Safety in Mines Research Advisory Committee

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Part 2

Evaluation of immittance testing for the identification of middle ear pathology in South African mineworkers

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Executive summary

The study evaluated immittance measures, specifically tympanometry and acoustic reflex testing, for the identification of middle ear pathology among South African mineworkers. The outcomes of medical history reviews, otoscopy, tympanometry, acoustic reflex testing and pure-tone screening audiometry were considered for 181 gold mine workers, within the context of the employer's medical surveillance programme for noise-induced hearing loss (NIHL).

Different screening procedures were compared with regards to the ability to identify middle ear problems Acoustic reflexes were found to be too sensitive for use in this population. Otoscopy identified 49.7 per cent of workers as having active or previous middle ear problems while tympanometry identified 27.1 per cent of workers. The workers all had normal hearing and would not have been identified by normal audiometric screening procedures.

Otoscopic examinations identified retracted tympanic membranes as the most common type of middle ear pathology, followed by scarred, inflamed and dull tympanic membranes, all of which corresponded with tympanometry findings. However, otoscopy requires considerable experience and interpretational skill on the part of the examiner, which may account for its lack of sensitivity in comparison with immittance measures

In addition to a possible need to improve their otological skills, mine Occupational Health personnel were found to be insufficiently familiar with middle ear barotrauma, which may have negative impact on the appropriateness of decisions regarding referral and further assessment of susceptible individuals. This indicates a need for Occupational Health personnel to become more familiar with predisposing factors that increase the risk of barotrauma, and appropriate courses of action where these are identified.

Despite the fact that middle ear pathology dramatically increases the risk of barotrauma during vertical conveyance, mineworkers were generally unaware of the need to report middle ear problems and, hence, often continued with their

underground work despite the presence of such conditions. Workers should be made aware of the consequences of middle ear pathology and be encouraged to report problems such as pain, suspected infection or tympanic membrane perforation. Education to increase workers' awareness of hazards, and training in appropriate behaviour to reduce risks are needs that could both be addressed by Occupational Health personnel in conjunction with Certificate of Fitness examinations.

The risks to underground workers posed by middle ear pathology and the greater sensitivity of immittance measures, particularly tympanometry, in identifying it indicate that employers and employees would benefit from the incorporation of this procedure into medical surveillance programmes. Benefits would include earlier identification of such conditions and individuals susceptible to them, thereby reducing treatment and recovery periods and limiting the consequential occurrence of barotrauma during vertical conveyance. Instrumentation costs and training requirements for technicians are both minimal, and the proposed additional measures should not entail any need for additional staff members as the additional time required for testing is minimal. A proposal and recommendations are offered for the incorporation of tympanometry into mines' medical surveillance programmes.

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Abbreviations

ANSI	American National Standards Institute
ASLHA	American Speech Language and Hearing Association
cc	cubic centimetres
CC	Compensation Commissioner
COMRO	Chamber of Mines Research Organization
daPa	deca Pascal
dB	decibel
DME	Department of Minerals and Energy
HL	hearing level
HPD	hearing protection device
Hz	Hertz
kHz	kilohertz
ml	millilitres
n.a.	no author
n.d.	no date
NUM	National Union of Mineworkers
OH	occupational health
OHP	occupational health practitioner
OMP	occupational medical practitioner
SOC	superior olivary complex
TM	tympanic membrane
WHO	World Health Organisation

Definitions and nomenclature

Acoustic reflex: involuntary contraction of the stapedius muscle in the middle ear in response to an acoustic stimulus, as part of the aural or auditory palpebral reflex (Blakiston's Gould Medical Dictionary, Third Edition)

Acoustic reflex threshold: the lowest intensity of acoustic stimulus that causes involuntary contraction of the middle ear stapedius muscle (Auburn University Department of Communication Disorders 2003)

Barotrauma: tissue damage that occurs when pressure in a gas-filled body space (e.g. middle ear, lungs) is not equalised to changing ambient pressure (WebMD Corp 2001, Newton 2001)

Eustachian tube: a 3-4 cm tubular structure linking the ear with the throat and nose, providing for the equalisation of pressure in the middle ear (Hoffman 1996)

Health hazard: any physical, chemical or biological hazard to health, including anything declared to be a health hazard by the Minister (DME 1996)

Immittance testing: the use of tympanometry and acoustic reflex testing to measure tympanic membrane compliance, in order to determine the status of structures medial to the eardrum (Evergreen Speech and hearing Clinic 2002)

Normal hearing: hearing sensitivity to a level of 25 dB or below (Hoffman 1996)

Medical surveillance: a planned programme of periodic examinations, which include clinical examinations, biological monitoring or medical tests of employees, conducted by an occupational health practitioner or occupational medical practitioner, as contemplated in Section 13 of the Mine Health and Safety Act (DME 1996)

Occupational disease: any health disorder including an occupational disease as contemplated by the Compensation for Occupational Injuries and Diseases Act (Act No. 130 of 1993) or the Mine Health and Safety Act (Act No. 29 of 1996)

Occupational health: a programme to ensure the health of workers that includes occupational hygiene and occupational medicine (DME 1996)

Occupational health practitioner: a person who holds a qualification in Occupational Health and is registered with the South African Health Professions Council (DDME 1996)

Occupational injury: any injury arising out of and during the course of a person's employment (Compensation for Occupational Injuries and Diseases Act No. 130 of 1993)

Occupational medical practitioner: a medical practitioner who holds a qualification in occupational medicine or an equivalent qualification, and who is registered with the South African Health Professions Council, or a medical practitioner engaged in accordance with Section 13(4) of the Compensation for Occupational Injuries and Diseases Act of 1993 (Mine Health and Safety Act 1996)

Pneumatic otoscopy: a two-step procedure to evaluate the tympanic membrane that includes, firstly, visualisation of the ear canal and eardrum with a light source and, secondly, observation of the tympanic membrane while very slight positive and negative pressure is applied to the sealed ear canal (Australian Department of Health and Aging 2001)

Risk: the likelihood that occupational injury or harm to persons will occur (DME 1996)

Safety: the prevention of accidental loss (DME 1996)

Screening: the rapid application of tests or other procedures for the purpose of identifying pre-clinical disease (Community Practice Handbook and Logbook 2001)

Screening test: a test performed without a clinical indication to detect pre-clinical disease (Community Practice Handbook and Logbook 2001)

Screening programme: systematic application of screening tests applied to an identified population or sub-population (Community Practice Handbook and Logbook 2001)

Sensitivity: the number of diseased individuals detected by a test in relation to the number of diseased individuals in the population being screened, expressed as a percentage (Community Practice Handbook and Logbook 2001)

Specificity: the number of non-diseased individuals whose response to the test is negative in relation to the number of non-diseased individuals in the population, expressed as a percentage (Community Practice Handbook and Logbook 2001)

Surveillance: the twin notions of careful, ongoing observation and timely intervention (Community Practice Handbook and Logbook 2001)

Tympanogram: a graphic representation of middle ear status and function (Wiley 1997)

Tympanometry: the measurement of middle ear impedance or admittance at positive and negative ear canal pressure, by means of instrumentation incorporating a probe with a speaker and microphone, and a microprocessor-controlled pressure pump (Shanks 1984)

1 Introduction

1.1 Background

Middle ear pathology constitutes a significant public health problem in many countries (WHO and CIBA 2000), with middle ear diseases and their sequelae imposing substantial economic and social costs, both directly and indirectly. Identification of such conditions relies on the appropriateness, accuracy and availability of diagnostic tools and procedures, which over the last decade have increasingly included immittance measures for both children and adult populations (ASLHA 1990).

The findings of screening programmes that employ techniques recommended by ASLHA (1990) and the British Society of Audiology (Cooper and Lightfoot 2000) have enabled the refinement of screening strategies and certain audiometric procedures, including the augmentation of pure-tone audiometry with otoscopy and immittance testing. A review of recent audiological research has indicated that identification programmes that incorporate history-taking, otoscopy, pure-tone screening and acoustic immittance tests provide the best means of identifying individuals in need of audiological and/or otological intervention for middle ear pathology (ASLHA 1993).

Some controversy exists regarding the efficacy of otoscopy in screening for outer and middle ear disorders, as the skills and experience of clinicians vary considerably. It can therefore be expected that subtle visual indications of middle ear disorders will be detected by some examiners but not by others (ASLHA 1990). It has also been found that the reliability of historical information provided by patients varies considerably (ASLHA 1993).

Pure-tone screening audiometry is a component of current medical surveillance procedures for NIHL, as well as the proposed screening protocol evaluated during the present study. The findings of Eagles, Wishik and Doefler (ASLHA 1990) indicate that pure-tone screening audiometry alone is inadequate for detecting all medically significant otological diseases. However, the Chamber of Mines Sub-committee on Hearing Conservation (COMRO 1988) and the Department of Minerals and Energy (2001) both recommended the use of medical histories, otoscopic examinations and screening audiometry, but regarded immittance measures (tympanometry and acoustic reflex testing) as optional.

1.2 Causal factors and prevalence of middle ear pathology

Environmental risk factors in the occurrence of middle ear pathology include poverty, overcrowding, inadequate housing, poor hygiene and nutrition, as well as exposure to air pollution (WHO and CIBA 2000). This is particularly true in developing countries where workers may also be subjected to occupational hazards and pollution in their general environment (WHO 1997), especially when they live close to their place of work. The prevalence of aural disease, therefore, can be associated with poor living conditions, as evident from the finding that active ear disease was present in more than one-third of individuals living under unfavourable social conditions (Socio-Economic Factors 1990), particularly in the poorer communities of developing countries (WHO and CIBA 2000).

A study of underground coal miners (Hopkinson 1981) showed a high prevalence of outer and middle ear abnormalities, and 90 per cent of local mineworkers were reported to be living in overcrowded and unhygienic hostels in close proximity to mines (NUM 1996). Given the present size of the mining industry's work force, a combination of unfavourable environmental and socio-economic factors may pose potential health risks to a significant portion of South Africa's population.

Risks are compounded when employees live close to the workplace, and in 2000 the Greater Johannesburg Metropolitan Council expressed concern that people living near industrial and mining areas commonly suffer from upper respiratory tract disorders associated with air pollution, particularly those affecting the ears, nose and throat. In local communities the occurrence of such conditions coincides with poverty, imposing a synergy of environmental, socio-economic and occupational health risks. This, combined with the risk of noise-induced hearing loss (NIHL), constitutes a serious threat to the health of mineworkers.

It should also be recognised that mineworkers can be subjected to the risk of middle ear damage from explosions and blasts, or from sudden changes in atmospheric pressure (WCC 2001).

1.3 Symptoms and complications of middle ear pathology

The existence of a medical condition that creates the likelihood of illness or injury should be of particular concern (DME 2001). A review of previous research in the South African mining industry has indicated that rapid changes in atmospheric pressure to which workers are subjected during vertical conveyance between surface and deep-level workings present a significant risk of barotrauma for susceptible individuals (Franz 2001).

Walling (2000) found that pressure changes within the ear can result in barotrauma if the normal function of the Eustachian tube is compromised. The non-compressible middle ear cavity makes the ear susceptible to damage from rapid changes in ambient pressure (Harril 1995), as uncompensated pressure causes distortion and increased vascularisation of the tympanic membrane. This can lead to oedema of the middle ear mucosa and, in extreme cases, bleeding into the middle ear (Walling 2000).

Middle ear pressure is governed by Boyle's Gas Law. During descent, as ambient pressure increases, the volume of the middle ear cavity decreases unless the internal pressure is equalised, either through deliberate swallowing actions or by movement of the lower jaw to open the Eustachian tubes and admit outside air to the middle ear cavities. Where the internal pressure is not equalized, the space will be filled by tissue engorged with fluid and blood (Newton 2001).

Rapid changes in air pressure can cause perforation of the tympanic membrane or inner ear barotrauma (Slaughter and Quinn 1992). Depending on the extent and location of damage, temporary or permanent hearing loss may result (Harril 1995). Other findings indicate that the risk of barotrauma is greatest among individuals with a chronic predisposing medical condition involving the ear or the upper respiratory tract, which is anatomically associated with the ears. Scarring of the tympanic membrane as a result of previous barotrauma, middle ear infection or damage caused by insertion of a foreign object would render it more susceptible to rupture, as the interface between normal tissue and scar tissue would constitute a weak point in the membrane (Franz 2001). Slaughter and Quinn (1992) demonstrated the phenomenon of individual susceptibility to barotrauma.

Previous research in the South African mining industry has recommended screening for the prospective identification of susceptible individuals, by means of risk-based medical examinations (RBME). Where an unacceptable risk of barotrauma is demonstrated, susceptible individuals could be validly excluded from work in deep workings, thereby protecting them from injury. Although barotrauma would be a particular concern in envisaged ultra-deep operations, there are indications that the condition already occurs at current mining depths (Franz 2001).

