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Experimental tympanometry

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ENHANCED possibilities for surgical intervention in conductive hearing loss have increased the demand for accurate differential diagnosis of the site of a lesion in the middle ear. Impedance audiometry has been used extensively in recent years as a highly sensitive indicator of several causes of conductive hearing loss, including middle ear effusion, ossicular discontinuity and otosclerosis (Jerger *et al.*, 1974). The combined results of static compliance, tympanogram and acoustic reflex achieve the greatest sensitivity of impedance audiometry to a particular source of conductive loss. Some authors (Moon and Hahn, 1978), however, indicate that tympanometry and static compliance—without acoustic reflex—can be of considerable use in differentiating specific sites of lesion.

Tympanometry records changes in acoustic impedance resulting from variations in the external air pressure on the tympanic membrane. The tympanometric curve plots pressure versus compliance sweep. The amplitude of the curve indicates the integrity of the middle ear structures. Static compliance ascribes a numerical value to the difference between the mobility of the tympanic membrane at +200 mm H_2O (C_1) pressure and mobility at the peak compliance point (C_2).

Fig. 1 shows the most commonly used classification system for tympanometry, devised by Jerger (1970, 1974). Normal ears, represented by inverted V-shaped curves peaking near 0 mm H_2O, are called type A. Type C tympanograms, indicative of initiating or resolving middle ear effusion, are represented by curves whose shape resembles type A but whose compliance peak is shifted to the −100 to −400 mm H_2O region. Type B tympanograms, indicative of middle ear effusion, are characterized by curves with little or no compliance change with change in pressure. Type A^s tympanograms, similar in shape to type A curves, have reduced height and are considered indicants of ossicular fixation. Finally, type A^d tympanograms, indicative of disarticulation, are represented by open-ended curves with peak compliance greater than the range of the equipment.

The present study examines whether tympanometry and static compliance can clearly differentiate the site of experimentally-induced lesions in the middle ear of human temporal bones. If so, the value of

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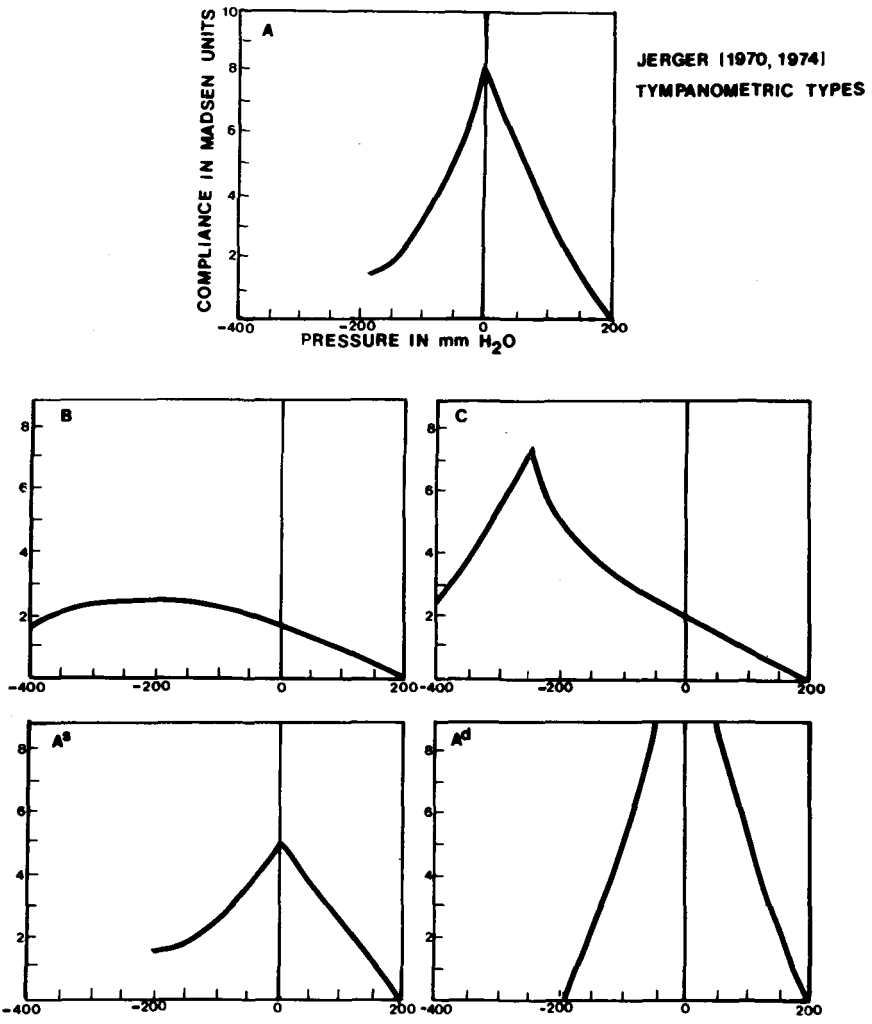


