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Hydrogen Sulfide and the Probabilities of 'Inhalation' Through a Tympanic Membrane Defect

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We conclude that workers with tympanic membrane defects (perforated eardrums) should not be excluded from working in atmospheres containing concentrations of hydrogen sulfide (H_2S). Several existing requirements and recommendations exclude workers with perforated eardrums from working in or around H_2S. Such protective measures stem from the belief that H_2S can enter the body through the perforation in sufficient measure to compromise the wearer's respiratory protection. However, based on calculations of anticipated leakage of H_2S for a variety of eustachian tube conditions and in the absence of either medical literature or personal reports documenting H_2S poisoning due to eardrum perforation, the recommendation for excluding workers with such a condition from working in or around H_2S is not supported. The anatomy, physiology, and pathology of the eustachian tube are discussed, including the effects such devices as tympanomaxillary shunts might have on contaminant leakage. The National Institute for Occupational Safety and Health (NIOSH) criteria for respirator tests and sources of respirator leakage are examined and NIOSH recommendations for respiratory protection against H_2S are outlined.

Hydrogen sulfide (H_2S) is a toxic gas capable of rapidly inducing dizziness, unconsciousness, respiratory paralysis, and death. At a concentration of approximately 0.77 ppm, H_2S has an unmistakable "rotten egg" odor. However, at higher concentrations (100 ppm) olfactory paralysis occurs, and at still higher concentrations (700 to 900 ppm) death ensues rapidly.[1]

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It is possible that toxic quantities of H_2S can be absorbed through the skin, but the evidence is not conclusive.[2] Protective measures against skin sorption are considered unnecessary by the National Institute for Occupational Safety and Health (NIOSH) at concentrations suitable for respirator use.[2]

Because of the toxic respiratory effect, many protective measures have been taken to safeguard the worker from H_2S poisoning. Most of these precautionary measures have substantially improved worker safety. One such requirement, however, appears to be unjustified and is examined critically in this report.

Several existing requirements and recommendations state that: "Even with a perfectly functioning self-contained breathing apparatus, a person who has a perforated eardrum can become over-exposed. There is less resistance to outside atmosphere via the perforation than via the breathing apparatus, and H_2S can thus be inhaled through the ear . . . . All persons with perforated drums have been excluded from work in or around H_2S."[1,3] The rationale behind this requirement is that sufficient H_2S may enter the wearer's system through a tympanic membrane defect (perforated eardrum) to compromise the respiratory protection. On the basis of the following literature review and calculations, we conclude that the above rationale is not supported.

Tympanic Membrane Perforation

The tympanic membrane (commonly called the "eardrum") is oval in shape and measures about 9 mm across and from 10 to 11 mm vertically. Separating the external and middle ear, it transforms sonic pressure into mechanical vibration to be received by the malleus (one of the three ossicles of the middle ear).[4]

A tympanic membrane defect (or perforated eardrum) is the most common serious ear injury and may be caused by infection, a blow to the ear, intense noise, explosion, object penetration, or other miscellaneous causes.[5] Perforations may range from tiny tears to large injuries and are generally accompanied by a hearing loss corresponding to the magnitude and extent of the injury. Such losses rarely exceed 30 dB if the injury is limited to the tympanic membrane.[6]

Most perforations heal by themselves within seven to 10 days without problems, but occasionally medical and surgical intervention is necessary.[7]

Anatomy and Physiology of the Eustachian Tube

"The eustachian tube. . .connects the anterior wall of the middle ear with the nasopharynx. It is about 1½ inches length and consists of an outer bony portion (one third of the tube that opens into the middle ear) and an inner cartilaginous part (two thirds of the tube that opens into the throat). The lumen of the bony part is permanently opened while that of the cartilaginous portion is closed except during certain periods such as swallowing, yawning, or blowing the nose. To hear optimally, the atmospheric pressure on both sides of the eardrum should be equal. The act of swallowing, for example, forces air up and into the middle ear and thus equalizes the atmospheric pressure on either side of the tympanic membrane."[8] This is called "active opening."

Of particular importance is the fact that in the normal resting condition, the eustachian tube is closed.[8] Therefore, air exchange through the eustachian tube between the ambient atmosphere and the nasopharynx normally does not occur even in the perforation (or absence) of the tympanic membrane, "except during swallowing, yawning or blowing the nose."[8]

"Pressure differentials of greater than 300 mm H_2O (320 to 400 mm H_2O) are required to effect passive opening of the eustachian tube in normal subjects, and even considerably higher pressure differentials are required in some abnormal patients with tympanic membrane perforations."[9]

Pathology of the Eustachian Tube

Certain pathological conditions affecting the eustachian tube can modify the tube's function significantly.