Early diagnosis and appropriate management can improve the outcomes of many conditions associated with occupational or environmental risk factors, and it is essential that the health practitioner is sufficiently aware of all risks to which the patient is exposed while considering his or her medical history (Boehlecke and Bernstein 1992). Congestion of the Eustachian tubes or their blockage by inflammation or swelling of surrounding tissue can impede incremental equalisation during underground descent. In such instances a pressure differential develops between the middle ear and the atmosphere, which may lead to barotrauma (Franz 2001). Congestion or inflammation of the Eustachian tube openings, as a result of infection in the upper respiratory tract, middle or inner ears or allergy greatly increases the risk of barotrauma during changes in ambient pressure (Hoffman 1996, Ear Barotrauma 2001).

1.4 Identifying middle ear pathology and susceptibility

Screening for hearing disorders constitutes an essential element of mine operators' medical surveillance programmes. The Mine Health and Safety Act (1996) requires the employer to establish and maintain a system of medical surveillance for all employees exposed to known health hazards, in order to identify and respond to the risk of occupational diseases and injuries. In addition, appropriate health education, health and safety training, as well as early detection and treatment of illnesses all serve to protect the wellbeing of mineworkers. The importance of early detection and identification of susceptible individuals is highlighted by the likelihood of barotrauma risks increasing as mining depths are extended beyond current levels. The occupational health practitioner (OHP) conducting medical examinations should be satisfied that no disease is present that could be aggravated by further exposure, or present an unacceptable health risk to the individual concerned. Any disorders identified during medical surveillance should be addressed by the occupational medical practitioner (OMP), either directly or through specialist referrals.

Middle ear problems are best treated by addressing the cause (WebMD Corp. 2002), but symptomatic treatment for congestion of the Eustachian tubes or paranasal sinuses involves the administration of decongestants, anti-histamines or appropriate antibiotics. Workers suffering from conditions that prevent the equalisation of pressure differences (e.g. occluded Eustachian tubes) are best excluded from work in deep level areas until their condition has been resolved (Franz 2001).

The identification of individual workers in need of audiological or otological intervention has traditionally relied on pure-tone testing and otoscopic examinations. If the purpose of screening is also to identify persons with middle-ear pathology, acoustic immittance screening (tympanometry and acoustic reflex testing) should be considered, along with otoscopic examinations and medical histories for otological abnormalities, in accordance with recommendations by ASLHA (1993).

Over the past 30 years, immittance measures have evolved from specialist procedures to routine audiological evaluation techniques (Wiley 1997). There is no better, quicker, or less expensive procedure for assessing the status of middle ear structures, the cochlea, VIIIth nerve and lower auditory brainstem than a comprehensive immittance assessment that incorporates tympanometry and acoustic reflex testing (Hall and Mueller 1997). In addition, immittance tests can diagnose tympanic membrane perforations too small for otoscopic detection, even by experienced clinicians (Martin 1994).

Tympanometry measures the mobility of the tympanic membrane and associated middle ear ossicles, enabling a quantitative assessment of middle ear function (American Academy of Otolaryngology 2000). It is a straightforward procedure, requiring no special preparation of the patient (Evergreen Speech and Hearing Clinic 2002), and provides important clinical information regarding middle ear status (Petrak 2001). Middle ear function is classified into three categories on the basis of the tympanogram's configuration (Alford 2001). It may reflect a normal mechanism, an abnormally compliant middle ear (as in ossicular dislocation/erosion or loss of elastic fibres in the tympanic membrane), or a stiff middle ear system (as in otosclerosis or chronic middle ear disease).

Where a hearing loss exists, tympanometry may be used to determine whether the loss includes a conductive component and, if so, to identify the cause (Smith and Evans 2000). It can also provide useful information where other diagnostic methods are not feasible, e.g. where visualisation of the tympanic membrane is difficult (Patient evaluation 2001).

Acoustic reflex testing is also sensitive to conductive hearing losses, even those as small as 5 dB (Alford 2001). Normal reflexes can be present at normal threshold and sensation levels, while elevated reflexes, indicating reduced cochlear sensitivity or a disorder of the VIIIth nerve, can occur as a result of recruitment. Absence of the acoustic reflex may reflect an abnormal middle ear system, severe loss of cochlear sensitivity, or a lesion in the VIIIth nerve or ipsilateral VIIth nerve (Alford 2001).

Immittance screening has the advantage of being objective, in that it requires no response from the subject, thereby obviating any attempt to influence results (as commonly occurs with conventional pure-tone audiometry). Its use would allow the immediate and positive identification of early-stage middle ear pathology and individuals who are susceptible to barotrauma. Accordingly, immittance screening offers the means to identify and manage those employees who are most at risk.

1.5 Statement of research question

In developing the experimental design, the following question was posed:

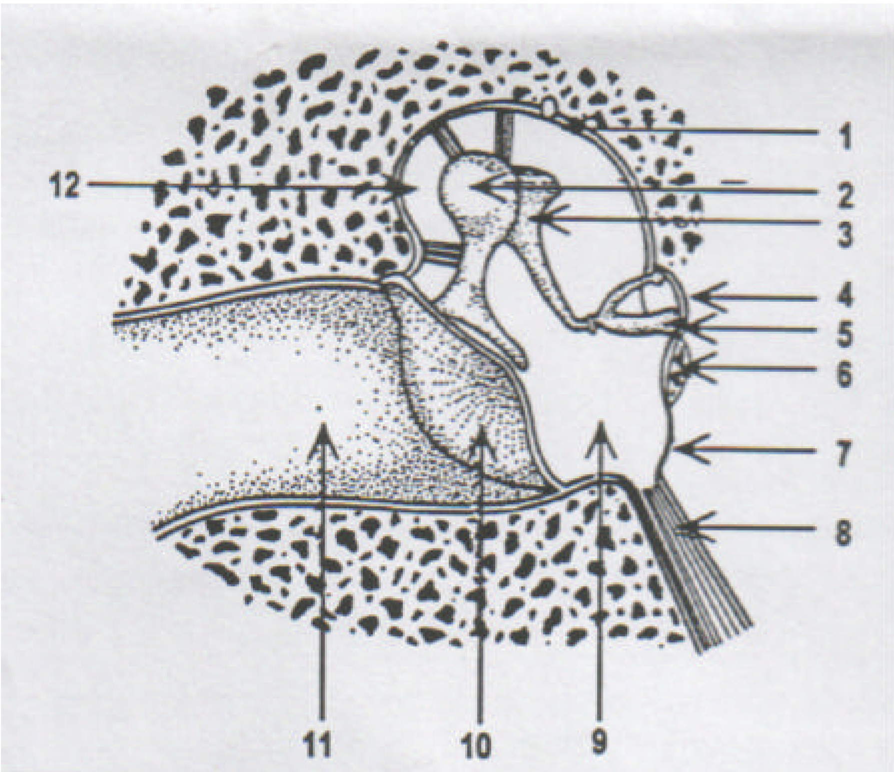
“*If immittance testing is incorporated into middle ear screening procedures together with history-taking, otoscopy and pure-tone audiometry, a higher incidence of middle ear pathology should be identified than if immittance testing is omitted and only history-taking, otoscopy and pure-tone audiometry are used.*”

The present study evaluated the practicability of immittance testing and otoscopy to identify middle ear pathology within employers’ medical surveillance programmes. Additional issues that were addressed included the relevance of guidelines and criteria for assessing symptoms, and the benefits of early identification and management of susceptible individuals.

2 Identification of middle ear pathology

2.1 Middle ear structure and function

For ease of reference, the anatomy of the human ear is illustrated in Figure 2.1.



1-Aditus ad antrum 4-Oval window 7-Round window 10-tympanic membrane
2-malleus 5-Stapes 8-Eustachian tube 11-external auditory canal
3-Incus 6-promontory 9-middle ear space 12-epitympanic recess

(Placed with the permission of the Department of Communication Pathology , UP)

Figure 2.1 Anatomy of the human ear

2.1.1 Tympanic membrane

A normal eardrum is translucent, with the appearance of ground glass, and pearly grey in colour (Australian Department of Health and Aging 2001). The tympanic membrane has a surface area of approximately 63 mm^2 and, despite being only 0,07 mm thick, consists of three tissue layers. It is highly vascularised, making it appear red in the presence of infection or inflammation. Embedded in the fibrous portion of the tympanic membrane's medial surface is the malleus or hammer, the first and largest of the middle ear ossicles (Martin 1994).

2.1.2 Middle ear cavity

The average adult's middle ear cavity is shaped like a flattened sphere, has a volume of approximately 2,8 cm^3 (38 mm high x 12 mm wide x 6 mm deep) and is filled with air (Martin 1994). A thin layer of bone separating the middle ear from the brain forms the roof of the cavity. The jugular bulb is situated below the floor of the middle ear, and the carotid artery runs behind the anterior wall. The lateral portion of the middle ear cavity supports the tympanic membrane at the distal or medial end of the ear canal, and the space above the tympanic membrane is called the epitympanic recess. Medial to the tympanic membrane is a set of three small bones called ossicles, which mechanically transmit sound energy from the air-filled ear canal to the fluid-filled inner ear. Each of these bones bears a Greek name descriptive of its shape: malleus (hammer), incus (anvil) and stapes (stirrup). The middle ear is connected to the nasopharynx (back of throat) via the Eustachian tube, which provides for pressure equalisation between the middle ear and surrounding air (Martin, 1994).

2.1.3 Eustachian tube function and middle ear pathology

In adults, the Eustachian tube consists of two truncated cones joined at their narrow ends (Hoffman 1996). It is between 31 and 38 mm in length, and extends from the middle ear cavity to the nasopharynx. The normal Eustachian tube is collapsed when at rest with slight negative pressure in the middle ear, and opens during chewing, swallowing, sneezing, or yawning. It has three functions: ventilation, drainage, and protection. When open, it allows ventilation of the middle ear and equalisation of pressure differences between the middle ear and the atmosphere, and drains the middle ear of accumulated secretions. When closed, it excludes nasopharyngeal secretions and sound generated in the mouth from the middle ear (Alford 2001). A dysfunctional Eustachian tube may cause negative pressure in middle ear lead to various middle ear disorders (Wiley 1997).

2.1.4 Middle ear impedance/admittance

Impedance is defined as resistance to the flow of energy through a system (Bess and Humes 1995). When acoustic energy reaches the eardrum of a normal ear, some of it is transmitted to the cochlea by the middle ear ossicles, and the remainder is reflected back out through the ear canal. The reflected sound forms a wave with an amplitude and phase determined by the resistance encountered at the tympanic membrane. The energy of the reflected wave is greatest when the middle ear system is stiff or immobile, as in pathologic conditions such as otitis media, effusion and otosclerosis. In contrast, an interruption in the ossicular chain, as with a dislocated ossicle, will result in considerately less energy being reflected back to the ear canal, because the reduced stiffness of the tympanic membrane allows most of the energy to pass through to the middle ear. This indicates that the reflected energy wave carries useful information regarding middle ear status and function, which is evaluated during immittance testing.

Admittance, the reciprocal of impedance, describes the relative ease with which energy flows through a system, and immittance testing considers both impedance and admittance. Some researchers regard the measurement of acoustic immittance as an important part of audiological evaluations (Bess and Humes 1995), contrary to previously mentioned characterisations of such measures as optional (COMRO 1988, DME 2001).

2.2 Assessing middle ear function and status

Structural changes in the outer or middle ear can affect hearing function and sometimes lead to impairment. Outer ear problems commonly involve cerumen (earwax) obstruction or stenosis (narrowing) of the ear canal. When such conditions occur, sound is prevented from reaching the tympanic membrane and results in a conductive hearing loss. Function of the tympanic membrane can also be affected by its perforation or accumulations of sclerotic tissue adding to its mass. These conditions reduce the responsiveness of the tympanic membrane and, hence, the conduction of sound to the ossicular chain (Stach 1998:173).

2.2.1 Medical history

Before the audiologic examination begins, a medical history should be recorded, considering previous records and information provided by the patient. Questions regarding the nature of past and present hearing problems, other medical problems and any previous medical treatment should be raised (Bess and Humes 1995:105). An accurate and comprehensive medical history should serve as the basis for any additional or specialised investigations that may be required. It should include the date of onset of any signs or symptoms of middle ear disorders, previous treatment and compliance with treatment regimes, as well as relevant environmental risk factors (Australian Department of Health and Aging 2001).

2.2.2 Otoscopy

The first step in the process of assessing outer and middle ear status should be a visual inspection of the ear canal and tympanic membrane by otoscopy. Otoscopes range in sophistication from simple hand-held instruments with a light source, to devices with a video camera and outputs to a recording deck (Stach 1998:174).

A physical examination of the head and neck should include the nose and throat, with special attention to the ears and adjacent structures (Alford 2001). The largest speculum that fits comfortably into the external meatus should be used, and the pinna should be gently pulled backwards and upwards. Surgical scars and congenital defects or abnormalities should be noted, and the external ear canal should be carefully examined for cerumen, exostosis, evidence of infection, flaking, dry skin, and osteomas. The postero-superior area of the canal should be inspected for any surgically produced mastoid cavity or cholesteatoma (Alford 2001), and the tympanic membrane examined for evidence of scarring, perforation, tympanosclerosis or abnormal colouration. Acute middle ear effusion makes the tympanic membrane appear amber, whereas chronic middle ear effusion makes it pale and dull. The area superior to the lateral process of the malleus should be carefully inspected for evidence of a retraction pocket or attic cholesteatoma, which are sequelae of middle ear infection (Alford 2001). The appearance of the tympanic membrane is the first key to diagnosing middle ear disorders (College of Family Physicians 2001), and familiarity with the appearance of a normal eardrum will enable the examiner to immediately recognise signs of middle ear pathology (College of Family Physicians 2001).

