Diagnosis

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Since there is an ever-increasing rise in the prevalence of antibiotic-resistant bacteria causing otitis media, there is a need to accurately diagnose
otitis media to avoid unnecessary treatment. Diagnosis of otitis media in children is determined from medical history and physical examination. For more than a century, clinicians have used the otoscope, but it is only relatively recently that a pneumatic attachment to it has been advocated. When used appropriately, the otoscope with the pneumatic attachment is the most feasible and cost-effective method for diagnosis of otitis media and many of its associated complications and sequelae. In the 1970s, the acoustic admittance (immittance) audiometer (formerly called the electroacoustic impedance bridge) became available, with which a tympanogram can be obtained. This is now the most accurate objective method to diagnose middle-ear effusion. Also, a handheld spectral gradient acoustic reflectometer has become available for diagnosis of middle-ear effusion. Audiometry is of limited value as a diagnostic method for identifying otitis media, but it can be helpful in evaluating the effect of middle-ear disease on hearing. It can also help in the selection of management options.

SIGNS AND SYMPTOMS OF OTITIS MEDIA

Children with acute otitis media (AOM) may have nonspecific signs and symptoms, including fever, irritability, headache, apathy, anorexia, vomiting, and diarrhea. Fever occurs in one-third to two-thirds of children with otitis media, and high fever (temperature above 40°C) is unusual unless it is accompanied by bacteremia or a significant focus elsewhere.

Nine specific signs and symptoms are associated with otitis media and its complications and sequelae.

Otalgia, or ear pain, is by far the most common complaint in children with AOM and is the best predictor of AOM. In infants, however, pulling at the ear or irritability, especially when it is associated with fever, may be the only sign of ear pain. Otalgia may also result from inflammation of the external canal or may originate outside the ear (e.g., from the temporomandibular joint, teeth, or pharynx). In most cases, otalgia not associated with otitis media can be identified as referred pain due to discomfort with swallowing (tonsillitis), nasal obstruction, or pain in the throat (pharyngitis). However, any lesion in the areas of the trigeminal, facial, glossopharyngeal, vagus, great auricular, or lesser occipital nerve supply can result in earache. On the other hand, earache does not occur in some children with AOM; approximately one-fifth of 335 consecutively diagnosed episodes in a pediatric practice were without earache (usually among children older than 2 years).

Otorrhea, a discharge from the ear, may be from one or more of the following sites: the external auditory canal, middle ear, mastoid, inner ear, or intracranial cavity.

Hearing loss is a frequent symptom associated with otitis media when it is elicited from older children. In infants and younger children who are not able to verbalize this loss of function, the only sign of disease in the middle ear may be the parents’ suspicion of hearing loss.

Vertigo is not a common complaint in children, but otitis media and eustachian tube dysfunction are the most common causes of this disorder. The vestibular system is more commonly affected by unilateral middle-ear effusion than it is by bilateral disease. Vertigo may also be due to labyrinthitis. Older children describe a feeling of spinning or turning, whereas younger children may not be able to describe these symptoms but manifest dysequilibrium by falling, stumbling, or “clumsiness.”

Nystagmus, which is usually associated with vertigo of labyrinthine origin, is of the unidirectional, horizontal, jerk type in otitis media.

Tinnitus is another symptom that children describe infrequently, but like vertigo, it is commonly due to otitis media and eustachian tube dysfunction.

Swelling about the ear, especially in the postauricular area, may indicate disease of the mastoid (e.g., periostitis or subperiosteal abscess) but must be differentiated from diffuse external otitis, adenopathy, or adenitis.

Facial paralysis in children, when it is due to disease within the temporal bone, most commonly occurs as a complication of AOM, chronic otitis media with perforation and discharge, or cholesteatoma.
Purulent conjunctivitis can be associated with AOM. The conjunctivae are injected with pain; there is tearing or purulent discharge and, in some children, concurrent ear pain. Simultaneous cultures of conjunctivae and middle-ear exudates reveal nontypeable Haemophilus influenzae in almost all cases. It has been suggested that AOM caused by Streptococcus pneumoniae can present as a more severe disease than when the bacterial etiology is either H. influenzae or Moraxella catarrhalis, but this was not found to be correct in a study in which tympanocentesis confirmed the offending bacterial organism.

**PHYSICAL EXAMINATION**

Aside from the history, the most useful method for diagnosis of otitis media is a physical examination that includes pneumatic otoscopy. Adequate examination of the head and neck can lead to identification of a condition that may predispose the patient to, or be associated with, otitis media.

The appearance of the child’s face may be an important clue to susceptibility to middle-ear disease. Many craniofacial anomalies, such as mandibulofacial dysostosis (Treacher Collins syndrome) and trisomy 21 (Down syndrome), are associated with increased incidence of ear disease.

The character of speech may be altered. Mouth breathing and hyponasality may indicate intranasal or postnasal obstruction. Hypernasality is a sign of velopharyngeal insufficiency.

Examination of the oropharyngeal cavity may uncover an overt cleft palate or a submucous cleft palate (Figure 1), both of which predispose an infant to otitis media with effusion. A bifid uvula is also associated with an increased incidence of middle-ear disease. Posterior nasal or pharyngeal inflammation and discharge may be present.

Pathologic conditions of the nose, such as polyposis, severe deviation of the nasal septum, or a nasopharyngeal tumor, may be associated with otitis media.

Examination of the ear is the most critical part of the clinician’s assessment of the patient, but it must be performed systematically. The auricle and external auditory meatus should be examined first. Although not common, congenital aural atresia can be associated with otitis media and even cholesteatoma, which is more common when the ear canal is stenotic. Too frequently, these areas are overlooked in the physician’s haste to make a diagnosis by otoscopic examination. The presence or absence of signs of infection in these areas may later help in the differential diagnosis or evaluation of complications of otitis media. For instance, eczematoid external otitis may result from AOM with discharge, or inflammation of the postauricular area may indicate a periostitis or subperiosteal abscess that has extended from the mastoid air cells. Palpation of these areas determines whether tenderness is present; exquisite pain on palpation of the tragus indicates the presence of acute, diffuse external otitis.

After examining the external ear and canal, the clinician may proceed to the most important part of the physical assessment, the otoscopic examination.

**OTOSCOPY**

Positioning the Patient for Examination

The position of the patient for otoscopy depends on the patient’s age, his or her ability to cooperate,
the clinical setting, and the examiner’s preference. Otoscopic evaluation of an infant is best performed on an examining table, and a parent or assistant is necessary to restrain the baby because undue movement usually prevents an adequate evaluation (Figure 2). Some clinicians prefer to place the infant prone on the table, whereas others prefer the patient to be supine. Use of the examining table is also desirable for older infants who are uncooperative or when a tympanocentesis or myringotomy is performed without general anesthesia.

Figure 3 shows that infants and young children who are just apprehensive and not actively struggling can be evaluated adequately while sitting on the parent’s lap. When necessary, the child may be restrained firmly on an adult’s lap; the child’s wrists are held over the abdomen with one of the parent’s hands, and the child’s head is held against the parent’s chest with the other hand. If necessary, the child’s legs can be held between the adult’s thighs. Some infants can be examined by placing the child’s head on the parent’s knee (Figure 4). Cooperative children sitting in a chair or on the edge of an examination table can usually be evaluated successfully.

The otoscope should be held with the hand or finger placed firmly against the child’s head or face so the otoscope will move with the head rather than cause trauma (pain) to the ear canal if the child moves suddenly (Figure 7-5). Pulling up and out on the pinna usually straightens the ear canal enough to allow exposure of the tympanic membrane. In the young infant, the tragus must be moved forward and out of the way.

**Removal of Cerumen**

Before the clinician can adequately visualize the external canal and tympanic membrane, all obstructing cerumen must be removed from the canal. Many children with AOM have moderate to large accumulations of cerumen in the ear canal. Cerumen in the external auditory canal even causes chronic cough probably due to
stimulation of Arnold’s nerve reflex. For optimal visualization of the tympanic membrane, mechanical removal was necessary in approximately one-third of 279 patients observed by Schwartz and colleagues; cerumen removal was inversely proportional to age, with more than half of these infants younger than 1 year.

Removal of cerumen can usually be accomplished by using an otoscope with a surgical head and a wire loop or a blunt cerumen curet (Figure 6) or by irrigating the ear canal gently with warm water delivered through a dental irrigator (Water Pik) (Figure 7). Carbamide peroxide in glycerol (Debrox, GlaxoSmithKline, Research Triangle Park, NC) can be used by the patient for a few days before irrigation. Reported use of other commercial preparations (eg, triethanolamine polypeptide oleate-condensate) may cause severe eczematoid allergic reactions of the external canal. Also, these agents do not seem to have any beneficial effect compared with saline irrigation alone. Recently, a new product, OtoClear Safe Irrigation System (Bionix Development Corporation, Toledo, OH) was used with success in clearing ear wax in children in a clinical study conducted at the Children’s Hospital of Pittsburgh.

**Otoscope**

To properly assess the tympanic membrane and its mobility, the clinician should use a pneumatic otoscope with a diagnostic head having an adequate seal. Currently, the quality of the otoscopic examination is limited by deficiencies in the designs of commercially available otoscopes. The speculum used should have the largest lumen that can comfortably fit in the
child’s cartilaginous external auditory meatus. If the speculum is too small, adequate visualization may be impaired, and the speculum may touch the bony canal, which can be painful. In most models, an airtight seal is usually not possible because of a leak of air within the otoscope head or between the stiff ear speculum and the external auditory canal, although leaks in the external auditory canal can be stopped by cutting off a small section of rubber tubing and slipping it over the tip of the ear speculum (Figure 8).

The otoscope should have sufficient brightness for adequate visualization of the tympanic membrane and external auditory canal. Barriga and colleagues evaluated the output of lights in 221 otoscopes in various clinical settings and reported that one-quarter of the lights failed to meet the minimum recommended standards.29 A halogen bulb with 100 foot-candles or more is currently recommended.30 Batteries should be

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**Figure 6.** Method for removing cerumen from the external ear canal by employing the surgical head attached to the otoscope. Instruments that can be used are also illustrated.

**Figure 7.** Irrigation of the external canal with a dental irrigator to remove cerumen.

**Figure 8.** Pneumatic otoscope, with rubber tip on the end of the ear speculum to give a better seal in the external auditory canal.
replaced frequently, or if the instrument is rechargeable, it should have recently been recharged before use to ensure optimal light.

**Examination**

Inspection of the tympanic membrane should include evaluation of its position, color, degree of translucency, and mobility. Assessing the light reflex is of limited value because it does not reflect the status of the middle ear in evaluation of tympanic-membrane–middle-ear disorders. Clinical otoscopic examinations compare favorably with histologic temporal bone specimens.

**Position of the Tympanic Membrane**

Figure 9 illustrates the positions of the tympanic membrane when the middle ear is aerated and when effusion is present.

The normal eardrum should be in the neutral position, with the short process of the malleus visible, but not prominent, through the membrane.

Mild retraction of the tympanic membrane usually indicates the presence of negative middle-ear pressure or an effusion, or both. The short process of the malleus and posterior malleal fold are prominent, and the manubrium of the malleus appears to be foreshortened.

Severe retraction of the tympanic membrane is characterized by a prominent posterior malleal fold and short process of the malleus and a severely foreshortened manubrium. The tympanic membrane may be severely retracted, presumably owing to high negative pressure associated with a middle-ear effusion.

Fullness of the tympanic membrane is initially apparent in the posterosuperior portion of the pars tensa and the pars flaccida, because these two areas are the most highly compliant parts of the tympanic membrane. The short process of the malleus is commonly obscured. The fullness is caused by increased air pressure or effusion, or both, within the middle ear. When bulging of the entire tympanic membrane occurs, the malleus is usually obscured; this occurs when the middle-ear–mastoid system is filled with an effusion.

**Appearance of the Tympanic Membrane**

The normal tympanic membrane has a ground-glass appearance; a blue or yellow color usually indicates a middle-ear effusion seen through a translucent tympanic membrane (Figures 10 to 17 [see CD-ROM for otoscopic appearance of common tympanic membranes shown in color and animation]). A red tympanic membrane alone may not indicate a pathologic condition, because the blood vessels of the eardrum head may be engorged as the result of the patient's crying, sneezing, or nose blowing. A “red eardrum” has been described as one that is bulging,
fiery red, or dark red-purple hemorrhagic, which has been sometimes associated with AOM caused by group A streptococci infection or highly virulent pneumococcal disease.\textsuperscript{33}

It is critical to distinguish between translucency and opacification of the eardrum to identify a middle-ear effusion. The normal tympanic membrane should be translucent, and the observer should be able to look through the eardrum and visualize the middle-ear landmarks (the incudostapedial joint, promontory, round window niche, and, frequently, chorda tympani

Figure 10. Normal right tympanic membrane and middle ear. (See color figure on accompanying CD-ROM.)

Figure 11. Bulging right tympanic membrane in acute otitis media. (See color figure on accompanying CD-ROM.)

Figure 12. Air-fluid level and bubbles visible through right retracted, translucent tympanic membrane in otitis media with effusion. (See color figure on accompanying CD-ROM.)

Figure 13. Severely retracted, opaque right tympanic membrane in otitis media with effusion. (See color figure on accompanying CD-ROM.)
nerve) (Figure 18). If a middle-ear effusion is present medial to a translucent eardrum, an air-fluid level or bubbles of air admixed with the liquid may be visible. Inability to visualize the middle-ear structures indicates opacification of the eardrum, which is usually the result of thickening of the tympanic membrane or the presence of an effusion, or both. Vesicles on the tympanic membrane are most likely a sign of myringitis bullosa. The presence of an aural polyp or a white mass, or both, could be associated with a cholesteatoma and should

Figure 14. Retraction pocket in the posterosuperior quadrant of right tympanic membrane and middle ear effusion. (See color figure on accompanying CD-ROM.)

Figure 15. Large “dry” central perforation of right tympanic membrane. (See color figure on accompanying CD-ROM.)

Figure 16. Middle ear cholesteatoma visualized through perforation of right tympanic membrane. (See color figure on accompanying CD-ROM.)

Figure 17. Cholesteatoma within right tympanic membrane. (See color figure on accompanying CD-ROM.)
prompt an otologic referral (see Chapter 9, “Complications and Sequelae: Intratemporal”).

The light reflex is due to the light from the otoscope reflecting off the tympanic membrane, usually in the anteroinferior quadrant, but is of little diagnostic significance, and thus, can essentially be ignored. Scarring of the tympanic membrane is common in children who have had recurrent and chronic middle-ear disease (with or without tympanostomy tube placement), and is even more common in teenagers and adults who have many years of eustachian tube dysfunction and otitis media.

**Mobility of the Tympanic Membrane**

Abnormalities of the tympanic membrane and middle ear are reflected in the pattern of tympanic membrane mobility when first positive and then negative pressure is applied to the external auditory canal with the pneumatic otoscope. As shown in Figure 19, this is achieved by first applying slight pressure on the rubber bulb (positive pressure) and then, after momentarily breaking the seal, releasing the bulb (negative pressure). It is important to start with slight positive pressure by gently pressing on the rubber bulb, because the child will experience ear pain if the bulb is completely depressed vigorously and the tympanic membrane–middle ear is normal. Excessive pressure applied to a normal tympanic membrane–middle ear will result in an unhappy patient who is likely to be frightened by future attempts to perform otoscopy with a pneumatic attachment. If the tympanic membrane does not move when slight positive pressure is applied, progressively more pressure, as described later, can be used to determine the mobility. Indeed, one study revealed that a normal eardrum moves with as little as 10 to 15 millimeters of water (mm H₂O) pressure, whereas fluid-filled ears require a great deal more pressure to move, and many have little or no mobility to maximal applied pressure; pneumatic otoscopes can deliver 1,000 mm H₂O or more when the rubber bulb is fully depressed.
same cautious approach should be used in evaluating the response to applied negative pressure (releasing the depressed rubber bulb), because excessive negative pressure applied initially can also result in moderate to severe otalgia when the tympanic membrane–middle ear is normal or when only slight middle-ear negative pressure is present.

Effusion or high negative pressure within the middle ear can markedly dampen the movements of the eardrum. It is important to diagnose high negative pressure because it may be a sign of eustachian tube dysfunction. When middle-ear pressure is ambient, the normal tympanic membrane moves inward with slight positive pressure in the ear canal and outward toward the examiner with slight negative pressure. The motion observed is proportionate to the applied pressure and is best visualized in the posterosuperior quadrant of the tympanic membrane (Figure 20). If a dimeric membrane is present—that is, two-layered membrane or atrophic scar (“monomeric” membrane is a misnomer)—which is usually secondary to a healed perforation, mobility of the tympanic membrane can also be assessed more readily by observing the movement of the flaccid area.

The movement of the tympanic membrane to the applied pressure from the rubber bulb attached to the otoscope can generally determine whether there is relatively normal pressure within the middle ear, whether there is negative or positive pressure, or whether there is a possible effusion. Figure 21 shows a simple relationship between the pressure applied by the pneumatic otoscope and the response of that applied positive and negative pressure to the medial (in) and lateral (out) movement of the tympanic membrane. Figure 22 shows a more specific relationship between mobility of the tympanic membrane and the applied pressure from the rubber bulb attached to the otoscope.

