difficulty. It would probably be an efficient procedure to eliminate all "Poor" cases at the start or until they received appropriate treatment.

We conclude that a preliminary test of ability at the Valsalva maneuver provides only a rough guide to a man's ability to take a subsequent pressure test.

e. Previous Experience with Pressure.

Another factor which is probably related to the ability to take pressure without ear damage, is demonstrated ability to have taken it in the past. We have compared a group of 495 candidates for Submarine School with a group of 658 experienced submariners. Almost none of the former had ever taken pressure

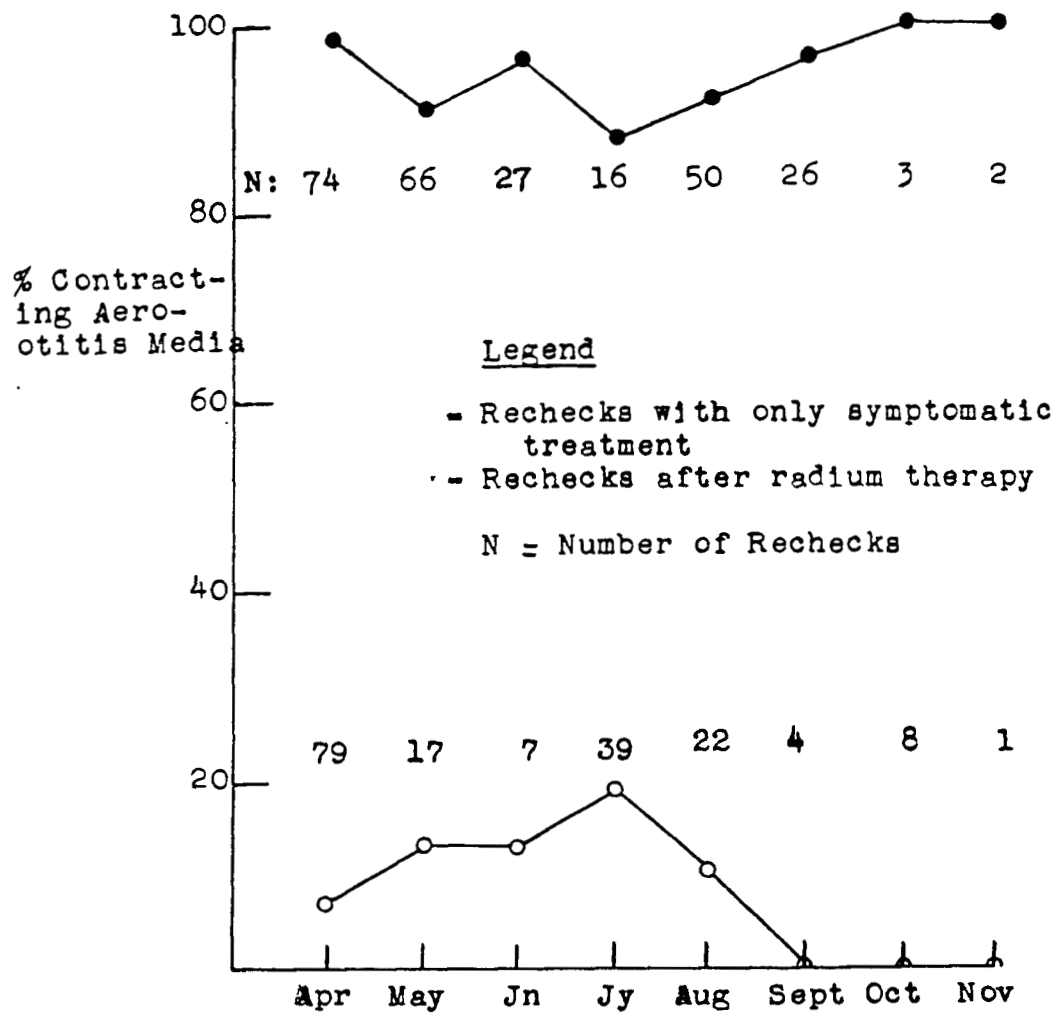
while all of the latter were more or less familiar with pressure from experience with our Training Tank, that at Pearl Harbor, in diving school or salvage operations, or in the escape hatch of a submarine. The two groups were given pressure during the same time intervals, and often the groups were simultaneously in the pressure chamber. The natural selection operating in the case of the experienced men is reflected in the fact that only 18.0% of them contracted aerotitis media as against 27.2% for the inexperienced men. This difference is highly reliable and it is a defensible hypothesis that it rests upon the fact of previous acquaintance with the whole situation.

It can certainly not be said, however, that repeated exposure to pressure will alone finally result in the ability to overcome an initial failure. The top curve of Fig. 17 shows that when men contract aerotitis media on a first pressure test and are then given a second try with only symptomatic treatment in the intervening days, more than 90% will again contract the condition. We have a number of cases in our files of men who have been sent through pressure a half-dozen times or more, each time waiting until the previous trouble had cleared up, and each time the same symptoms appeared.

We conclude that if a man can pass our pressure test once he can pass it twice, but if he cannot pass it the first time, he needs more than cursory attention before he attempts it again.

f. Discussion and Conclusions of Prediction Experiments.

The reader will have noted that one of the major aims of our study has failed; namely, to find a means of stating



Effect of Radium Therapy on Incidence of Aero-Otitis Media

Fig. 17

with precision whether a man can sustain pressure without ear damage. We have been disappointed not only in our attempt to predict individual cases, but even in an attempt to lower the overall incidence of 25-30%. We had been led by Dr. Teed's work to expect a distinct drop in incidence as a result of more careful selection. He says, "A large percentage of damaged ears among submarine personnel could be avoided by a routine check of the ability of each candidate to autoinflate his ears. This is done by having him perform the Valsalva maneuver while the examiner observes the eardrum..... In my experience, in any group of 30 men 7 to 9 would be unable to inflate the ears. If examination of the nose and throat disclosed infection, the infection would be treated. In a week or 10 days the group would be tested again, and if then able to inflate the ears, would be allowed to take the tests. If not, more time would be given for recovery. Probably all but 1 or 2 would eventually pass, the small remainder, requiring further treatment.

"It is therefore not necessary to test the man under pressure to find out whether or not he can inflate his ears and equalize air pressure. It is my contention that if this program were carried out, the number of cases with pathologic changes would be 2 percent or 3 percent rather than the present 25 percent or 30 percent."

Unfortunately we saw from Table II that if we consider only those men who perform the Valsalva satisfactorily, still 14.5% contract aerotitis media, and we therefore feel that Teed's figure of 2-3% is not attainable with the use of Valsalva only. It would seem that an incidence of about 15% is a sort of theoretical "floor" below which present selection methods cannot go. At least, in all

the thousands of men examined here, our lowest incidence for a reasonably large sample of experienced men has never been lower than 18%.

Referring again to Fig. 8, where the month-by-month incidence of aerotitis media is charted as practically a flat line, makes it fairly clear that all we did in prediction and selection was of little avail. When this fact is combined with work to be reported later on in this paper concerning the effect of radium therapy on the incidence of aerotitis media, the conclusion is forced on us that in this case a distinct difference exists between the prediction of aerotitis media and the determination of its cause. It will be shown that the cause of aerotitis media in most cases is the presence of excess tissue in and around the opening of the Eustachian tube; but we have already seen from Fig. 14 that the size of adenoids is itself not a very precise indicator of subsequent aerotitis media. Evidently a rather clear knowledge of the cause of aerotitis media is not as yet sufficient to prevent its occurrence with any real certainty.