Although the tympanic membrane’s colour, translucence and resting position can be assessed during otoscopy (Australian Department of Health and Aging 2001), otoscopic examinations are subjective. Even when performed by an experienced clinician, static otoscopy may identify otitis media with effusion in only 50 per cent of cases (Palmu 2001), in contrast with tympanometry which can be expected to identify virtually all such cases. Also, it may be necessary to remove wax, dead skin or foreign material from the ear canal before an adequate view can be obtained, and narrow or crooked ear canals can impede visual examination (Australian Department of Health and Aging 2001).

Because the skill and experience of clinicians varies considerably, it should be expected that subtle visual indications of middle ear disorder will sometimes be overlooked. Apparent structural defects of the ear, head or neck, which may include complete absence of the pinna and atresia of the ear canal, mal-positioned pinnae or pre-auricular pits and tags, should lead to immediate specialist referral, as such defects may mask the presence of more serious otological abnormalities requiring medical intervention. Inflammation, bleeding, effusion, excessive cerumen, tumours, or foreign bodies in the ear canal are also grounds for referral. Eardrum abnormalities may be indicative of active middle ear infection requiring immediate treatment, but reliable detection by otoscopy requires considerable skill and experience, implying that only the most obvious indicators (e.g. perforation, inflammation, and severe retraction) can be reliably identified by otoscopy (ASLHA 1990).

2.2.3 Immittance testing

Following otoscopic inspection of outer ear structures, the next step in the evaluation process should be to assess the function of the outer and middle ear using immittance measures (Stach 1998), which include tympanometry and acoustic reflex testing. Tympanometry is not a test of hearing but of middle ear function, as it measures middle ear impedance to acoustic energy (Australian Department of Health and Aging 2001). It provides quantitative information on the mobility of the tympanic membrane and middle ear structures (Smith and Evans 2000, Franz 2001). In contrast, acoustic reflex measures provide an indirect indication of middle-ear status.

Tympanometric screening is most often conducted in paediatric populations, but there is direct evidence to suggest that it is also a useful in identifying treatable causes of hearing loss in adults. Results from 16 500 patients over a five-year period indicated that tympanometry can significantly enhance the effectiveness of screening programmes for middle ear pathology, e.g. by detecting middle ear conditions that require medical treatment despite the presence of normal pure-tone thresholds (Katz 1994:297). In the field of primary health care, screening audiometry is now commonly augmented by the use of inexpensive hand-held tympanometers, and the screening of patients for hearing abnormalities would benefit from the use of immittance measures to more effectively assess middle ear function (Katz 1994:297), especially if they are applied prior to audiometric screening.

2.2.4 Pure-tone audiometry

Pure-tone audiometric screening is generally accepted as the most reliable measure of hearing function (Petrak 2001) and, hence, is the most commonly used audiological technique (Quinn 2000). The main purpose of screening is to obtain reliable, frequency- and ear-specific hearing thresholds (Petrak 2001), defined by the American Standards Institute (ANSI) as the minimum effective sound pressure level of an acoustic signal that produces an auditory sensation "in a specified fraction of trials". (Quinn 2000). Threshold is generally defined as the lowest intensity of acoustic stimulus that elicits a response to 50 per cent of stimulus presentations.

Pure tones are well suited for measuring auditory sensitivity, as they can be varied in terms of intensity as well as frequency, and signals can be delivered via air or bone conduction pathways. The spectral specificity of pure-tone testing makes it useful in evaluating cochlear function at relatively discrete sites within that structure. Thresholds are measured in 5-dB steps, and typically recorded over the range of 250 to 8 000 Hz in octave intervals (Quinn 2000). If hearing loss occurs mainly at the lower frequencies (ostensibly a result of changes in the outer or middle ear) it is likely to be a conductive loss, but this should be confirmed by a comparison of air- and bone-conduction thresholds (Stach 1998:179).

Eagles, Wishik and Doefler (ASLHA 1990) recommend that pure-tone audiometry be included in all screening protocols, as presently required for all workers exposed at an equivalent level of 85 dB or greater (SABS 083: 1996).

2.3 Application of immittance measures

A thorough understanding of the basic principles of acoustic immittance measurement and identification audiometry is essential for the competent design and implementation of a screening protocol (ASLHA 1990), which should include tympanometry to provide important clinical information regarding middle ear status (Petrak 2001).

By the time immittance audiometry became clinically viable, the comparison of air- and bone-conduction thresholds was well entrenched as the preferred method for determining whether an outer or middle ear disorder was contributing to a conductive hearing loss, albeit indirectly. Where an air-bone gap was present, it was generally inferred that the conductive hearing loss originated in the middle ear and, conversely, where there was no gap middle ear status was thought to be normal (Stach 1998:259).

Immittance audiometry has been shown to be a more sensitive indicator of middle ear status, which can be abnormal even in the absence of a significant air-bone gap (Stach 1998:259). However, clinical practice was somewhat slow to adopt immittance techniques, continuing to use air-bone gap as the principal criterion for identifying middle ear disorders, despite the greater sensitivity and specificity of immittance measures.

Current practice is to conduct immittance testing first, before pure-tone audiometry. If all immittance measures (tympanometry, static immittance and ipsi- and contra-lateral acoustic reflex) are normal, any hearing loss identified is regarded as sensorineural irrespective of any air-bone gap (identification of which relies on the accuracy of difficult-to-measure bone-conduction thresholds). Many clinicians tend to omit bone-conduction testing where immittance results are normal, which is reasonable practice given that the latter is more objective and sensitive. If immittance results are abnormal it must be determined whether the middle ear disorder is causing any conductive hearing loss, which is then resolved by comparing air- and bone-conduction thresholds (Stach 1998:260).

2.3.1 Electro-acoustic immittance tests

Mobility and impedance of the tympanic membrane can be evaluated by means of tympanometry, which provides objective and quantitative measures of middle ear status. The tympanometer's probe has variously sized "plugs" to seal the entrance of the external ear canal, and its tip incorporates a transducer to vary pressure in the ear canal from negative to ambient, and from ambient to positive. While the pressure is varied, a low-frequency (e.g. 220 Hz) tone is directed towards the tympanic membrane (TM), which reflects some (depending on TM status and that of the ossicular chain) of the sound back to a microphone in the probe. Eardrum compliance is plotted against applied pressure to yield a tympanogram comprising a graph and a test report, which can be stored in a linked computer for record-keeping and data management purposes, or printed out on a plotter. Impacted cerumen, eardrum perforation, canal stenosis or incorrect probe placement can cause a false-positive result (Australian Department of Health and Aging 2001), indicating the value of a preliminary otoscopic inspection.

While meaningful assessments using otoscopy alone require an experienced, knowledgeable and observant examiner, implying the likely need for an ENT specialist or medical practitioner, tympanometry does not require the same level of interpretational skills and the results are quantitative, thereby enabling the use of pre-determined action and referral levels (Franz 2001).

There is presently a lack of normative tympanometry data for adults, but clinical findings support the use of these methods for identifying middle ear pathology in children. Correlations between tympanometry and pure-tone audiometry results for 581 children aged three to ten indicated a high positive-predictive value for hearing impairment in cases with type B tympanograms, and those with peaked tympanograms were 78,6 per cent more likely to have a hearing loss exceeding 25 dB. Tympanometry can be conducted in any reasonably quiet room, indicating that specialised acoustic treatment is unnecessary provided ambient noise does not exceed 50 dB (Smith and Evans 2000).

2.3.2 Principal components of immittance testing

Three basic procedures commonly make up the acoustic immittance test battery, viz. tympanometry, static acoustic immittance and acoustic reflex threshold (Bess and Humes 1995), which are discussed in the sub-sections that follow.

2.3.2.1 Static admittance/compliance

A static admittance/compliance assessment uses the maximum amplitude of the admittance-magnitude tympanogram relative to its tail value, to objectively categorise the tympanogram on the basis of shape (ASLHA 1990). Amplitude gives additional information about the compliance or elasticity of the middle ear system. A stiff middle ear system (as with ossicular chain fixation or fluid accumulation) will reflect most of the acoustic signal back to the probe, yielding a tympanogram with a shallow amplitude plot that indicates high impedance/low compliance. In contrast, a flaccid middle ear system (as with a dislocated ossicular chain or perforated eardrum) will absorb most of the signal, producing a tympanogram with a steep plot that indicates low impedance/high compliance. Eardrum compliance is measured in cubic centimetres (cc) or millilitres (ml).

If the middle ear cavity contains air at or near ambient pressure and the eardrum and ossicles are intact, some of the sound energy from the probe will be absorbed, producing a plot that indicates normal impedance and compliance of the middle ear system.

2.3.2.2 Equivalent ear canal volume

Ear canal volume is conventionally subtracted from measures of total aural admittance, to yield an estimate of middle ear admittance that is referred to as compensated admittance. Estimates of ear canal volume are routinely included in tympanometry to provide information about the volume of air medial to the probe, obtained by measuring admittance at a high-positive or high-negative ear canal pressure (Katz 1994). Ear canal volume is generally 0,5 ml for infants; 0,8 to 1,0 ml for children and 1,5 to 1,8 ml for adults, with larger volumes for geriatric patients. Volumes greater than these suggest tympanic membrane perforation or an open Eustachian tube (Quinn 2000), while lower values indicate occlusion of the ear canal by cerumen or a foreign object (Patient Evaluation 2001).

2.3.2.3 Tympanometric peak pressure

Tympanometry reflects the mobility of the middle ear when air pressure is varied from +200 to -400 daPa (Quinn 2000). The normal peak pressure for adults is between -50 and +50 daPa, indicating that the middle ear functions optimally at or near ambient pressure (Katz 1994:294). A peak pressure below the normal range suggests a dysfunctional Eustachian tube, early/resolving acute otitis media or chronic otitis media.

2.3.2.4 Acoustic reflex

Acoustic reflex threshold is defined as the lowest intensity of stimulus that elicits an involuntary middle ear contraction (Bess and Humes 1995). The reflex involves two small muscles in the middle ear that are anatomically and functionally associated with the ossicular chain. The tensor tympani muscle is attached to the wall of the Eustachian tube and the upper margin of the malleus' manubrium. It is innervated by cranial nerve V (the Trigeminal), and contracts involuntarily during a "startle response". This draws the malleus inward, stiffening the ossicular chain and, in turn, the tympanic membrane, which increases impedance and, thus, reduces acoustic admittance. Impedance is further increased by the simultaneous inward movement of the tensor tympani to reduce middle ear volume, thereby increasing middle ear pressure and further limiting acoustic admittance.

The second middle ear muscle, the stapedius, originates at a small bony canal adjoining the facial canal, and is attached to the head of the stapes. It is innervated by the motor or stapedial branch of the VIIth cranial or facial nerve. The stapedius muscle involuntarily contracts in response to an acoustic stimulus of sufficient intensity and duration, or to certain non-acoustic stimuli. This pulls the stapes downward and away from the oval window, the interface with the inner ear. As the head of the stapes is drawn back, its anterior base is tilted towards the tympanic cavity, stiffening the ossicular chain and correspondingly decreasing acoustic admittance at the lateral surface of the tympanic membrane. This reduction in admittance is time-locked with the activating stimulus, thereby enabling clinical measurements of the stapedius muscle response, i.e. the acoustic reflex.

The stapedius reflex is normally bilateral involving both ears, thereby allowing its assessment either by ipsilateral or contralateral stimulation. Ipsilateral reflex testing presents a stimulus to the ear undergoing immittance testing, and contra-lateral reflex testing involves the opposite ear. Ipsilateral responses are more pronounced than those to contralateral stimuli.

Acoustic reflex testing provides information on the integrity of the entire auditory system up to the level of the superior olivary complex (SOC) in the brainstem, and the motor branch of the facial nerve. Threshold is classified as "normal" if responses are recorded for stimuli at levels between 70 and 90 dB. Where responses occur at levels below 70 dB the threshold is termed "abnormal-with-recruitment", and thresholds above 90 dB are classified as "abnormal-elevated" (Wiley 1997). If it is impossible to elicit a reflex response at any level, the threshold is termed "absent".

Acoustic reflex testing is useful for differentially assessing auditory disorders and predicting hearing sensitivity (Stach 1998:270), but interpreting the results can be difficult because a given abnormality may result from a number of pathologic conditions. It is for this reason that uncrossed reflex measurements, tympanometry and static immittance testing are all essential for accurate diagnosis. Each measure is firstly evaluated separately against normative data, after which they are considered in combination to identify any patterns of pathology or dysfunction (Stach 1998:274).