FIG. 1

tympanometry might then be extended to reflect the objective status of the middle ear and identify middle ear disease in clinical populations.

Materials and Methods

Ten temporal bones were obtained at autopsy immediately after death and were frozen in aluminium foil. For visualization and access, the middle ear was exposed with a burr through an opening in the tegmen tympani, using an operating microscope. This procedure avoids disturbance of the ossicular chain. The ossicles were palpated for mobility, and the opening in the tegmen was then sealed with silicone rubber.

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Tympanometry was performed with an electro-acoustic impedance bridge (Madsen Model ZO-70) coupled to an automatic recorder (Hewlett-Packard 7035 X-Y Recorder). Results were obtained from multiple sweeps through the pressure range -400 mm H_2O to $+200$ mm H_2O and were recorded automatically for later perusal.

Before testing, the external auditory canal was examined under the operating microscope and was cleaned of any cerumen or debris. Any abnormalities in the tympanic membrane were noted. The size of the external auditory canal was then calculated by measuring the volume of water required to fill it completely. Canal walls that were collapsible or had an abnormal course were noted, but these were later found not to affect the tympanometric results. A tip of appropriate size, generally of soft material, was fitted into the canal and the air-tight seal was validated. When sealing the external canal proved problematic, silicone rubber was used around the tip.

Once an air-tight seal was achieved, testing began. Each temporal bone preparation was tested before implementing any experimental lesions. These results served as baseline measurements and represent what are called 'normal' results. Following baseline measurements, the middle ear space was gradually filled with water and then glycerine and the measurements were repeated. The middle ear was then cleaned and experiments with ossicular fixations and disarticulations were performed.

Results

(1) Normal tympanograms—The tympanograms of ten temporal bone preparations were plotted prior to inducing lesions in the middle ear structures (Fig. 2). Static compliance values ranged from ·6 to ·8 cc. Curve height varied from 5 to 10, while slope of curve ranged from ·5 to 2·0. The form of this curve represents the sound-transmitting properties of each temporal bone specimen.

All temporal bones tested belonged to middle-aged adults with no available otologic history. Bones of the elderly or very young children were not used because two possible conditions could have existed. One was conductive presbycusis. Glorig and Davis (1961) described the presence of an air-bone gap in the high frequencies the size of which increased with increasing age. Belal (1975) showed that middle ear structures undergo progressive degenerative changes with aging, but argued that these changes seem not to affect auditory thresholds as tested by pure tone audiometry. Jerger *et al.* (1972) found that age was related to acoustic impedance results only for static compliance and that these values decrease gradually after the age of 40. Nerbonne *et al.* (1978), however, showed that the decrease in static compliance values with age is insignificant, and thus the use of separate compliance norms for the elderly is unwarranted.