In this paper we have shown that a sizable percentage of men with small adenoids, open Eustachian tubes, and with good ability at Valsalva, still may contract aerotitis media. One reason why this may be so is that, in the pressure chamber, some men may let the increasing pressure "get ahead" of them one or more times, and inflate their ears only after some damage has been done. This may occur even with men perfectly capable of auto-inflation.

Another explanation may be that some men are especially susceptible to pressure so that even though they are inflating their ears regularly and without discomfort during increasing pressure, nevertheless the slight pressure differential existing each time before

the ears are voluntarily inflated is enough cumulatively to cause some otopathology.

5. Therapy

- a. dental
- b. radium
- c. x-ray
- d. topical
- e. psychological

a. The Effect of Dental Therapy.

In collaboration with the present writers, a dentist, William J. Kelly, Lt. Comdr. (DC), USNR, selected for special treatment a number of men unable to take pressure and whose dental occlusion was not normal. It was reasoned that dysfunction of the temporomandibular joint could affect the normal operation of the Eustachian tube. Remarkable results were achieved in helping these men to take pressure normally, and we believe such treatment is definitely indicated in certain cases. A complete description of the technique and results appears elsewhere(11).

b. The Effect of Radium Therapy.

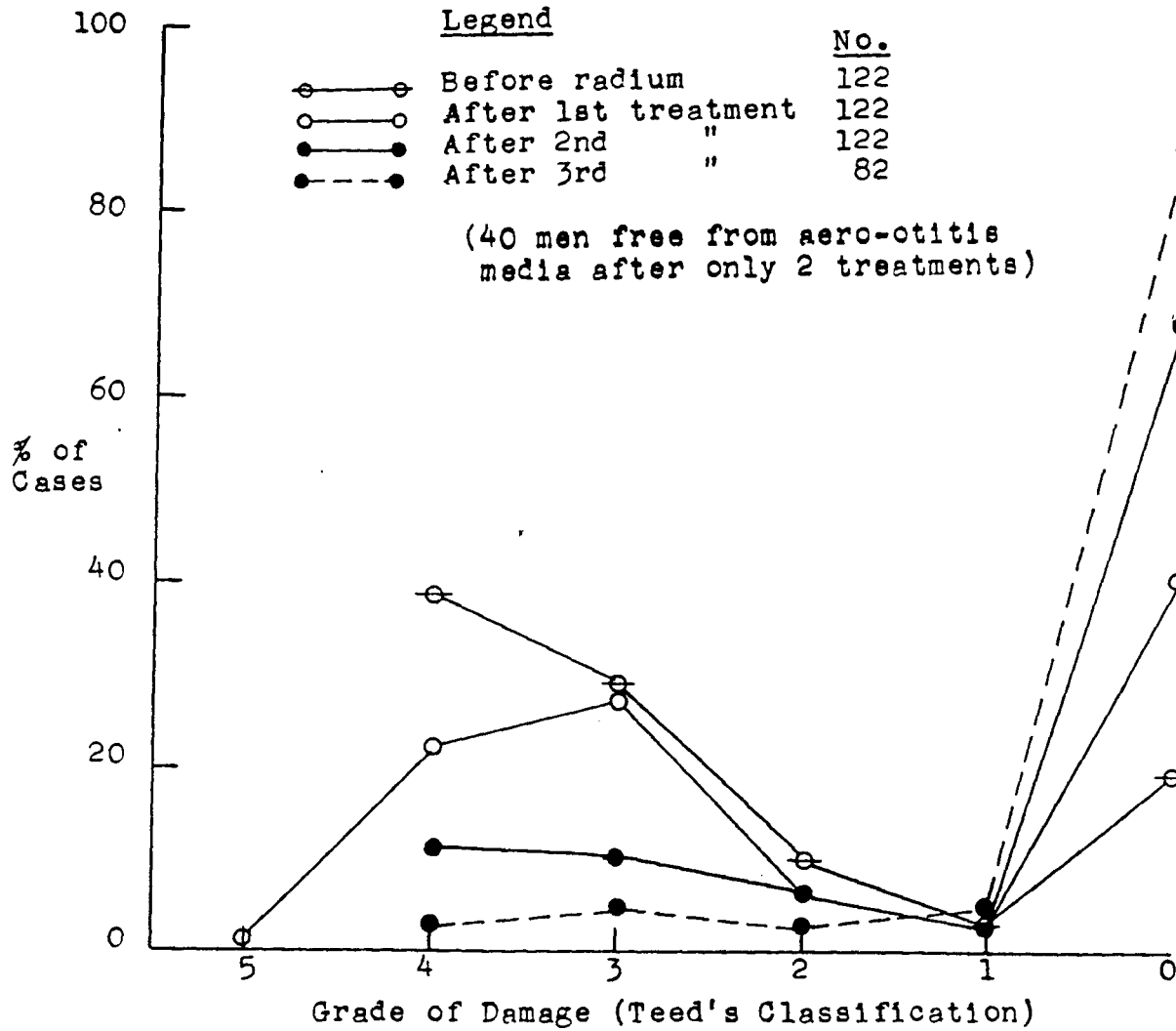
It can quickly be shown from Fig. 17 that radium therapy has a most satisfactory effect on men who could not take pressure without suffering ear damage. The lower line represents the incidence of aerotitis media in men after they had completed a course of radium treatments. The percentage has dropped to an amount considerably less than that of a usual group of men. A control group, similar in all respects to the treated group, is represented by the top line of Fig. 17. Of these men, sent back through pressure with only symptomatic treatment, well over 90% again contracted aerotitis media as contrasted with an

average of about 10% for those following completion of radium therapy.

The number of men involved is enough that we are able to conclude that radium therapy is successful in 9 cases out of 10. For those men whom radium does not assist in taking pressure, it may be true that further radium would be effective, or it may well be that other conditions besides excessive tissue produced the trouble in the first place.

During the final month of our study, for example, 3 cases failed to respond to radium treatment. In 2 of these cases old mastoiditis had caused considerable scarring, while the other had a post diphtheritic paralysis of the right side of the throat and palate. The latter failed to move or open the Eustachian tube on swallowing or inflation. His tympanum could, however, be inflated easily with a Eustachian catheter. The tympani of the other two men could not be inflated with catheterization.

In order to study the effects of successive radium treatments, a group of 122 men were sent through pressure again after every treatment instead of their waiting until the radium series was completed. For these men, not only incidence of aerotitis media was noted but also the grade of damage to each ear. Fig. 18 gives the percentage of each grade of damage for the ears before treatment, and the percentage of each grade of damage for each succeeding treatment. The graph may be read in vertical dimension, thus: 38% of the ears were rated No. 4 before treatment, 21% were rated No. 4 after 1 treatment, 9% after 2 treatments, and 2% after 3 treatments. Conversely, 20% of the ears were rated No. 0 before treatment, and 88% after 3 treatments.



Frequency Distributions of Ear Damage following Successive Radium Treatments

Fig. 18

The average grade of damage throughout the radium series for these 122 men is summarized in Fig. 18. A steady and highly reliable decrease in damage is seen, starting from nearly a No. 3 ear and declining practically to a No. 0 ear. Forty men were available for two treatments only, but even after two treatments Fig. 18 shows that most ears sustain little or no damage when again subjected to pressure.