2.4 Analysis and classification of tympanometry results

Various systems for classifying the results of single-component low-frequency tympanometry have been proposed. Jerger's system, which dates from 1970 (Katz 1994:284), is simple and clinically popular, as results are classified into three main groups on the basis of the tympanogram's configuration (Alford 2001):

Type A: Peak compliance occurring at or near atmospheric pressure, indicating normal pressure in the middle ear. Type A is divided into three subgroups:

- Type An: Symmetrical shape, indicating a normal middle ear system
- Type Ad: Deep curve with a tall peak, indicating an abnormally compliant middle ear, as seen in ossicular dislocation or erosion, or with loss of elastic fibres in the tympanic membrane

? Type As: Shallow curve indicating a stiff or non-compliant middle ear system, as in otosclerosis or chronic middle ear disease

Type B: No definite peak, with little or no variation in impedance over a wide range of pressures, often secondary to the presence of non-compressible fluid in the middle ear (otitis media), tympanic membrane perforation or obstructing cerumen

Type C: Peak compliance significantly below zero, indicating negative pressure (sub-atmospheric) in the middle ear cavity that is often associated with Eustachian tube dysfunction or middle ear effusion (Alford 2001)

Tympanometry provides important clinical information regarding the condition of the middle ear system (Petrak 2001) and a high concordance in physicians' interpretations of tympanograms has been demonstrated, with a sensitivity and specificity of 94 and 87 per cent, respectively (Margolis and Hunter 2000). In addition, the positive-predictive value, crucial to appropriate clinical decisions, has been shown to be excellent. Tympanometry is useful in assessing the risk of otitis media developing from a respiratory infection (negative middle ear pressure increases the risk of secondary infection occurring within the next three weeks), and in improving the diagnosis of ear infections (Australian Department of Health and Aging 2001).

In cases of acute middle ear infection, tympanometry can confirm the presence of coinciding effusion, and is a required procedure for confirming acute otitis media in clinical studies. Tympanometry may also be useful for identifying infections that can be treated by expectant follow-up without antibiotics (Palmu 2001). Tympanograms can be interpreted with confidence and reduce the cost of health care by limiting unnecessary referrals for undiagnosed hearing-related problems (Thunderbay District Health Unit 2001).

Immittance testing for the diagnosis of middle ear disorders is not regarded as the gold standard for unequivocal diagnosis, as a surgeon's report based on myringotomy testing is more widely accepted. However, the specialised nature of this procedure makes it unfeasible for general application, compelling many researchers to rely on tympanometry. Otoscopy is often used to validate tympanometry findings but, irrespective of otoscopic or myringotomy confirmation, experience has shown that the sensitivity and specificity of immittance testing are most dependent on the variables measured and the evaluation criteria used.

A primary rationale for the clinical use of acoustic immittance measures is that they are sensitive to middle ear disorders, even in cases where no functional hearing loss is apparent (Wiley 1997:1).

3 Methods

3.1 Aims of the study

The primary aim of the study was to clinically evaluate immittance testing as a means of identifying middle ear pathology among mineworkers. The secondary aims were, firstly, to determine the prevalence of middle ear pathology as identified by conventional and proposed methods and, secondly, to investigate discrepancies between results from conventional and the proposed screening methods.

3.2 Approach

A review of previous research relevant to the research problem contributed to a better understanding of issues related to the use of immittance measures for identifying middle ear pathology. The principal means of identification was through comparisons of results from medical histories, questionnaires, otoscopy, pure-tone screening audiometry and, in the case of the experimental group, immittance testing. Data were summarised in terms of prevalence and frequency to enable inferences regarding the occurrence of middle ear pathology in the population of mineworkers. The outcomes of conventional and the proposed methods were compared, to provide quantitative data for statistical analysis and an evaluation of immittance testing.

Internal validity was ensured by applying the same procedures for the proposed screening methods and those currently used, with the exception that immittance testing was introduced as the single variant between subject groups. The study was constructed so as to select and screen the same people within the same time frame and setting for both conventional and proposed screening procedures. External validity was provided for by using a representative sample of 181 subjects, sequentially selected from workers reporting for Certificate of Fitness examinations at the mine's Occupational Health Centre.

The formulation of guidelines for incorporating immittance testing into medical surveillance systems required a qualitative research component, provided for by a questionnaire to elicit closed- and open-ended responses as a source of descriptive information on the nature and occurrence of middle ear pathology, the environment in which screening procedures are performed, to facilitate an evaluation of the proposed screening methods.

3.3 Basis for evaluation of proposed screening protocol

Two closely related hypotheses were formulated as the basis for evaluating the proposed screening protocol:

- Current screening methods for middle ear pathology in employers' medical surveillance systems are inadequate in that they fail to identify middle ear pathology with the same sensitivity and specificity as immittance testing (Wiley 1997), and
- The proposed methods, incorporating immittance testing along with otoscopy and pure-tone screening audiometry can more accurately identify middle ear pathology.

3.4 Sample

3.4.1 Population

Subjects were unskilled and semi-skilled males aged 18 to 55, solicited from underground and surface workers reporting to the Occupational Health Centre at a gold mine for annual Certificate of Fitness examinations. The population of workers at the mine totalled 31 000.

3.4.2 Sample size

Statistical analysis showed the sample of 181 to be sufficiently representative for evaluating differences in the prevalence of middle ear pathology in mining and non-mining populations (Levin 2003).

3.4.3 Criteria for selection of subjects

Criteria for the selection of subjects were as follows:

- Gold mine workers
- Reporting for periodic Certificate of Fitness examinations
- Normal pure-tone screening results
- Informed consent provided

As indicated above, only workers with normal pure-tone screening results were included in the study, as it is possible for middle ear pathology to occur in the absence of appreciable hearing loss. Immittance testing was the only difference in procedures for the two protocols, providing for the primary focus of the study, i.e. an evaluation of immittance measures for the identification of middle ear pathology not detected by conventional screening methods.

3.4.4 Selection procedures

Between 100 and 150 workers reported to the Occupational Health Centre each day for Certificate of Fitness evaluations, from whom subjects were selected with the permission of mine management and the occupational medical practitioner. The purpose and procedures of the research were fully explained to each worker by reading aloud a consent form, which informed the worker of his right to decline participation without any negative consequences. The first 20 workers with normal hearing (consenting) were selected each day of the experimental research.

Most workers agreed to participate and duly signed their informed consent forms, but final selection was subject to the outcomes of history-taking, otoscopy and pure-tone screening audiometry, all of which were conducted by Occupational Health staff with results later evaluated by the audiologist. Audiometry was performed by Occupational Health staff, and results were classified into five categories, using the Schilling hearing loss categorisation system, as summarised in Table 3.4.4. Only workers with summated hearing levels below the tabulated warning and referral levels, i.e. Category 1 or "Normal" were considered as subjects.

Table 3.4.4

Categorisation of hearing threshold levels **(COMRO 1988)**

Age in years	**Sum of hearing levels for given test frequencies**			
	Referral level		**Warning level**	
	Low (0,5; 1; 2 kHz)	**High (3; 4; 6 kHz)**	**Low (0,5; 1; 2 kHz)**	**High (3; 4; 6 kHz)**
?24	60	75	45	45
25-29	66	87	45	45
30-34	72	99	45	45
35-39	78	111	48	54
40-44	84	123	51	60
45-49	90	135	54	66
50-54	90	144	57	75
55-59	90	144	60	87
60-64	90	144	65	100
?65	90	144	70	115

All results and findings were recorded in employees' medical files, and consenting individuals were routed to the Audiology Department on the same day for final selection, based on the audiologist's evaluation of conventional screening results. On any given day approximately 20 subjects were selected, after which they underwent otological examinations and immittance testing conducted by the audiologist.

After the initial study was completed the question was raised on the clinical significance of the tympanometry results. A further 78 workers were evaluated by an audiologist only doing tympanometry. The first 61 workers referred to the audiologist for diagnostic audiology were selected as well as a further 17 workers attending medical surveillance (one day).All the workers with abnormal tympanometry results were referred to either an OMP.or an ENT.specialist.

3.5 Data collection and recording

3.5.1 Subject questionnaire and medical history

Subject questionnaires (Appendix A) were administered to identify individuals with a history of ear or hearing-related complaints, particularly conditions involving the middle ear (e.g. infection or barotrauma), as well as to gather information on occupation and overall medical history. Questionnaires were read aloud to subjects in Fanakalo by an interpreter, and completed by the audiologist.

Relevant information was extracted from workers' previous medical reports and confirmed as accurate with each subject before being recorded and collated on a purpose-designed form (Appendix B).

3.5.2 Otoscopy

Otoscopic examinations of prospective subjects were performed by Occupational Health personnel using hand-held Heine Beta K 180 otoscopes to identify any outer or middle ear disorders, as summarised in Table 3.5.2. Findings were recorded on a purpose-designed form (Appendix C), noting abnormalities such as tympanic membrane perforation, otitis media, impacted cerumen or the presence of ventilation tubes.

Table 3.5.2

Ear pathology checks performed during otoscopic examinations

Outer ear (pinna/mastoid)	**Scoring**	
	YES	**NO**
Malformations (specify):	1	2
Traces of scarring	1	2
Pinna tenderness	1	2
Mastoid tenderness	1	2
Growths (specify):	1	2
Ear canal		
Foreign object in ear canal	1	2
Bleeding	1	2
Swelling	1	2
Wax plug	1	2
Otitis externa	1	2
Red/Irritated/Inflamed	1	2
Scratch marks in ear canal	1	2
Eczema-like appearance	1	2
Growths (specify):	1	2
Abnormal shape of canal (specify):	1	2
Tympanic membrane		
Retracted	1	2
Outward bulge	1	2
Red/Inflamed	1	2
Otitis media	1	2
Discharge	1	2
Fluid behind ear drum	1	2
Perforation (specify small/large):	1	2
Light reflex absent	1	2
Grommets in place	1	2
Dull	1	2
Infected	1	2
Scar tissue on ear drum	1	2
Air bubbles behind ear drum	1	2
Blood behind ear drum	1	2

3.5.3 Screening audiometry

Pure-tone air-conduction screening tests were conducted by an audiometrist using a Tremetrics computerised audiometer system (calibrated in accordance with SABS 0154:

1996) and the Everest test program. The system automatically determined thresholds, categorised audiograms and printed out test reports. Eight workers were seated inside individual Metalair test booths (to limit the effects of background noise) and tested simultaneously.

3.5.4 Immittance tests

All immittance tests were conducted by the audiologist with a calibrated Grason-Stadler GSI 38 AUTO TYMP, using variously sized re-usable probe tips (disinfected in Milton hygiene solution) selected in accordance with subjects' ear canal size. After instrument settings were confirmed, tympanometry and ipsilateral acoustic reflex tests were conducted at 500, 1 000, 2 000 and 4 000 Hz, and the results were printed out in hardcopy. The procedure was repeated if there was any indication that the results were unreliable, which occasionally occurred due to poor probe fit or alignment. Results were captured on a purpose designed record form shown in Appendix D, and the tympanogram was classified by the audiologist in accordance with criteria listed in Table 3.5.4a.

<u>Table 3.5.4a</u>

Classification of tympanometry results

Findings		Outcome
Type A	Normal 0,3 to 1,75 cm^3 at middle ear pressure of 50 daPa	**Pass**
Type As	Stiff middle ear system consistent with otosclerosis <0,3 cm^3 at middle ear pressure of 50 daPa	**Refer**
Type Ad	Flaccid middle ear system consistent with eardrum flaccidity/ossicular disarticulation >2,5 cm^3 at middle ear pressure of 50 daPa	**Refer**
Type B	Consistent with middle ear fluid build-up No compliance peak at pressure of +200 to -400 daPa	**Refer**
Type C	Consistent with Eustachian tube malfunction 0,3 to 1,75 cm^3 at pressure of -51 to -400 daPa	**Refer**
Equivalent ear canal volume	0,8 to 2,0 cm^3	**Pass**

Equivalent ear canal volume, the amount of air in front of the measurement probe, was measured because it can help identify any tympanic membrane perforations accompanied by middle ear mucosa. Values between 0,8 and 2,0 cm^3 were accepted as normal (Margolis and Heller 1987:197-8).

Hearing thresholds for 500, 1 000, 2 000 and 4 000 Hz, established during air-conduction screening audiometry, were used to determine stimulus intensity levels for acoustic reflex tests as indicated in Table 3.5.4b. Reflex responses were classified as “Normal”, “Absent”, “Elevated” or “Recruited”, as shown in Table 3.5.4c.