<table>
<thead>
<tr>
<th>RESPONSE TO APPLIED POSITIVE PRESSURE</th>
<th>RESPONSE TO APPLIED NEGATIVE PRESSURE</th>
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<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Normal ME pressure</td>
<td>Positive ME pressure</td>
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<tr>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Negative ME pressure</td>
<td>No</td>
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<tr>
<td>Middle ear effusion, or very high ME pressure, or both</td>
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**Figure 20.** The four quadrants of the pars tensa of a right tympanic membrane.

**Figure 21.** Middle-ear pressure as determined by response of the tympanic membrane when positive and negative pressures are applied with the pneumatic otoscope. If the tympanic membrane moves medial (in) to applied positive pressure and lateral (out) to applied negative pressure, middle-ear pressure is within relatively normal limits. If the eardrum moves on applied positive pressure but not when negative pressure is applied, positive pressure is within the middle ear (with or without effusion). If the eardrum moves on applied negative pressure but not when positive pressure is applied, negative pressure is within the middle ear (with or without effusion). If the tympanic membrane fails to move after application of positive and negative pressures, effusion in the middle ear, or very high negative middle-ear pressure, or both, are present.
membrane, as measured by pneumatic otoscopy, and the middle-ear contents and pressure. In Figure 22, Frame 1 shows the normal tympanic membrane when the middle ear contains only air at ambient pressure. A hypermobile eardrum (Frame 2) is seen most frequently in children whose membranes are atrophic or flaccid. The mobility of the tympanic membrane is greater than normal (the eardrum is said to be highly compliant) if the eardrum moves when even slight positive or negative external canal pressure is applied. If the eardrum moves equally well to both applied positive and negative pressures, the middle-ear pressure is approximately ambient. However, if the tympanic membrane is hypermobile to applied negative pressure but is immobile when positive pressure is applied, the tympanic membrane is flaccid, and negative pressure is present within the middle ear. A middle-ear effusion is rarely present when the tympanic membrane is hypermobile, even though high negative middle-ear pressure is present. A thickened tympanic membrane (secondary to inflammation or scarring) or a partly effusion-filled middle ear (in which the middle-ear air pressure is ambient) shows decreased mobility to applied pressures, both positive and negative (Frame 3).

Normal middle-ear pressure is reflected by the neutral position of the tympanic membrane as well as by its response to both positive and negative pressures in each of the previous examples (Frames 1 through 3). In other cases, the eardrum may be retracted—usually because

<table>
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<tr>
<th>PNEUMATIC OTOSCOPY</th>
<th>MIDDLE EAR</th>
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<tbody>
<tr>
<td>EARDRUM POSITION*</td>
<td>EARDRUM POSITIVE† PRESSURE</td>
</tr>
<tr>
<td>1. NEUTRAL</td>
<td>1+ 2+</td>
</tr>
<tr>
<td>2. NEUTRAL</td>
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</tr>
<tr>
<td>6. RETRACTED</td>
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</tr>
<tr>
<td>7. FULL</td>
<td>0 1+</td>
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<tr>
<td>8. BULGING</td>
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* POSITION OF EARDRUM:
- AT REST; - - POSITIVE PRESSURE APPLIED (BULB COMPRESSED);
- -NEGATIVE PRESSURE APPLIED (RELEASE BULB)
† DEGREE OF TYMPANIC MEMBRANE MOVEMENT AS VISUALIZED THROUGH
THE OTOSCOPE; 0 = NONE, 1+ = SLIGHT, 2+ = MODERATE, 3+ = EXCESSIVE
‡ COMPRESSION OF BULB EXERTS POSITIVE PRESSURE; RELEASE OF A
COMPRESSED BULB INDUCES NEGATIVE PRESSURE

Figure 22. Pneumatic otoscopic findings related to middle-ear contents and pressure.
negative middle-ear pressure is present (Frames 4 through 6). The compliant membrane is maximally retracted by even moderate negative middle-ear pressure, and hence cannot visibly be deflected farther inward with applied positive pressure in the ear canal. Negative pressure produced by releasing the rubber bulb of the otoscope will, however, cause a return of the eardrum toward the neutral position if a negative pressure equivalent to that in the middle ear can be created by releasing the rubber bulb, a condition (Frame 4) that occurs when air, with or without an effusion, is present in the middle ear. When the middle-ear pressure is even lower, there may be only slight outward mobility of the tympanic membrane (Frame 5) because of the limited negative pressure that can be exerted through the otoscopes currently available. If the eardrum is severely retracted with extremely high negative middle-ear pressure or in the presence of a middle-ear effusion, the examiner is not able to produce significant outward movement (Frame 6).

The tympanic membrane that exhibits fullness (Frame 7) will move to applied positive pressure but not to applied negative pressure if the pressure within the middle ear is positive and air, with or without an effusion, is present. In such an instance, the tympanic membrane is stretched laterally to the point of maximal compliance and will not visibly move outward any farther to the applied negative pressure but will move inward to applied positive pressure as long as some air is present within the middle-ear–mastoid-air-cell system. When this system is filled with an effusion and little or no air is present, the mobility of the bulging tympanic membrane (Frame 8) to both applied positive and negative pressure is severely decreased or absent.

Figure 23 shows examples of common conditions of the middle ear as assessed with the otoscope. Position, color, degree of translucency, and mobility of the tympanic membrane are diagnostic aids.

Figure 24 depicts the pneumotoscopic method used to determine whether a line that is visualized on the lower portion of the tympanic membrane is the tympanic membrane touching the promontory, an effusion level, or a scar within the tympanic membrane. When the tympanic membrane is severely retracted and no middle-ear effusion is present, the tympanic membrane may touch the promontory, and a line can be seen through the membrane. However, if the tympanic membrane can be pulled laterally when negative pressure is applied with the pneumatic otoscope, the line disappears because the membrane is no longer touching the promontory (Figure 24A). A line that is due to a fluid level moves up when positive pressure is applied because the middle-ear cavity is made smaller, and down when negative pressure is
applied because the middle-ear cavity is made larger (Figure 24B). If the line is a scar, it stays in the same place on the tympanic membrane when positive or negative pressure is applied (Figure 24C).

**Otoscopy in the Newborn Infant**

The position of the tympanic membrane in the neonate is different from that in the older infant and child. If this is not kept in mind, the examiner may perceive the eardrum to be smaller and retracted because in the neonate, the tympanic membrane appears to be as wide as it is in older children but not as high (Figure 25). Figure 26 shows that this perception is due to the more horizontal position of the neonatal ear-drum, which frequently makes it difficult for the examiner to distinguish the pars flaccida of the tympanic membrane from the skin of the wall of the deep superior external canal.

In the first few days of life, the ear canal is filled with vernix caseosa, but this material is easily removed with a small curet or suction tube.
The canal walls of the young infant are pliable and tend to expand and collapse with insufflation during pneumatic otoscopy. Because of the pliability of the canal walls, it is necessary to advance the speculum farther into the canal than for the older child. The tympanic membrane often appears thickened and opaque during the first few days. In many infants, the membrane is in an extreme oblique position, with the superior aspect proximal to the observer (see Figure 25). The tympanic membrane and the superior canal wall may appear to lie almost in the same plane, so that it is often difficult to distinguish the point where the canal ends and the pars flaccida begins. The inferior canal wall bulges loosely over the inferior position of the tympanic membrane and moves with positive pressure, simulating the movement of the tympanic membrane. The examiner must distinguish between the movement of the canal walls and the movement of the membrane. The following should be considered to distinguish the movement of these structures: vessels are seen within the tympanic membrane but not in the skin of the ear canal; the tympanic membrane moves during crying or respiration; and inferiorly, the wall of the external canal and the tympanic membrane lie at an acute angle. By 1 month of age, the tympanic membrane has assumed an oblique position, as in the older
During the first few weeks of life, however, examination of the ear requires patience and careful appraisal of the structures of the external canal and the tympanic membrane.

**COMPLETEs: A Mnemonic for Otoscopic Examination**

Kaleida has proposed a mnemonic that clinicians can use when examining the tympanic membrane for the presence or absence of otitis media (Table 1).

**Accuracy and Validation**

Otoscopy is subjective and is thus usually an imprecise method of assessing the condition of the tympanic membrane and middle ear. Many clinicians do not use a pneumatic otoscope, and few have been adequately trained to make a correct diagnosis. The primary reason for this lack of proper education is the method of teaching. Because otoscopy is a monocular assessment of the tympanic membrane, the teacher cannot verify that the student actually saw the anatomic features that led to the diagnosis. A new otoscope with a second viewing port is available (Figure 27). Teacher and student can make observations together, and student errors can be corrected immediately. One of the most effective means of education currently available is the correlation of otoscopic findings with those of the otomicroscope, which has an observer tube for the student. In this manner, the instructor can point out critical landmarks and demonstrate tympanic mobility.

Assessment techniques can also be improved by correlating otoscopy findings with a tympanogram taken immediately after the otoscopic examination. If the otoscopic findings and tympanometry do not agree, a second otoscopic examination is usually performed because tympanometry is generally accurate in distinguishing between normal and abnormal tympanic membranes and middle ears (specifically, in identifying middle-ear effusions). The presence or absence (and degree) of negative pressure within the middle ear measured by pneumatic otoscopy can be verified only by similar results on the tympanogram.

Validation of otoscopic skills is important for educating individuals and for documenting the adequacy of participants in research programs.

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**Table 1. COMPLETEs: A MNEMONIC FOR THE OTOSCOPIC EXAMINATION**

<table>
<thead>
<tr>
<th>Color</th>
<th>Gray, white, yellow, amber, pink, red, blue</th>
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<tbody>
<tr>
<td>Other conditions</td>
<td>Fluid level, bubbles, perforation, retraction pocket, atrophic area, otorrhea, bullae, tympanosclerosis, cholesteatoma</td>
</tr>
<tr>
<td>Mobility</td>
<td>4+, 3+, 2+, 1+</td>
</tr>
<tr>
<td>Position</td>
<td>Neutral, bulging, retracted</td>
</tr>
<tr>
<td>Lighting</td>
<td>Battery charged, halogen or bulb</td>
</tr>
<tr>
<td>Entire surface</td>
<td>Visualize all quadrants: anterosuperior, posterosuperior, anteroinferior, posteroinferior</td>
</tr>
<tr>
<td>Translucency</td>
<td>Translucent or opaque</td>
</tr>
<tr>
<td>External auditory canal and auricle</td>
<td>Inflammation, foreign body, displacement, deformed</td>
</tr>
<tr>
<td>Seal</td>
<td>Appropriate-sized speculum, airtight pneumatic system</td>
</tr>
</tbody>
</table>

Reproduced with permission from Kaleida PH. 44
To validate the presence or absence of effusion as observed by otoscopy, a tympanocentesis or myringotomy should be performed immediately after the examination. When surgical opening of the tympanic membrane is indicated, preliminary otoscopy by the examiner is an effective way of validating the otoscopist. When otoscopists, who ranged from house officers to pediatric otolaryngologists, were tested against myringotomy findings in their ability to diagnose middle-ear effusion, sensitivity ranged from 84 to 91, and specificity was between 74 and 93. This method has been described for research purposes, but it should be part of every clinician-otoscopist's method to improve the accuracy of diagnosis of otitis media.

In a report from Australia, Eikelboom and coworkers used digitized still images of the eardrum, along with the clinical history, audiometry and tympanometry from patients' primary care providers in remote communities for the ear specialist to provide an expert opinion using television at a central site. This method holds promise for improved diagnostic capabilities in areas around the world where otologists are not readily available.

Other Teaching Tools. In addition to the color animated (movement of the tympanic membrane with pneumatic otoscopy) figures in the enclosed CD-ROM, Phillip H. Kaleida, MD, and his colleagues at the Children's Hospital of Pittsburgh have developed a teaching tool and self-assessment test on the web: the DxEar 50-ear online self-assessment test and the Enhancing the Proficiency of Residents in Otitis Media (ePROM) modules. Individuals should register on the Pitt Med Navigator site: <http://navigator.medschool.pitt.edu>. The URL for ePROM is <http://www.eprom.pitt.edu>. This type of self-teaching and assessment tool is especially beneficial for pediatric residents, since one study revealed problematic diagnostic capabilities in these trainees. But other trainees, such as those in family medicine and otolaryngology, as well as medical students, could benefit from this innovative teaching method.

**Clinical Description**

**Acute otitis media**

The usual picture of AOM is seen in a child who has had an upper respiratory tract infection for several days and suddenly develops otalgia, fever, and hearing loss. Examination with the pneumatic otoscope reveals a hyperemic, opaque, bulging tympanic membrane that has poor mobility (see Figure 23C). Purulent otorrhea is usually also a reliable sign. In addition to fever, other systemic signs and symptoms may include irritability, lethargy, anorexia, vomiting, and diarrhea. Sore throat and night restlessness have also been shown to be associated with AOM. However, none of these may be present, and even earache and fever are unreliable guides and may frequently be absent. Likewise, otoscopic findings may consist of only a bulging or full, opaque, poorly mobile eardrum without evidence of erythema. Hearing loss will not be a complaint of the very young and may not even be noted by parents.

Because of the variability of symptoms, infants and young children presenting with diminished or absent mobility and opacification of the tympanic membrane should be suspected of having AOM. Certainty in making the diagnosis has been advocated in an effort to reduce the amount of unnecessary prescriptions for antibiotics.

The clinical practice guideline of the American Academy of Pediatrics and American Academy of Family Physicians was an attempt to provide a uniform definition of AOM consistent with the above discussion: acute onset; identification of signs of middle-ear effusion; and signs and symptoms of middle-ear inflammation. The guideline identified the following elements:

1. Abrupt onset of signs and symptoms of middle ear inflammation;
2. Presence of middle-ear effusion identified by any of the following:
   a. Bulging of the tympanic membrane;
   b. Limited or absent mobility of the tympanic membrane;
   c. Otorrhea.
3. Signs of symptoms of middle-ear inflammation identified by either:
   a. Erythema of the tympanic membrane or
   b. Otalgia.

**Otitis Media with Effusion**

Most children with otitis media with effusion for prolonged periods are asymptomatic. Some may complain of hearing loss and, less commonly, tinnitus and vertigo. In children, the attention of an alert parent or teacher may be drawn to a suspected hearing loss. Sometimes, the child presents with a behavioral disorder that is due to the hearing deficit and consequent inability to communicate adequately. More often, the reason for referral is the detection of a hearing loss during a school hearing screening test or when AOM fails to resolve completely. On occasion, the first evidence of the disease is discovered during a routine examination or in high-risk cases, such as in children with a cleft palate.

Older children will describe a frank hearing loss or, more commonly, a “plugged” feeling or “popping” in their ears. The symptoms are usually bilateral. Unilateral signs and symptoms of chronic middle-ear effusion may uncommonly be secondary to a nasopharyngeal neoplasm, such as an angiofibroma, or even a malignant neoplasm.

Pneumatic otoscopy frequently reveals either a retracted or full tympanic membrane that is usually opaque (see Figure 23E). However, when the membrane is translucent, an air-fluid level or air bubbles may be visualized, and a blue or amber color is present. The mobility of the ear-drum is almost always altered (see Figure 23D).

It is evident from the preceding clinical description of AOM and otitis media with effusion that there is considerable overlap, and it is often difficult for the clinician to distinguish between acute and chronic forms unless the child has been observed for a time before the onset of disease or there are associated specific (otalgia) or systemic (fever) symptoms. It may not be possible to distinguish between them even when the middle-ear effusion is aspirated (tympanocentesis) because in both acute and chronic otitis media, the effusion may be serous, mucoid, or purulent. In approximately half of chronic effusions, bacteria have been cultured that are frequently found in ears of children with classic signs and symptoms of AOM.

Because it is important today in the decision to treat or not to treat otitis media, especially with the increasing incidence of antibiotic-resistant bacteria causing otitis media, the clinician must appreciate the diagnostic differences between AOM and otitis media with effusion. Otitis media with effusion is usually not treated unless it becomes chronic. Table 2 summarizes the important diagnostic differences between these forms of otitis media.

<table>
<thead>
<tr>
<th>Signs and Symptoms</th>
<th>Acute Otitis Media</th>
<th>Otitis Media with Effusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otalgia, fever, irritability</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Middle-ear effusion</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Opaque</td>
<td>Yes</td>
<td>Yes (air-fluid level)</td>
</tr>
<tr>
<td>Bulging tympanic membrane</td>
<td>Yes</td>
<td>No (usually)</td>
</tr>
<tr>
<td>Retracted tympanic membrane</td>
<td>No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Decreased mobility of tympanic membrane</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>Yes</td>
<td>Yes (usually)</td>
</tr>
</tbody>
</table>

**Eustachian Tube Dysfunction**

Some children, especially older ones, complain of a periodic popping or snapping sound in the ear that may be preceded or accompanied by a feeling of fullness in the ear, hearing loss, tinnitus, or vertigo. Otoscopic examination may reveal a normal tympanic membrane or possible slight retraction of the eardrum, but the middle-ear pressure is within normal limits. These children have obstruction of the eustachian tube (i.e., the tube is too closed or will not open, or both) that is not severe enough to cause atelectasis or a middle-ear effusion but nevertheless may be disconcerting. This disorder is not uncommon in girls who are in puberty and may be present even when there has not been a history of middle-ear disease in the past. The etiology of this problem, primarily in young girls, may be related...
to hormonal changes associated with puberty. When this condition is troublesome, management should be as for the children who have middle-ear effusion, such as myringotomy and tympanostomy tube placement.