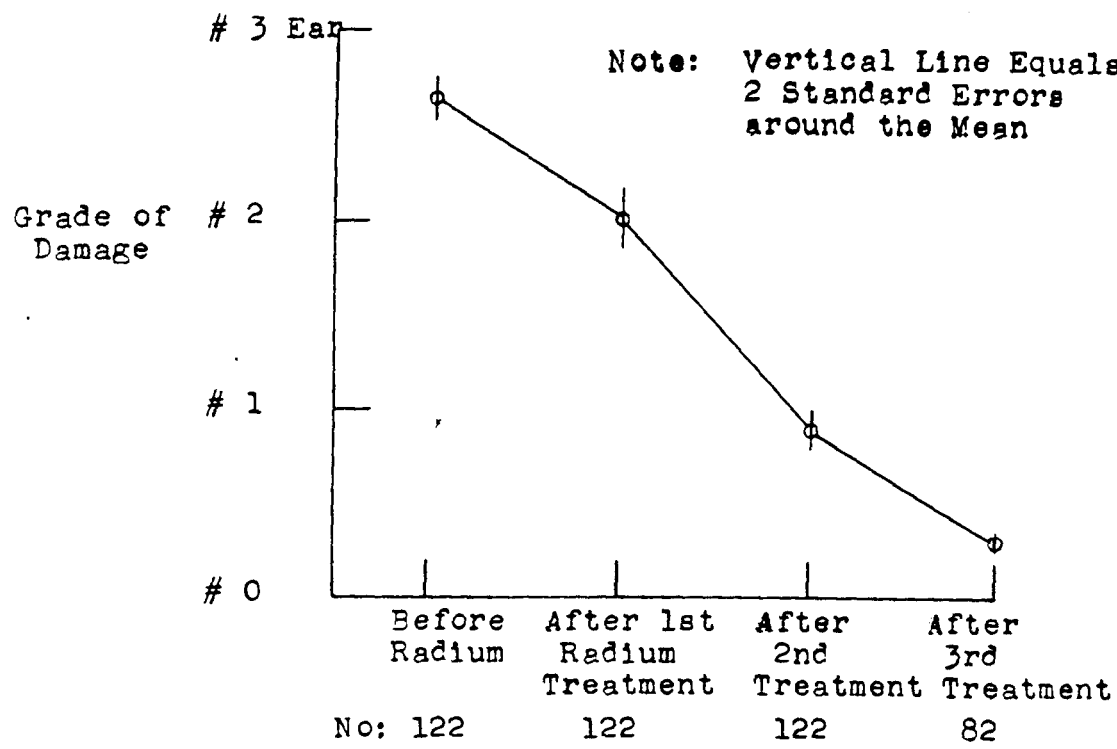
c. The Effect of X-ray Therapy.

Our program for investigating x-ray as a means of shrinking excess tissue around the Eustachian tube was stopped for administrative reasons before conclusive results were obtained. We sent 5 patients to Lt. E. Dubiler, (MC), USNR, of Brooklyn Naval Hospital. Although we do not have data of our own, we feel that x-ray should prove beneficial(14).

d. The Effect of Topical Therapy.

The effect of topical therapy in the form of nose drops was investigated by treating men with 1/4% solution of neosynephrine in normal saline solution. A random sample of men contracting aerotitis media on their first pressure test was instructed to administer 5 drops every 2 hours starting at 0730. These men were then sent through pressure a second time at approximately 1300.

Little effect of the nose drops could be discerned. The average incidence of aerotitis media on the second test ranged from 83.1 - 84.0. This figure is slightly better than that with men who receive a second pressure test with no therapy at all.



Ear Damage as Related to Number of Radium Treatments

Fig. 19

9. The Effect of Psychological Therapy.

A number of procedures of a minor nature were tried in an attempt to reduce the undesirable effects of pressure. Specifically, the use of chewing gum, the playing of music, and man-to-man encouragement by the otologist, were all given extensive trial.

In none of this work was any reduction observed either in percent of pressure failures or incidence of aerotitis media. A group of 120 men were instructed to chew gum vigorously during pressure, and compared with a group of 142 men given no gum. No difference between the groups was found.

Music* provided by a 5-piece orchestra through a loudspeaker in the pressure chamber was presented to a total of 276 men, compared with a total of 586 men during the same time interval but given no music. There was a difference of only .6% between the groups.

For a period of two months, small groups of men contracting aerotitis media on a first pressure test were told that their trouble was of a minor character and would clear up in a week or ten days, and that they would experience no trouble in passing a second test. No therapy other than this suggestive sort was given. In addition, they were told that if they did not pass the second test, their off-the-base liberty would be removed for a day. Then, during the second test, the otologist took the pressure along with the men, encouraging and instructing them by example and by talking to them individually. No effect whatever on the incidence of aerotitis media

* The use of music was suggested by Comdr. H. Berman, (MC), USNR.

was found from our most strenuous efforts in the psychological direction. Pressure failures, however, were reduced.

f. Discussion and Conclusions on Therapy.

We conclude that since a variety of therapeutical measures of a psychological nature have been given a fair trial and have been found valueless, it is probably true that no such therapy will prove effective, and that other measures will have to be sought.

From the number of men given symptomatic treatment with no improvement in ability to take pressure, we conclude that effective therapy must necessarily consist of some radical alteration of the structure of the ear system. Our experiments with x-ray were incomplete, but therapy by dentistry where indicated, and more generally by radium, both demand an extensive change, either the removal of hyperplastic lymphoid tissue around and in the opening of the Eustachian tube, reduction in congestion of tissue about the tube, or realignment of muscles attached to the tube. It appears that a mechanical alteration must take place if a man who cannot take pressure easily is to do so in the future.

The reader will have noticed that the word therapy has been used here not referring to the treatment of symptoms of aerotitis media, but to a procedure which permits a man to take pressure successfully in the future. The treatment of aerotitis media as seen in divers and submariners is a very simple matter, consisting in most cases of letting well enough alone--more secondary infections result from attempts to clean out the ear than if it is left strictly without treatment. Extravasated blood will shortly be

resorbed, and separated layers of tissue will usually heal in a very few days. To afford some relief, nose drops may be administered or local shrinkage with cocaine of tissue about the tube may be indicated.

6. The Effect of Aerotitis Media on the Absolute Threshold.

a. History.

The literature contains a variety of seemingly contradictory statements on the factor of auditory acuity. It is claimed, for example (19) that typically the syndrome is characterized by a high tone loss, and (12) that low tones are first and typically affected; again, it is stated (19) that the deafness may be severe and permanent, and (10) that any acuity loss is usually regained in a matter of hours.

There is no question but that most of the apparent contradiction can be explained on the basis of the quite different conditions to which the patients of the several studies were subjected. We now know enough of the relation between aerotitis media and auditory acuity to resolve most of the difficulties, and to approach something like a final statement.

In the early literature on the subject, mostly from studies on caisson workers, the question of the etiology of deafness is complicated by several factors. In the first place, only relatively crude tests of hearing could be administered. In one study (3) on 13 caisson workers, "The hearing tests were made oftentimes under unfavorable circumstances, being made at times in saloons, in boarding houses, and in other places where it was not possible to secure quiet for tests with the whispered voice."