Table 3.5.4b

Audiometric test frequencies used to determine stimulus intensity for acoustic reflex testing

Ear and test frequency (Hz)	HL from audiometry
Right ear	
500 Hz	dB
1 000 Hz	dB
2 000 Hz	dB
4 000 Hz	dB
Left ear	
500 Hz	dB
1 000 Hz	dB
2 000 Hz	dB
4 000 Hz	dB

Table 3.5.4c

Scoring of results from acoustic reflex testing

Classification of ipsilateral acoustic reflex test result for given test frequency	Outcome	
	YES	NO
500 Hz		
Normal: 70-90 dB above PTT	1	2
Absent: No Response	1	2
Elevated: >90 dB above PTT	1	2
Recruitment: <70 dB above PTT	1	2
1 000 Hz		
Normal: 70-90 dB above PTT	1	2
Absent: No Response	1	2
Elevated: >90 dB above PTT	1	2
Recruitment: <70 dB above PTT	1	2
2 000 Hz		
Normal: 70-90 dB above PTT	1	2
Absent: No Response	1	2
Elevated: >90 dB above PTT	1	2
Recruitment: <70 dB above PTT	1	2
4 000 Hz		
Normal: 70-90 dB above PTT	1	2
Absent: No Response	1	2
Elevated: >90 dB above PTT	1	2
Recruitment: <70 dB above PTT	1	2

The results of immittance testing, including tympanometry and ipsilateral acoustic reflex testing, were recorded on a strip chart for each ear. Display formats are presented in Figures 3.5.4a and 3.5.4b, respectively, indicating test mode, test parameters and results. These were classified according to type of tympanogram, i.e. Type A, As, Ad, B or C (Table 3.5.4a). Tympanogram classification and interpretations were recorded on a test report form, along with acoustic reflex threshold results classified in accordance with Table 3.5.4c.

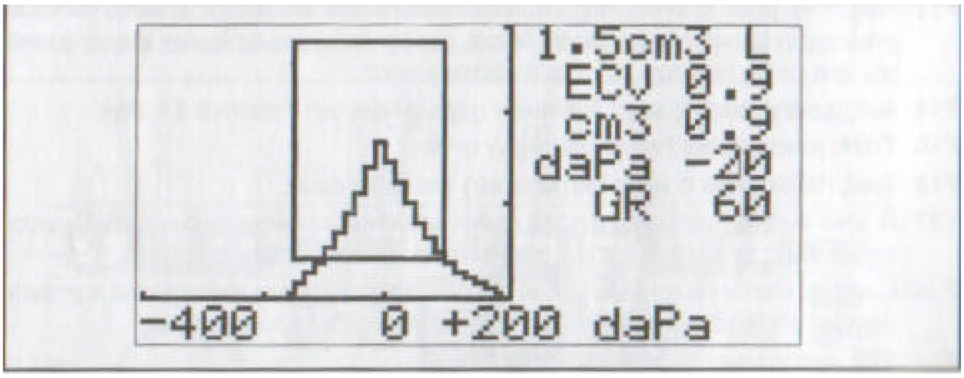


Figure 3.5.4a Display format for tympanometry results

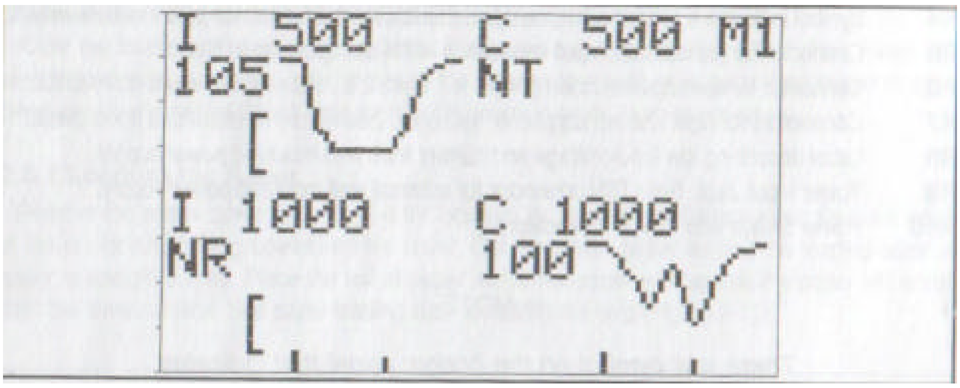


Figure 3.5.4b Display format for acoustic reflex test results

The results from each subject's immittance tests were recorded by the audiologist on a summary and scoring form (Appendix D), along with comments and subjective observations under the relevant headings. These results were considered along with otoscopy findings (Appendix C), information from subjects' medical records (Appendix B), employment history and work environment, as well as the findings of conventional screening procedures conducted by Occupational Health personnel. Where pathology was identified, additional information was recorded for use in a qualitative analysis of findings. This completed the procedures for identifying middle ear pathology and acquiring data for comparing and evaluating existing and proposed screening protocols.

3.5.5 Occupational Health personnel

Occupational Health personnel conducting middle ear screening procedures were asked to provide information regarding the incidence of middle ear pathology, the effectiveness of otoscopic examinations and medical surveillance/referral procedures, as well as their knowledge of middle ear pathology and barotrauma. An informed consent form was signed by participating staff members, before the questionnaires (Appendix E) were administered by the audiologist. Questionnaires for OH personnel included multiple-choice and open-ended questions, to supplement information on the effectiveness of current screening procedures.

3.6 Analysis of results

The Stata Version 7 software program was used for the statistical analysis of data, incorporating univariate procedures (t-tests and chi-square tests) and stepwise multiple-regression modelling, with comparisons made between subjects who were referred and those who were not. Data were taken from immittance test printouts, otoscopy forms, medical records and questionnaires, then recorded on digotome scales (yes/no answers) and lickert scales (multiple answers) for collation and analysis.

The audiologist's findings were compared with those recorded by Occupational Health staff. For employees with normal hearing, OH personnel rely solely on otoscopy to identify middle ear pathology, which results in a referral. The audiologist applied the additional measures of tympanometry and acoustic reflex testing, for which a PASS or REFER result was recorded on a digotome scale.

The prevalence of PASS and REFER results was compared and correlated for conventional and proposed screening procedures, to determine which protocol most effectively identified middle ear pathology. In addition, each subject's otoscopy results were directly compared with his immittance results to evaluate the sensitivity of otoscopic examinations.

Figure 3.6 summarises conventional screening procedures as currently applied in employers' medical surveillance programmes. Where no abnormalities are found the employee is classified as "Fit for work" with regard to hearing status. If otoscopy performed by Occupational Health staff reveals any pathology, the individual is referred for treatment before undergoing audiometric screening. Where screening identifies significant hearing loss, the employee is referred to the audiologist for an investigation of hearing-related medical history, as well as otoscopy, immittance testing and diagnostic audiometry. The employee's fitness is then reviewed by the occupational medical practitioner, considering the audiologist's findings.

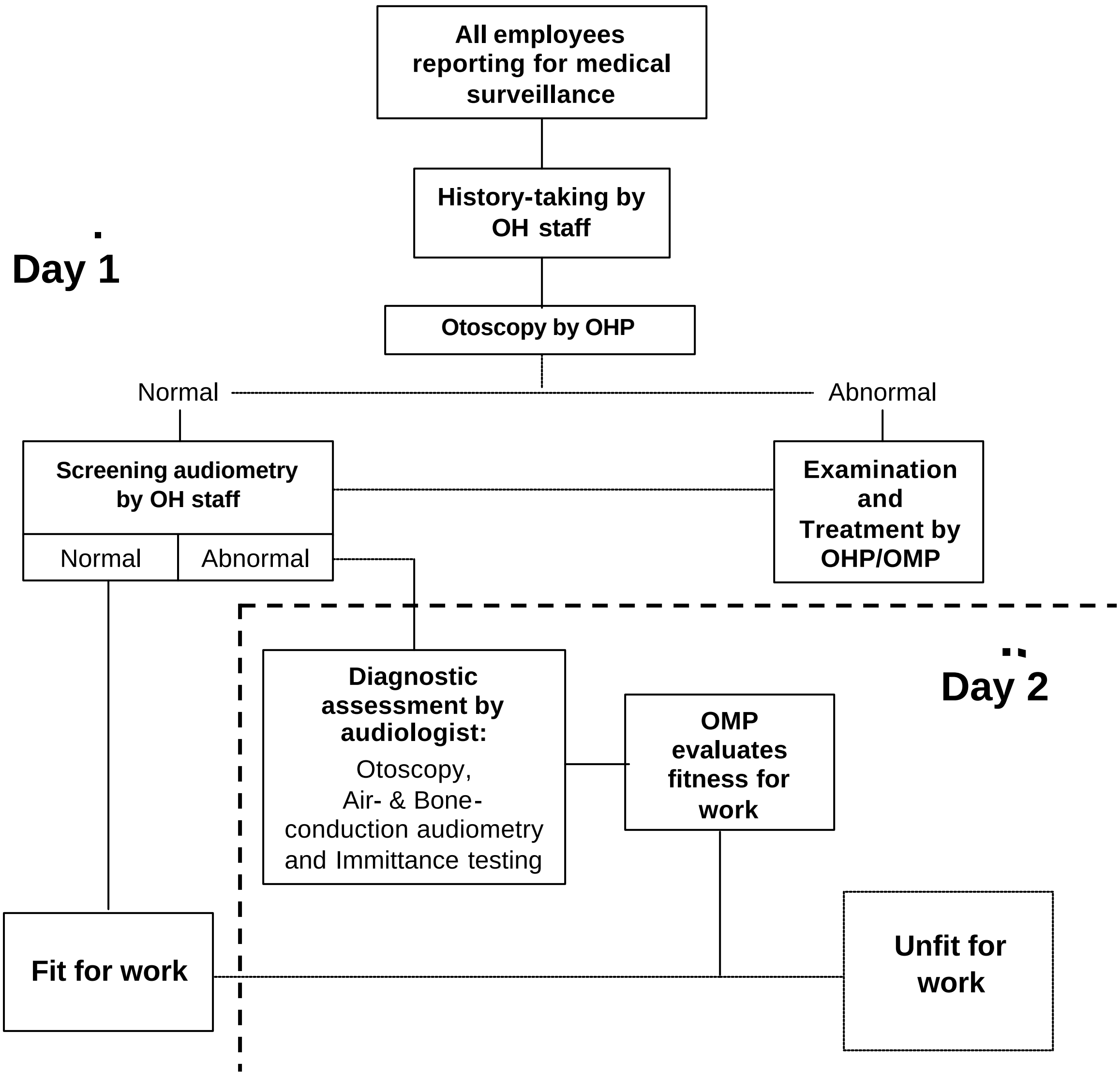


Figure 3.6 Current screening procedures in medical surveillance

4 Results and discussion

4.1 Sample

The present sample consisted of 181 males working at a gold mine with a labour force of approximately 31 000. Subjects included surface and underground employees, most of whom were unskilled or semi-skilled workers. They were sequentially selected from consenting individuals found to have normal hearing (HL 0-25 dB at 500-8 000 Hz) during periodic screening audiometry. Subjects' ages ranged from 18 to 55 years, with a mean of 39,4.

4.2 Referral rates for various screening procedures

Referral rates for various components of the existing and experimental screening protocols are compared in Figure 4.2

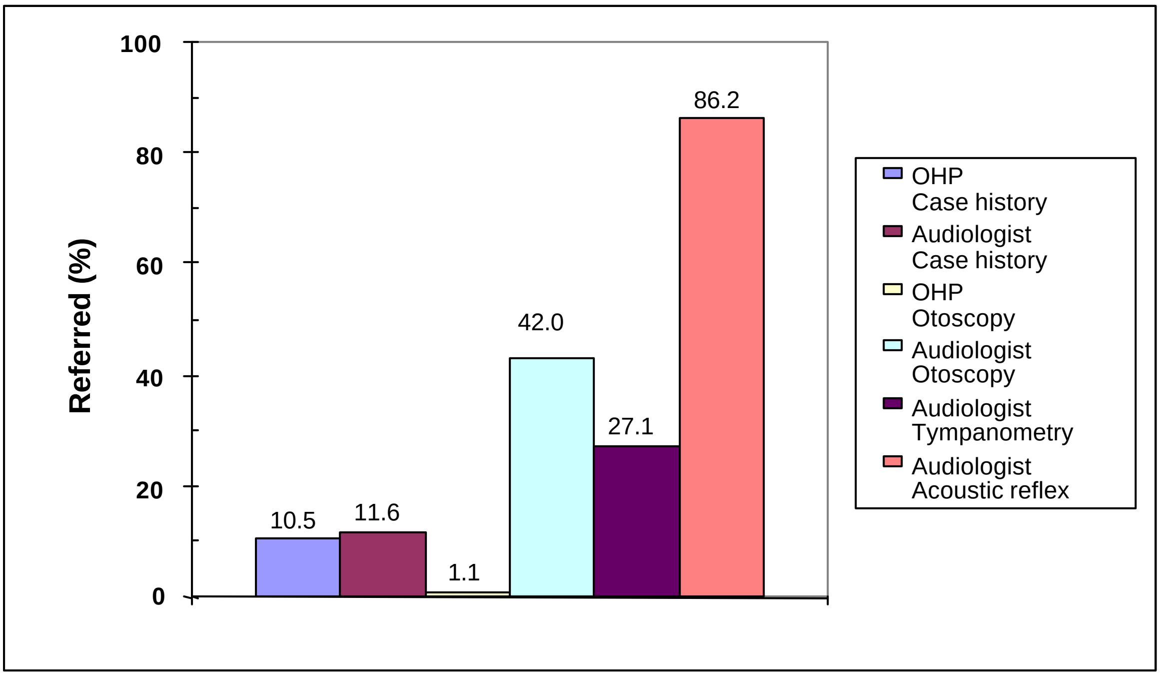


Figure 4.2 Referral rates for various middle ear screening procedures

The proposed screening procedures referred 107 or 59,1 per cent of the 181 mineworkers studied. This corresponds with results from a study of middle and external ear disorders among underground coal miners in the US (DHHS 1981). It will, nevertheless, be noted that the experimental protocol was far too sensitive, particularly acoustic reflex testing. This procedure identified 86,2 per cent of experimental subjects as referable. A further point to consider is that tympanometry would also identify individuals who do not have active ear disease, based on signs of previous pathology (e.g. scar tissue immobilising the middle ear system).