On occasion, older children may complain of autophony (hearing one’s own voice in the ear) and hearing their own breathing. In these cases, the eustachian tube is most likely patulous (abnormally patent), and the tympanic membrane will appear normal when it is visualized through the otoscope. Middle-ear pressure is normal. However, if the child is asked to breathe forcefully through one nasal cavity while the opposite one is occluded with a finger, the posterosuperior portion of the tympanic membrane is observed to move in and out with respiration, which confirms the diagnosis. Tympanometry may also aid in diagnosis.

Atelectasis of the Tympanic Membrane—Middle Ear and High Negative Pressure

Atelectasis of the tympanic membrane may be acute or chronic, generalized or localized, and mild or severe. The tympanic membrane may be retracted or collapsed. High negative pressure may be present or absent (see Figure 23B). When middle-ear effusion is also present, the clinical description is the same as for cases in which an acute or chronic otitis media is present. In such cases, it is not unusual to visualize through the otoscope a severely retracted malleus associated with a tympanic membrane that is full or even bulging in the posterior portion. The malleus is retracted by concurrent high negative middle-ear pressure or chronic inflammation of the tensor tympani muscle or the malleal ligaments, or both. The hydrostatic pressure of the effusion (which does not completely fill the middle ear and mastoid air cell system) results in bulging of the most compliant (floppy) portion of the pars tensa (the posterosuperior and posteroinferior quadrants). An effusion is frequently evident by the presence of an air-fluid level or bubbles behind a severely retracted tympanic membrane.

Just as when a middle-ear effusion is present, there may be a lack of specific otologic symptoms when atelectasis is present with no effusion. The child may have a severely retracted translucent tympanic membrane with evidence of high negative pressure by pneumatic otoscopy (immobile to applied positive pressure and either decreased or absent mobility to applied negative pressure) or a high negative middle-ear pressure tracing on the tympanogram. The otoscopist can look through the tympanic membrane and see that no effusion is present. Some children with such an otoscopic (and tympanometric) examination result may not have any complaint, whereas others may have a feeling of fullness in the ear, otalgia, tinnitus, hearing loss, and even vertigo. The condition may be self-limited and, in some, physiologic because of temporary eustachian tube obstruction. In others, especially those with symptoms, the condition is pathologic and should be managed in a manner similar to when an effusion is present.

When there is localized atelectasis or a retraction pocket, especially in the pars flaccida or posterosuperior portion of the pars tensa of the tympanic membrane, the condition may be more serious than when only generalized atelectasis is present. A portion of the tympanic membrane may be atrophic (also termed a dimeric membrane), which implies only two layers of the drum when, in reality, there are three layers but the lamina propria lacks the normal organized collagenous architecture. The child may be totally asymptomatic, but the retraction pocket may be associated with a significant conductive hearing loss, especially if there is erosion of one or more of the ossicles. Erosion of the long process of the incus may be present when a deep posterosuperior retraction pocket is seen (Figure 28). It is extremely important to inspect these areas of the tympanic membrane to determine whether a retraction pocket is present and, if it is present, whether there is destruction of one of the ossicles.

It is important to distinguish between a retraction pocket and a cholesteatoma. If the otoscopic examination is not adequate to make
this differential diagnosis, referral to an otolaryngologist for examination with an otomicroscope should be considered; the otolaryngologist should not hesitate to perform otomicroscopic examination under general anesthesia when indicated. Cholesteatoma, like its precursor, the deep retraction pocket, may be without signs and symptoms (other than the otoscopic appearance) unless conductive hearing loss or otorrhea is present (see Chapter 9, “Complications and Sequelae: Intratemporal”).

**AURAL ACOUSTIC IMPITTANCE MEASUREMENTS, INCLUDING TYMPANOMETRY**

Acoustic immittance describes the transfer of acoustic energy. It can be measured in terms of acoustic impedance (commonly used by clinicians in the past), which is the opposition to the flow of sound waves, or acoustic admittance, which expresses the ease of energy flow. Acoustic admittance is the more appropriate term and the one currently used. The function of the aural acoustic immittance instrument (previously called an electroacoustic impedance bridge) depends on the principles of sound in relation to the physiologic characteristics of the ear. The most effective transfer of energy occurs when energy flows from one medium to another medium of similar impedance (ie, with similar physical properties of stiffness, mass, and friction). The middle ear facilitates the transfer of sound from an air medium with low impedance to a liquid medium with relatively high impedance (cochlea) (Figure 29A). The tympanic membrane and middle ear, therefore, act as an impedance-matching transformer. Abnormalities that interfere with this function impair hearing.

**Figure 28.** An atelectatic membrane that has a severe retraction pocket in the posterosuperior quadrant of the pars tensa.

**Figure 29.** Examples of normal, increased, and decreased middle-ear impedance. A. In the normal condition, some sound is transmitted through the tympanic membrane–middle ear to the cochlea, and some portion is reflected back into the external canal. B. When there is increased impedance, such as with an effusion in the middle ear, less sound is transmitted to the cochlea and more sound is reflected back into the ear canal than in the normal condition. C. When middle-ear impedance is decreased, such as with an ossicular chain discontinuity, sound is stored in the middle ear instead of being effectively transferred to the cochlea and reflected back into the ear canal, but at a point in time that is opposite to that when the tympanic-membrane–middle-ear impedance is increased.
Three basic observations can be made with aural acoustic immittance instruments: (1) tympanometric pattern, (2) middle-ear muscle reflex, and (3) equivalent ear canal volume. The instrument has become increasingly popular and it is currently used in a wide variety of clinical settings for both diagnosis and screening. A tympanic-membrane–middle-ear system that has an increase in one or more of the components of impedance (stiffness, mass, or friction) does not transfer sound energy efficiently to the cochlear fluids. In such an instance, acoustic impedance is increased, or stated reciprocally, acoustic admittance is reduced. Therefore, a greater amount of sound energy is reflected from the tympanic-membrane–middle-ear region and a smaller amount of sound energy is transmitted to the cochlea. An excellent example of this type is a middle ear that contains an effusion (Figure 29B). Conversely, the tympanic membrane and middle ear may have a decrease in impedance (or increase in admittance), which may occur with disarticulation of the ossicular chain. In this case, an increased amount of sound energy is received by the middle ear but is not transmitted to the cochlea (Figure 29C).

**Instrumentation**

The clinical instrumentation used to perform acoustic immittance measurements has changed. Aural acoustic immittance instruments have replaced the older instruments referred to as electroacoustic impedance bridges. The design differs, although both instruments provide an objective assessment of the mobility of the tympanic membrane and the dynamics of the ossicular chain, the intra-aural muscles with their attachments, and the middle-ear air cushion. Regardless of which instrumentation is used, the same principles apply.

The instruments allow a signal to be introduced through an opening in the probe tip, which is hermetically sealed in the external auditory canal (Figure 30). A certain amount of the signal is transmitted into and through the tympanic membrane and middle ear, and a certain amount is reflected back into the ear canal. The reflected sound is received by a microphone circuit that has a certain amplitude and phase related to the physical properties of the tympanic membrane. The frequency of the signal is determined by the frequency of the probe tone, which is commonly 226 Hz.

Another component of the probe assembly is a connection to an air pump that varies the air pressure in the closed ear canal. With this arrangement, immittance can be monitored with a varying air pressure load or static air pressure load on the tympanic membrane. The air pressure can be varied either manually or automatically with most instruments. Measuring immittance changes at the tympanic membrane with changes in air pressure is called tympanometry, and when there is a static pressure load, static immittance can be measured.

**Tympanometry with Impedance Instruments**

Tympanometry involves varying canal air pressure in a single sweep from +400 or +200 to −400 mm H2O (or −600 decapascals [daPa]), thereby altering the stiffness of the tympanic membrane. Changing the stiffness of the tympanic membrane results in an alteration of the relationship between the probe tone and the sound pressure level in the canal. The microphone receives the reflected sound and changes it from an acoustic signal to an electric signal. The tympanogram, a graphic display of the changing relationship of the probe tone to the sound pressure level in the canal, is recorded as tympanic membrane impedance. The abscissa of
the tympanogram records air pressure in millimeters of water (mm H₂O), and the ordinate records compliance, an arbitrary unit. Figure 31 shows an example of a normal tympanogram.

Because tympanic membrane compliance is maximized when air pressure on both sides of the eardrum is equal, the peak of the normal tympanogram tracing occurs at approximately 0 mm H₂O. If pressure within the middle ear is negative, the tympanometric peak is in the negative pressure zone of the tympanogram (Figure 32). Thus, the position of the peak of the trace along the horizontal axis usually indicates the middle-ear pressure. Also important is the height of the peak. Normally, the height of the peak is between half-scale and full-scale on the ordinate. Conditions that increase the impedance of the tympanic-membrane–middle-ear system (eg, middle-ear effusion) can result in a tympanogram peak that is less than half-scale, showing decreased or low compliance. Conversely, conditions that decrease the impedance of the system (eg, a flaccid tympanic membrane) elevate the peak to exceed full-scale deflection. Therefore, the position of the peak along both the ordinate and the abscissa provides information regarding middle-ear pressure and the acoustic impedance of the system. In addition, the shape of the peak, or more specifically, the gradient (slope) is also important. A peak that has a gradual (rounded) slope rather than a steep one is usually associated with some degree of tympanic-membrane–middle-ear disorder.

**Tympanometry with Admittance Instruments**

Tympanometry with an admittance instrument uses the same basic techniques as tympanometry with an impedance instrument. Both vary ear canal pressure and measure the resulting sound pressure level in the ear canal. However, there are some differences.

With admittance instruments, the sound pressure level of the probe tone is kept constant with automatic gain control circuitry. The electrical current required to keep a constant sound pressure level is directly proportional to admittance magnitude at the probe tip. The
tympanogram obtained from an admittance instrument is measured in absolute units rather than in the arbitrary units that impedance-measuring instruments use. The ordinate of the tympanogram records admittance (Y) of a volume of air (in cubic centimeters or milliliters) that has equivalent acoustic admittance, or in units called millimhos (mmho), and the abscissa records air pressure in decapascals (1 daPa = 1.02 mm H2O). The height of the peak varies with age; values range from a mean of 0.5 (90% range of 0.22 to 0.8) in children 3 to 5 years of age to a mean of 0.7 (90% range of 0.3 to 1.4) in adults. The measurement of admittance allows information regarding the transfer of acoustic energy to be taken directly from the tympanogram.

Validation of Tympanometry

Tympanograms obtained from impedance instruments are analyzed qualitatively because of the use of relative, or arbitrary, units. As a result, tympanometric patterns are classified and related to various pathologic conditions involving the eardrum and middle ear. By assessing the pressure, compliance, and shape of the tympanometric trace, the normal tympanic-membrane–middle-ear system can be distinguished from the abnormal one with a reasonable degree of certainty. In addition, the types of abnormality may also be determined.

Bluestone and colleagues attempted to relate these patterns (with the Madsen instrument [Madsen Electronics, Copenhagen, Denmark]) to the presence or absence of effusion at myringotomy but found a high percentage of false-positive results (ie, the tympanometric patterns indicated the presence of an effusion but none was found at myringotomy). In a later study from Pittsburgh, Paradise and colleagues proposed a pattern classification with the same type of instrument to identify middle-ear effusion based on otoscopy and, in many instances, the myringotomy findings. The accuracy of the diagnosis of effusion was higher with the Paradise and colleagues classification than with the previously proposed patterns. The study also demonstrated that tympanometry in infants younger than 7 months was not valid because of their highly compliant external auditory canals. In a subsequent study conducted in San Antonio, Gates and colleagues confirmed the diagnostic accuracy of this pattern classification. Beery and coworkers, employing the Grason-Stadler otoadmittance meter (Grason-Stadler Company, Madison, WI), also related myringotomy findings to the tympanometric patterns and proposed a pattern classification for diagnosis of middle-ear effusion. The patterns were 93% accurate. Shurin and colleagues also employed the Grason-Stadler instrument and proposed a pattern classification based on measurements with a planimeter. Cantekin and colleagues compared the two instruments—the Madsen electroacoustic impedance bridge and the Grason-Stadler otoadmittance meter—by their abilities to identify middle-ear effusions; the tympanometric findings were validated by myringotomy, and the same number of false-negative and false-positive patterns were recorded for both instruments.

In a Finnish study, Palmu and Syrjanen increased sensitivity and specificity of tympanometry (Grason-Stadler GSI 38 Auto Tymp and Audiometer) in the diagnosis of otitis media infants by comparing the child’s sick visits with ones that were obtained when the child was well. Thus, serial examinations in the clinical setting can aid in an accurate diagnosis.

Unfortunately, the instruments that were validated for the presence or absence of middle-ear effusion are no longer available and have been replaced by admittance-measuring devices. Few of the instruments currently on the market have been validated. In addition, quantitative analysis has replaced classification schemes using shape. Of the instruments available, the GSI 33 Middle Ear Analyzer (Grason-Stadler) has been validated by Nozza and coworkers. Two groups of subjects were studied; one was made up of children undergoing myringotomy and tube insertion for management of recurrent AOM or chronic otitis media with effusion, and
the other was a group of children in an allergy outpatient setting who were considered to be more representative of the general population. The admittance measures were analyzed with respect to presence or absence of middle-ear effusion when the myringotomy was performed and, in the outpatient study, by a validated (ie, previously validated against myringotomy findings) otoscopist. Calculations of the sensitivity, specificity, and positive and negative predictive values were made on different immittance criteria to determine the presence or absence of effusion based on findings at the time of myringotomy (Table 3). The Maico Screening Immittance Bridge (Model No. 610 [Medical Acousns Instrument Compaing, MN]) has also been validated against the findings at myringotomy.45 Fields and coworkers validated the Microtymp (Welch Allyn, Skaneaties ralls, MN) and the Amplaid 720 impedance bridge using a modified Jerger classification, Ovesen and colleagues validated the Madsen model ZS330 (Medsen Electronics, Minnetonka, MN),66 and van Balen and de Melker validated the AR 85 portable Micotymp (Welch Allyn) tympanometer.67 Another method of validating these instruments is to compare the tympanogram patterns with the otoscopic assessment of a validated otoscopist.65,68 Other instruments that are currently in use should have similar validation procedures performed and published. The American National Standards Institute has published standards for measurements of acoustic impedance and admittance (aural acoustic immittance),69 which were used in part by the American Speech-Language-Hearing Association updated guidelines.70 Additional information is greatly needed from large-scale studies using standard measuring techniques to develop normative clinical data.

Therkildsen and Gaihede assessed a newer instrument, the MEA 901 tympanometer (Madsen Electronics, Copenhagen, Denmark) and found the high rates of pressure change (common among the newer instruments) can lead to decreasing accuracy in detecting the middle-ear pressure, which they attributed to the intrinsic hysteresis of the middle ear.71

### Tympanometric Patterns

From all of these studies, it appears that use of the acoustic immittance instrument is an accurate way of identifying middle-ear effusions, but it is not perfect. The instrument can be an invaluable aid in diagnosing and, under certain conditions, screening for middle-ear disease, but there is still no consensus on the patterns that accurately identify middle-ear effusion. The first attempt to classify patterns on the basis of contour was made by Jerger;72 he described types A, B, C, and D, but these types were not validated either with myringotomy findings or by a validated otoscopist. Paradise and coworkers proposed a classification that was based on myringotomy findings.61

Figure 33 shows the types of tympanograms obtained from immittance instruments and their common variants that relate to expected conditions of the eardrum and middle ear. This chart is based on myringotomy findings. Tympanograms that are considered normal are those included in the first frame of the figure. Ears that yield variant tympanograms will on occasion (2%) be found to have an effusion, especially a scant, thin, serous effusion usually seen as an air-fluid level or bubbles behind a translucent eardrum. Variant 1b, even though it has a somewhat low compliance, is usually not obtained when an effusion is present. The tympanogram type that

<table>
<thead>
<tr>
<th>Variable</th>
<th>Criterion</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ym or Peak Y</td>
<td>0.1</td>
<td>67</td>
<td>100</td>
</tr>
<tr>
<td>(mmho or cm³)</td>
<td>0.2</td>
<td>78</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>78</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>78</td>
<td>89</td>
</tr>
<tr>
<td>TW (daPa)</td>
<td>&gt; 150</td>
<td>89</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>&gt; 200</td>
<td>78</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>&gt; 250</td>
<td>78</td>
<td>100</td>
</tr>
</tbody>
</table>

Adapted from Nozza RJ, et al.5 and Nozza RJ, et al.45

Ym = peak admittance; TW = tympanometric width; mmho = millimho; daPa = decapascal.
has an open end (peak off graph) at or near the normal pressure zone (Frame 2) is the result of high compliance and is most commonly associated with a flaccid tympanic membrane that is secondary to wide fluctuations in middle-ear pressure and loss of eardrum elasticity resulting from eustachian tube dysfunction. However, an effusion is not present. When this type of tympanogram is associated with a significant conductive hearing loss (usually between 40 and 60 decibels [dB]), an ossicular discontinuity should be suspected.