The other consideration in the restricted use of temporal bones was the

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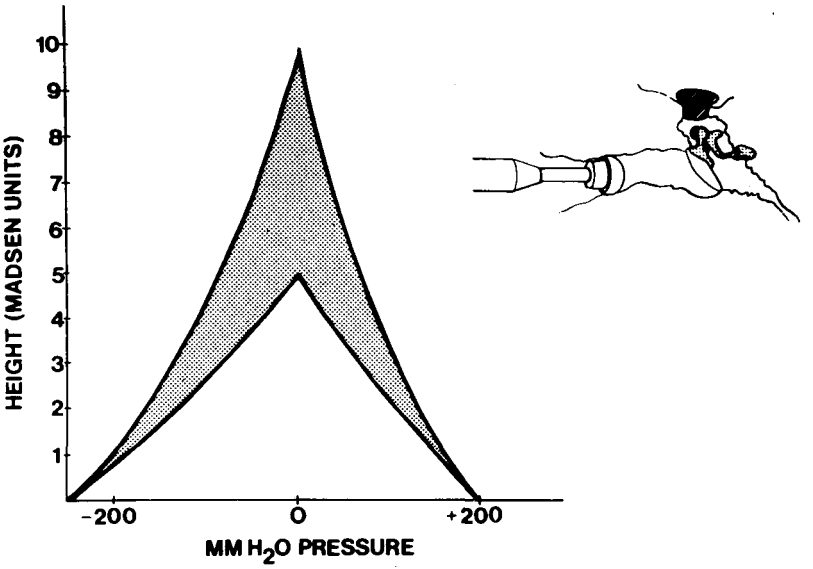


FIG. 2
Normals.

possibility of unresolved mesenchymal tissue in the middle ears of newborns. Tympanometry is a less useful indicator of middle ear disease in newborns than in middle-aged subjects.

Possible effects of post-mortem changes (time interval between time of removal and time of testing) were also considered. Temporal bones removed less than one month after death had normal tympanic results. Two temporal bones removed and frozen for three months before testing gave extremely flat tympanometric curves and very low static compliance. These results probably reflect the effects of freezing, drying, and post-mortem changes in the tissues, especially the tympanic membrane. One bone, tested for ten days to monitor the effects of drying, did not show any effect.

We assume that temporal bones used in these experiments have the same sound-conducting properties as the ear in a living subject, and thus our experimental results may be applied *in vivo*.

(2) Middle ear effusions—Recurrent middle ear effusion is one of the most common causes of hearing loss in children. Many studies (Paradise *et al.*, 1976; Beery *et al.*, 1975) have shown that impedance audiometry is sensitive to the presence of middle ear effusion. Forquer and Linthicum (1978) examined whether impedance audiometry in conjunction with air-bone gap data could differentiate between patients with thin fluid and those with thick fluid in the middle ear space. They found that effusion was present in 97 per cent of children under 9 years of age, with tympanometric type B or C and an air-bone gap greater than 15 dB. Of these 97 per cent,

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75 per cent had thick fluid. No pattern of tympanometric type and air-bone gap level was found to be specifically predicative of thin fluid.

In the present study, two parameters of fluid, viscosity and level, were evaluated. Using a clinical population, the Forquer and Linthicum (1978) study did not indicate that it was possible to specify whether the fluid was thick or thin solely from tympanometric results. For temporal bones, on the other hand, viscosity and fluid level changes were found to have a very consistent effect upon tympanogram height and static compliance. Fig. 3 shows the effect of fluid level and viscosity in a single bone. A clear, gradual reduction in curve height is seen with increased amount and viscosity of fluid. Static compliance also showed a gradual reduction. Of interest is the fact that the heights associated with thin fluid (water) are within what is considered to be the normal range. Fig. 4 shows the range of curve heights seen with thin and thick fluid. For water, the curve height varied from 7–10, the static compliance from ·6 to ·8, and the slope from ·5 to ·75. Except for the slope of the curve, these results closely approximate those seen in normal bones. When glycerine (thick fluid) was used, the results were markedly different from those seen with thin fluid. Curve height ranged from 1 to 2, static compliance was always less than ·45, and slope from ·5 to ·75. All the curves with the thick fluid would be considered Jerger Type B curves.

The present study showed that tympanometry is highly sensitive to the difference between thick and thin fluid in temporal bones. Unfortunately, it can not differentiate between thin fluid and absence of fluid.

(3) Ossicular fixation—This study (Fig. 5) duplicated a large number of ossicular fixations, including stapes footplate fixation, incudo-stapedial and incudo-malleal joint fixations, stapedius tendon fixation, and fixation of the short process to the incus.