Audiologist-administered case histories in the experimental screening protocol identified otological abnormalities in 11,6 per cent of subjects, compared with 10,5 per cent identified through case histories recorded by occupational health practitioners (OHP). Although the reliability of historical information from patients is often questionable (ASLHA 1993), these two detection rates correspond. Among the subjects for whom OHP-recorded case histories found no previous middle ear pathology, 3,1 per cent were subsequently referred for further investigation on the basis of otoscopy findings by the audiologist. After completion of the experimental research the researcher endeavoured to study the clinical significance of the identified pathology. It was found that there were no records in the workers' file on the otoscopic findings of the occupational health centre's staff.

It was also found that 62,9 per cent of subjects who smoke or are exposed to second-hand smoke (n=140) had outer and/or middle ear abnormalities (n=88), in comparison with 47,2 per cent (n=17) of those not so exposed (n=36). This difference was only found to be significant at the 10 per cent level (chi-square =2,91 and p=0,0889). No association was demonstrated between age and middle ear disorders, as the mean age of subjects with abnormalities was 41,6 years (SD=8,41), vs. a mean and standard deviation of 39,3 and 8,56 years, respectively, for normal subjects (t=0,68 and p=0,49).

The high prevalence of abnormalities among all groupings of subjects may be partially attributable to environmental risk factors such as poverty, overcrowding, inadequate housing, poor hygiene and nutrition, as well as environmental and occupational exposure to air pollution, including dust (WHO and CIBA 2000). It should also be considered that explosions or blasts in the workplace and changes in atmospheric pressure constitute additional risk factors (Compensation Commissioner 2001). A convergence of multiple risk factors, as can occur with mineworkers in developing countries, may create the potential for negative synergies between social, economic, environmental and occupational health risks.

4.2.1 Otoscopic examinations

Otoscopy was the second component in experimental screening protocols, performed by the OHC staff or the audiologist, respectively, depending on which protocol was applied. When performed by the audiologist, otoscopy identified abnormalities in 41.98 per cent of subjects (only middle ear pathology), in contrast with 1,1 per cent when performed by Occupational Health staff. Almost midway between these two values is the 19 per cent prevalence found by Hopkinson among coal miners (1981). The variance among these findings may support the contention that clinicians' skill and experience greatly influence the sensitivity and, hence, effectiveness of otoscopic examinations (ASLHA 1993), and that subtle visual signs of pathology may go undetected in many instances (ASLHA 1990). Occupational Health staff may also be disinclined to refer a patient with longstanding chronic middle ear problems now presenting with scar tissue, because this would not be regarded as an active condition.

In both the conventional and experimental screening protocols, otoscopic examinations sought to identify any symptoms of existing or previous pathology, such as malformations, scarring and infections. Table 4.2.1 indicates the type of pathology observed by the audiologist.

Table 4.2.1

Identification of middle ear abnormalities by otoscopic examination

Region of ear and condition	***number of ears observed***
Tympanic membrane	
Retracted	38
Outward bulge	0
Red	21
Otitis media	0
Discharge	0
Fluid behind ear drum	0
Perforation	0
Light reflex absent	1
Grommets in place	0
Dull	8
Infected	2
Scar tissue on ear drum	23
Air bubbles behind ear drum	6
Blood behind ear drum	0

Otoscopic examinations found retracted tympanic membranes to be the most common type of middle ear problem observed. This is an important finding in that retracted eardrums indicate negative middle ear pressure and, thus, possible Eustachian tube dysfunction that could contribute to barotrauma and should, therefore, be investigated

Eardrum scarring was also observed in 23 eardrums. This is also an important finding, as it is indicative of previous middle ear pathology. This high incidence of tympanic scarring can also explain the discrepancy in the audiologist and OHC staffs' referral rate. There is clearly no reason to refer a patient for previous pathology. A red or inflamed tympanic membrane (21ears) can indicate active middle ear pathology, as can a dull tympanic membrane (8 ears)). These findings, and the fact that all subjects had previously been found to have normal hearing on the basis of screening audiometry, show that audiometry cannot be expected to identify all middle ear pathology, even in its later stages, and that otoscopy is a more effective screening procedure for such conditions.

These findings correspond with those of the previously cited DHHS study (1981), which found impacted cerumen, retracted tympanic membranes and eardrum scarring to be prevalent among coal miners.

4.2.2 Immittance measures

Abnormal tympanometry results were recorded for 27,1 per cent of subjects, which approximately corresponds with the prevalence of 23,4 per cent previously found among coal miners through the use of tympanometry (Hopkinson 1981). In a further study of the significance of the abnormal tympanometry results it was found that 5.9 per cent of workers evaluated at that stage had abnormal tympanometeric results. The discrepancies can be explained due to different time of the year evaluations as well as the norms adapted for a study.

The present study found acoustic reflexes to be abnormal in 86,2 per cent of subjects. Although acoustic reflex testing can detect sensory neural hearing loss in the presence of normal middle ear function, its ability to specifically identify middle ear disorders themselves is limited. The acoustic reflex is an indirect index of middle ear status that can be used to identify middle ear pathology. However, tympanometry can more directly and reliably detect such conditions with a lower incidence of false-positives that can lead to unnecessary referrals (ASLHA 1990). Clearly, the acoustic reflex referral rate of 86,2 per cent among individuals with functionally normal hearing is due in part to the inclusion of false-positive results, as evident from comparing this rate with that of other procedures. Accordingly, the use of acoustic reflex testing appears to offer more problems than benefits.

In a subsequent study, workers with abnormal tympanometry results were evaluated by an OMP or an ENT in order to test the clinical significance of the abnormal tympanometry. All cases (100 per cent) of the workers with abnormal tynpanometric results had middle ear problems confirmed by medical diagnosis.

4.2.3 Identification of risk factors for middle ear pathology

Subjects' responses to questionnaires indicated that 84,1 per cent frequently scratch at their ear canals with foreign objects, e.g. matchsticks. The epithelium lining the external auditory canal is thin and easily abraded by such behaviour (Hawke and McCombe 1995), which can easily lead to otitis externa. Otoscopic examinations identified ear canal abrasions in 1, 1 per cent of subjects and red or irritated ear canals in 6, 1 per cent. Hearing protectors may also cause abrasions, as 13, 3 per cent of participants complained that their HPDs were painful to wear.

Mineworkers' questionnaires further indicated that 79, 6 per cent of subjects smoke or are exposed to passive cigarette smoke, thus increasing their risk of upper respiratory tract infection. Of these individuals, 62, 9 per cent were referred for treatment of middle ear pathology.

With regard to influenza, 8, 1 per cent of respondents receive annual 'flu vaccinations, and 5,1 per cent had contracted this disease during recent months. Of the respondents that received flu injections, only one complained of ear ache and only two subjects were referred by tympanometric procedures. The association between upper respiratory infection and the risk of middle ear barotrauma indicates that underground workers in particular should be counselled regarding the likelihood of colds and 'flu leading to middle ear pathology and an increased risk of barotrauma.

Overcrowding, inadequate housing, poor hygiene and poor nutrition and exposure to air pollution are all risk factors in the development of middle ear pathology (WHO and CIBA 2000). The present study revealed that 10,9 per cent of respondents do not regard their living conditions as hygienic or clean, possibly indicating risks to workers' health.

4.2.4 Barotrauma risk

Data obtained from questionnaires administered to Occupational Health personnel performing otoscopy indicated that they are largely unfamiliar with middle ear barotrauma and, hence, may fail to detect its symptoms, recognise susceptible individuals or appropriately advise them with regard to prevention. The risk of barotrauma during vertical conveyance increases dramatically in the presence of middle ear pathology, and the study findings indicate that workers often continue with underground work while suffering from conditions of the middle ear. It was also evident that mineworkers commonly fail to report suspected ear infections or tympanic membrane perforations to Occupational Health staff, indicating the need for education and counselling with regard to the prevention, recognition and consequences of middle ear conditions, including the greater risk of middle ear barotrauma they impose.

5 Conclusions and recommendations

5.1 Conclusions

The present research demonstrated that immittance measures offer potential benefits for employers' medical surveillance programmes by identifying middle ear abnormalities that might otherwise go undetected. This statement is supported by the fact that the proposed screening protocol identified such conditions in 27, 1 per cent of subjects that had normal hearing. Audiologists and OHC staffs'' otoscopic findings varied depending on their level of experience and interpretational skills. The study's use of more examiners with varying levels of training and experience may have provided a clearer picture of the extent of variability that can be expected with current procedures. Although there was a clear association between abnormal otoscopic findings and abnormal immittance test results, the lower sensitivity of otoscopy, especially in comparison with tympanometry, clearly demonstrates the latter's objectivity and immunity to examiner influences. Of the two immittance measures evaluated, tympanometry and acoustic reflex testing, tympanometry was shown to be more useful, due to the common absence of acoustic reflexes in noise-exposed workers, even those with functionally normal hearing.

The pronounced differences demonstrated between the two protocols in their identification of middle ear abnormalities may be explained by a lack of sensitivity in current screening methods, allowing middle ear pathology to go undetected and, hence, increasing the risk of barotrauma for underground workers. In this regard, Occupational Health personnel's apparently inadequate knowledge of barotrauma may limit their ability to identify this condition or its predisposing factors and to advise workers regarding its prevention.

Timely intervention, made possible through the use of tympanometry, can reduce the risk of further middle ear damage, including barotrauma, thereby better protecting the health and well being of mine workers. Early identification would serve to shorten treatment and recovery periods in comparison with neglected cases, which in some instances could eventually require surgical intervention. This study indicated that there are problems in following up outcomes of referral and the lack of documentation of follow up precluded accurate determination of the sensitivity and specificity for screening of middle ear pathology. An additional study conducted on persons with abnormal hearing (Appendix F) was valuable in that it indicates that tympanometry is apparently always abnormal when there is pathology.

5.2 Recommendations

The study findings indicate a need for competent otoscopic examinations and, accordingly, it is recommended that programmes be implemented by Occupational Health service providers to evaluate the otoscopic skills of Occupational Health staff in comparison with those of audiologists and Occupational Health practitioners and, where indicated, to provide training based on the needs and deficiencies identified by comparative evaluations.

Irrespective of the preceding recommendation and based on the findings of the present and previous work, it is further recommended that immittance measures, specifically tympanometry, be considered for incorporation into employers' screening protocols for middle ear pathology and barotrauma susceptibility, as outlined in Figure 5.2. This course of action would enable earlier identification and treatment of such conditions, thereby limiting recovery periods and associated costs of specialist referrals. Tympanometry would enhance the effectiveness of screening protocols, as it is more specific and requires less training or experience on the part of examiners, compared with acoustic reflex testing. Furthermore, tympanometry provides quantitative results that would facilitate the application of predetermined action levels.