The negative pressure type of tympanogram (Frame 3) has many variants, of which the four most common are shown. Unfortunately, there is currently no totally reliable way of predicting the presence or absence of effusion by the variant, because all may be associated with a middle-ear effusion. However, the probability that an ear yielding a tympanogram of variant 3a has an effusion is less than the probability of effusion in ears giving the other three variants. An ear from which a tympanogram of variant 3d (with a rounded peak) is recorded has the highest probability of having an effusion. When the tympanogram trace is open without a peak and is in the negative pressure zone (Frame 4), the tympanic membrane is flaccid, and only rarely will an effusion be present within the middle ear. The explanation for the floppy tympanic membrane is the same as that described for the type of tympanogram in Frame 2, but in this type, negative pressure is evident at the time of testing. Again, as described previously (Frame 2), if a significant air-bone audiometric gap is found, an ossicular chain discontinuity should be suspected. The tympanogram type that shows a high positive pressure (Frame 5) may be associated with an effusion, usually AOM with effusion, particularly with variant b. All of the variants shown for the types of tympanograms that have low compliance (Frame 6) are usually associated with a middle-ear effusion. Ears from which tympanograms of variants 6a and 6b are recorded may or may not have an effusion, whereas 90% of ears with tympanograms of variants c and d will have an effusion. One study found that the type B tympanogram (ie, flat) could predict the magnitude of the air-bone gap in otitis media with effusion.\textsuperscript{73} Other pathologic conditions that can result in this type of pattern are conditions that can increase the acoustic impedance of the system (eg, thickening of the tympanic membrane, ossicular chain fixation, or adhesive otitis media).

The most accurate method of determining the presence or absence of middle-ear effusion is

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**Figure 33.** Tympanogram types related to presumptive conditions of the middle ear.

<table>
<thead>
<tr>
<th>TYPANOGRAHAM TYPES</th>
<th>COMMON VARIANTS</th>
<th>PRESumptive Diagnosis of Tympanic Membrane Middle Ear Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NORMAL</td>
<td>a</td>
<td>NORMAL</td>
</tr>
<tr>
<td>2. HIGH COMPLIANCE (NORMAL PRESSURE)</td>
<td>b,c</td>
<td>FLACCID Tympanic Membrane OR OSSICULAR DISCONTINUITY</td>
</tr>
<tr>
<td>3. NEGATIVE PRESSURE (NORMAL COMPLIANCE)</td>
<td>a,b,c,d</td>
<td>HIGH NEGATIVE PRESSURE WITH OR WITHOUT MIDDLE EAR EFFUSION</td>
</tr>
<tr>
<td>4. HIGH NEGATIVE</td>
<td></td>
<td>FLACCID Tympanic Membrane AND</td>
</tr>
</tbody>
</table>

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*Diagnosis* 171
tympanometric width (see Table 3). When inhalant anesthesia is used, such as when tympanostomy tubes are to be inserted, tympanograms should be obtained prior to (as opposed to during or after) the anesthetic for accuracy of the test.

The shapes of tympanograms recorded from an immittance device that measures total admittance \( Y \) using a low-frequency probe tone are similar to those recorded from an impedance device. For example, in conditions that increase the stiffness or impedance of the middle-ear system, such as middle-ear effusion, otosclerosis, or ossicular fixation, the tympanograms show a reduced height of the peak, show a reduced admittance, or may be flat. However, in certain cases, the admittance \( Y \) is within an acceptable range yet the tympanogram is abnormally wide. Some instruments separate admittance \( Y \) into susceptance \( B \) and conductance \( G \) components or have the ability to change the probe tone to higher frequencies. Recording the separate components and changing the probe tone to a higher frequency can add diagnostic information and increase the usefulness of tympanometry. Multiple frequency and multiple component tympanograms are more difficult to classify and interpret clinically and, until recently, have been more limited in their use. However, it is important to have some understanding of the findings with use of multiple-frequency, multiple-component tympanometry.

If admittance is separated into susceptance \( B \) and conductance \( G \) components or if higher probe tones are used, variations in tympanometric shape can occur. The overall amplitude of the tympanogram will be altered, and quantification of admittance becomes important. For most normal ears, the single-peak tympanogram is obtained for \( B, G, \) and \( Y \) for both high- and low-frequency probe tones, although with high-frequency probes, \( B \) and perhaps \( Y \) may be notched. In cases of middle-ear disease that changes the stiffness of the system, it is easier to detect the middle-ear abnormality with a higher frequency probe tone, such as 660 or 667 hertz (Hz), because there is a greater proportional change than with the low-frequency tone. This is because the 660/667 Hz probe tone is close to the resonant frequency of the middle ear and is less dominated by stiffness in the system.

In cases of otosclerosis or ossicular fixation (also stiffening pathologic processes), tympanograms obtained with multiple components recorded are different from tympanograms obtained from normal ears. That is, in most normal ears, \( B \) and \( G \) have similar shapes, and \( G \) is greater than \( B \). When there is ossicular fixation, \( B \) is greater than \( G \). In middle-ear conditions that increase admittance and mass, such as ossicular discontinuity, there may be a notching in the \( B \) and perhaps \( G \) tympanogram when high-frequency probe tones are used. When low-frequency probe tones are used, notching usually does not occur.

Multiple-frequency, multiple-component tympanometry yields more useful information for most middle-ear diseases than single-component, single-frequency tympanometry. However, even with multiple-frequency, multiple-component tympanometry, there is no one-to-one correspondence between specific tympanometric findings and specific pathologic processes that affect the tympanic membrane. Furthermore, pathologic processes that affect the tympanic membrane, such as those that cause high admittance, can obscure middle-ear pathologic processes of low admittance because tympanometry is recorded at the plane of the tympanic membrane and the condition of the tympanic membrane has primary influence on the tympanometric pattern. An example is a middle ear with one of the ossicles fixed (eg, the stapes, with adhesive otitis media), but a tympanogram is either normal or reveals high admittance because the tympanic membrane is flaccid. Therefore, definitive diagnosis of an ossicular pathologic disorder usually depends on an audiogram or, ultimately, an exploratory tympanotomy.

**Acoustic Middle-Ear Muscle Reflex**

The aural acoustic immittance instrument can also detect contraction of the middle-ear muscle, the stapedius, to intense sound stimulation. This contraction is called the acoustic middle-ear muscle reflex (or the acoustic stapedial reflex) or, simply, the acoustic reflex.
The anatomy of the acoustic reflex arc is depicted in Figure 34. The afferent portion of the arc, up to and including the superior olivary complex, is shared with the hearing mechanism. The efferent fibers of the acoustic reflex arc arise from neuronal connections in the brain stem between the olivary and the facial nerve nucleus for the stapedius muscle.

The acoustic immittance instrument indicates the status of the acoustic reflex in two ways. First, the reflex results in a stiffening of the ossicular chain and a concomitant increase in impedance. Second, because the reflex is bilateral to a unilateral stimulus (the muscles of both sides contract when one ear is stimulated), delivery of an intense stimulus to one ear, with the probe tip of the immittance instrument inserted in the opposite ear, can detect the immittance change caused by the reflex.

When the immittance instrument is used to detect an acoustic reflex elicited by stimulation of the opposite ear, the response is commonly called the contralateral, or crossed, acoustic reflex. Many acoustic immittance instruments marketed today have probe tips designed to both stimulate and detect the acoustic reflex in the same ear: the reflex is elicited and its effect on immittance is detected in the same ear. Under these conditions, the response is called the ipsilateral, or uncrossed, acoustic reflex.

The threshold of the acoustic reflex is operationally defined as the minimal stimulus intensity required to produce an observable change in monitored immittance. This minimal intensity, or acoustic reflex threshold, is typically specified as a certain number of decibels, referenced to hearing level. Hearing level refers to normal hearing for a group of young adults (ie, 0 dB on the audiogram).

In adults with normal hearing, the contralateral acoustic reflex threshold for pure tones of different frequencies is approximately an 85- to 95-dB hearing level. Approximately 20 dB less intensity is required to elicit a reflex with a broadband noise stimulus. Ipsilateral reflex thresholds are approximately 10 dB better than contralateral thresholds.

The influence of a middle-ear effusion and attendant conductive hearing loss on the reflex is not simply a result of the mode of reflex stimulation. Ipsilateral acoustic reflex tests stimulate and detect the response in the same ear through the immittance instrument probe tip. In the middle ear with an effusion, the immittance is already abnormally altered, and further changes in immittance, due to middle-ear muscle contraction, may not be observable; to be detectable, these changes may require elevated stimulus intensity levels.

It follows that ipsilateral acoustic reflex testing in a middle ear with an effusion will most probably yield no response. If the response is present, the threshold of the response will tend to be elevated.

The influence of a middle-ear effusion on the contralateral acoustic reflex may be somewhat more difficult to understand. The contralateral reflex will probably be absent if the middle ear with the probe tip has an effusion or if the effusion-filled middle ear with the stimulus

![Diagram](image-url)
earphone has a moderate to moderately severe conductive hearing loss. The reason for the first situation was described before. In the second situation, the conductive hearing loss necessitates reflex stimulus levels that may be beyond the instrument’s output capabilities. For these reasons, the contralateral acoustic reflex is generally absent in cases of bilateral otitis media with effusion. When the effusion is unilateral, the contralateral reflex will probably be absent for both ears if the impaired ear has a moderate to moderately severe conductive hearing loss.

**Equivalent Ear Canal Volume**

Estimating the volume of air medial to the probe tip can be useful, especially when a flat tympanogram is obtained. This measurement can be used to determine whether the tympanic membrane is intact or perforated and whether a functioning tympanostomy tube is present. Clinically, the volume estimate obtained with a low-frequency probe tone can detect a microscopic perforation, even when the tympanic membrane appears to be mobile when positive or negative pressure is applied by the pneumatic otoscope (assuming that the perforation is small enough and the magnitude of the pressure exerted by the otoscope is sufficient to move the eardrum). A similar condition frequently exists when a tympanostomy tube is in the tympanic membrane but the patency of the tube is questionable.

The volume of the middle ear is measured by applying +200 or −400 mm H₂O pressure to the external canal with the immittance instrument. If the tympanic membrane is intact, the measurement should be approximately 0.5 to 1 mL in a younger child and between 0.65 and 1.75 mL in an older child or adult. If the eardrum is not intact, greater values are found: more than 2 mL in the child and 2.5 mL in the adult. However, some children have large ear canal volumes that may exceed 2 mL when the tympanic membrane is intact. Therefore, in such a case, an additional method should be attempted to determine whether a nonintact tympanic membrane is present. The external canal pressure should be raised to 400 daPa. If the eardrum has an opening, the eustachian tube will be forced open in most children, and rapid drops in pressure are noted. All infants and children from whom a tympanogram is obtained should also have ear canal volume recorded because a flat or rounded tympanogram apparently indicating an effusion may be found in a child who actually has a non-intact eardrum.

The American Speech-Language-Hearing Association has published criteria for equivalent ear canal volume measures in children 1 to 7 years of age (Table 4).70

<table>
<thead>
<tr>
<th>Table 4. ASHA GUIDELINE FOR EQUIVALENT EAR CANAL VOLUME MEASURES FOR CHILDREN 1 TO 7 YEARS OF AGE BEFORE AND AFTER PLACEMENT OF TYPANOSTOMY TUBES</th>
</tr>
</thead>
<tbody>
<tr>
<td>90% Range for Ears with and without Tubes</td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>5th percentile–95th percentile</td>
</tr>
</tbody>
</table>

Adapted from American Speech-Language-Hearing Association.70

**Screening for Middle-Ear Disease with Acoustic Immittance Measurements**

Emphasis has been placed here on interpreting the three acoustic immittance measurements—tympanometric pattern, equivalent ear canal volume, and acoustic reflex—as a whole. This approach provides the best opportunity for accurate diagnostic assessment. There have been many attempts, however, to separate certain immittance measurements as screening tools, particularly to detect middle-ear disease in children.

Several published investigations have evaluated the screening effectiveness of tympanometry, the acoustic reflex, or both.58,59,76-88 Brooks supported the utility of the acoustic reflex alone as a screening tool to detect middle-ear disease in children.89 These investigators commonly agree that immittance measurements are easy to perform, noninvasive, reliable, and highly sensitive to the presence of middle-ear disease. These factors would favor the use of tympanometry and the acoustic reflex as screening measurements to detect disease. However, there
are still no definitive data supporting the validity of immittance measurements for screening. Although the measurements are sensitive to disease when it is present, they are considerably less accurate in sorting out children without disease, and the percentage of false-positive errors is uncomfortably high. The resulting over-referral rate argues against the cost-effectiveness of mass screening for middle-ear disease with acoustic immittance measurements. A review of the state of the art and suggested guidelines for impedance screening for middle-ear disease in children were presented at a workshop on screening by Bluestone and coworkers.

**Tympanometric Screening for Middle-Ear Effusion**

Screening for middle-ear effusion is a process intended to identify children who may have the disease but in whom it would otherwise go undetected. Otitis media is a disease for which screening appears to be important because it is highly prevalent, it is associated with varying degrees of conductive hearing loss, and it may lead to other more serious complications and sequelae. Otoscopy performed by an expert is an excellent method to identify otitis media and should be employed as a routine part of the examination by professionals who care for children. This is especially important in infants and young children. However, for mass screening, otoscopy is not feasible. Audiometry, employing the routine audiologic screening criteria, has been shown to identify only half of a group of children with middle-ear effusion. In addition, audiometry, employing standard screening methods, cannot be performed on young infants, in whom the prevalence of the disease is the highest. However, immittance screening employing tympanometry is a highly sensitive method to screen for middle-ear effusion. The use of the acoustic reflex as the sole screening measurement is highly sensitive but is not specific enough to use because too many children are over-referred to their physicians. Immittance testing is acceptable to both the child and the health care provider because it is safe, noninvasive, and simply executed. Studies have shown immittance measurements to be reliable, but these studies have not involved subjects of all age groups or all instruments that are available, many of which have been designed specifically for screening purposes.

The validity of referral criteria for specific diagnoses based on immittance measurements (ie, their association, singly or combined, with the presence or absence of middle-ear effusion) has not been established completely, and further studies are required. In addition, neither the epidemiology nor the natural history of the disease has been adequately studied in the various age groups affected, which makes most of the methods of management currently employed difficult to evaluate. In many instances, middle-ear effusion spontaneously disappears. Because of these problems, the referral criteria for children who are identified with a middle-ear effusion remain controversial.

Not only are there no currently agreed upon criteria for pattern classification related to the presence or absence of middle-ear effusion, but the patterns may be interpreted differently by the tester. The detection of middle-ear effusion by tympanometry is not as accurate during the first year of life as it is in the second year of life. However, in a study from Finland, 58 infants (2 to 11 months of age) who had AOM were evaluated with use of the GSI 38 Autotym (Grason-Stadler), and 74% had a tympanocentesis to validate the presence or absence of effusion. The investigators found tympanometry technically successful in 94% of ears; the sensitivity of a flat pattern (type B) to detect ears with effusion was 0.70 and the specificity 0.98 with a positive predictive value of 0.93 and a negative predictive value of 0.94. The sensitivity was somewhat lower in infants younger than 7 months (0.61), but specificity and positive and negative predictive values were good in all infants in the study. The study showed that AOM can be detected by use of this instrument, which is helpful for clinical practice.
Nevertheless, the most recent American Speech-Language-Hearing Association panel on audiologic assessment has proposed guidelines for screening infants and children with outer- and middle-ear disorders when it is needed, requested, or mandated or when they have conditions that place them at risk. For infants and children 7 months to 6 years old, screening is recommended for the following characteristics (as cited from Bluestone and Klein):

- A first episode of AOM before 6 months of age.
- Infants who have been bottle-fed.
- Children with craniofacial anomalies, stigmata, or other findings associated with syndromes known to affect the outer and middle ear.
- Ethnic populations with documented increased incidence of outer- and middle-ear disease, such as Native Americans and Eskimo populations.
- A family history of chronic or recurrent otitis media with effusion.
- Those in group day-care settings or crowded living conditions.
- Those exposed to excessive cigarette smoke.
- Children diagnosed with sensorineural hearing loss, learning disabilities, behavior disorders, or developmental delays and disorders.
- For children in this age group, it is recommended to conduct the first regularly scheduled screening program in the fall in conjunction with screening for hearing impairment. A second regularly scheduled screening program is also recommended for those children who failed or were missed in the fall screening. It is not necessary to screen children who are under the care of a physician for middle-ear disease.

Table 5 shows the currently recommended initial tympanometric screening test criteria.

**Table 6. ASHA RECOMMENDED INITIAL TYPANOMETRIC SCREENING TEST CRITERIA**

<table>
<thead>
<tr>
<th>Infants</th>
<th>1 Year to School Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_{tm} &lt; 0.2$ mmho</td>
<td>$Y_{tm} &lt; 0.3$ mmho*</td>
</tr>
<tr>
<td>$TW &gt; 235$ daPa</td>
<td>$TW &gt; 200$ daPa</td>
</tr>
</tbody>
</table>

Adapted from American Speech-Language-Hearing Association, Roush et al., and Nozza et al.

*For children older than 6 years, when using +400 or −400 daPa for compensation or ear canal volume, $Y_{tm}$ of less than 0.4 mmho is the recommended criterion.