(A). Stapes footplate—The stapedial footplate may be fixed in a variety of pathological conditions. The most common is otosclerosis; others include congenital fixation, osteogenesis imperfecta, osteopetrosis, tympanosclerosis, Paget's disease, and fibrous dysplasia of the temporal bone. Jerger (1970) showed that otosclerosis is usually associated with a low static compliance, type A^s tympanogram, and absent acoustic reflexes. Similar findings were seen in congenital fixation of the stapes (Belal and Forquer, unpublished data).

In the present study, the under-surface of the stapes footplate was exposed through the vestibule and was fixed with dental cement. Tympanometric measurements included static compliance of ·5, height of 5, and slope of ·75.

(B). Incudo-stapedial (IS) and incudo-malleal (IM) joint fixation was experimentally induced with dental cement. Fixation of these joints has been previously reported in a variety of conditions, including aging, otosclerosis, middle ear infections, congenital syphilis, and developmental anomalies (Belal and Stewart, 1974). These authors found that such

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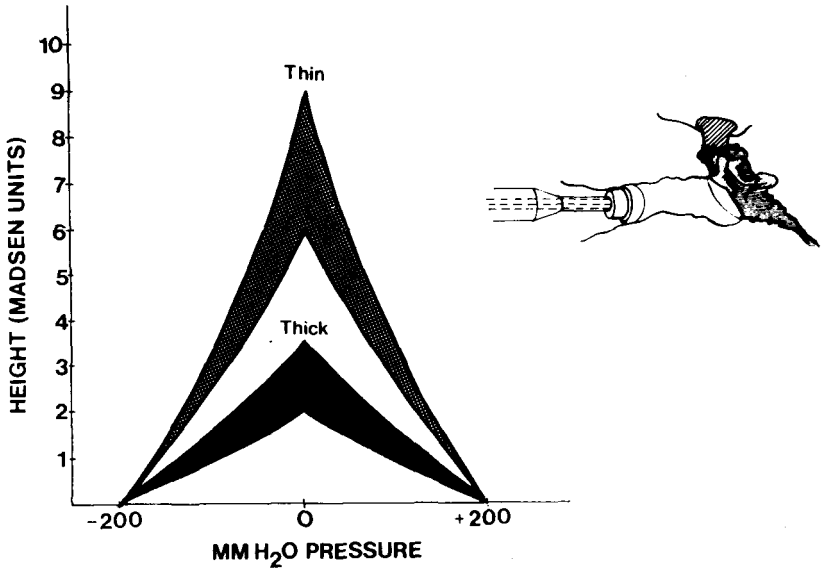


FIG. 3
Effect of viscosity of fluid.

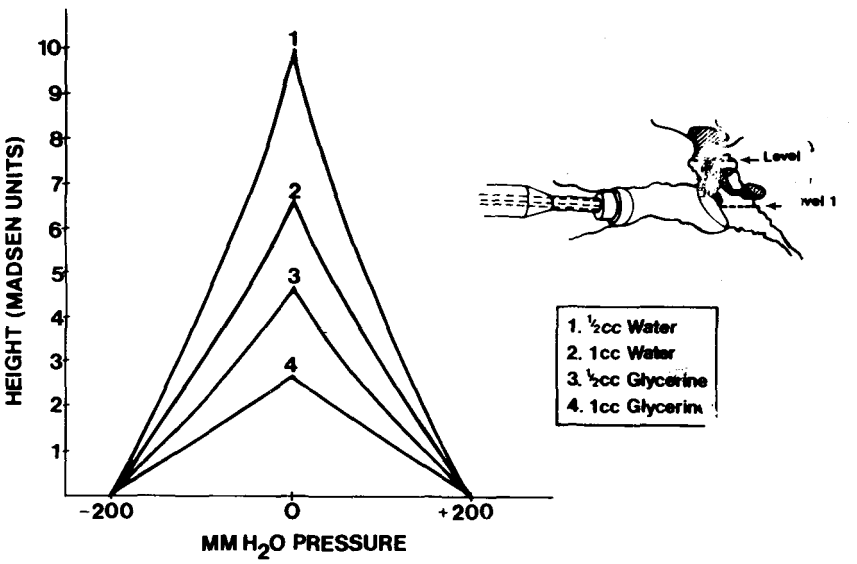


FIG. 4
Effect of fluid height.

