Review Article

Current Concepts

RESPIRATORY PROTECTION

JOHN MARTYNY, PH.D., CRAIG S. GLAZER, M.D., AND LEE S. NEWMAN, M.D.

THE use of anthrax as a biologic weapon in 2001 and concern about the health effects of exposure to particles and gases at the World Trade Center site (discussed by Prezant et al.[1] elsewhere in this issue) have raised awareness of personal respiratory-protection devices — colloquially referred to as "dust masks" or "gas masks." For decades, many people have used respirators on the job or around the home. Federal regulations mandate the use of respirators in a variety of occupational settings if the levels of toxins in the air cannot be effectively controlled. Clinicians need to be aware of their patients' occupational exposures to airborne toxins[2,3] (Table 1) and should be familiar with the common forms of respiratory protection as well as the benefits and limitations of respirator use. No respirator is fully protective.[4] In fact, respirators are a relatively inefficient form of protection.[1] Respirators should be relied on only as a secondary means of protection from airborne toxic materials. Whenever possible, it is better to reduce airborne contamination by using exhaust ventilation, enclosing the process that produces the exposure, adapting work practices to reduce airborne dust and fumes, or replacing toxic materials with safer alternatives.

TYPES OF RESPIRATORY PROTECTION

Respirators are used to protect against a wide variety of airborne toxins, including chemicals, biologic materials, radiation, toxic dusts, and metal fumes (Table 1), and to supply air in situations of low oxygen, such as those encountered by firefighters.[4-9] Few respirators can protect simultaneously against airborne particulates, gases, and vapors. Many different types of respirators are available (Table 2). When clinicians counsel patients to use a respirator, they must know how to select the correct respirator.

TABLE 1. EXAMPLES OF TOXIC COMPOUNDS COMMONLY NECESSITATING THE USE OF RESPIRATORY PROTECTION.

GASES*	VAPORS†	PARTICULATES‡
Ammonia	Benzene	Asbestos
Carbon monoxide	Carbon tetrachloride	Beryllium
Chlorine	Mercury	Biologic agents (e.g., *Bacillus anthracis, Mycobacterium tuberculosis,* hantavirus)
Ethylene oxide	Nitric acid	
Formaldehyde	Pesticides	
Hydrogen cyanide	Styrene	Cadmium
Hydrogen sulfide	Sulfuric acid	Coal dust
Nitrogen oxides	Toluene	Latex
Sulfur oxides	Trichloroethylene	Radiation (alpha and beta)
		Silica

*A gas is a formless fluid that completely occupies the space of an enclosure at standard atmospheric pressure and temperature.

†A vapor is the gaseous phase of a material that is a liquid or solid at standard atmospheric pressure and temperature.

‡Particulates are particles of microscopic size dispersed in a gaseous medium. They may be a dust (particles 0.1 to 0.50 μm in diameter), a fume (an aerosol formed by volatilization of molten metal), or a mist (an aerosol of suspended liquid droplets).

Respirators can be divided into two types: air-supplying and air-purifying. Depending on the type, they may fit tightly or loosely.[4] In environments where oxygen levels are low, the types and levels of chemicals are unknown, or the conditions are immediately dangerous to life or health, the highest degree of protection is required.[5,10,11] In these situations, the only acceptable type of respiratory protection is a positive-pressure, self-contained breathing apparatus (referred to as an SCBA).[5] This is an air-supplying, tight-fitting type of respirator. Exposure to many forms of dust, on the other hand, may require the use of only a half-face disposable respirator. Some type of respirator is available for use against most potential exposures. The choice of respirator and filter is determined by the expected types and levels of contaminants, the characteristics of the job, and to some extent, individual characteristics, such as the user's facial features and medical fitness to use respiratory protection.[4,5,10-12]

Air-supplying respirators offer the highest degree of protection[5,13] (Fig. 1A). These respirators provide a breathing atmosphere for the wearer and can thus protect against most exposures. They are normally worn by members of hazardous-material ("hazmat")

From the Division of Environmental and Occupational Health Sciences, Department of Medicine, National Jewish Medical and Research Center, and the Department of Preventive Medicine and Biometrics and the Division of Pulmonary Science and Critical Care Medicine, Department of Medicine, University of Colorado Health Sciences Center — both in Denver. Address reprint requests to Dr. Newman at the Division of Environmental and Occupational Health Sciences, National Jewish Medical and Research Center, 1400 Jackson St., Denver, CO 80206, or at deohs@njc.org.

TABLE 2. CHARACTERISTICS OF SPECIFIC TYPES OF RESPIRATORS.