**Table 6. REFERRAL CRITERIA FOR MEDICAL EVALUATION**

<table>
<thead>
<tr>
<th>I. A. Otalgia</th>
<th>B. Otorrhea</th>
</tr>
</thead>
<tbody>
<tr>
<td>II. Visual Inspection of the Ear</td>
<td></td>
</tr>
<tr>
<td>A. Structural defect of the ear, head, or neck</td>
<td></td>
</tr>
<tr>
<td>B. Ear canal abnormalities</td>
<td>1. Blood or effusion</td>
</tr>
<tr>
<td>2. Occlusion</td>
<td>3. Inflammation</td>
</tr>
<tr>
<td>4. Excessive cerumen, tumor, foreign material</td>
<td></td>
</tr>
<tr>
<td>C. Eardrum abnormalities</td>
<td>1. Abnormal color</td>
</tr>
<tr>
<td>2. Bulging eardrum</td>
<td>3. Fluid line or bubbles</td>
</tr>
<tr>
<td>4. Perforation</td>
<td>5. Retraction</td>
</tr>
<tr>
<td>III. Identification Audiometry</td>
<td></td>
</tr>
<tr>
<td>Fail air conduction screening at 20 dB HL at 1, 2, or 4 kHz in either ear (ASHA, 1985) (These criteria may require alteration for various clinical settings and populations.)</td>
<td></td>
</tr>
<tr>
<td>IV. Tympanometry</td>
<td></td>
</tr>
<tr>
<td>A. Flat tympanogram and equivalent ear canal volume (Vec) outside normal range</td>
<td></td>
</tr>
<tr>
<td>B. Low static admittance (Peak Y) on two successive occurrences in a 4- to 6-week interval</td>
<td></td>
</tr>
<tr>
<td>C. Abnormally wide tympanometric width (TW) on 2 successive occurrences in a 4- to 6-week interval</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from American Speech-Language-Hearing Association.

**Recommendations**

The most recent screening protocol recommended by the American Speech-Language-Hearing Association is based on a four-part procedure consisting of case history, visual inspection, pure-tone audiometry, and tympanometry. Referral criteria are presented in Table 6. The protocol is presented in flow chart format in Figure 35. The flow chart is a representation of the logic used to determine the need for referral. It does not represent the order in which test procedures are administered. With the exception that visual inspection should precede tympanometry, the order of test procedures is unimport...
tant. Each test component, indicated by a numbered box in Figure 35, is described here.

1. A recent otologic history of otalgia or otorrhea is sufficient cause for immediate medical referral.

2. Visual inspection of the ear may produce sufficient cause for medical referral without the need for further testing. Referral criteria include structural defect of the ear, head, or neck; inflammation, blood, effusion, excessive cerumen, tumors, or foreign body in the ear canal; or eardrum appearance consistent with active middle-ear disease. When visual inspection indicates the need for medical referral, tympanometry is not necessary. When visual evidence of middle-ear infection is present, or when a pressure-equalization tube is in place, tympanometry should not be performed unless it is requested by a physician.

3, 4. Audiometric screening should be performed by the method described in the American Speech-Language-Hearing Association Guidelines for Identification Audiometry. The guidelines recommend screening with pure-tone stimuli presented at a 20-dB hearing level (re: ANSI S3.6-1969) with frequencies of 1,000, 2,000, and 4,000 Hz. Failure to respond to any frequency constitutes failure of the audiometric screening. In accordance with the Guidelines for Identification Audiometry, failure of the audiometric screening should be confirmed by repeated screening, either on-site or by additional testing at a later date. If the audiometric screening is failed on the second administration, a complete audiologic evaluation should be performed.

5, 6. Low static admittance (Peak Y) associated with an abnormally large volume in front of the probe is evidence of a tympanic membrane perforation and warrants immediate referral. The presence of ear canal volume (estimated at 200 daPa) exceeding the 90% range in the presence of a flat tympanogram is evidence of a large volume and should result in a medical referral.

7. Low static admittance (Peak Y) may or may not be associated with significant middle-ear disorders. In the absence of other positive findings, a Peak Y below the 90% range requires observation during an extended period before a medical referral is warranted. Only after two successive abnormal findings during an interval of 4 to 6 weeks should a medical referral be made.

8, 9. Abnormal tympanometry width may occur in the absence of other findings in cases with otitis media. These cases may represent transient secretory otitis media, which does not require medical referral. Like low static admittance, abnormal tympanometry width in the absence of other signs of middle-ear disorders requires retesting after 4 to 6 weeks, and only then should a medical referral be based on this finding alone.

Even though tympanometric screening for middle-ear effusion is not recommended for the general population of children, screening of special
populations, as a method to identify effusion for epidemiologic research, is valuable.\(^\text{101,102}\)

**Immittance Instrumentation**

During the last 15 years, an increasing number of instrument companies have introduced immittance instruments to the market. This has been primarily because of the widespread acceptance of this technique of assessment, which is related to the ever-growing number of studies showing that immittance testing improves the accuracy of diagnosis of otitis media and related conditions. Tympanometry is a reliable, simple procedure that is easily carried out in a short time by nonprofessional personnel. For all of these reasons, the instruments have become enormously popular.

With this has come a technologic explosion in instrumentation that has resulted in confusion among professionals who wish to purchase new instruments and concern by those who find their relatively new instruments outdated in only a few years. In addition, most of the new or modified instruments are not field tested and validated before being marketed; this presents a distinct problem for the clinician who wishes to use a validated, reliable instrument. However, some of the instruments have been validated and are reliable, as demonstrated during many years of use by both clinicians and investigators.

The first commercially available instrument to measure acoustic impedance was developed in Denmark during the 1950s by Terkildsen and Nielsen,\(^\text{6}\) and it was manufactured in 1958 by Madsen Electronics as their model ZO61. In 1963, Madsen introduced model ZO70, which rapidly became the prototype for all the impedance bridges that followed and has provided the latest information on the invaluable diagnostic capabilities of electroacoustic impedance measurements. In 1971, Madsen introduced the ZO72, which incorporated an audiometer so that a contralateral acoustic reflex could be measured. A later model added the ability to measure the ipsilateral acoustic reflex. In 1970, the Grason-Stadler Company introduced the otoadmittance meter, which measures the complex components of acoustic impedance. The measurement as described by the developers is termed acoustic admittance, which is divided into acoustic susceptance (compliance) and acoustic conductance (resistance), and it is expressed in acoustic milliohms.\(^\text{103}\) Subsequent to the popularity of the Madsen model ZO70, many other companies began manufacturing impedance bridges. Some are designed for diagnostic use, others are purely for screening, and still others can be used for both diagnostic and screening purposes. The clinician should decide which instrument to purchase on the basis of need; however, availability of repair services should also be considered.

The instruments that have been validated by comparing the patterns obtained by impedance audiometry with the findings at myringotomy are the Madsen model ZO70,\(^\text{60,61,104}\) Grason-Stadler model 1720,\(^\text{63,64,104}\) Grason-Stadler model 1722,\(^\text{105}\) Grason-Stadler GSI 33 Version I Middle Ear Analyzer,\(^\text{66}\) Maico Screening Impedance Bridge (model 610),\(^\text{45}\) Microtymp,\(^\text{47}\) and the Amplaid 720 impedance bridge,\(^\text{47}\) the Madsen model ZS330,\(^\text{66}\) and the Grason-Stadler GSI 38 Autotymp.\(^\text{96}\)

**ACOUSTIC REFLECTOMETRY**

Acoustic reflectometry was introduced by Teele and Teele in the early 1980s as a method to accurately and objectively diagnose middle-ear effusion.\(^\text{106}\) At that time, a handheld instrument was developed and used in several studies, with mixed results.\(^\text{107–111}\) Then an improved instrument became available with great promise: handheld a lightweight portable instrument available for clinical use and a similar device for home use.\(^\text{112}\)

Acoustic reflectometry, improved with spectral gradient analysis, is available in the EarCheck-PRO Otitis Media Detector (Innovia Medical, LLC, Lenexa, KS) (Figure 36).\(^\text{113}\) The earlier approach to acoustic reflectometry analyzed only the difference in sound intensity between incident and reflected waves. Accurate results depended on operator technique, because it required a direct line of sight to the tympanic membrane. Spectral gradient is less technique-
dependent and does not require a direct line of sight to the tympanic membrane. Unlike tympanometry, it does not require pressurization of the ear canal or an ear seal to obtain a reading. The new device determines the probability of middle-ear effusion by measuring the response of the eardrum to a frequency sweep in the audible range of 1.8 to 4.4 kHz. The instrument emits a tone into the external auditory canal, and its microprocessor analyzes the sum of the emitted tone and its reflection. The data from the instrument can be printed as a curve on a graph. The slopes of the curve, representing the data from the incident and reflected sound waves around the frequency of maximal nullification, are the spectral gradients. The replaceable plastic tip of the instrument is inserted into the external auditory canal of the patient, and a reading is taken with the push of a button. The spectral gradient is displayed on the back of the instrument. Results are sorted into five ranges of spectral gradient angles that indicate the probability of middle-ear effusion. Figure 37 shows the spectral gradient display for the instrument.

A clinical study of the EarCheck was reported by Block and coinvestigators that involved 528 subjects (870 ears) in four centers. They compared acoustic reflectometry with tympanometry and found similar sensitivity, specificity, and positive and negative predictive values (Table 7). The percentage of ears with
middle-ear effusion—as documented by pneumatic otoscopy—related to the level of spectral gradient acoustic reflectometry is shown in Table 8. In a follow-up study by Block and another group of colleagues, the instrument was found to be useful in diagnosing middle-ear fluid when the child had AOM. In a study by Barnett and associates, spectral gradient reflectometry was compared with the findings at myringotomy, tympanometry, and pneumatic otoscopy for the diagnosis of middle-ear effusion. They concluded that acoustic reflectometry was comparable to tympanometry for diagnosis of middle-ear effusion with the presence or absence of effusion at surgery and pneumatic otoscopy.

It appears from these two studies that spectral gradient acoustic reflectometry is of value for clinical use because of its ease of use, relatively inexpensive, and comparable to the more expensive tympanometry as an objective method to diagnose middle-ear effusion. More studies are recommended. The consumer product could be helpful for selected parents whose children have recurrent or severe ear infections.

### ASSESSMENT OF HEARING

The assessment of hearing in infants and children is not an accurate method for identifying the presence of a middle-ear effusion. However, hearing assessment can be valuable in determining the effect of middle-ear disease on hearing function and is important in making decisions regarding management.

Hearing loss is by far the most prevalent complication and morbid outcome of otitis media, and it may be caused by one or more of the intra-aural complications or sequelae. To a varying degree, fluctuating or persistent loss of hearing is almost always associated with otitis media. An audiogram usually reveals a mild to moderate conductive hearing loss; when otitis media is present, the average loss is 27 dB. However, there may be a sensorineural component, generally attributed to the effect of increased tension and stiffness of the round window membrane. This hearing loss is usually reversible when the effusion resolves, but permanent conductive hearing loss can result from irreversible changes secondary to recurrent acute or chronic inflammation (eg, adhesive otitis media, tympanosclerosis, or ossicular discontinuity). Irreparable sensorineural hearing loss may also occur, presumably when infection spreads through the round or oval window membrane or labyrinthitis due to perilymphatic fistula occurs. Audiometry can be performed reliably in children as young as 6 months. Children younger than 2 years are the group at highest risk for effusions and associated hearing loss, and in these patients, standard audiometric assessment may be difficult to perform reliably. Therefore, infants and young children may require nonbehavioral tests of hearing.

All infants and children should have their hearing evaluated, if possible, when a chronic middle-ear effusion is present. The clinician

### Table 7. COMPARISON BETWEEN SPECTRAL GRADIENT ACoustIC REFLECTOMETRY (SG-AR) AND Tympanometry DOCUMENTED BY PNEUMATIC OTOSCOPY IN 528 SUBJECTS

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive Predictive Value</th>
<th>Negative Predictive Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SG-AR</td>
<td>67</td>
<td>87</td>
<td>57</td>
<td>91</td>
</tr>
<tr>
<td>Tympanometry</td>
<td>61</td>
<td>91</td>
<td>66</td>
<td>89</td>
</tr>
</tbody>
</table>

Adapted from Block SL, et al. 114
considers the type (ie, conductive, sensorineural, or both) and the degree of hearing loss for the selection and timing of the various management options available.

**Methods**

In general, there are two methods of evaluating hearing in children: behavioral and nonbehavioral. The age and the ability of the child to cooperate usually dictate which tests are selected.\(^{119}\)

**Behavioral Tests**

Neonatal reactions to sudden, intense sound are predominantly reflexive and include the Moro reflex, the aural palpebral reflex, and the arousal and cessation responses.

The *Moro reflex* is a generalized motor response that is commonly known as the startle reflex. Classically, neonates (and most infants) thrust the head backward and suddenly move the arms and legs up and outward when a stimulus of 80 to 85 dB sound pressure level is presented. The *aural palpebral reflex*, or eyeblink reflex, consists of a contraction of the *musculus orbicularis oculi* and, frequently, closing of the eyelids. A stimulus of 105 to 115 dB sound pressure level is usually required. The arousal and cessation reflexes involve clear contrasts in the neonate’s activity before and after the stimulus. A stimulus of 90 dB sound pressure level should awaken or arouse the sleeping or drowsy neonate; in the cessation reflex, a decrease or inhibition of activity in the restless or crying baby is observed. However, these reactions are primarily reflexive, require intense stimuli, and are qualitative rather than quantitative.

*Behavioral observation audiometry* is a technique used for neonates and young infants in which the examiner presents a stimulus sound and observes the child’s associated behavioral response, which does not require conditioning. Simple noisemakers such as rattles, squeak toys, and bells are common stimulus devices used in the office setting. Calibrated stimuli are used in a test booth in audiology centers.

*Visual reinforcement audiometry* also involves the presentation of a stimulus sound and the observation of the child’s conditioned head-turn response (Figure 38). The response, however, is rewarded with a visual reinforcement, such as a blinking light, an illuminated picture or toy, or an animated toy that is located above the loudspeaker through which the stimulus is presented. The test is most successful for assessing infants aged 6 months to 2 years.

*Tangible reinforcement audiometry*, or *tangible reinforcement operant conditioning audiometry*, uses candy or sugar-coated cereal to reward the child for pressing a bar when the sound stimulus is presented (Figure 39). It is appropriate for assessing children who are difficult to test, including the mentally retarded and infants.
These tests provide some indication of the degree of hearing loss present but not the type (conductive or sensorineural). However, in some children, visual reinforcement audiometry and tangible reinforcement operant conditioning audiometry may be able to determine the hearing level in the individual ear. They are appropriate for children younger than 3 years.

Play audiometry is similar to conventional tests given to older children and adults and can be used to assess the hearing of children 2 years of age and older. Conventional audiometric techniques can be used, but they must be modified to be more interesting for the young child, usually in the form of play. The assessment can provide information regarding both speech and pure-tone stimuli and can determine the degree of hearing loss for the individual ear. In addition, play audiometry can provide threshold information on both air and bone conduction and, therefore, can determine whether a loss is conductive, sensorineural, or both.

Conventional audiometry is usually reserved for children 5 years of age and older but can be used for certain younger children, depending on the examiner and the cooperation of the child. The assessment should include pure-tone and speech audiometry to determine air and bone conduction thresholds of children with chronic otitis media with effusion to identify the type and degree of hearing loss for each ear.

Nonbehavioral Tests

Nonbehavioral techniques to assess hearing include acoustic impedance measurements, auditory brain stem response recordings, cardiac audiometry, and respiratory audiometry. However, of all of these tests, the auditory brain stem response (ABR) is currently the best available and most widely used method. It is a test that is relatively independent of the child’s behavioral response and is ordinarily used to evaluate infants and children for whom information on behavioral hearing tests is either unobtainable or unreliable. Figure 40 shows a diagram of the equipment used for the test procedure. Three miniature electrodes placed on the scalp...
record the responses. The ABR consists of five to seven vertex-positive waves, labeled I to VII, occurring in the first 10 milliseconds after the onset of the stimulus (Figure 41). Waves I through III presumably reflect activity of the eighth cranial nerve fibers and auditory centers in the pons. Waves IV and V apparently reflect activity of the auditory centers in the mid to rostral pons and the caudal midbrain, respectively; the neural generators for waves VI and VII are less certain.

The electrical configuration for the ABR includes the active electrode on the vertex of the skull, or mid-forehead at the hairline, and the reference and ground electrodes, respectively, on the ipsilateral and contralateral mastoid processes or earlobes. The responses to clicks of 2,000 to 4,000 Hz, filtered clicks, or brief pure-tone bursts are typically averaged for each stimulus intensity employed. The stimuli are presented at a rapid rate (10 to 30 per second), and a complete run, at a given stimulus intensity, requires 1.5 minutes; in most cases, the entire procedure for both ears at several stimulus intensities averages less than an hour.

Because excessive muscle activity can interfere with the test, the child must be completely relaxed or, preferably, asleep. Natural sleep can be facilitated by feeding babies, up to about 6 months of age, immediately before the test. Children 7 years of age or older can lie quietly for the procedure. Infants and children between these ages require sedation or even general anesthesia.

The test can be sensitive in identifying a conductive hearing loss associated with a chronic middle-ear effusion, and it is especially valuable in the young infant. However, the technique does not assess the perceptual event called hearing. The ABR reflects auditory neural electric responses that are adequately correlated to behavioral hearing thresholds. However, a normal result on the ABR suggests only that the auditory system up to the midbrain level is responsive to the stimulus employed—it does not guarantee normal hearing.

In cases of middle-ear impairment, the entire series of ABR waves is delayed in time by an amount commensurate with the degree of attendant conductive hearing loss. Latency of wave I provides a better index of middle-ear impairment (Figure 42). The consistent nature of the ABR in young infants makes it particularly useful in evaluating hearing when a chronic middle-ear effusion is present.

**Figure 41.** Auditory brain stem response (ABR) to a 60-dB normal hearing level click stimulus in a patient with normal hearing. Major wave components are labeled I through VII.