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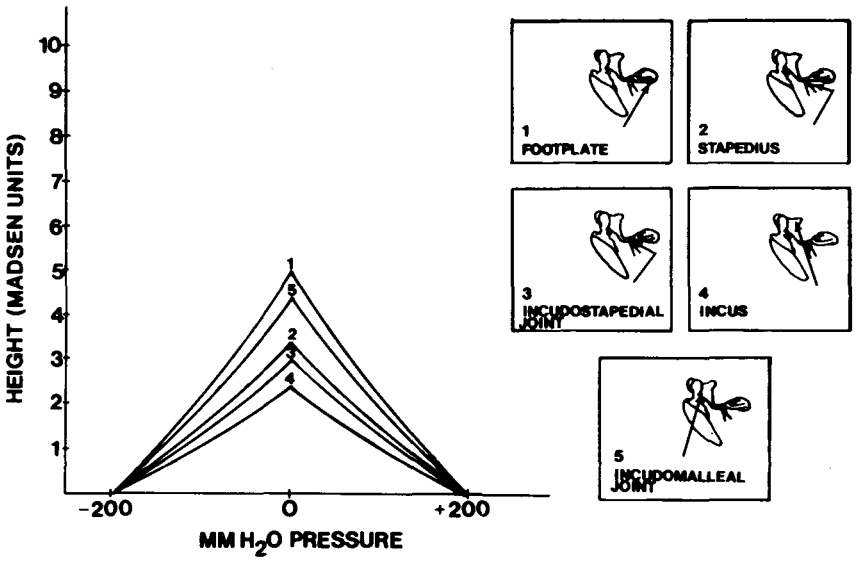


FIG. 5
Ossicular fixations.

fixations had no effect upon pure tone thresholds. The same finding was reported by Moller (1965), who tested the effect of experimental fixation of these joints upon auditory thresholds.

Experimental fixation of the IS joint was associated with static compliance of ·5, height 3·5, and slope from 1 to 1·5. Experimental fixation of the IM joint showed static compliance of ·6, type A^s tympanograms with height of 4·5 and slope 1·0 to 1·5.

(C). Stapedius tendon—Ossification of the stapedius tendon has been previously reported as a developmental anomaly (Schuknecht and Trupiano, 1957) or in association with otosclerosis (Patel, 1972) or tympanosclerosis (Belal *et al.*, 1977). This ossification may be found in association with a minor conductive hearing loss or may be detected incidentally at the time of surgery.

Experimental fixation of the stapedius tendon resulted in static compliance of ·15, tympanogram type A^s with height of 3·5 and slope of ·5.

(D). Short process of the incus—House (1956) reported three cases of fixation of the short process of the incus in the fossa incudis. These cases were associated with a history of hearing loss, and a flat audiometric pattern. Ossification of the posterior incudal ligament was also reported with advanced age (El-Ficky, 1972; Belal, 1975) as well as with tympanosclerosis.

Experimental fixation of the incus to the fossa incudis resulted in static compliance of ·2, tympanogram height of 3—clearly a Jerger type A^s tympanogram—and slope from ·5 to ·75.

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All experimental fixations of the ossicular chain in this study were similar in pattern. Under the Jerger classification system, fixations of the stapedius tendon, short process of the incus and incudo-stapedial joint had type A^s tympanograms. Interestingly, one bone that could not be used for experimental lesions was found to have otosclerosis. Its impedance values were: static compliance = ·5, height = $2\frac{1}{2}$, slope = ·5. These results closely resembled the results of the above-mentioned three experimental fixations of the ossicular chain. Fixation of the stapes footplate and the incudo-malleal junction yielded type A tympanograms.

(4). Ossicular discontinuity—Ossicular chain discontinuities (Fig. 6) may occur in a variety of otologic conditions, such as trauma, middle ear infections or tumours, and as a complication of stapedectomy surgery. The most common site of ossicular interruption is the incudo-stapedial joint. It has been reported that incudo-stapedial joint disarticulation has occurred following trauma, avascular necrosis of the incus, or inflammatory incus necrosis associated with cholesteatoma.