CATEGORY AND TYPE OF RESPIRATOR	NIOSH PROTECTION FACTOR*	USE FOR UNKNOWN EXPOSURES AND CONCENTRATIONS	SPECIFIC CARTRIDGES NEEDED	REQUIRED MAINTENANCE LEVEL	INTERFERENCE WITH EYEGLASSES	CAN BE WORN BY PERSONS WITH FACIAL HAIR
Air-supplying						
Positive-pressure, self-contained breathing apparatus	10,000	Yes	No	High	Yes	No
Supplied air (air line)	10–2000†	No‡	No	High	Yes	Yes§
Air-purifying						
Tight-fitting, powered	50	No	Yes	High	Yes	No
Loose-fitting, powered	25	No	Yes	High	No	Yes
Full-face cartridge	50	No	Yes	Moderate	Yes	No
Half-face cartridge	10	No	Yes	Moderate	Maybe	No
Half-face disposable	10	No	No	Low	Maybe	No

*The National Institute for Occupational Safety and Health (NIOSH) assigns a numerical, theoretical protection factor to each type of respirator. A respirator with a protection factor of 10, for example, should reduce the concentration of particles or gases inside the respirator to at least 1/10 of the outside concentration.[8]

†The value depends on the type of mask used (e.g., half-face or full-face).

‡The device cannot be used unless a supplemental escape-bottle self-contained breathing apparatus is provided.

§Only a loose-fitting device can be used.

teams and emergency-response crews when dangerous or unknown exposures are likely.[5-7,9] This high degree of protection comes at a cost. A self-contained breathing apparatus is heavy, and its use is limited to less than 30 minutes.[5,7,9] The combination of a sealed protective suit, the extra weight of the tank, high temperatures, and high workload can exact a heavy toll on the wearer's endurance.

Air-purifying respirators are light and easier to use than air-supplying types,[6,7,9] but they afford less protection (Fig. 1B). Air-purifying respirators are the most commonly used and consequently misused type. A variety of filter cartridges can be attached to the inlets of tight-fitting, air-purifying respirators. They may filter particles, or they may contain a medium that absorbs gases and vapors. Although some combination filters can protect against more than one type of hazard, there is no single filter that will work for all exposures under all conditions.

One of the most common errors is the use of the wrong filter. Thus, it is important to establish the potential types and levels of toxins to which the wearer will be exposed in order to ensure that the respirator will provide adequate protection.[6,10,11] Industrial hygienists are usually responsible for selecting the appropriate respirator for a given work environment. It is important for the wearer to know the circumstances in which a given respirator will provide adequate protection.[4,10,11] For example, a filter designed to protect against very small particles and fibers, such as asbestos, may offer no protection against chlorine and other toxic gases. Improper use can result in injury to or the death of the wearer.[14] Even when the filter is the right one, a person using an air-purifying respirator needs to be able to determine when the respirator is no longer working. For this reason, air-purifying respirators should be used only when the hazardous substance has warning properties (such as being an irritant or having a distinctive smell) that will let the wearer know the respirator is failing.[6] For example, when workers can smell or taste solvents, they can assume the respirator is no longer functioning effectively.

Although many air-purifying respirators operate under negative pressure, with the wearer drawing air into the mask through the filter, powered air-purifying respirators are available that blow air into the mask. Although they are more expensive, powered air-purifying respirators eliminate the problems of heat buildup, dead-space ventilation, and airflow resistance. Loose-fitting powered air-purifying respirators can be worn by people with facial hair, are tolerated for longer periods, are more comfortable, and may result in better compliance with respirator use.

Disposable respirators (Fig. 1C) are far more comfortable than the other types of respirators and interfere less with speech. Disposable respirators can be used for a wide variety of exposures, especially airborne particles. They are frequently used by health care workers who may be exposed to mycobacteria or other biologic aerosols.[8,15] The primary limitation of the half-face disposable respirator is the fit.[15] Because of leakage, these and other loose-fitting respirators may not provide the protection necessary for situations involving high levels of exposure, such as those encoun-