**Figure 42.** The Auditory brain stem response (ABR) in a 6-month-old infant with otitis media with effusion showing an example of latency delay. The top trace was recorded immediately before myringotomy, and the bottom trace immediately thereafter. Reproduced with permission from Fria TJ, and Sabo DL.
Indications

Infants and children who have frequently recurrent otitis media or chronic otitis media with effusion, or both, should have their hearing assessed.\(^{121}\) It is important to know the degree of hearing loss and whether that loss is conductive, sensorineural, or both. Obtaining bone conduction audiometry is recommended to determine the presence or absence of a sensorineural loss; there may be a Carhart's notch (ie, a false depression of bone conduction thresholds) in the presence of effusion.\(^{122}\) If the loss is only conductive and mild, management may consist of watchful waiting in the hope that the natural history of the effusion is in favor of spontaneous resolution. On the other hand, if there is significant bilateral conductive loss, such as greater than 30 dB, surgical intervention (eg, tympanostomy tubes) may be an appropriate option, because the hearing loss may interfere with the child's development. The degree of conductive loss present in each ear is more desirable information, because there may be a sequela or chronic middle-ear effusion present in one ear and not in the other. An ossicular chain disarticulation secondary to rarefying osteitis, or ossicular fixation resulting from adhesive otitis media, may cause a maximal conductive hearing loss (ie, 50 to 60 dB). In addition, a cholesteatoma may also be present even though there is no apparent defect in the tympanic membrane, and this may cause ossicular damage and a conductive loss. When the hearing loss (conductive) appears to be out of proportion to that expected with chronic otitis media with effusion, an examination with an otomicroscope is necessary to exclude the possibility of a retraction pocket or cholesteatoma, or both, in either the pars flaccida or the posterosuperior quadrant of the pars tensa. General anesthesia is required if a child cannot be examined adequately while awake. At this time, a myringotomy and aspiration can be performed and a tympanostomy tube can be inserted. In addition, if the patient is too young for assessment of hearing with behavioral methods, is difficult to assess, or is not cooperative, an ABR can be performed at the time of general anesthesia. The test should be performed after the aspiration of the effusion to determine whether a residual conductive hearing loss is present that might indicate an ossicular abnormality.

When a conductive hearing loss associated with a middle-ear effusion is present, and the effusion either resolves in response to medical treatment or is removed by myringotomy, another audiogram should be obtained to verify that hearing has returned to normal limits. An audiogram should be obtained for every child approximately 2 weeks after tympanostomy tubes are inserted (as long as there is no otorrhea present). A persistent, marked conductive hearing loss without any effusion is strong evidence of an acquired ossicular defect or a concurrent congenital anomaly. The presence of both a chronic otitis media with effusion and a congenital ossicular deformity is frequent in the child with Down syndrome.

When a mixed hearing loss (conductive and sensorineural) is identified after the assessment, the clinician must suspect a middle-ear effusion that may be causing a serous (toxic) labyrinthitis resulting from penetration of the round window or, possibly, a congenital or acquired defect in either the oval or round window, or both. In these cases, the infection spreads directly into the labyrinth. Progressive or fluctuating sensorineural hearing loss with or without vertigo may be present, and if it is documented, the patient should have further assessment (eg, vestibular testing or computed tomography of the temporal bone) and possible exploration (tympanotomy) of the middle ear to search for a perilymphatic fistula.\(^{118,123}\)

If the sensorineural hearing loss is due to a known cause in children (such as neonatal asphyxia or meningitis), not to a condition that can be corrected, as described previously, more aggressive management of chronic otitis media with effusion may be required than is needed for a child who does not have a sensorineural hearing loss. The conductive hearing loss added to a permanent sensorineural hearing loss may be handicapping for the child. This is especially true for the patient who has a moderate to severe sensorineural hearing loss and is “main-
streamed” or is in a school for the deaf. Myringotomy and tympanostomy tubes are early treatment options for such children, rather than prolonged observation. Again, if a mixed hearing loss is suspected because the degree of loss appears to be greater than would be expected from otitis media with effusion, an accurate assessment of hearing is mandatory, regardless of the child’s age. High-risk infants and children, in whom there is a family history of sensorineural hearing loss, are the greatest concern. For such an infant, a procedure including examination under anesthesia, myringotomy, and insertion of tubes followed by ABR is the best method to establish a definitive diagnosis and treat the chronic otitis media with effusion.

Screening for Hearing Loss

Identification of hearing loss is an important part of screening programs for preschool and school-aged children because such identification must be followed by more definitive testing, evaluation, and possibly habilitation or rehabilitation of the child. However, audiometric screening to identify a middle-ear effusion does not have high enough sensitivity and specificity to warrant its use. Bluestone and coworkers found that only half of a group of children (58 ears) with chronic middle-ear effusion would have been identified by an auditory screening test if 25 dB had been used as the criterion for failure (Figure 43). However, audiometric screening of children is still necessary to identify those children who have sensorineural or conductive hearing loss.

Recommended Audiometers

A handheld screening instrument that provides audiometric testing at 500, 1,000, 2,000, and 4,000 Hz at a 25 dB hearing level has been developed by the Welch-Allyn Company (Audioscope). Gershel and colleagues compared the Audioscope with traditional audiological screening and pure-tone and speech audiometry. There was general agreement between traditional hearing screening results and those obtained from the Audioscope. More experience in using the Audioscope under office conditions is required to determine its value for screening children for hearing loss.

Every otolaryngologist and pediatrician should have an audiometer available to test children. For the pediatrician, a soundproof room and a sophisticated instrument are not necessary, but a screening audiometer should be part of pediatric ambulatory clinical facilities. Those children found to have a hearing loss that is out of proportion to the disease under management (eg, otitis media) or those infants and children who are difficult to treat should be referred to an otolaryngologist or diagnostic hearing center, or both.

Otoacoustic Emissions

Otoacoustic emissions are a measure of cochlear activity and have been used as an objective test to evaluate hearing. Owens and coworkers have used this promising test to identify middle-ear effusion in children, but the validity and feasibility in the clinical setting are currently being investigated. Dhooge and colleagues have used click-evoked otoacoustic emissions to evalu-
uate hearing before and after tympanostomy tube insertion. Yeo and colleagues reported that otoacoustic emissions have a prognostic value in children with middle-ear effusions. The same team of investigators also reported on the effect on distortion-product otoacoustic emissions related to clinical and biochemical factors in children with middle-ear effusion. At the Children’s Hospital of Pittsburgh, otoacoustic emission testing has been found to be very useful in evaluating hearing following placement of tympanostomy tubes in infants and other children who are difficult to test using behavioral methods. Employing both otoacoustic emissions and tympanometry have been found to be useful in screening infants and young children for hearing loss and middle-ear effusion, although follow-up audiologic testing is needed for those who fail the otoacoustic emissions testing to determine the type and degree of hearing loss.

**Special Populations**

Because of high risk, serious consequences, or a known high prevalence of middle-ear disease, certain populations of children warrant special consideration, beginning soon after birth, for early detection of and surveillance for this disorder. These populations include children with known sensorineural hearing loss, developmentally delayed and mentally impaired children, children with cleft palate or other craniofacial anomalies, and Native American children (First Nations and Inuit).

**VESTIBULAR TESTING**

Otitis media with effusion and eustachian tube dysfunction are the most common causes of dysequilibrium (eg, vertigo, falling, and clumsiness) in infants and children. The dysequilibrium is almost invariably resolved when the middle-ear effusion is absent or the child no longer has fluctuating middle-ear pressures. Parents will frequently report a dramatic disappearance of dysequilibrium immediately after tympanostomy tubes are inserted for recurrent acute or chronic otitis media with effusion or eustachian tube obstruction (fluctuating high negative pressure). For most infants and children with otitis media and signs and symptoms of dysequilibrium, sophisticated vestibular testing is not indicated because nonsurgical or surgical management of the eustachian-tube–middle-ear disorder will resolve the problem. In addition, the tests currently available in the usual vestibular test center are usually not feasible in children, especially infants and young children. However, when the dysequilibrium persists, even when the middle-ear effusion resolves and middle-ear pressures return to normal levels (especially after tympanostomy tube insertion), the child should be referred to an otolaryngologist for assessment of vestibular function to rule out the possibility of another cause of imbalance. Children who have frequent attacks of vertigo in association with otitis media, with or without fluctuating or progressive sensorineural hearing loss, should be suspected of having a labyrinthine fistula (see Chapter 9, “Complications and Sequelae: Intratemporal”). Casselbrant and colleagues described tests that can assess vestibular function in infants and children. They evaluated children’s standing balance with use of a moving posture platform to assess the velocity of sway before and after tympanostomy tube insertion. This team reported use of this method of vestibular testing in 22 Pittsburgh children with success. Casselbrant and colleagues reported that children who had had otitis media in the past had abnormal balance testing later in life when no middle-ear effusion was present. The effect of middle-ear effusion on the balance system is discussed in more detail in Chapter 9, “Complications and Sequelae: Intratemporal”.

**HIGH-RISK POPULATIONS**

**Cleft Palate**

Ear disease and hearing loss have long been recognized as common problems in patients with
cleft palate. Alt, in 1878, first reported this association. He noted that hearing improved when otorrhea associated with cleft palate was treated. Thorington, in 1892, reported increased hearing in a patient after artificial correction of a destroyed palate. In 1893, Gutzmann noted hearing loss in half of his patients with cleft palate. In 1906, Brunck stressed the need for otologic examination of patients with cleft palate. Since these early descriptions, many reports have appeared in the literature related to the incidence, nature, and degree of hearing loss in patients with cleft palate.

**Hearing Loss**

The prevalence of hearing loss in the cleft palate population varies considerably, as reported in the literature. Of all studies, the average prevalence is approximately 50%. Even though the criteria of hearing loss have not been generally agreed on, it has been identified as conductive and usually bilateral.

Halfond and Ballenger found that, of 69 patients tested, 37 (54%) had a hearing loss of 20 dB or greater. Miller reported that 19 (54%) of 35 children with cleft palate had a hearing loss greater than 30 dB. Walton studied 93 school-aged children with cleft palate and suggested that the prevalence may be even greater; half of those who would have passed conventional audiometric screening at the 20 dB level were found to have air-bone gaps that indicated conductive hearing loss. Bluestone and colleagues support this contention by having found high-viscosity middle-ear effusions in children, including those with cleft palate, who would have passed a 25 dB screening audiogram. One study revealed that the hearing of children who had bilateral cleft lip and palate was worse than that of children who had isolated cleft palate. In a study using ABR testing of 3-month old infants, the mean thresholds were 53 dB in the left ear and 49 dB in the right ear; tympanometry at the time of the hearing testing revealed a flat pattern in 83%. Even though a conductive hearing impairment would be expected, Bennett and colleagues reported that 30% of 100 adults with cleft palate had either sensorineural or mixed hearing loss. This finding might be explained by the work of Paparella and coworkers, who found sensorineural hearing loss in some patients with otitis media and ascribed this to directly associated pathologic changes in the inner ear, presumably mediated through the round window.

When hearing is tested over time in infants and young children with cleft palate, they consistently have worse hearing as a group, compared with children without cleft palate in the same age group. Even though some reports have indicated that middle-ear disease and its associated hearing loss decrease after repair of the palate, others have found the need for placement of ventilation tubes to persist in many of the children, despite repair.

**Aural Pathology**

**Infants.** Variot, in 1904, was the first to report ear disease in an infant with cleft palate. Sataloff and Fraser, in 1952, reported that, in their experience, “examination of the ears of very young children with cleft palate reveals a high incidence of pathologic changes, despite the absence of subjective symptoms of otitis media.” In 1958, Skolnick reported that only 6% of cleft palate patients younger than 1 year, and only 27% of those between the ages of 1 and 4 years, had aural disorders. However, Linthicum and colleagues in 1959 discovered pathologic ear changes in 77% of a group of 100 infants and children with cleft palate. In 1967, Stool and Randall reported that middle-ear effusion was present at myringotomy in 94% of 25 infants with cleft palate. In 1969, Paradise and colleagues, using standard office otoscopy, diagnosed middle-ear disease in 49 of 50 infants with cleft palate. Most had full or bulging, opaque, immobile tympanic membranes, but they also observed spontaneous perforations and otorrhea. Subsequent studies by the same team indicate that, throughout the first 2 years of life in infants with unrepaird cleft palate, otitis media is a virtually constant complication.
Older Children and Adults. Although the criteria for aural disorders in older children and adults with cleft palate vary considerably, their prevalence appears to be high. Meissner examined 213 such patients between the ages of 10 and 35 years and found that 83% had abnormal tympanic membranes. Skolnick found that the prevalence of aural pathologic change was 67% in patients older than 5 years. Graham and Lierle found ear disorders in 44% of 29 patients with cleft palate and in 55% of 146 patients with a cleft of both palate and lip. In a group of 82 patients, Aschan found that 78% had aural disorders. In a retrospective, longitudinal study of 191 patients with cleft palate between the ages of 5 and 27 years, Severeid reported that 83% had a middle-ear effusion confirmed by myringotomy. In Bennett's study of 100 adults with cleft palate, 30% had aural pathologic signs consisting of eustachian tube obstruction (13%), chronic suppurative otitis media with or without mastoiditis (8%), dry tympanic membrane perforation (6%), and chronic adhesive otitis media (3%). Ovesen and Blegvad-Andersen examined 44 11-year-old children with repaired, complete or unilateral cleft lip and palate and reported that 24% had hearing impairment, 44% had abnormal middle-ear pressures, 23% had retraction of the tympanic membrane, and 67% had a tympanic membrane that appeared abnormal.

Since otitis media is so common in the patient with a cleft palate, either unrepaired or after repair, otologic examination and management is an important part of their health care team's program.

Other High-Risk Populations

Infants and children who have parents or siblings, or both, with otitis media with effusion appear to have an increased risk for development of the disorder compared with those whose parents or siblings have no evidence of the disease. Teele and colleagues studied 2,565 infants from birth to their third birthday. They found that children who had single or recurrent episodes of otitis media were more likely to have parents or siblings with histories of significant middle-ear infections than were children who had no episodes of otitis media. Therefore, children whose siblings have had otitis media are at higher risk and should have more frequent otologic examinations than children whose siblings have not had the disease.

Upper respiratory allergy is thought to be involved in the development of otitis media and, therefore, requires close surveillance. Even though there is no proof that children who have an upper respiratory allergy have a higher incidence of otitis media than do children without such an allergy, they should be examined frequently for possible occurrence of otitis media.

Any child with a craniofacial malformation should be suspected of having a middle-ear effusion. Children with Down syndrome have a high prevalence and incidence of middle-ear disease. Sculerati and coworkers evaluated 22 female patients with Turner syndrome and found that 82% had a history of recurrent or chronic ear infections; 45% had middle-ear effusion at the time of the examination.

Certain racial groups, such as Native Americans (First Nations and Inuit), Maoris of New Zealand, and Aborigines of Australia are known to have a high prevalence of otitis media, which in the past, has been characterized as chronic suppurative otitis media with perforation and discharge. However, as these groups obtain improved health care, otitis media has become increasingly less prevalent.

Other possible risk factors warrant consideration for close surveillance, such as prematurity or other reason for being in a neonatal intensive care unit, being in a pediatric intensive care unit, first episode of otitis media during early infancy, malnutrition, child abuse, and being born to human immunodeficiency virus-infected mothers. In addition, day-care center attendance is a known risk factor for recurrent AOM in infants and young children, making closer surveillance necessary.
The Deaf

Severely deaf to profoundly deaf children (primarily those whose hearing loss is sensorineural), whether they are enrolled in a special class in a regular school (mainstreamed) or in a residential school for the deaf, are of particular concern when middle-ear effusion is present. If a conductive hearing loss secondary to chronic or recurrent otitis media with effusion or high negative pressure, or both, is superimposed on the preexisting hearing loss, auditory input may be severely affected. This may critically interfere with the education of such children.174

The incidence of middle-ear problems in deaf children has not been studied systematically, but the few studies that have been reported indicate the incidence to be equal to or possibly higher than that in non-deaf children. Porter found that 25% of 79 deaf children aged 6 to 10 years had abnormal tympanograms.175 Brooks reported that 5-year-old children in a residential school for the deaf in England had a higher incidence of abnormal tympanograms than did non-deaf children.176 Mehta and Erlich found a high incidence of otitis media with effusion in children in a school for the deaf.177 Rubin reported the incidence of middle-ear effusion in children 3 to 6 years of age to be 30%.178 During a period of 1 year, Stool and colleagues conducted otoscopic, tympanometric, and audiometric evaluations of 446 students at the Western Pennsylvania School for the Deaf and reported that the incidence of middle-ear effusion was 8%, whereas that of high negative middle-ear pressure was 21%.179 However, the incidence of otitis media with effusion in this study was 26% in the 2- to 5-year-old group. In addition, they found that 79% of the students who were initially identified as having high negative middle-ear pressure consistently had abnormal negative pressures during the 1-year observation period.

From these few studies, it is apparent that surveillance for middle-ear disease and early treatment should be part of every program or school for deaf children. This is especially critical for those children with some residual hearing who benefit from amplification, because even the slightest conductive hearing loss may decrease or eliminate the efficacy of amplification. It is recommended that every school for deaf children be afforded appropriate health care professionals who are competent in otoscopy, tympanometry, audiometry, and treatment of otologic disorders to carry out this program. Most schools for the deaf do not have sufficient provisions for such care.