In the second place, the reason for deafness could usually not be determined; it could have been caused by the immediate action of compressed air on the auditory mechanism, by lesions due to previous attacks of aerotitis media, by nitrogen bubbles in the fluids of the inner ear, or indeed may have existed prior to the investigation.

With old caisson workers a definite and often extreme permanent loss of hearing was found to be common, some men dominantly of the perceptive and some of the conductive type. Nothing could be said about the locus of trouble in middle-ear deafness, since damage occurred in all tissues and with all degrees of severity. When such damage results in permanent alteration of tissues, principally thickening of the tympanic membrane, hearing loss may be permanent. In cases of inner-ear deafness the damage to the cochlear structures caused an immediate and permanent loss of acuity predominantly but not exclusively for the higher tones.

Because these early clinical studies had not controlled conditions so that clear relationships appeared, a thorough-going experiment was needed involving the application of pressure to a large number of normal ears, with complete audiometric examination both before and after pressure. Obviously such an experiment is impossible with caisson workers and divers where no uniformity of conditions can be obtained. The present experiment fulfills all necessary qualifications. Our men have had little or no previous otopathology, compressed-air illness does not arise, and finally, auditory fatigue cannot occur. In short, no complicating factor need intrude, with the result that the opportunity presents itself for determining in clear cut fashion the relation between aerotitis media and acuity.

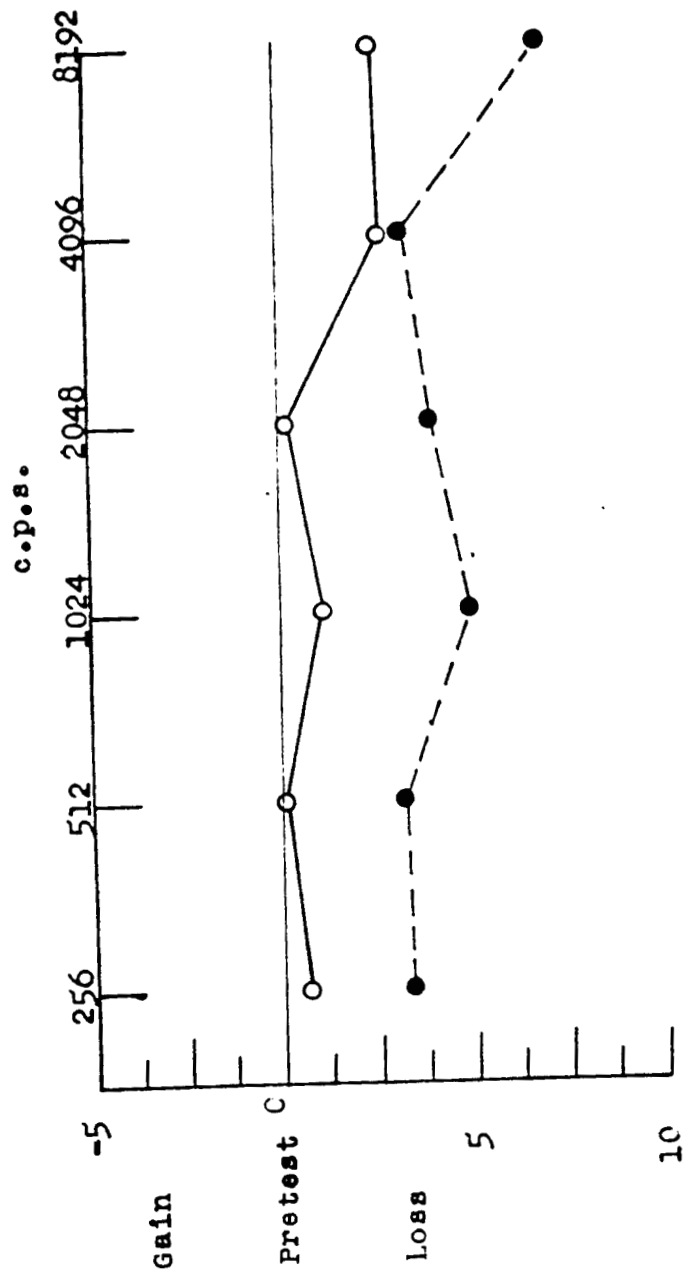
In 1942 Shilling and Everley(18) considered the question, presenting data on 18 cases of aerotitis media of the more severe sort with audiograms showing for several subjects a disabling loss in hearing, and describing in some detail the course of recovery of hearing as a function of time. These 18 men were compared with a control group matched for age and submarine experience, but without aerotitis media. With the data of the control group treated as a zero reference, the 18 men had average losses of 14.8 - 25.9 db through 7 octaves, 128-8192 cycles per second. Because of the manner in which their cases were collected, Shilling and Everley were unable to present pre-pressure audiograms for any of the 18 cases. The difference between the 18 men and the control group is highly reliable, and subsequent audiograms show a tendency to return to what was probably the pre-pressure level; it is nevertheless impossible to be certain about the extent of loss in any particular man. Some of these men had had many years of submarine experience and their audiograms may have been depressed as a result of gunfire, blast, intense diesel engine noise, age, or disease.

Teed(20) studied hundreds of cases and noted that, following pressure, men now and again volunteered the information that they had a subjective sensation of lowered hearing. Unfortunately Teed was unable to provide complete audiometry for his series of subjects, so that his statements have only a qualitative value. In the matter of the subjective sensation of lowered hearing, however, it is our experience that a feeling of fullness or congestion may readily be confused with true lowered acuity. We have seen many scores of cases of men who state that their hearing was "fuzzy" whose audiograms were nevertheless perfectly normal.

b. The Factor of Pain.

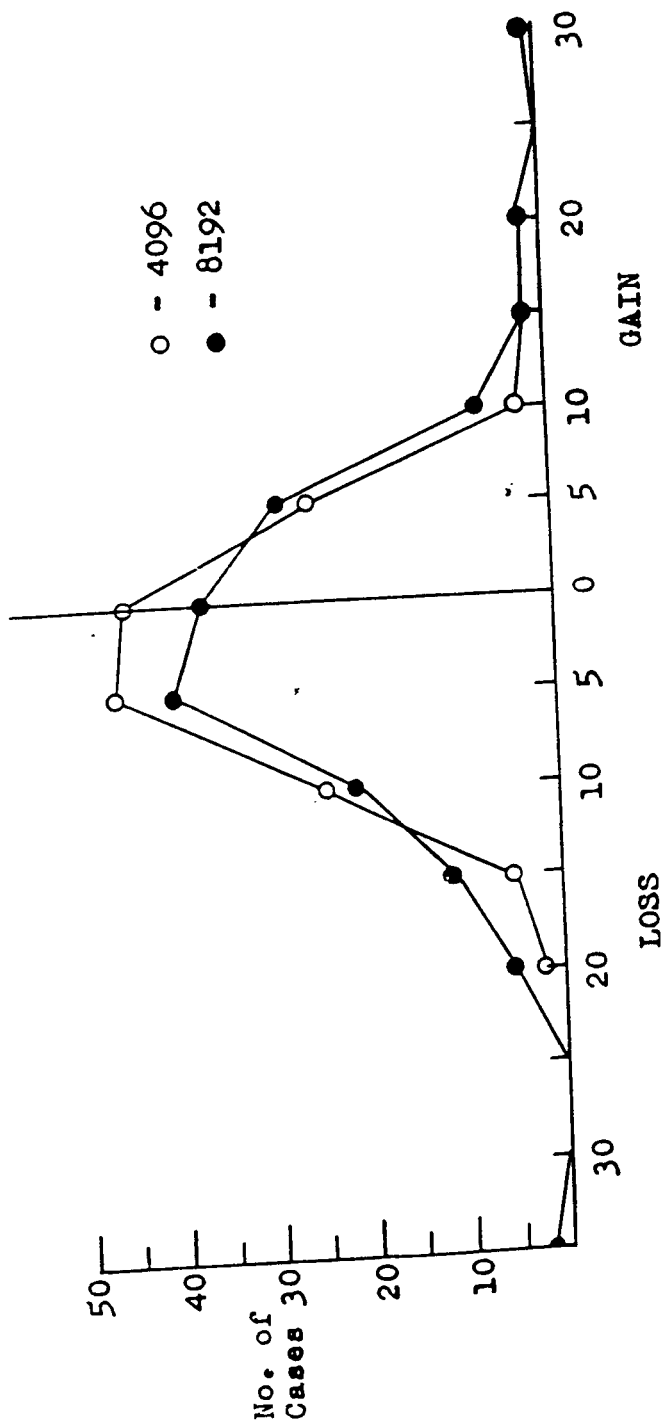
It was reasonably supposed very early in our work that a fairly accurate index of the extent of otopathology would be furnished by the amount of pain present. Teed mentioned this possibility. In order to check the point in the present study, nearly 100 subjects were chosen at random; this group was persistently questioned as to the amount of pain suffered. From 62 men no report of noticeable pain could be elicited; the difference audiogram is presented in Figure 20 as a solid line. For those subjects volunteering or reporting pain under questioning, the difference audiogram is presented as a broken line. A comparison of the acuity loss for these two groups shows that pain in and of itself is no indication of loss of acuity. We are not now here concerned with whether pain is related to otopathology.