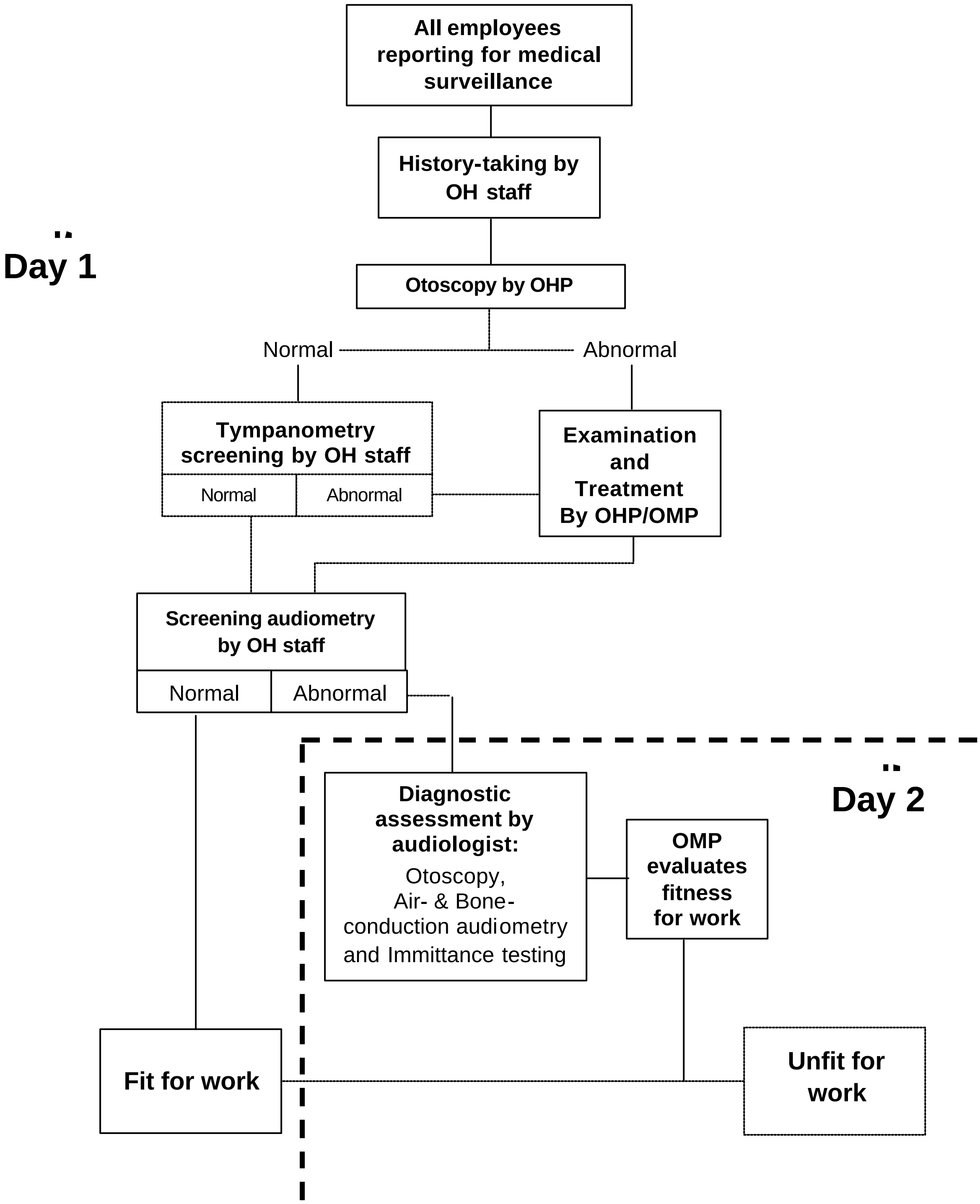


Figure 5.2 Incorporation of immittance measures into medical surveillance

Individuals identified with middle ear pathology or as susceptible to such conditions should be educated and counselled with regard to signs and symptoms, in order to promote informed and appropriate behaviour aimed at controlling the risk of protracted illness or, in the case of underground workers, middle ear barotrauma. Of primary importance is the need for affected individuals to report any middle ear or pressure-related problems to supervisors and Occupational Health personnel, and this should be emphasised during education and counselling. Employee awareness of hazards and risks must be regarded as a fundamental requirement that should be addressed through educational programmes that incorporate the crucial input of Occupational Health personnel.

In planning for the incorporation of tympanometry into mines' medical surveillance programmes, the cost of equipment, staffing and training requirements must be considered. Training for technicians in the use of immittance techniques could be readily provided by the consulting audiologist, in consultation with the occupational medical practitioner and in collaboration with instrument suppliers. Accordingly, no direct costs for training are foreseen. Because tympanometry testing is very quick and easy to perform, tests could be conducted by employed audiometrists at the Occupational Health Centre.

The current cost of instrumentation for immittance testing, which requires no special acoustic treatment of the test room, is approximately R 14 000, excluding VAT.

5.2.1 Recommendations for further research

Although commonly seen at mines' occupational health centres, the prevalence of middle ear pathology is poorly documented in South Africa, mainly as a result of inconsistent reporting practices. A possible topic for further research is a determination of prevalence for various types of middle ear pathology among mineworkers in relation to working depth, considering the influence of aural hygiene and HIV/AIDS. Subject to the findings of prevalence, the development of relevant educational/motivational training programmes and materials should then be considered.

This study on gold miners has emphasised the clinical value of immittance testing within employers' medical surveillance systems, but its use in screening for barotrauma susceptible individuals is yet to be evaluated. Deep-level mineworkers are exposed to the risk of barotrauma during vertical conveyance, particularly where middle ear pathology exists, and a preliminary investigation should be conducted to determine the current prevalence of barotrauma among South African mineworkers.

It is lastly recommended that the incidence of abnormal or absent acoustic reflexes among mineworkers with normal hearing be investigated, to determine the clinical significance of this phenomenon and identify underlying causes.

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Appendix A

Questionnaire for mineworkers

Industry number: ____________ V1 1-10

Date 2002/ / /

Age ______________________________ V2 ☐☐ 11-12

Mine ______________________________

Level ______________________________ V3 ☐☐☐ 13-15

Occupation ______________________________

1 Do you go for annual flu vaccinations?

Yes	1
No	2

V4 ☐ 16

2 Do you smoke or does someone near you smoke regularly?

Yes	1
No	2

V5 ☐ 17

3 Do you live in clean sanitary conditions?

Yes	1
No	2

V6 ☐ 18

4 Do you currently suffer from any of the following:

	Yes	**No**
Cold/Flu	1	2
Asthma	1	2
Diabetes	1	2
Allergies e.g. hay fever	1	2

V7 ☐ 19
V8 ☐ 20
V9 ☐ 21
V10 ☐ 22

5 Do you scratch your ears with foreign objects?

Yes	1
No	2

V11 ☐ 23

6 Are your hearing protectors painful to wear?

Always	1	V12 ☐ 24
Sometimes	2	
Never	3	

7 What type of hearing protectors do you use?

	Yes	No	
Earplugs	1	2	V13 ☐ 25
Earmuffs	1	2	V14 ☐ 26
Custom-made	1	2	V15 ☐ 27
None	1	2	V16 ☐ 28

8 Do you have any history of ear infections?

Yes	1	V17 ☐ 29
No	2	

Complete section 8.1 to 8.8 if patient answered yes to question 8

8.1 Did you report possible ear infections immediately to medical staff?

Always	1	V18 ☐ 30
Sometimes	2	
Never	3	

8.2 Were you referred for medical treatment once you reported a possible ear infection?

Yes	1	V19 ☐ 31
No	2	

8.3 If medications were prescribed did you go back for medical follow-ups?

Yes	1	V20 ☐ 32
No	2	

8.4 Did you keep your ear(s) clean and dry while healing?

Yes	1	V21 ☐ 33
No	2	

8.5 How long did this ear infection continue?

For days	1	V22	☐	34
For months	2			
For years	3			

8.6 Did you go underground with an ear infection present?

Yes	1	V23	☐	35
No	2			

8.7 Do you suffer from one of the following when transported in the cage?

	Always	**Sometimes**	**Never**			
Ear pain	1	2	3	V24	☐	36
Dizziness/vertigo (head spinning)	1	2	3	V25	☐	37
Nausea/vomiting	1	2	3	V26	☐	38
Head aches	1	2	3	V27	☐	39
Diminished hearing	1	2	3	V28	☐	40
Bleeding ear	1	2	3	V29	☐	41
Fullness in ear	1	2	3	V30	☐	42

If you experience ear discomfort, is it relieved by yawning, swallowing or chewing?

Always	1	V31	☐	43
Sometimes	2			
Never	3			

8.8 Have you ever been taught or informed about techniques to prevent further damage to your ears when using the cage?

Yes	1	V32	☐	44
No	2			

If yes, please explain:

____

9. Do you currently suffer from one of the following problems?

	Yes	No			
Ear infection	1	2	V33	☐	45
Ear discharge	1	2	V34	☐	46
Ear pain	1	2	V35	☐	47
Tinnitus (ringing sound in ear, like a cricket)	1	2	V36	☐	48
Fullness in your ear	1	2	V37	☐	49
Vertigo (head spinning)	1	2	V38	☐	50

If yes to any one of the above, how long has this problem continued?

For days	1	V39 ☐ 51
For months	2	
For years	3	

10 Have you had any ear operations?

None	1	V40 ☐ 52
One	2	
Two	3	
Three	4	
Four	5	
Five and more	6	

If yes, specify the reason for ear operation?

---

11 History of injury to ears?

Yes	1	V41 ☐ 53
No	2	

If yes, when and what happened?

---

12 Have you ever experienced a bleeding ear after scratching with foreign object?

Yes	1	V42 ☐ 54
No	2	

Appendix B

Information gathered from subjects' medical records

1 Has patient <u>previously</u> suffered from or had treatment for the following?

	Yes	No			
Allergies e.g. hay fever	1	2	V43		55
Otitis media	1	2	V44		56
Diabetes	1	2	V45		57
Asthma	1	2	V46		58
Ear operations	1	2	V47		59
Ear trauma	1	2	V48		60
Tympanic membrane perforation	1	2	V49		61
Cold or flu	1	2	V50		62
Hearing loss	1	2	V51		63

2 Any <u>current</u> ear pathology noted by the medical staff?

	Yes	No			
Otitis media	1	2	V52		64
Ear trauma	1	2	V53		65
Tympanic membrane perforation	1	2	V54		66
Cold or flu	1	2	V55		67
Other outer and middle ear pathologies, please specify	1	2	V56		68

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Appendix C

Recording form for otoscopic examinations

(To be completed by Audiologist)

Right ear					
Outer ear (pinna/mastoid)	**YES**	**NO**			
Malformations (specify):	1	2	V57		69
Traces of scarring	1	2	V58		70
Pinna tenderness	1	2	V59		71
Mastoid tenderness	1	2	V60		72
Growths (specify):	1	2	V61		73
Ear canal					
Foreign object in ear canal	1	2	V62		74
Bleeding	1	2	V63		75
Swelling	1	2	V64		76
Wax plug	1	2	V65		77
Otitis externa	1	2	V66		78
Red/Irritated/Inflamed	1	2	V67		79
Scratch marks in ear canal	1	2	V68		80
Eczema-like appearance	1	2	V69		81
Growths (specify):	1	2	V70		82
Abnormal shape of canal (specify):	1	2	V71		83
Tympanic membrane					
Retracted	1	2	V72		84
Outward bulge	1	2	V73		85
Red	1	2	V74		86
Otitis media	1	2	V75		87
Discharge	1	2	V76		88
Fluid behind ear drum	1	2	V77		89
Perforation (specify small/large):	1	2	V78		90
Light reflex absent	1	2	V79		91
Grommets in place	1	2	V80		92
Dull	1	2	V81		93
Infected	1	2	V82		94
Scar tissue on ear drum	1	2	V83		95
Air bubbles behind ear drum	1	2	V84		96
Blood behind ear drum	1	2	V85		97

Comments/Other:____

____

____

Left ear					
Outer ear (pinna/mastoid)	**YES**	**NO**			
Malformations (specify):	1	2	V86		98
Traces of scarring	1	2	V87		99
Pinna tenderness	1	2	V88		100
Mastoid tenderness	1	2	V89		101
Growths (specify):	1	2	V90		102
Ear canal					
Foreign object in ear canal	1	2	V91		103
Bleeding	1	2	V92		104
Swelling	1	2	V93		105
Wax plug	1	2	V94		106
Otitis externa	1	2	V95		107
Red/Irritated/Inflamed	1	2	V96		108
Scratch marks in ear canal	1	2	V97		109
Eczema-like appearance	1	2	V98		110
Growths(specify):	1	2	V99		111
Abnormal shape of canal (specify):	1	2	V100		112
Tympanic membrane					
Retracted	1	2	V101		113
Outward bulge	1	2	V102		114
Red	1	2	V103		115
Otitis media	1	2	V104		116
Discharge	1	2	V105		117
Fluid behind ear drum	1	2	V106		118
Perforation (specify small/large):	1	2	V107		119
Light reflex absent	1	2	V108		120
Grommets in place	1	2	V109		121
Dull	1	2	V110		122
Infected	1	2	V111		123
Scar tissue on ear drum	1	2	V112		124
Air bubbles behind ear drum	1	2	V113		125
Blood behind ear drum	1	2	V114		126

Comments/Other:____

____

____

Appendix D

Recording form for immittance testing

Section 1: Tympanometry

Right ear					
TYPE A NORMAL =0,3 cm^3 and =1,75 cm^3 at -50 to +50 daPa	**PASS**	1	V115	☐	127
TYPE As STIFF MIDDLE EAR SYSTEM Consistent with otoschlerosis <0,3 cm^3 at -50 to+50 daPa	**REFER**	2			
TYPE Ad FLACCID MIDDLE EAR SYSTEM Consistent with eardrum flaccidity and ossicular disarticulation >2,5 cm^3 at -50 to +50 daPa	**REFER**	3			
TYPE B Consistent with middle ear fluid build-up No Compliance Peak at -400 to +200 daPa	**REFER**	4			
TYPE C Consistent with Eustachian tube malfunction =0,3 cm^3 and =1,75 cm^3 at -51 to -400 daPa	**REFER**	5			
VOLUME (Right ear) =0,8 cm^3 and =2,0 cm^3	**PASS**	1	V116	☐	128
<0,8 cm^3 or >2,0 cm^3	**REFER**	2			

Left ear					
TYPE A NORMAL =0,3 cm^3 and =1,75 cm^3 at -50 to +50 daPa	**PASS**	1	V117	☐	129
TYPE As STIFF MIDDLE EAR SYSTEM Consistent with otoschlerosis <0,3 cm^3 at -50 to +50 daPa	**REFER**	2			
TYPE Ad FLACCID MIDDLE EAR SYSTEM Consistent with eardrum flaccidity & ossicular disarticulation >2,5 cm^3 at -50 to +50 daPa	**REFER**	3			
TYPE B Consistent with middle ear fluid accumulation No Compliance Peak at -400 to +200 daPa	**REFER**	4			
TYPE C Consistent with Eustachian tube malfunction =0,3 cm^3 and =1,75 cm^3 at -51 to -400 daPa	**REFER**	5			
VOLUME (Left ear) =0,8 cm^3 and =2,0 cm^3	**PASS**	1	V118	☐	130
<0,8 cm^3 or >2,0 cm^3	**REFER**	2			