Because the external auditory canals of deaf children are often obstructed with cerumen, frequent examination and removal of the cerumen may be extremely beneficial, especially for those who wear a hearing aid.180 This finding alone is reason enough for frequent, periodic otologic examination, but a schedule for screening for otitis media with effusion and high negative pressure should also be established. Until a formal long-term study has been completed that offers recommendations for a screening program in schools for the deaf, we propose the following schedule of examinations of such children based on the findings of Craig and colleagues, Findlay and colleagues, Riding and coworkers, and Stool and colleagues.179–182

All children should have an otoscopic, tympanometric, and audiometric examination on entering the school and periodically during the first school year (Table 9). Because infants and young children are at highest risk, they should be examined once a month by otoscopy (and tympanometry when indicated) during this first year.

Older children and adolescents can probably be evaluated on entry and every 3 months during the first year, because the incidence of middle-ear disease in this age group is less than in the younger age group.

All students should be examined during periods of an upper respiratory tract infection and whenever there are signs or symptoms related to the ear, such as otalgia or otorrhea. In addition, a child should be examined if the teacher or parent suspects a middle-ear problem because of a noticeable lack of attention, sudden
or gradual failure to benefit from the amplification, or overt, progressive loss of hearing.

After the first year of follow-up, the children will usually separate into one of four groups based on the occurrence of otitis media with effusion or high negative pressure, or both: (1) no disease; (2) infrequent disease, of short duration when it is present; (3) frequently recurrent disease; and (4) chronic disease.

Infants and young children who fit into either of the first two categories, based on the examination of the first year, may be examined at less frequent intervals, such as every 2 to 3 months during the second year.

Older children who have no evidence of disease during the first year can probably be examined once a year, either on entering in the fall or, more ideally, during the winter months.

Older children with infrequent problems during the first year should probably be examined every 3 months during the second year.

All infants and children who have frequently recurrent or chronic middle-ear disease during the first year must be examined each month and with each upper respiratory tract infection until they, too, have a year without significant problems. Screening during the succeeding years should be related to the occurrence of middle-ear disease in the preceding year.

Children who have multiple handicaps in addition to deafness are considered to be at high risk for middle-ear disease, which can significantly compound their handicap as a result of the associated conductive hearing loss. Therefore, screening for all such students during the first year should be the same as the program recommended for infants and young children.

Ideally, every examination should be conducted by a physician who is expert in the diseases of the middle ear, but this is not always feasible. Therefore, a nurse should be trained to perform routine otoscopy, examine the nose and throat, and remove any cerumen from the external canal. Tympanometry can be performed by a nurse, a technician, or an audiologist if one is available. Even though an otologist cannot examine every child with the frequency recommended, every school for the deaf must have a physician, preferably an otologist, assigned to the school for diagnosis and treatment of those children found to have middle-ear disease.

All children with severe or profound deafness must be considered at risk for development of middle-ear disease. Therefore, they should have regular periodic ear examinations by competent health care professionals and appropriate early treatment so that their educational handicap is not further compromised by a condition that is amenable to medical or surgical management.

### MICROBIOLOGIC DIAGNOSIS

The correlation between bacterial cultures of the nasopharynx or the oropharynx and cultures of middle-ear fluids is poor. In most cases, this poor correlation occurs because the upper respiratory tract is frequently colonized with organisms of known pathogenicity for the middle ear. Less
commonly, it is because cultures of the pathogen responsible for the middle-ear infection are absent in the oropharynx or nasopharynx. Thus, cultures of the upper respiratory tract are of limited value in specific bacteriologic diagnosis of otitis media. The consistent results of microbiologic studies of middle-ear fluid of children with AOM provide an accurate guide to the most likely pathogens. Thus, in an uncomplicated case, initial therapy does not require obtaining specimens for bacterial diagnosis.

A specific microbiologic diagnosis can be made by culturing middle-ear fluid obtained by tympanocentesis (needle aspiration through the intact tympanic membrane). If the patient has toxic symptoms or a localized infection elsewhere, culture of the blood for the focus of infection should be performed.

**Tympanocentesis**

When the diagnosis of AOM is in doubt or when determination of the etiologic agent is desirable, aspiration of the middle ear should be performed. Indications for tympanocentesis or myringotomy (Figure 44) include the following:

- Otitis media in patients who are seriously ill or appear toxic (eg, septic).
- Unsatisfactory response to antimicrobial therapy.
- Onset of otitis media in a child who is receiving antimicrobial agents.
- Presence of suppurative complications.
- Otitis media in the newborn infant or in the immunologically deficient patient, in whom an unusual organism may be present.

An example of how valuable tympanocentesis can be in the management of children with middle-ear infection is the infant suspected of having sepsis in which the middle ear may be the source. Arriaga and colleagues reviewed the charts of 40 such infants at the Children’s Hospital of Pittsburgh and reported that, in 80%, the clinical management of these babies was directly affected by the results of the tympanocentesis. Infants and children who are in intensive care units have a high frequency of otitis media, and tympanocentesis has been shown to be a valuable aid in diagnosis and identification of the causative organisms.

Both tympanocentesis and myringotomy can usually be performed without general anesthesia. In certain instances, premedication with a combination of a short-acting barbiturate and either morphine or meperidine hydrochloride, or...
even a general anesthetic, is advisable. The procedures can be carried out by use of an otoscope with a surgical head or with an otomicroscope. Adequate immobilization of the patient is essential when a general anesthetic is not used. This procedure can be part of the pediatrician’s expertise in diagnosing and subsequently effectively treating AOM.

Diagnostic aspiration may be performed through the inferior portion of the tympanic membrane by an 18-gauge spinal needle attached to a syringe or collection trap (Figure 45). The ear canal should be cultured and cleansed with alcohol before the procedure (Figure 46). The canal culture is helpful in determining whether organisms cultured are contaminants from the exterior canal or pathogens from the middle ear. When therapeutic drainage is required, a myringotomy knife should be used and the incision should be large enough to allow the middle ear to be adequately drained and aerated.

After tympanocentesis, the effusion caught in the syringe or collection trap is sent to the laboratory for culture. A Gram-stained smear may provide immediate information about the bacterial pathogens. The smear is of particular value if cultures are negative because antibiotics were administered before the culture, or if infection is due to fastidious organisms such as anaerobic bacteria. A new antigen test, the Now test, for *S. pneumoniae* has been shown to be rapid, simple and reliable, and relatively inexpensive, and is similar to the urinary antigen test.186

To isolate the likely organisms, the external ear swab and the fluids aspirated from the middle ear are inoculated onto appropriate solid media.
and into broth. Sensitivities of organisms isolated should be tested by the standard method described by Bauer and coworkers.\textsuperscript{187} If available, techniques for assay of pneumococcal antigens may yield useful information. Future studies may use rapid diagnostic tests for the virus.

When spontaneous perforation has occurred, the exudate will generally be contaminated with a mixed flora. The ear canal should be carefully cleaned and cultures taken from the area of the perforation or, preferably, from within the middle ear by needle aspiration.

**Nasopharyngeal Culture**

For identification of the causative organism in a child with AOM, a nasopharyngeal culture is less traumatic than a tympanocentesis or myringotomy. The concept is an attractive one, because the bacteria found in middle-ear aspirates are the same type found in the nasopharynx of children with AOM. However, the correlation between the organisms found in the middle ear and nasopharynx reported in the past has not proven to be high enough in the usual clinical setting to justify its routine use. A possible exception is when an ampicillin-resistant strain of *Haemophilus influenzae* is suspected. Schwartz and coworkers and Long and associates reported a technique that improved the correlation of organisms isolated by the nasopharyngeal culture with bacteria identified by the culture of the middle-ear fluid.\textsuperscript{188,189} The method involved immediate plating of the nasopharyngeal swab on solid media and a semiquantitative estimation of colonies growing on culture plates. Colonization of the nasopharynx of potential pathogens is a risk factor for persistent and recurrent AOM, which would make identification of these organisms important for prevention.\textsuperscript{190}

**Fluorescence Emission Spectrophotometry**

Fluorescence emission spectrophotometry is an exciting method that has been reported to be capable of detecting the four common pathogens that cause AOM. This method works by non-invasively determining the optical fluorescence through the tympanic membrane.\textsuperscript{191} The technology and clinical applicability require more research, but this type of advance may replace invasive procedures.

**Blood Culture**

Bacteremia is rarely associated with otitis media due to nontypeable strains of *H. influenzae*, uncommonly associated with otitis media due to *S. pneumoniae*, and frequently associated with otitis media due to type b strains of *H. influenzae*.\textsuperscript{192} House officers at Boston City Hospital obtained blood for culture from 600 consecutive children aged 1 to 24 months coming to the walk-in clinic with fever. Otitis media was diagnosed in 166 children, and 2 (1.2%) had concomitant bacteremia.\textsuperscript{193} Studies of young infants include information that is selected because those who had cultures taken of blood showed toxic symptoms or were hospitalized. In four series of infants 8 weeks of age or younger\textsuperscript{194–197} and in two series of patients 3 months of age or younger,\textsuperscript{198,199} five of 136 infants (3.7%) with otitis media had positive results of blood cultures (two group B streptococcus, one *S. pneumoniae*, one *Pseudomonas aeruginosa*, and one enterococcus). The yield of cultures of blood is low in children with uncomplicated otitis media, but it is likely to be higher in children who have toxic symptoms, high fever, or concurrent infection at other foci (eg, pneumonia, meningitis).

**White Blood Cell Count**

In general, white blood cell counts are too variable to be helpful in distinguishing the child with otitis media due to a bacterial pathogen from the child with otitis media and a sterile effusion. However, data suggest that mean white blood cell counts of children with bacterial otitis media are higher than those of children with sterile middle-ear effusions.
Lahikainen noted that the mean white blood cell count of children with otitis was 13,400/mm³ when it was due to *Streptococcus pyogenes*, 10,500/mm³ when it was due to *S. pneumoniae*, and 11,500/mm³ when it was due to *H. influenzae*.²⁰⁰ Of children with sterile middle-ear effusion, the mean count was 8,700/mm³. Mortimer and Watterson found similar results in children who had a bacterial pathogen in the middle-ear effusion, in whom the mean white blood cell count was 10,300/mm³; the mean white blood cell count was 6,700/mm³ in children with sterile effusions.¹⁰ Feingold and colleagues found an association of higher white blood cell counts with isolation of a bacterial pathogen from the middle-ear effusion²⁰¹; of 35 children with white blood cell counts of 15,000/mm³ or more, 27 (77%) had a bacterial pathogen grown from the middle-ear effusion whereas, of children with a white blood cell count of 9,000/mm³ or less, 8 of 20 (40%) had a bacterial pathogen grown from the middle-ear effusion.

**Sedimentation Rate**

Lahikainen found increases in sedimentation rate in children with otitis media and differences among the bacterial pathogens isolated from the middle-ear effusion.²⁰⁰ The mean sedimentation rate for 104 children with otitis media due to *S. pyogenes* was 43.7; for 171 children with otitis media due to *S. pneumoniae*, 30.2; for 43 children with otitis media due to *H. influenzae*, 17.3; and for 85 children with sterile effusion, 21.3.

**Allergy Testing**

When children have the signs and symptoms of nasal allergy and have recurrent otitis media, allergy testing and possible management seems reasonable, even though there is no existing evidence that nasal allergy is involved in the pathogenesis of middle-ear disease. The methods of testing for the existence of allergy have been covered in detail elsewhere.

**Radiologic Imaging**

For the uncomplicated case of AOM or chronic otitis media with effusion, radiography or imaging of the temporal bone is not indicated. However, computed tomographic scans or more sensitive magnetic resonance imaging will identify middle-ear and mastoid effusions more accurately than either otoscopy or tympanometry.²⁰³ Caution is advised in over-interpreting these images. They are so sensitive in detecting middle-ear effusion that fluid may be identified in the middle ear and mastoid of an otherwise healthy child who is then diagnosed with mastoiditis, when the child only has an asymptomatic effusion (see “Mastoiditis” in Chapter 9, “Complications and Sequelae: Intratemporal”).

When recurrent acute or chronic otitis media with effusion is present, radiographic evaluation of the paranasal sinuses may be helpful in identifying sinusitis that may be causally related to the otitis media. When signs and symptoms of sinusitis are present (eg, purulent nasal discharge, cough, and fetor oris), conventional radiographic examination of the paranasal sinuses is the simplest, least expensive, and most practical examination. The occipitomental (Waters), frontal (Caldwell), basal (submentovertical), and lateral erect views should be obtained. In addition, the lateral view is beneficial in assessing the size of the adenoids in relation to the nasopharynx. The submentovertical view is helpful in evaluating the ethmoid and sphenoid sinuses, and both views can reveal a nasopharyngeal tumor, which can mechanically obstruct the eustachian tube and cause otitis media. However, computed tomography is the most definitive method of assessing children with recurrent or chronic sinusitis who require radiographic studies. Chronic nasal obstruction associated with otitis media, with or without epistaxis or cervical lymphadenopathy, should prompt the clinician to suspect a nasopharyngeal tumor. The A-mode ultrasound examination can also be useful in determining whether an effusion is in the maxillary sinuses.²⁰⁴,²⁰⁵
When certain complications or sequelae of otitis media are suspected or present, radiologic evaluation of the temporal bone is indicated. Plain radiographs (Towne, Law, Stenver) can be helpful in diagnosing osteitis of the mastoid or a cholesteatoma, but computed tomography and magnetic resonance imaging are more precise and should be obtained if a suppurative intratemporal or intracranial complication is suspected (see Chapter 9, “Complications and Sequelae: Intratemporal” and Chapter 10, “Complications and Sequelae: Intracranial”).

EUSTACHIAN TUBE FUNCTION TESTING IN THE CLINICAL SETTING

The radiographic tests developed for assessment of the protective and clearance functions of the eustachian-tube–middle-ear system are not feasible in the usual clinical setting. However, methods for assessment of the ventilatory function of the system are readily available to the clinician and should be performed when indicated. The ventilatory function is the most important of the three functions because adequate hearing depends on equal air pressure on both sides of the tympanic membrane being maintained. In addition, impairment of the ventilatory function can result not only in hearing loss but also in otitis media. This section provides an overview of these tests, and the interested reader can find a more comprehensive description of them in the recently published, Eustachian Tube: Structure, Function, Role in Otitis Media. The various studies conducted at the Children’s Hospital of Pittsburgh using these tests are available elsewhere.

Before the patient is examined, the presence of certain signs and symptoms may indicate eustachian tube dysfunction. Conductive hearing loss, otalgia, otorrhea, tinnitus, or vertigo may be present with this disorder.

Otoscopy

Visual inspection of the tympanic membrane is one of the simplest and oldest ways of assessing how the eustachian tube functions. The appearance of a middle-ear effusion or the presence of high negative middle-ear pressure, or both, determined by a pneumatic otoscope, is presumptive evidence of eustachian tube dysfunction, but the type of impairment, such as functional or mechanical obstruction, and the degree of abnormality cannot be determined by this method. Moreover, a normal-appearing tympanic membrane is not evidence of a normally functioning eustachian tube. For example, a patulous or semipatulous eustachian tube may be present when the tympanic membrane appears to be normal. In addition, the presence of one or more of the complications or sequelae of otitis media (such as a perforation or atelectasis that can be seen through an otoscope) may not correlate with dysfunction of the eustachian tube at the time of the examination because eustachian tube function may improve with growth and development.

Nasopharyngoscopy and Endoscopy of the Eustachian Tube

Indirect mirror examination of the nasopharyngeal end of the eustachian tube is an old but still important part of the clinical assessment of a patient with middle-ear disease. For instance, a neoplasm in Rosenmüller’s fossa may be diagnosed by this simple technique. The development of endoscopic instruments has greatly improved the accuracy of this type of examination. Not only can certain aspects of the structure of the eustachian tube be determined with the aid of currently available instruments, but some investigators have assessed eustachian tube function.

Tympanometry

Using an admittance instrument to obtain a tympanogram is an excellent way of determining the status of the tympanic-membrane–middle-ear system, and it can be helpful in assessing eustachian tube function (see Figure 33). The presence of a middle-ear effusion or high
negative middle-ear pressure determined by this method usually indicates impaired eustachian tube function.

Unlike the otoscopic evaluation, tympanometry is an objective way of determining the degree of middle-ear negative pressure. Unfortunately, assessing the abnormality of values of negative pressure is not so simple. High negative pressure may be present in some patients, especially children, who are asymptomatic and who have relatively good hearing. In others, symptoms such as hearing loss, otalgia, vertigo, and tinnitus may be associated with modest degrees of negative pressure or even with normal middle-ear pressures. The middle-ear air pressure may depend on the time of day, season of the year, or condition of the other parts of the system, such as the presence of an upper respiratory tract infection. For instance, a young child with a common cold may have transitory high negative middle-ear pressure while he or she has the cold but may be otherwise otologically normal. Whether high negative pressure is abnormal or is only a physiologic variation should be decided by taking into consideration the presence or absence of signs and symptoms of middle-ear disease. If severe atelectasis or adhesive otitis media of the tympanic-membrane–middle-ear system is present, the tympanogram may not be a reliable indicator of the actual pressure within the middle ear.

Therefore, a resting pressure that is highly negative is associated with some degree of eustachian tube obstruction, but normal middle-ear pressure does not necessarily indicate normal eustachian tube function; a normal tympanogram is obtained when the eustachian tube is patulous.