On the other hand it is not necessarily true that those with no pain have suffered no loss in acuity. When the difference audiograms at the high frequencies (4096-8192) are inspected it will be seen that some loss has occurred. Figure 21 presents distributions for the difference audiograms at the high frequencies: the zero vertical line represents no difference between the pre and post-pressure audiograms; a point to the left of this zero vertical represents loss of acuity, and a point to the right represents a gain. Since it is clear that there is a preponderance of cases to the left of the zero, it is concluded that some loss of acuity may be present even where conditions are favorable and with subjects whose discomfort could have been only mild. Of course, it is possible that some of this loss may have been occasioned in subjects who for one reason or another did not admit having experienced any pain. Even though the losses at the high tones for these subjects are small, they are nevertheless several times their own Standard Errors.



Open Circles: Difference audiogram of 154 men reporting no pain
 Closed Circles: " " " 29 " " pain

Fig. 20



Distribution of audiogram changes of 154 men with no pain

Fig. 21

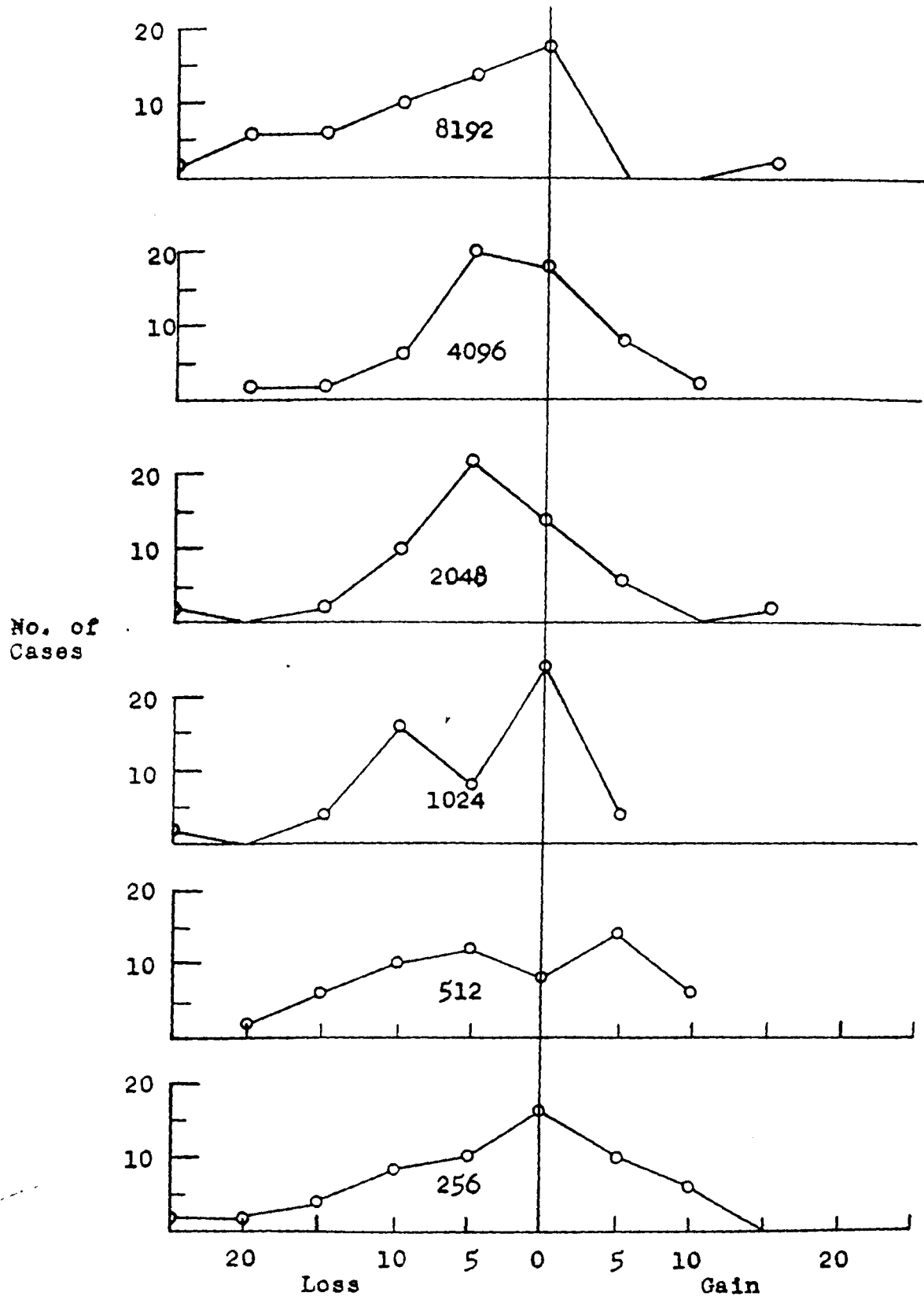
Haines(9) has mentioned that not all otopathology is accompanied by pain. The extent of this lack of overlap can be estimated from the fact that although nearly 30% of all individuals in escape training develop more or less severe otopathology, only 12% of all ears give rise to so much discomfort that subjects are willing to report it. It is of interest to examine the differential frequency effect of the damage giving rise to pain. Figure 22 is constructed exactly as Figure 21 except that each frequency is given its own coordinates--a shift to the left of the zero line indicates loss of acuity. It is clear from Fig. 22 that low tones may or may not be affected, but that for frequencies of 2048 and above, some loss of acuity is usual.

c. The Effect of Rupturing the Tympanic Membrane.