Obstruction — The tube may become partially or totally obstructed temporarily or permanently, resulting in a decrease or absence of airflow between the middle ear and the nasopharynx. This occurs commonly in conjunction with an otitis media and, in fact, may have to be resolved in the successful treatment of this condition. Serous otitis media is a frequent cause of tympanic membrane rupture due to this blockage.

Nonfunctioning — The eustachian tube may be patent but nonfunctional. No active opening occurs even with extreme activity, but the tube may be opened passively. Normal swallowing will not cause any airflow in this condition.

Both Nonfunctioning and Nonpatent — The tube is both blocked and nonfunctional and neither passive nor active opening occurs.

Patulous — The tube may be patulous, which means it remains open due to certain pathological conditions. As noted below, patulous tubes are frequently encountered:

"This condition should be anticipated in any patient who has had a significant weight loss leading to depletion of the soft tissue mass surrounding the eustachian tube. Patulous eustachian tubes have been noted in patients with chronic illnesses, such as heart disease, diabetes, rheumatoid arthritis, and cancer. This condition has also been associated with neuromuscular disorders, such as strokes, poliomyelitis, multiple sclerosis, and parkinsonism. The symptoms are found temporarily in patients with acute illness and in the postoperative period before full health is regained. Nearly one third of the women observed suffering from this condition have been pregnant, taking birth control pills, or taking some other estrogenic hormone at the time of diagnosis. Men treated with estrogens for carcinoma of the prostate have also been found to have the problem. The fact that nearly one fifth of the patients with symptoms of an abnormally patulous eustachian tube were labeled neurotic or psychotic may suggest the unpleasantness and disturbing nature of this condition."[10]

Of these four conditions, only the last, an abnormally patulous eustachian tube, can be expected to contribute to airflow from the ambient air to the nasopharynx.

A fifth condition, surgically induced ventilation, which includes either the provision of a tympanomaxillary shunt[11] or an artificial eustachian tube, may be encountered.[12] The tympanomaxillary shunt is basically a temporary connection between the middle ear and the maxillary sinus by way of a silicone rubber tube. It has the effect of a patulous eustachian tube. Airflow through this 1.2-mm inside diameter rubber tube, which is 7 to 10 cm long, has been shown to be less than that of a concurrent tympanic membrane defect and a patulous eustachian tube.

The artificial eustachian tube is inserted through the tympanic membrane in conditions of blockage of the eustachian tube as a temporary means of ventilating the middle ear pending resolution of the tube blockage. The contribution to airflow between the ambient air and nasopharnyx is nil because of the preexisting tube blockage. That is, the artificial eustachian tube serves only as a temporary eardrum perforation but active tube opening is unlikely.

It is unlikely that an artificial eustachian tube and a tympanomaxillary shunt would be used concurrently since each serves independently to provide middle ear ventilation. It is also unlikely that a tympanomaxillary shunt would be used with a perforated tympanic membrane, or that an artificial eustachian tube would be used with a patulous tube, for the same reason. Therefore, airflow between the ambient air and nasopharnyx is unlikely in either case.

Respirator Operating Characteristics

Inhalation Resistance — NIOSH test criteria for respirators differ among the several types of approved respirators. The maximum allowable negative face piece pressure (inhalation resistance) is about 100 mm H_2O when measured on the standard breathing machine with the peak airflow of about 120 l/min, corresponding to a minute volume of 40l. This is, the maximum pressure differential between the ambient air and the nasopharynx is about 100 mm H_2O under a moderate work rate of 40 l/min volume.[13]

This figure, 100 mm H_2O, has been used in all subsequent calculations.

Respirator Leakage — The efficiency of a respirator, that is, its protection factor or how much it reduces the wearer's exposure to the ambient atmosphere, is a factor of the sum of the leakages or penetrations allowed by various components of the respirator system.

Three major sources of such leakage must be considered: exhalation valve leakage, air supply penetration, and face seal leakage.

Exhalation Valve Leakage — Tests of exhalation valve leakage are conducted under a static pressure differential of 25 mm H_2O, and the leakage rate must not exceed 30 ml/min.[14] Assuming, as a first-order approximation, that the exhalation valve leakage is proportional to the pressure differential, then at 100 mm H_2O inboard leakage of some 120 ml/min could be expected (or about 0.3%) at the 40 l/min volume.