**Manometry**

The pump-manometer system of the electroacoustic impedance audiometer is usually adequate for assessing eustachian tube function clinically when the tympanic membrane is not intact. However, owing to the limitations of the manometric systems of all of the commercially available instruments, a controlled syringe and manometer (a water manometer will suffice) should be available when these limitations are exceeded (eg, when eustachian tube opening pressure exceeds +400 to +600 mm H₂O).

**Methods of Assessing Eustachian Tube Function in the Clinical Setting**

**Classic Tests of Tubal Patency**

Valsalva and Politzer (see Chapter 8, “Management,” Figures 4 and 5) developed methods to assess eustachian tube patency. When the tympanic membrane is intact and the middle ear inflates after one of these methods, the tube is not totally mechanically obstructed. Likewise, if the tympanic membrane is not intact, passage of air into the middle ear indicates patency of the tube. When the tympanic membrane is not intact, the assessment is more objective with a manometric observation on the impedance instrument. However, inflation of the eustachian tube and middle ear from the nasopharynx end of the system by one of these classic methods is an assessment only of tubal patency, not of function, and failure to inflate the middle ear does not necessarily indicate a lack of patency of the eustachian tube.

Elner and coworkers reported that 86% of 100 otologically normal adults could perform Valsalva’s maneuver. In young children, Valsalva’s maneuver is usually more difficult to perform than Politzer’s method. However, in a study by Bluestone and coworkers, six of seven children who had a traumatic perforation but who were otherwise otologically “normal” could perform Valsalva’s maneuver, but only 11 of 28 children who had a retraction pocket or a cholesteatoma could do so. Valsalva’s maneuver and Politzer’s method may be more beneficial as management options in selected patients than as methods of assessment of tubal function, although there is controversy about the efficacy of this procedure for treatment of middle-ear effusion.
Toynbee Test

One of the oldest, and still one of the best, tests of eustachian tube function is the Toynbee test (Figure 47). Test responses are usually considered positive when an alteration in middle-ear pressure results. More specifically, if negative pressure (even transitory in the absence of a patulous tube) develops in the middle ear during closed-nose swallowing, the eustachian tube function can most likely be considered normal.

When the tympanic membrane is intact, the presence of negative middle-ear pressure must be determined by pneumatic otoscopy or, more accurately, by obtaining a tympanogram before and immediately after the test (Figure 48). When the tympanic membrane is not intact, the manometer of the impedance audiometer can be observed to determine middle-ear pressure.

In the study by Elner and coworkers, results of the Toynbee test were positive in 79% of normal adults.216 Cantekin and colleagues reported that only 7 of 106 ears (6.6%) of subjects (mostly children) who had had tympanostomy tubes inserted for otitis media could show positive results with a modification of the Toynbee test (closed-nose equilibration attempt with applied negative middle-ear pressure of 100 or 200 mm H₂O).220 Likewise, in a series of patients, most of whom were older children and adults with chronic perforations of the tympanic membrane, only 3 of 21 (14.3%) passed the test. However, in children with a traumatic perforation of the tympanic membrane but who otherwise had a negative otologic history, 3 of 10 (30%) could pass the test. In the study by Bluestone and coworkers of normal children with traumatic perforations, 6 of 7 children could change the middle-ear pressure, but none of the
21 ears of children who had a retraction pocket or a cholesteatoma showed pressure change. The test is of greater value in determining normal or abnormal eustachian tube function in adults than it is in children. The test is still of considerable value; regardless of age, if negative pressure develops in the middle ear during or after the test, the eustachian tube function is most likely normal, because the eustachian tube actively opens and is sufficiently stiff to withstand nasopharyngeal negative pressure (ie, it does not “lock”). If positive pressure is noted or no change in pressure occurs, the function of the eustachian tube may still be normal, and other tests of eustachian tube function should be performed.

**Patulous Eustachian Tube Test**

If a patulous eustachian tube is suspected, the diagnosis can be confirmed by otoscopy or objectively by tympanometry when the tympanic membrane is intact. One tympanogram is obtained while the patient is breathing normally, and a second is obtained while the patient is holding his or her breath. Fluctuation of the tympanometric trace that coincides with breathing confirms the diagnosis of a patulous tube (Figure 49). Fluctuation can be exaggerated by asking the patient to occlude one nostril with the mouth closed during forced inspiration and expiration or by performing the Toynbee maneuver. When the tympanic membrane is not intact, a patulous eustachian tube can be identified by the free flow of air into and out of the eustachian tube by using the pump-manometer portion of the electroacoustic impedance audiometer. These tests should not be performed while the patient is in a reclining position because the patulous eustachian tube will close.

**Nine-Step Inflation-Deflation Tympanometric Test**

Another method of assessing eustachian tube function when the tympanic membrane is intact, developed by Bluestone, is the nine-step inflation-deflation tympanometric test, although the applied middle-ear pressures are limited in magnitude. The middle ear must be free of effusion. The nine-step tympanometry procedure can be summarized as follows (Figure 50):

1. The tympanogram records resting middle-ear pressure.
2. Ear canal pressure is increased to +200 mm H$_2$O with medial deflection of the tympanic membrane and a corresponding increase in middle-ear pressure. The subject swallows to equilibrate middle-ear overpressure.
3. While the subject refrains from swallowing, ear canal pressure is returned to normal, thus establishing a slight negative middle-ear pressure (as the tympanic membrane moves outward). The tympanogram documents the established middle-ear underpressure.
4. The subject swallows in an attempt to equilibrate negative middle-ear pressure. If equilibration is successful, airflow is from the nasopharynx to the middle ear.
5. The tympanogram records the extent of equilibration.
6. Ear canal pressure is decreased to −200 mm H$_2$O, causing a lateral deflection of the tympanic membrane and a corresponding decrease in middle-ear pressure. The subject swallows to
equilibrate negative middle-ear pressure; airflow is from the nasopharynx to the middle ear.

7. The subject refrains from swallowing while external ear canal pressure is returned to normal, thus establishing a slight positive pressure in the middle ear as the tympanic membrane moves medially. The tympanogram records the over-pressure established.

8. The subject swallows to reduce over-pressure. If equilibration is successful,
airflow is from the middle ear to the nasopharynx.

9. The final tympanogram documents the extent of equilibration.

The test is simple to perform, can give useful information about eustachian tube function, and should be part of the clinical evaluation of patients with suspected eustachian tube dysfunction. In general, most normal adults can perform all or some parts of this test, but even normal children have difficulty performing it. However, if a child can pass some or all of the steps, eustachian tube function is considered good.

**Modified Inflation-Deflation Test (Nonintact Tympanic Membrane)**

When the tympanic membrane is not intact, the pump-manometer system of the electroacoustic impedance audiometer can be used to perform the modified inflation-deflation eustachian tube function test (see Figure 30), which assesses passive as well as active functioning of the eustachian tube. With use of this test, the middle ear should be free of any drainage for an accurate assessment of eustachian tube function.

The middle ear is inflated (ie, positive pressure is applied) until the eustachian tube spontaneously opens (Figure 51). At this time,

![Figure 51. Test of passive and active function of the eustachian tube after application of positive middle-ear pressure. A, Analogous ascent in an airplane. B, Assessment of passive function. C, Closing pressure. D, Assessment of active function (swallowing). E, Strip chart recording showing an example of normal pressure tracing. Black circles represent swallows.](image-url)
the pump is manually stopped, and air is discharged through the eustachian tube until the tube closes passively. The pressure at which the eustachian tube is passively forced open is called the opening pressure, and the pressure at which it closes passively is called the closing pressure. The patient is then instructed to equilibrate the middle-ear pressure actively by swallowing. The residual pressure in the middle ear after swallowing is recorded. The active function is also recorded by applying over-pressure and under-pressure to the middle ear, which the patient then attempts to equilibrate by swallowing. The residual negative pressure in the middle ear after the attempt to equilibrate applied negative pressure of $-200 \text{ mm H}_2\text{O}$ is also noted (Figure 52).

This procedure is not performed in patients who cannot equilibrate applied over-pressure. If the eustachian tube does not open after application of positive pressure with use of the admittance instrument, and if no reduction in positive pressure occurs during swallowing, the eustachian tube must be assessed by use of a manometric system other than that available with the admittance instrument. The opening pressure may be higher than 400 to 600 mm H$_2$O pressure or not present at all (severe mechanical obstruction).

Figure 53A shows that, after passive opening and closing of the eustachian tube during the inflation phase of the study, the patient was able to completely equilibrate the remaining positive pressure. Active swallowing also completely
equilibrated applied negative pressure (deflation). This is considered to be characteristic of normal eustachian tube function. Figure 7-53B shows the eustachian tube passively opened and closed after inflation, but subsequent swallowing failed to equilibrate the residual positive pressure. In the deflation phase of the study, the patient was unable to equilibrate negative pressure. Inflation to a pressure below the opening pressure but above the closing pressure could not be equilibrated by active swallowing. This type of result is considered abnormal but may be found in a few subjects who do not have any obvious otologic disease.

Failure to equilibrate the applied negative pressure during the test may indicate locking of the eustachian tube. This type of tube is considered to have increased compliance or to be floppy in comparison with a tube with perfect function. The musculus tensor veli palatini is unable to open (dilate) the tube.

Even though the inflation-deflation test of eustachian tube function does not strictly duplicate physiologic functions of the tube, the results are helpful in differentiating normal from abnormal function. The mean opening pressure for apparently normal subjects with a traumatic perforation and negative otologic history reported by Cantekin and coworkers was 330 mm H₂O (+70 mm H₂O). If the test results reveal passive opening and closing within the normal range, the residual positive pressure can be equilibrated by swallowing, and the applied negative pressure can also be equilibrated completely, the eustachian tube can be considered to have normal function. However, if the tube does not open to a pressure of 1,000 mm H₂O, one can assume that total mechanical obstruction is present. This pressure is not hazardous to the middle ear or inner ear windows if the pressure is applied slowly. An extremely high opening pressure (eg, greater than 500 to 600 mm H₂O) may indicate partial obstruction, whereas a low opening pressure (eg, less than 100 mm H₂O) indicates a semipatulous eustachian tube. Inability to maintain even a modest positive pressure within the middle ear is consistent with a patulous tube (ie, one that is open at rest). Complete equilibration of applied negative pressure by swallowing is usually associated with normal function, but partial equilibration, or even failure to reduce any applied negative pressure, may or may not be considered abnormal because even a normal eustachian tube will lock when negative pressure is rapidly applied. Therefore, inability to equilibrate applied negative pressure may not indicate poor eustachian tube function, especially when it is the only abnormal result of testing.

Other Methods Available for Laboratory Use

Other methods are available to test the functioning of the eustachian tube, but they are currently limited to use in the laboratory for investigational purposes. When the tympanic membrane is intact, the microflow technique or an impedance method (both of which require a pressure chamber), sonotubometry, sequential scintigraphy, microendoscopy, or direct insertion of a balloon catheter into the cartilagenous eustachian tube may be used. When the tympanic membrane is not intact, the forced-response test may be used. Sonotubometry and the forced-response test are currently in use in routine research studies but
are not yet available for clinical use. (A more
detailed description of eustachian tube function
tests may be found in *Pediatric Otolaryngology*.)

**CLINICAL INDICATIONS FOR TESTING
EUSTACHIAN TUBE FUNCTION**

**Diagnosis**

One of the most important reasons for assessing
eustachian tube function is the need to make a
differential diagnosis in a patient who has an
intact tympanic membrane without evidence of
otitis media but who has symptoms that might be
related to eustachian tube dysfunction (such as
otalgia, snapping or popping in the ear, fluctuat-
ing hearing loss, tinnitus, or vertigo). An example
of such a case is a child or adolescent who
complains of fullness in the ear without hearing
loss at the time of the examination, a symptom
that could be related to abnormal functioning of
the eustachian tube or caused by an inner-ear
disorder. A tympanogram that reveals high
negative pressure (−50 mm H₂O or less) is
strong evidence of eustachian tube obstruction,
whereas normal resting middle-ear pressure is
not diagnostically significant. However, when the
resting intratympanic pressure is within normal
limits and the patient can develop negative
middle-ear pressure after the Toynbee test or
can perform all or some of the functions in the
nine-step inflation-deflation tympanometric test,
the eustachian tube is probably functioning
normally. Unfortunately, failure to develop
negative middle-ear pressure during the
Toynbee test or an inability to pass the nine-step
test does not necessarily indicate poor eustachian
tube function; many children who are otologi-
cally normal cannot actively open their tubes
during these tests. Tympanometry is not only of
value in determining whether eustachian tube
obstruction is present, it can also identify
abnormality at the other end of the spectrum of
eustachian tube dysfunction, and the presence
of an abnormally patent eustachian tube can be
confirmed by the results of the tympanometric
patulous tube test.

Screening for the presence of high negative
pressure in certain high-risk populations (ie,
children with known sensorineural hearing
losses, developmentally delayed and mentally
impaired children, children with cleft palates or
other craniofacial anomalies, Native American
and Inuit children, and children with Down
syndrome) appears to be helpful in identifying
those individuals who may need to be monitored
closely for the occurrence of otitis media.

Tympanometry appears to be a reliable
method for detecting the presence of high
negative pressure as well as otitis media with
effusion in children. The identification of
high negative pressure without effusion in
children indicates some degree of eustachian
tube obstruction. These children and those with
middle-ear effusions should have follow-up serial
tympanograms because they may be at risk for
development of otitis media with effusion.

However, the best methods available to the
clinician today for testing eustachian tube func-
tion are the nine-step test when the eardrum is
intact, and the inflation-deflation test when the
eardrum is not intact. A perforation of the
tympanic membrane or a tympanostomy tube
must be present for performance of the inflation-
deflation test. The test uses the simple apparatus
described earlier, with or without the impedance
audiometer pump-manometer system. This test
aids in determining the presence or absence of a
dysfunction and the type of dysfunction
(obstruction versus abnormal patency) and its
severity when one is present. No other test
procedures may be needed if the patient has
either functional obstruction of the eustachian
tube or an abnormally patent tube. However, if
there is a mechanical obstruction, especially if the
tube appears to be totally blocked anatomically,
further testing may be indicated. In such
instances, computed tomography of the naso-
pharynx–eustachian-tube–middle-ear region can
be performed to determine the site and cause of
the blockage, such as a cholesteatoma or tumor.
In most cases in which mechanical obstruction
of the tube is found, inflammation is present at the
middle-ear end of the eustachian tube (osseous
portion), and this usually resolves with medical management or middle-ear surgery, or both. Serial inflation-deflation studies should show resolution of the mechanical obstruction. However, if no middle-ear cause is obvious, other studies should be performed to rule out the possibility of a neoplasm in the nasopharynx.

**Eustachian Tube Function Tests Related to Management**

Ideally, patients with recurrent AOM or chronic otitis media with effusion, or both, should have eustachian tube function studies as part of their otolaryngologic work-up. For most children with these conditions, one can assume eustachian tube function to be poor. However, patients in whom tympanostomy tubes have been inserted may benefit from serial eustachian tube function studies. Improvement in function as indicated by inflation-deflation tests might help the clinician determine the proper time to remove the tubes. Cleft palate repair, adenoidectomy, elimination of nasal and nasopharyngeal inflammation, treatment of a nasopharyngeal tumor, or growth and development of a child may be associated with improvement in eustachian tube function.

Studies of the eustachian tube function of the patient with a chronic perforation of the tympanic membrane may be helpful preoperatively in determining the potential results of tympanoplasty surgery. Holmquist studied eustachian tube function in adults before and after tympanoplasty and reported that the operation had a high rate of success in patients with good eustachian tube function (ie, those who could equilibrate applied negative pressure) but that, in patients without good tubal function, surgery frequently failed to close the perforation. These results were corroborated, but other investigators found no correlation between the results of the inflation-deflation tests and success or failure of tympanoplasty. Most of these studies failed to define the criteria for success, and the postoperative follow-up period was too short. Bluestone and coworkers assessed children before tympanoplasty and found that, of 51 ears from 45 children, eight ears could equilibrate an applied negative pressure (−200 mm H₂O) to some degree. In seven of these ears, the graft took, no middle-ear effusion occurred, and no recurrence of the perforation developed during a follow-up period of between 1 and 2 years. A subsequent study by Manning and coworkers had a similar outcome. However, as in the studies in adults, failure to equilibrate an applied negative pressure did not predict failure of the tympanoplasty.

The conclusion to be drawn from these studies is that, if the patient is able to equilibrate an applied negative pressure, regardless of age, the success of tympanoplasty is likely, but failure to perform this difficult test will not help the clinician decide not to operate. However, the value of testing a patient’s ability to equilibrate negative pressure lies in the possibility of determining from the test results whether a young child is a candidate for tympanoplasty, when one might decide on the basis of other findings alone to withhold surgery until the child is older (see Chapter 9, “Complications and Sequelae: Intratemporal”).

In children who have unilateral perforation of the tympanic membrane or a tympanostomy tube in place and a contralateral tympanic membrane that is intact, the status of the intact side, observed for at least 1 year, can aid in determining whether tympanoplasty should be performed or a tube should be removed. Repair of the eardrum or removal of the tube is usually successful if the contralateral intact side has remained normal (ie, no middle-ear effusion or high negative pressure). Conversely, if the opposite ear has developed middle-ear disease during the previous year, tympanoplasty should be postponed, or if a tympanostomy tube is in place, it should not be removed.

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