The question arose whether the existence of a ruptured drum membrane would lower auditory acuity. It seems that some lowering occurs, but it is mild, at worst, in cases of uncomplicated perforations. The average losses of 5 to 10 db do not conceal a single case where a loss greater than 15 db has been sustained.

d. The Factor of Grade of Damage.

Our original intention was to graph the average loss of acuity for each of the divisions of the Teed classification scheme. It soon appeared, however, that the less severe grades of damage were not accompanied by a great enough loss of acuity to distinguish from the acuity of normal ears--indeed in the vast majority of cases with ears rated 1, 2, or 3, no loss in acuity whatever could be demonstrated.



Distribution of audiogram changes of 29 men reporting pain

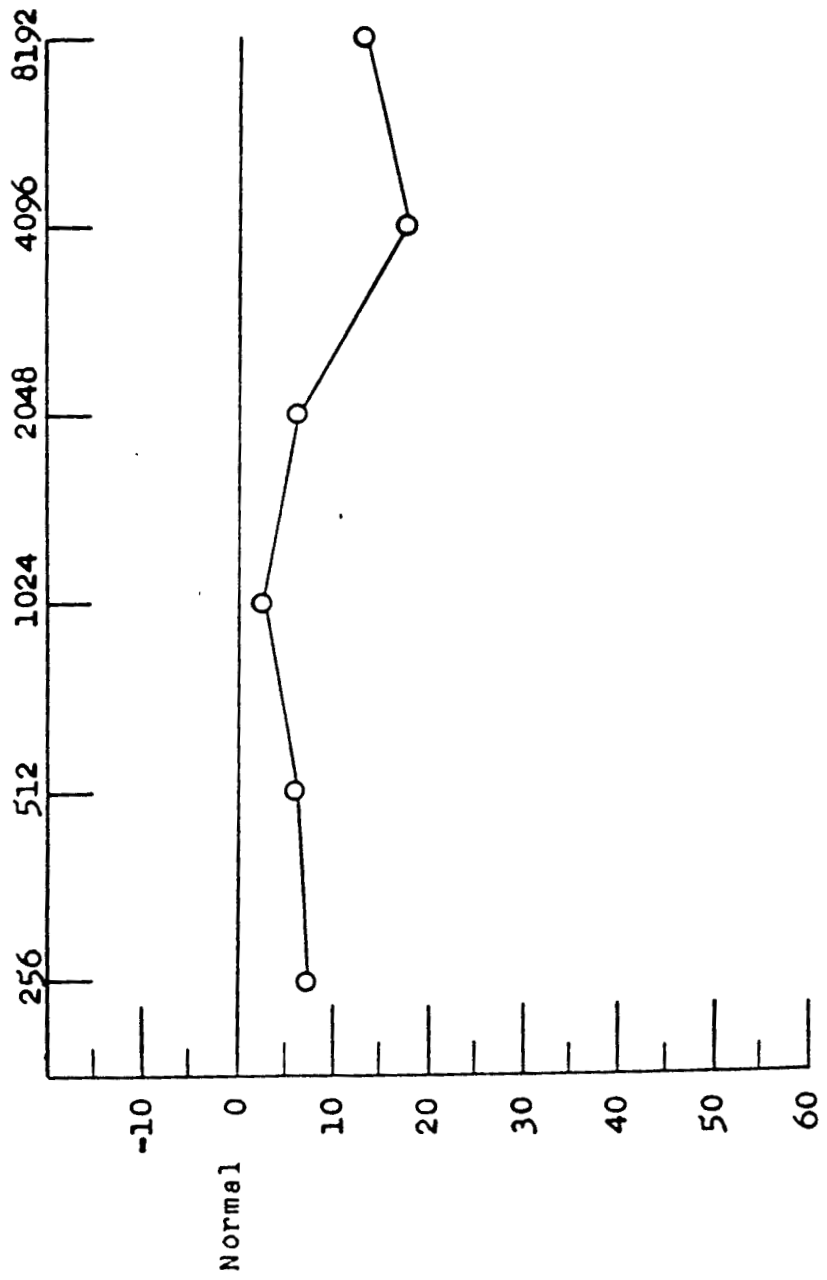
Fig. 22

Among those cases exhibiting the greatest loss of acuity there were several ears which had sustained a rather severe drop in acuity. Accordingly we collected the first 100 ears rated No. 4 according to Teed's original classification, and prepared a composite post-pressure audiogram for those ears. This audiogram is shown in Figure 23. It should be said that the loss of acuity is significant both in the statistical sense and in the sense that the subjects were aware of damaged hearing. However, in terms of the number of decibels loss which we ordinarily see in those individuals who are even mildly hard of hearing, the loss in these ears is certainly not severe.

As a matter of fact, there were many ears in this series of 100 cases of severe aerotitis media where a loss of acuity was definitely not present. Indeed, there were a few cases in which at least at some frequencies an improvement in acuity was exhibited. Figure 24 illustrates such a case. Enough of this material was collected and analyzed so that it is apparent to us that the otopathology of aerotitis media as seen through the otoscope is not a perfect or even a good index to the functional efficiency of the ear.

e. The No. 5 Category of Damage.

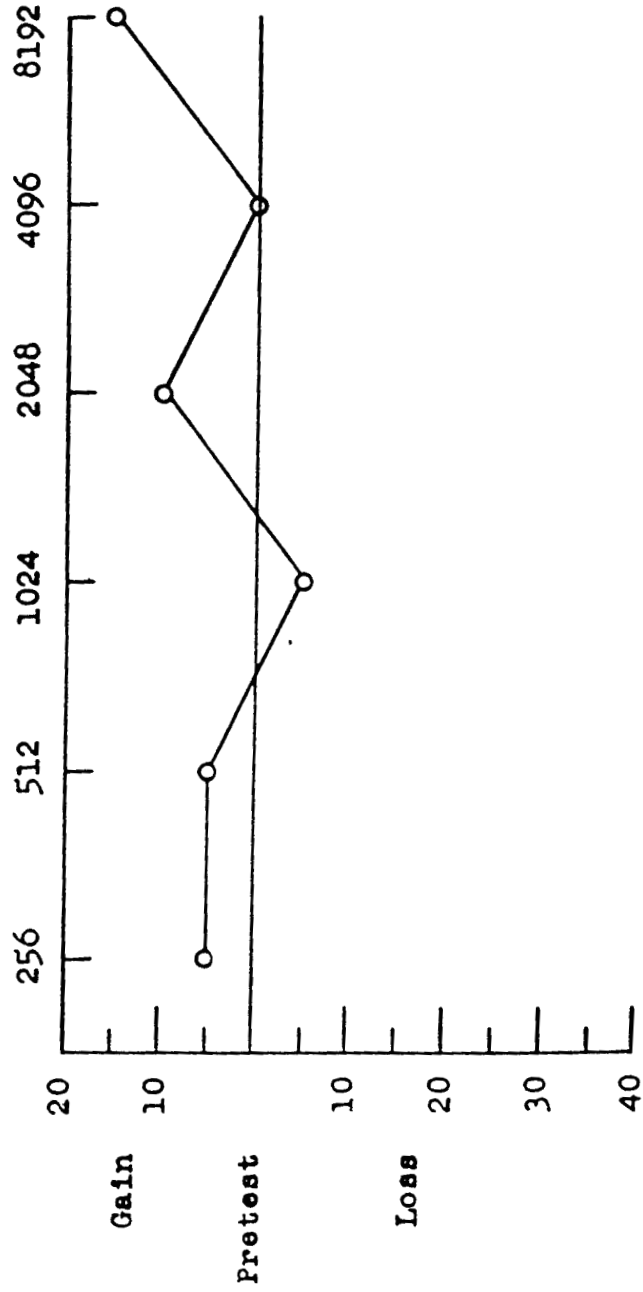
It was logically necessary therefore to look for some other explanation for those cases in which a severer and relatively long lasting impairment of hearing undoubtedly occurred. From a more careful perusal of the protocols of these 100 No. 4 ears, we noted that those ears in which a severe impairment of acuity was present were typically characterized by a dark purple or a bluish discoloration of the eardrum, indicating a middle ear filled with dark blood free of air. We found this to be the case for all of the severely deafened ears and for none of the



Composite Post-pressure audiogram for No. 4 Ears

FIG. 23

Subject: J.T.C.