The following tympanometric results were recorded after experimental interruption of the ossicular chain at different sites:

A. Stapes crura: static compliance = ·5; tympanogram height = 9; tympanogram slope = 3·0.
B. Incudo-stapedial joint: static compliance = 1·0; tympanogram height = 10+; slope = 3.
C. Incus removal: static compliance = 1·8 to 2·0; height = 10+; slope = 4·0.
D. Malleus neck sectioned: static compliance = 1·8 to 2·0; height = 7; slope = 4·0.

Experimental lesions effecting disarticulations were somewhat different in appearance depending upon the site of the lesion. Disarticulation of the incudo-stapedial joint and removal of the incus yielded clear type A^d tympanograms, indicative of disarticulation. Fracturing the stapes crura and sectioning the malleus neck yielded bones with type A tympanograms that resemble normal tympanograms. Clinical experience with fractured crura has also demonstrated the type A tympanogram to be the most common finding (Forquer, 1979, unpublished data).

(5). Perforated tympanic membrane—Recording of tympanic membrane mobility with impedance audiometry is predicated upon pressure differences between the outside and inside cavities. When the membrane is perforated, the sound is free to enter directly into the middle ear cavity and the sound sequence differential is abolished. Clinically, a perforated tympanic membrane yields a very flat tympanogram and very low static compliance. The value ascribed to mobility of the tympanic membrane at +200 mm H_2O is exceedingly large, as the impedance bridge is attempting to measure an infinitely large air space. Results in temporal bones exactly paralleled those seen clinically.

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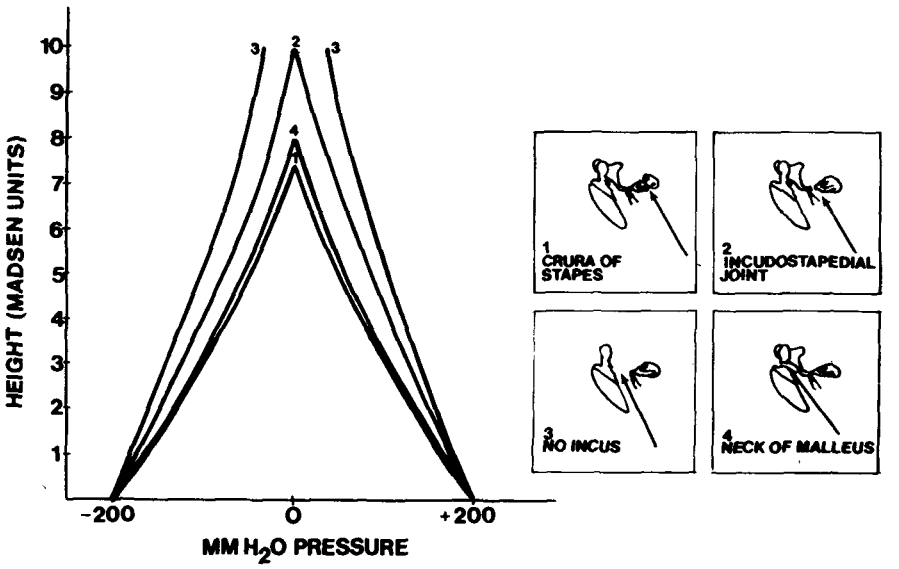


FIG. 6
Ossicular discontinuities.

(6). *Dual ossicular lesions*—It has been reported (Chesnutt, 1975) that tympanometry reflects the more lateral of dual ossicular lesions. The present study did not confirm this observation. After the incus was removed from two temporal bone preparations, dental cement was used to fix the head of the malleus to the anterior and superior walls of the epitympanum. In one bone, this produced static compliance of ·4, height of 7, and slope of 1; in the other, static compliance of ·8, height of 10 and slope of 3·0. Though measurements of dual ossicular lesions were significantly different from those of incus removal, they could not be differentiated from normal tympanograms.