Air Supply — Self-contained breathing apparatus and supplied-air respirators are required to use an air or oxygen supply that is essentially free of H_2S.[15] Air-purifying canisters for H_2S were approved by the Bureau of Mines (unpublished test protocol, 1970). These canisters were tested to a 5-ppm breakthrough at a challenge concentration of 20,000 ppm, or 0.025%, allowable penetration.

Face Seal Leakage — Face seal leakage in negative-pressure respirators varies between 2% and 10%[16] depending on the type of face piece (half or full face piece); seal design; face piece material; facial characteristics (such as size, shape, skin scars, facial hair); and face piece strap tension and placement. Positive-pressure self-contained breathing apparatus or pressure-demand supplied-air respirators have leakages of less than 0.01%.[16]

The sum of these sources of leakage results in a total leakage of about 2.3% to 10.3% allowable for approval of a negative-pressure respirator.

Eustachian Tube Airflows

In contrast to the respirator leakage values, the anticipated leakage or penetration as a result of tympanic membrane perforation has been measured or calculated to be (for these differing eustachian tube conditions) lower than that to be expected from a normal subject wearing an approved negative-pressure respirator.

Obstruction — The airflow or leakage in an obstructed eustachian tube would be expected to be less than in a patent, functional tube and with total blockage would approximate zero.[8]

Nonfunctioning — Since maximal allowed pressure differentials will not cause passive opening of a patent but nonfunctional eustachian tube, the airflow will approximate zero.[8]

Both Nonfunctioning and Nonpatent Eustachian Tube — Leakage will approximate zero.

Patulous — Measurements of airflow in both normal and abnormal subjects (but not necessarily patulous subjects) indicate that the patients were uncomfortable when flow rates in excess of 44 ml/min (steady-state airflow) were employed.[9] Assuming both a patulous eustachian tube and a concurrent tympanic membrane defect, this limiting flow rate or tolerance would equal 0.11% leakage at the 40-l/min volume. Since peak flows are from 2.4 to 3.9 times the minute volume,[17] any use of a respirator with increased inhalation resistance causing airflow through the patulous tube with a tympanic membrane defect is probably uncomfortable if not intolerable.

Normal Function — A normal, patent, functional eustachian tube in the presence of a tympanic membrane defect will only open and allow airflow on deglutition (swallowing) or other similar maneuvers when activated by the "contractions of the tensor veli palatini muscle which displaces the lateral wall from the cartilage-supported medial wall of the [eustachian tube]."[8] That is, active opening. Thus, a tympanic membrane defect will not result in the inward flow of air when the eustachian tube is closed. Measurements of airflow between the middle ear and nasopharynx have been made at several pressure differentials in both normal and abnormal subjects. At 100-mm H_2O pressure differential, the total flow (volume of air passing between the two points) is about 120 μl per swallow with an SD of about 40 μl of air to pass per swallow.[9] Therefore, more than 99% of all swallowing should allow less than 240 μl of air to pass per swallow. To compromise the respiratory protection afforded by a full face piece, negative-pressure self-contained breathing apparatus by 2%, or as much as the face piece itself leaks, the wearer would have to swallow some 3,300 times a minute during a moderate to heavy work rate, or swallow some 500 times a minute to equal exhalation valve leakage. Therefore, in no reasonable case can the presence of a tympanic membrane defect significantly affect respiratory protection against H_2S. In fact, no medical literature or personal reports documenting H_2S poisoning due to eardrum perforation have been located.

Conclusions

Individuals with perforated tympanic membranes should not be excluded from work in an H_2S environment.

Adequate respiratory protection should be provided for anyone exposed to atmospheres contaiing H_2S concentrations above the threshold limit value.[18] Positive-pressure, supplied-air, or self-contained breathing apparatus, as appropriate, with a full face piece is recommended. Wearers of these devices who have a tympanic membrane defect and a concurrent tympanomaxillary shunt or a patulous eustachian tube may experience the sensation of outward airflow, which could be annoying. However, inboard leakage from all sources will be less than 0.01% (a protection factor of at least 10,000) at work rates less than about 40 l/min.

The use of any air-purifying respirators for protection against H_2S, except for escape, is not recommended.