Section 2: Acoustic reflexes

Pure tone results: Right ear				
Pure tone threshold in right ear at 500 Hz	dB	V119		131 132
Pure tone threshold in right ear at 1 000 Hz	dB	V120		133 134
Pure tone threshold in right ear at 2 000 Hz	dB	V121		135 136
Pure tone threshold in right ear at 4 000 Hz	dB	V122		137 138

Right ear					
	YES	**NO**			
Ipsi-lateral acoustic reflex normal at 500 Hz (70-90 dB above PTT)	1	2	V123		139
Ipsi-lateral acoustic reflex absent at 500 Hz (No Response)	3	4			
Ipsi-lateral acoustic reflex elevated at 500 Hz (>90 dB above PTT)	5	6			
Ipsi-lateral acoustic reflex recruitment at 500 Hz (<70 dB above PTT)	7	8			
Ipsi-lateral acoustic reflex normal at 1 000 Hz (70-90 dB above PTT)	1	2	V124		140
Ipsi-lateral acoustic reflex absent at 1 000 Hz (No Response)	3	4			
Ipsi-lateral acoustic reflex elevated at 1 000 Hz (>90 dB above PTT)	5	6			
Ipsi-lateral acoustic reflex recruitment at 1 000 Hz (<70 dB above PTT)	7	8			
Ipsi-lateral acoustic reflex normal at 2 000 Hz (70-90 dB above PTT)	1	2	V125		141
Ipsi-lateral acoustic reflex absent at 2 000 Hz (No Response)	3	4			
Ipsi-lateral acoustic reflex elevated at 2 000 Hz (>90 dB above PTT)	5	6			
Ipsi-lateral acoustic reflex recruitment at 2 000 Hz (<70 dB above PTT)	7	8			
Ipsi-lateral acoustic reflex normal at 4 000 Hz (70-90 dB above PTT)	1	2	V126		142
Ipsi-lateral acoustic reflex absent at 4 000 Hz (No Response)	3	4			
Ipsi-lateral acoustic reflex elevated at 4 000 Hz (>90 dB above PTT)	5	6			
Ipsi-lateral acoustic reflex recruitment at 4 000 Hz (<70 dB above PTT)	7	8			

Pure tone results: Left ear				
Pure tone results: Left ear Pure tone threshold in left ear at 500 Hz	dB	V127		143 144
Pure tone threshold in left ear at 1 000 Hz	dB	V128		145 146
Pure tone threshold in left ear at 2 000 Hz	dB	V129		147 148
Pure tone threshold in left ear at 4 000 Hz	dB	V130		149 150

Left ear					
Ipsi-lateral acoustic reflex normal at 500Hz (70-90dB above PTT)	1	2	V131		151
Ipsi-lateral acoustic reflex absent at 500Hz (No Response)	3	4			
Ipsi-lateral acoustic reflex elevated at 500Hz (>90dB above PTT)	5	6			
Ipsi-lateral acoustic reflex recruitment at 500Hz (<70dB above PTT)	7	8			
Ipsi-lateral acoustic reflex normal at 1000Hz (70-90dB above PTT)	1	2	V132		152
Ipsi-lateral acoustic reflex absent at 1000Hz (No Response)	3	4			
Ipsi-lateral acoustic reflex elevated at 1000Hz (>90dB above PTT)	5	6			
Ipsi-lateral acoustic reflex recruitment at 1000Hz (<70dB above PTT)	7	8			
Ipsi-lateral acoustic reflex normal at 2000Hz (70-90dB above PTT)	1	2	V133		153
Ipsi-lateral acoustic reflex absent at 2000Hz (No Response)	3	4			
Ipsi-lateral acoustic reflex elevated at 2000Hz (>90dB above PTT)	5	6			
Ipsi-lateral acoustic reflex recruitment at 2000Hz (<70dB above PTT)	7	8			
Ipsi-lateral acoustic reflex normal at 4000Hz (70-90dB above PTT)	1	2	V134		154
Ipsi-lateral acoustic reflex absent at 4000Hz (No Response)	3	4			
Ipsi-lateral acoustic reflex elevated at 4000Hz (>90dB above PTT)	5	6			
Ipsi-lateral acoustic reflex recruitment at 4000Hz (<70dB above PTT)	7	8			

.

Appendix E

Questionnaire for Occupational Health personnel

1 Who performs otoscopic examinations?

Doctor	1
Nurse	2
Audiometrist	3

V1 ☐ 1

2 Do you perform an otoscopic examination during medical surveillance?

Always	1
Most of the times	2
Some of the times	3
Never	4

V2 ☐ 2

3 Which of the following do you look for during otoscopic examinations?

Outer ear (pinna/mastoid)					
	Yes	**No**			
Malformations	1	2	V3		3
Traces of scarring	1	2	V4		4
Pinna tenderness	1	2	V5		5
Mastoid tenderness	1	2	V6		6
Growths (specify):	1	2	V7		7
Ear canal					
Foreign object in ear canal	1	2	V8		8
Grommet in ear canal	1	2	V9		9
Bleeding	1	2	V10		10
Swelling	1	2	V11		11
Growths	1	2	V12		12
Wax plug	1	2	V13		13
Excessive wax	1	2	V14		14
Abnormal shape of canal	1	2	V15		15
Infection in ear canal	1	2	V16		16
Red/Irritated/Inflamed	1	2	V17		17
Scratch marks in ear canal	1	2	V18		18
Eczema-like appearance	1	2	V19		19

Ear drum					
Retracted	1	2	V20		20
Outward bulge	1	2	V21		21
Red	1	2	V22		22
Middle ear infection	1	2	V23		23
Discharge	1	2	V24		24
Fluid behind ear drum	1	2	V25		25
Perforation	1	2	V26		26
Light reflex absent	1	2	V27		27
Grommets in place	1	2	V28		28
Dull	1	2	V29		29
Infected	1	2	V30		30
Scar tissue on ear drum	1	2	V31		31
Air bubbles behind ear drum	1	2	V32		32
Blood behind ear drum	1	2	V33		33

4 Is middle ear barotrauma one of the following:

Pathology caused by trauma with foreign object	1	V34		34
Pathology from sudden changes in atmospheric pressure	2			
Pathology due to bacterial infection	3			

5 Do you counsel susceptible individuals to prevent barotrauma?
If always/sometimes, specify:

Always	1	V35		35
Sometimes	2			
Never	3			

6 Do you teach susceptible individuals techniques for going underground to prevent barotrauma?

Always	1	V35		35
Sometimes	2			
Never	3			

7 Do patients go underground when middle ear pathology is present?

Always	1	V36		36
Sometimes	2			
Never	3			

8 Your opinion on the following aspects:

8.1 Patients immediately report suspected ear infection to medical staff:

Always	1
Sometimes	2
Never	3

V37 ☐ 37

8.2 Patients immediately report suspected eardrum perforations to medical staff:

Always	1
Sometimes	2
Never	3

V38 ☐ 38

8.3 All patients receive treatment when middle ear pathology is diagnosed:

Always	1
Sometimes	2
Never	3

V39 ☐ 39

8.4 Patients receive one or more follow-ups when medication is prescribed for middle ear pathology:

Always	1
Sometimes	2
Never	3

V40 ☐ 40

8.5 Do you feel you've been sufficiently trained and informed about middle ear pathologies?

Yes	1
No	2

V41 ☐ 41

8.5.1 If you answered NO to the previous question, please specify the type of information needed on middle ear pathologies?

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APPENDIX F

THE CLINICAL SIGNIFICANCE OF TYMPANOMETRY

1. INTRODUCTION

Recently researchers in the audiological field have sung the praises of tympanometry as follows:

"The best measure of middle ear disorder is immitance audiometry" (Stach 2000:258)

"Tympanometry is one of the most highly used diagnostic tests for diagnosing specific disease in audiological practice." (Margolis & Hunter, 2000 :397)

2. SPECIFICITY AND SENSITIVITY OF TYMPANOMETRY

A summary of research findings:

2.1 Tympanometry is 73 % accurate in detecting middle ear effusion (Babonis et al 1991).

2.2 Type B tympanograms will identify 90 % of children with otitis media with effusion (Group, MrC.Multi-Centre Otitis media study 1999)

2.3 Sensitivity 87 %. specificity 77.5 % for otitis media with effusion (Schwartz & Schwartz 1987).

2.4 84 % specificity. Abnormal otoscopic finding showed significant association with abnormal tympanograms (p=0,02)(Bola 2001).

2.5 Otoscopy is 94 % sensitive and 78 % specific with highly trained experienced users of pneumatic otoscopes. (Tympanometry is less sensitive but more specific than otoscopy (Margolis & Hunter 2000).

2.6 Flat tympanograms are associated with 82 % of ears with OME (Otitis media with effusion). Sharply peaked tympanograms were associated with the absence of fluid in 100 % of ears (Margolis & Hunter 2000)

2.7 Normal tympanograms are associated with no OME in 95 % of ears. Sensitivity of 95 %, specificity 76 % (Margolis & Hunter 2000).

2.8 Cantekin et al (1980) combined otoscopy and tympanometry into an algorithm and found the combination better than either test alone.97 % sensitivity,90 % specificity.

3. RESEARCH DESIGN

From 08/01/2004 to 22/01/2004 all workers referred for diagnostic hearing testing were included in the study.

49 workers were referred from OHCs (Goldfields' operations on the West Rand).

12 Workers were referred from an ENT specialist.

A further 17 workers, attending their annual certificate of fitness assessments, were tested as well. They were not referred for diagnostic testing since they had no deterioration in hearing since previous screening evaluations.

A total of 78 workers were thus evaluated doing only tympanometry since acoustic reflexes were proven to be too sensitive in the study.

Three measures were collected eg.

1. Tympanometric peak pressure (a negative pressure of more than -100mm was taken as abnormal.)

2. Static admittance (0.40 – 1.70 mmho)

3. Equivalent volume (> 2.0cm)

Equipment was calibrated on 06/01/2004.

Subjects with abnormal tympanometric results were referred to either an ENT or OMP in order to do an otoscopic examination and report on their findings.

4. RESULTS

9 (n=49) workers referred from OHCs had abnormal tympanometric readings that is 18, 36 %.

6 out of 12 workers referred from an ENT specialist (50 %) had abnormal tympanometric readings.

1 out of 17 workers undergoing screening procedures had abnormal tympanometric readings (5.88 %).

Table F.1 lists all the abnormal tympanometric results found (shaded areas)

From Table F.1 it can be seen that every case with middle ear pathology had abnormal tympanometry.

5. CONCLUSION

It is recommended that tympanometry be introduced into medical surveillance procedures in the mining industry as recommended following the study.

TABLE F.1 ***Abnormal tympanometric results***

SUBJECT	***COMPLIANCE***		***PRESSURE***		***VOLUME***		***DOCTORS DIAGNOSIS***
	L	R	L	R	L	R	
1	0.2	0.3	196	22	0.5	1	L-discharge and perforation R-serous otitis media, no light reflex,retracted eardrum OMP
2	0.5	1.6	-206	-130	0.8	0.9	L-otitis media Tympanum intact R-NAD OMP
3	0.2	0.2	64	80	0.9	0.9	Chronic middle ear pathology(bilateral) OMP
4	0.02	0.16	-75	-390	0.74	0.71	7/10/03 bilateral grommits 4/11/03 discharge 20/1/04 middle ear infection ENT
5	0.25	0.02	-305	139	0.5	1.62	11/3/2003 discharge L Grommets bilaterally 3/9/2003 serous otitis media (bilaterally) ENT
6	0.03	0.09	149	34	1.43	1.48	Chronic middle ear infection L R-infection and perforation ENT
7	No reading	1.3	No reading	-209	No reading	1.5	L-Absent light reflex serous otitis media R- tympanum scarred OMP
8	0	0	- 0	- 0	0.8	1.1	L-perforation (central) R- sclerotic ear-drum OMP
9	0.2	0.5	173	168	1.7	2.4	L-perforation R-discharge & perforation OMP
10	0.2	0.4	143	35	1	1.5	Absent light reflex serous otitis media L R -NAD OMP
11	0	0.2	0	5	1.4	1.5	Absent light reflex L Serous otitis media (Bilaterally) OMP

12	0.7	0.3	19	69	1.3	1.3	Chronic otitis media R with perforation L-NAD OMP
13	0.87	0.28	-20	4	1.66	3.68	Perforation and infection R L-NAD ENT
14	0.59	0.13	-17	-80	0.79	1.02	Serious otitis media R L-NAD ENT
15	0.97	0.22	-17	-28	1.26	0.66	Chronic secretory otitis media OMP
16	0.5	0.3	9	-147	1.3	1.3	Absent light reflexes bilaterally OMP

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