Summary and Conclusions

Static compliance, height of tympanogram, and slope of tympanogram were analyzed in ten temporal bone preparations after experiments simulating a number of middle ear disorders, including middle ear effusion, ossicular fixation, ossicular disarticulation, tympanic membrane perforation, and dual ossicular lesions. Each measure was analyzed separately and in combination with each other measure. No measure alone was of value in differentiating the site of a lesion in the middle ear, although tympanogram height could easily distinguish middle ear effusion from ossicular discontinuity. The combination of static compliance and height of tympanogram yielded the greatest diagnostic sensitivity.

Fig. 7 shows four clusters of lesions that can be differentiated when both static compliance and height of tympanogram are considered together.

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Area I, demonstrating low compliance and low tympanogram height, which would be considered Jerger type B tympanograms, included three cases of thick effusion and one case each of fixation of the incus to the epitympanum, fixation of the stapedius tendon, and perforation of the tympanic membrane. The perforation case could, of course, be clearly differentiated from the effusion cases by its extremely large C_2 value. Area II, showing type A^s tympanograms, is an interesting cluster of ossicular fixations, including incudo-malleal fixation, incudo-stapedial fixation, stapes footplate fixation, true otosclerosis, and two cases of thin fluid. Although interpretation of tympanometric data could not differentiate the site of the lesion in ossicular fixation, they were clearly clustered together in a particular region. Area III, designated the normal area, included all cases of bones without any lesion and two cases of thin fluid. Finally area IV, demonstrating Jerger type A^d tympanograms and very high static compliance, contains three cases of incus removal, a case of a sectioned malleus neck, and a case of disarticulated incudo-stapedial joint.

Tympanometry alone, then, has only limited value in differentiating the various elements of conductive hearing loss. While it is possible to differentiate ossicular fixation from ossicular discontinuity and middle ear effusion, specific identification of the site of the lesion seems to be impossible and only gross categorization is possible. Of special difficulty was the differentiation of some of the milder fixations and disarticulations (as in fixing the stapedius tendon) and thin fluid from normal tympanograms. It would be expected, of course, that the addition of reflex data might

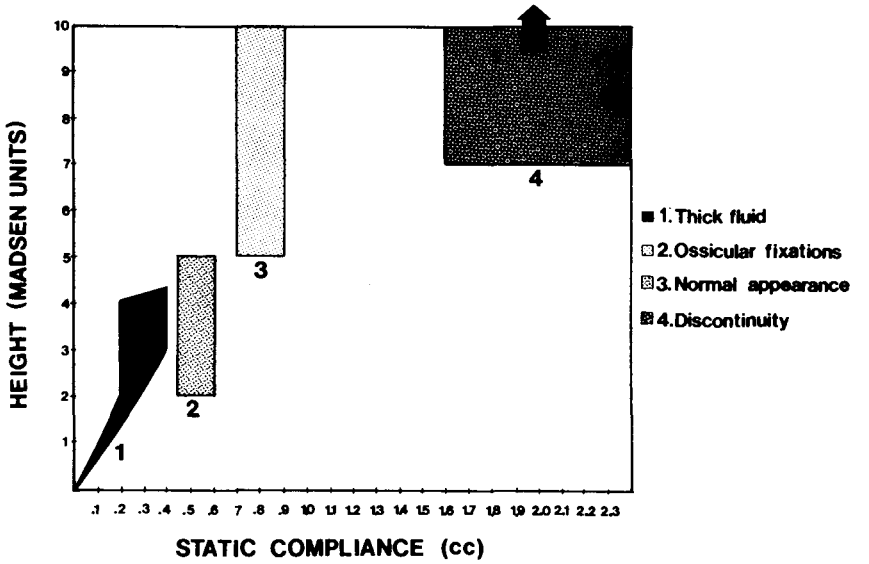


FIG. 7
Clusters of lesions; 2 dimensions.

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increase the differentiating potential of tympanometry. Considering, however, that even minimal (5–10 dB) conductive losses are known to abolish the acoustic reflex clinically, impedance audiometry can not be considered more than grossly sensitive to the site of a lesion in the middle ear.

Tympanometry, when interpreted in conjunction with the case history, otoscopy, audiometric studies and X-ray data, can be a valuable source of information on the acoustic characteristics of the middle ear system.

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