References

1. Poda, GA: Hydrogen sulfide can be handled safely. *Arch Environ Health* 12:795-800, 1966.
2. Criteria for a Recommended Standard — Occupational Exposure to Hydrogen Sulfide, publication 77-158. Washington, D.C.: National Institute for Occupational Safety and Health, 1977, p 52.
3. United States Geological Survey: Drilling procedures (GSS-OCS-2). *Federal Register* 40, (Nov 17): 53279, 1975.
4. The Industrial Environment — Its Evaluation and Control. Washington, D.C.: National Institute for Occupational Safety and Health, 1973, pp. 309-315.
5. Goodhill V: Ear Diseases, Deafness, and Dizziness. New York: Harper & Row Publishers, 1979, pp 504-505.
6. Prescod SV: Audiological Handbook of Hearing Disorders. New York: Van Nostrand Reinhold Co., 1978, p 62.

7. Freese AS: You and Your Hearing: How to Protect It, Preserve It, and Restore It. New York: Van Nostrand Reinhold Co., 1978, p 92.
8. Donaldson JA: Physiology of the eustacian tube. *Arch Otolaryngol* 97:9-12, 1973.
9. Cantekin EI, Bluestone CD, Saez CA *et al:* Airflow through the eustachian tube. *Ann Otol Rhinol Laryngol* 88:603-612, 1979.
10. Pulec JL, Hahn FW: The abnormally patulous eustachian tube. *Otolaryngol Clin North Am* 3:131-140, 1970.
11. Ekvall L, Drettner B: Tympanomaxillary shunt. *Arch Otolaryngol* 97:21-23, 1973.
12. Jons CD, Donaldson JA: The artificial eustachian tube. *Otolaryngol Clin North Am* 3:55-59, (1970).
13. Code of federal regulations title 30 — mineral resources part 11, in Respiratory Protective Devices; Tests for Permissibility; Fees. (30 CFR pt. 11)
14. Code of federal regulations title 30 — mineral resources part, 11, in Respiratory Protective Devices; Tests for Permissibility; Fees. (30 CFR pt. 11.102-2)
15. Code of federal regulations title 30 — mineral resources part 11, in Respiratory Protective Devices; Tests for Permissibility; Fees. (30 CFR pt. 11.79)
16. A Guide to Industrial Respiratory Protection, publication 76-189. Washington, D.C.: National Institute for Occupational Safety and Health, 1976, pp 54-56.
17. Silverman L, Lee G, Plotkin T, et al: Fundamental Factors in the Design of Protective Respiratory Equipment, Inspiratory and Expiratory Air Flow Measurements on Human Subjects With and Without Resistance at Several Work Rates, Office of Scientific Research and Development report 5732. Cambridge, Mass.: Harvard, 1945, Table 2.
18. Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment and Biological Exposure Indices With Intended Changes for 1984-85. Cincinnati: American Conference of Governmental Industrial Hygienists, 1983.

Cancer Risks and Prevention

A veritable wall stands between the citizen and the science of cancer prevention, although he is usually unaware of it. . . .The first thing that keeps the layman in a chronic state of ignorance is his inability to differentiate between the various cancer sciences and the kinds of information they produce. While such ignorance is not universal, it is extraordinarily common, and more often than not the layman, even the occasional doctor, cannot identify the specific science of "cancer prevention." In part, this confusion is due to the fact that all cancer sciences ultimately seek to become sciences of prevention. That is certainly the goal of basic science which studies the mechanisms of cancer, but despite continuing and brilliant advances, the same judgment that James Watson made in 1982 can be repeated today: For the purpose of prevention, the information is still "hopelessly inadequate" and the mechanisms of cancer are still "inherently unknown."

Prevention is also the goal of the science of epidemiology, which studies human mortality and incidence patterns and investigates groups of people at high risk for specific cancers. It is epidemiology which has identified every known risk factor for cancer in human beings (e.g., tobacco, asbestos, vinyl chloride) and is most commonly mistaken for the science of prevention. Epidemiology, however, can only conduct its studies *after* people have died of cancer. Once the epidemiologist has definitively discovered a risk factor for cancer, his knowledge can be applied to protect men in the future, but the science itself can only begin with cancer deaths; it cannot prevent cancer in advance. There is actually only one science which seeks to prevent cancer in advance: the science which exposes animals (or bacteria or cells) to chemicals, which identifies "potential" or "suspected" carcinogens and extrapolates the findings to man. Animal-man extrapolation *is* "cancer prevention," and it is applied by the state. The layman who cannot clearly differentiate the politically applied science of the "suspected" from the other sciences of cancer can neither understand nor judge cancer prevention and the cancer prevention establishment.

—From *The Apocalyptics—Cancer and The Big Lie* by Edith Efron.
Simon and Schuster, New York, 1984.