Shows Improvement in Acuity for a No. 4 Ear

Fig. 24

other No. 4 ears (i.e. those which did not exhibit a severe hearing loss). The evidence seemed so univocal that we felt it necessary to distinguish these ears in a separate category, and began the practice of labelling them No. 5.

In order to demonstrate the distinctness of these No. 5 ears as a functionally different category from those ears now labelled No. 4, Figure 25 may be consulted. Figure 25 represents the loss in acuity for those ears rated No. 4 but without a purple or bluish tympanic membrane compared with the loss of acuity in those ears characterized by the presence of fluid in the middle ear.

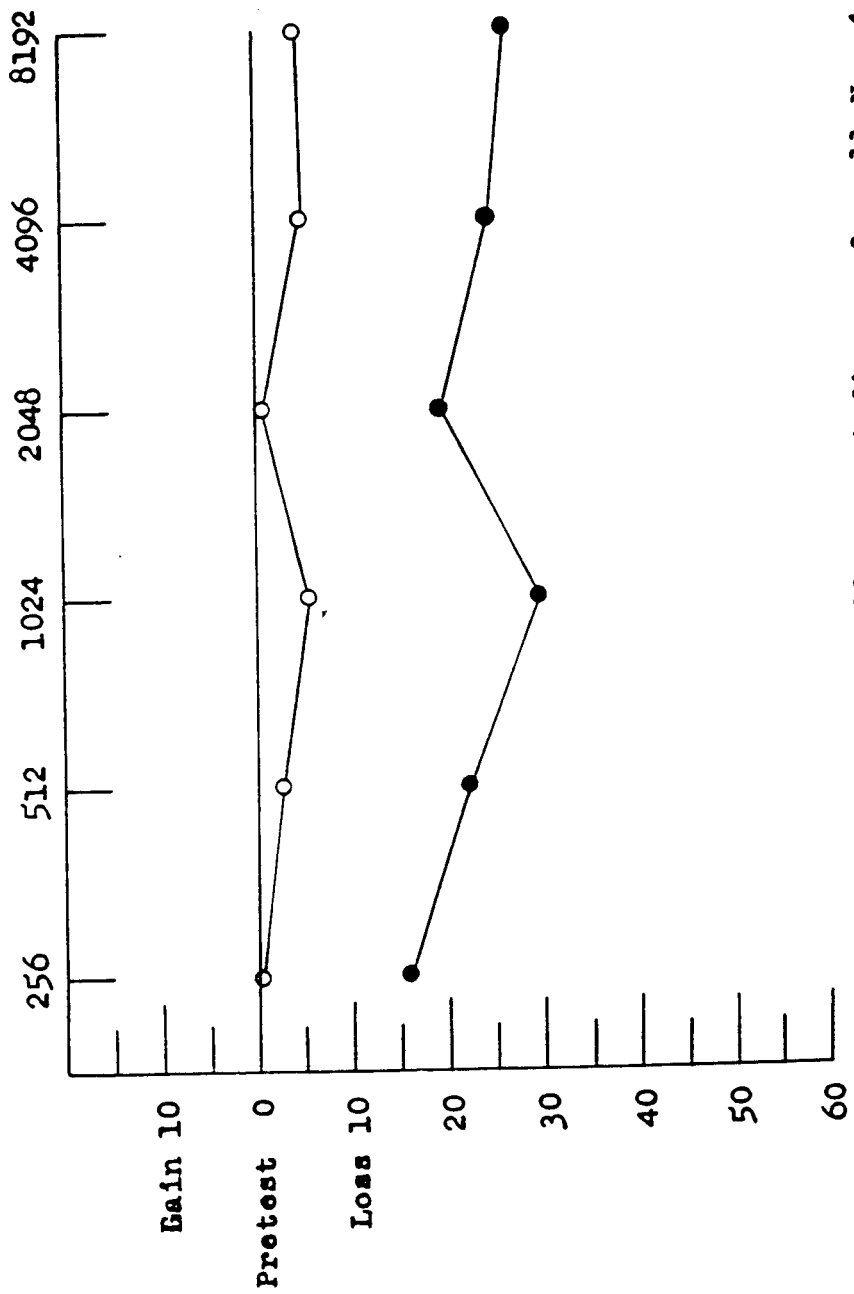
As Figure 25 is studied it must be emphasized that the No. 5 ears do not show any greater amount of otopathology--the essential difference is merely the presence in the middle ear of free serosanguineous fluid.

In Figure 26 is to be seen a difference audiogram for a typical No. 5 ear. It will be noted that the audiogram is typical of conduction deafness such as might be caused by removing the incus.

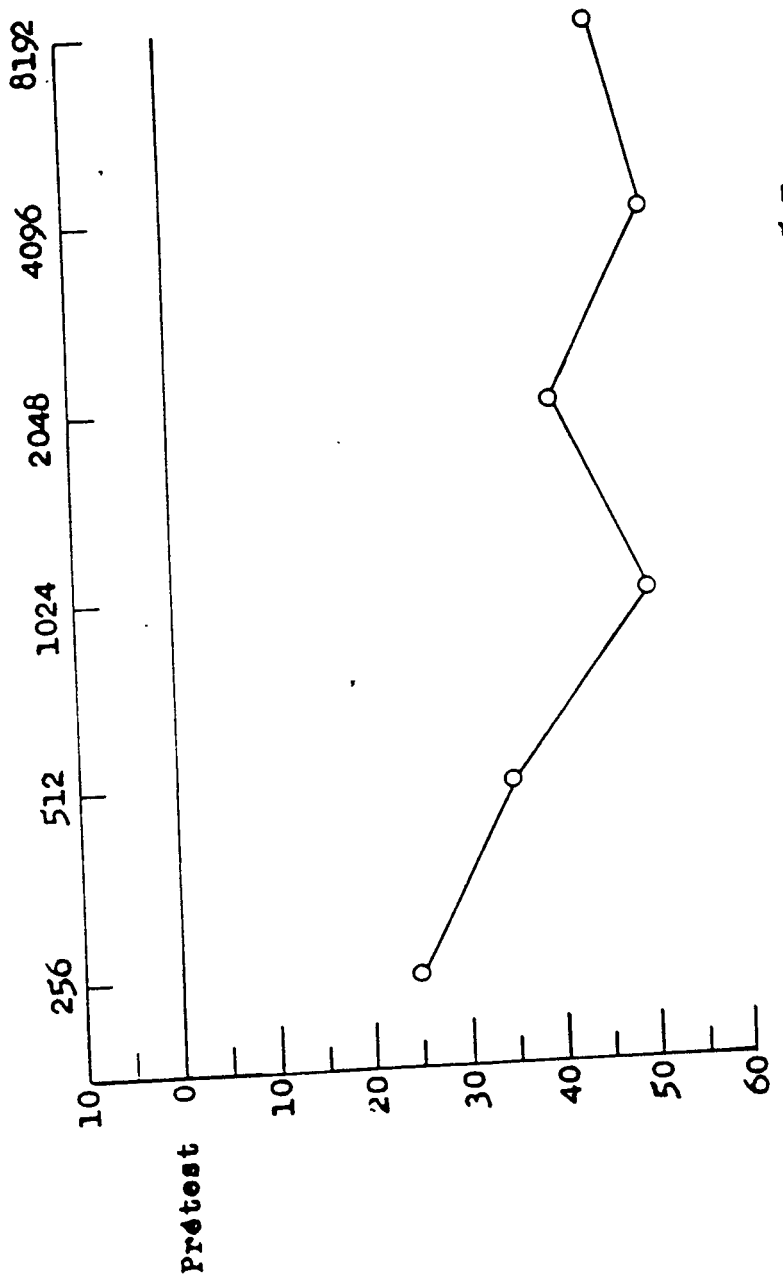
It is our hypothesis in the light of previous work(8, 10) that severe deafness occasionally encountered in aerotitis media among submariners is not caused by insult to the tissues but largely by the damping action of fluid in the tympanum.

f. Discussion.

But while this hypothesis is the most reasonable one to explain deafness as we see it in submariners, it may not completely explain the somewhat higher incidence of deafness under other pressure conditions.



Open Circles: Difference Audiogram for all No. 4 Ears
 Closed Circles: " " " " " No. 5 "



Sample Case of Severe Loss for No. 5 Bar

Fig. 26

In the services the commonest activity from which similar changes in pressure arise is that of high altitude flight; and much of the literature on the subject has been written by Air Forces personnel. With regard to the particular aspect of deafness in this syndrome, however, two things must be said: In the first place, lowered acuity during flight may arise from the actual difference in pressure across the eardrum. Such a difference in pressure by impairing transmission through the ossicular chain, reduces the efficiency of hearing. It is to be noted that this reduction is purely a transitory phenomenon arising and terminating in purely physical events and has no real relation to a discussion of lowered acuity as a result of the otopathology of aerotitis media.

In the second place, the reduced acuity which is commonly experienced subsequent to flight may, and it can be shown often does, arise as a result of auditory fatigue, again a factor unrelated as such to aerotitis media.

In describing the condition of acuity as a result directly of a clinical picture, these two effects, of pressure and of fatigue, need very careful control. It is difficult to construct an experimental design using actual flight conditions which provides an accurate index of loss of acuity as the result of otopathology. These difficulties are of course well known to flight surgeons(1,4,12).

But even when disturbing factors are controlled, it appears that our incidence of deafness is considerably less than that reported from the Air Forces. The difference must be explained in terms of the different barometric conditions which prevail between the two services. Although the pressure differentials are much

greater in the submarine service (for it is self-evident that no pressure greater than 1 Atmosphere need ever be considered in the Air Force), yet it is the relative differential rather than the absolute value which is significant. Moreover, we have shown⁽⁹⁾ that the large majority of men who cannot sustain pressure do so at pressures no greater than those to which aviators are commonly subjected. The main difference between submarine and Air Force pressure conditions is that the usual flight consists of a decompression followed by return to normal pressure, while submarine training consists of a compression followed by a return to normal pressure.

In the case of submariners, then, it will be seen that the negative pressure in the tympanum which produced vascular engorgement and rupture during the first or compression phase, changes to positive pressure during the second or decompression phase, and the result is that the vascular system tends to shrink and a form of therapy is achieved. The reverse is true for the aviators, in whom the second phase is one of compression, the men reaching the ground at a time when symptoms are most pronounced. One might for these reasons expect a greater incidence and severity of otopathology and loss of acuity among aviators than among submariners.

REFERENCES

1. Armstrong, H. G., and Heim, J. W.: The Effect of Flight on the Middle Ear. Jour. Amer. Med. Assoc., 109:417-421, 1937.
2. Beaven, C. L.: Chronological History of Aviation Medicine. Flight Surgeons' Topics, 2:185-206, 1938.
3. Boot, G. W.: Caisson Workers' Deafness. Annals Otology, Rhinology, and Laryngology, 22:1121-1132, 1913.
4. Campbell, P. A., and Hargreaves, J.: Aviation Deafness, Acute and Chronic. Arch. Otolaryngol., 32:417-428, 1940.
5. Crowe, S. J., and Baylor, J. W.: The Prevention of Deafness. Jour. Amer. Med. Assoc., 112:585-590, 1939.
6. Crowe, S. J., and Burnam, C. F.: Recognition, Treatment and Prevention of Hearing Impairment in Children. Annals Otology, Rhinology, and Laryngology, 50:1-17, 1941.
7. Farrior, J. B.: Histopathologic Considerations in Treatment of the Eustachian Tube. Arch. Otolaryngol., 37:609-621, 1943.
8. Fowler, E. P., Jr.: Radon Treatment for Otitis due to Barotrauma. Jour. Laryngol. and Otol., 58:489-492, 1943.
9. Haines, H. L.: Aero-Otitis Media in Submarine Personnel. Jour. Acous. Soc. Amer. 17:136-138, 1945.
10. Harris, J. D.: Auditory Acuity in Severe Aero-Otitis Media. Jour. Acous. Soc. Amer., 17:139-143, 1945.

11. Kelly, W. J.: The Results of Dental Therapy in Fifty Cases of Aerotitis Media in Submarine Personnel Based upon a New Functional Concept of Eustachian Tube Blockage. Annals Otology, Rhinology, and Laryngology (in Press).
12. McGibbon, J. E. G.: Aviation Pressure Deafness. Jour. Laryngol. and Otol., 57:14-22, 1942.
13. Poppin, J. R.: The Ear in Flying. The Laryngoscope, 51:974-982, 1941.
14. Rentschler, H. D., and Settle, J. W.: Treatment of Impaired Hearing by Radiation of Excessive Lymphoid Tissue in the Nasopharynx. Pennsylvania Med. Jour., 47:985-988, 1944.
15. Requarth, W. H.: Aero-Otitis Media in Compressed Air Workers. Jour. Amer. Med. Assoc., 116:1766-1769, 1941.
16. Rich, A. R.: Physiological Study of the Eustachian Tube and its Related Muscles. Bull. Johns Hopkins Hospital, 31:206, 1920.
17. Shilling, C. W.: Aero-Otitis Media and Loss of Auditory Acuity in Submarine Escape Training. Arch. Otolaryngol., 42:169-173, 1945.
18. Shilling, C. W., and Everley, I. A.: Auditory Acuity in Submarine Personnel. U. S. Naval Medical Bull., 40:664-686, 1942.
19. Simpson, J. F.: A General Survey of Otorhinological Considerations in Service Aviation. Jour. Laryngol. and Otol., 57:1-7, 1942.
20. Teed, R. W.: Factors Producing Obstruction of the Auditory Tube in Submarine Personnel. U. S. Naval Medical Bull., 42:293-306, 1944.
21. Yearbook of Eye, Ear, Nose, and Throat, 1941, S. J. Crowe, Ed., Chapter by Campbell, P.A., "Aviation Medicine."