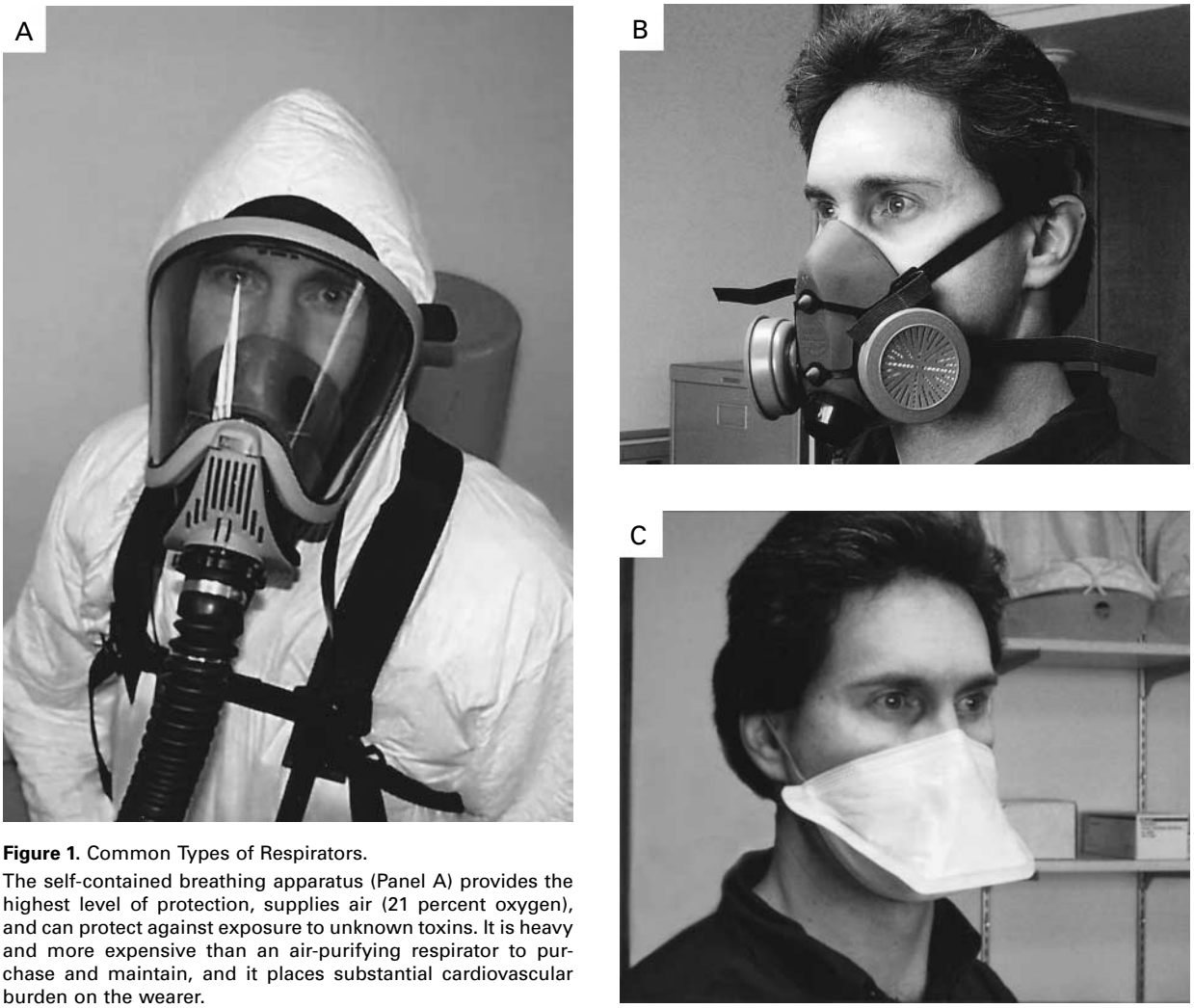

Figure 1. Common Types of Respirators.

The self-contained breathing apparatus (Panel A) provides the highest level of protection, supplies air (21 percent oxygen), and can protect against exposure to unknown toxins. It is heavy and more expensive than an air-purifying respirator to purchase and maintain, and it places substantial cardiovascular burden on the wearer.

The half-face air-purifying respirator (Panel B) has replaceable cartridges that can provide protection from many gases, vapors, and particulates. There is no single cartridge that provides universal protection. This type of respirator does not provide eye protection, and the cartridges must be selected appropriately and replaced frequently.

Half-face disposable respirators (Panel C) are inexpensive and light in weight. They may protect against particles but not against gases or vapors. The efficacy of this type of mask is limited by the difficulty of obtaining an adequate seal against the face.

tered by New York City firefighters during the first week after the collapse of the World Trade Center.[1]

Disposable respirators are manufactured and labeled according to their ability to resist degradation from oil-based liquid aerosols and their efficiency in filtration. The most commonly recommended respirator in the health care setting is the N95: "N" means "not oil-proof," and "95" means that it is at least 95 percent efficient at filtering particles with a median diameter of greater than 0.3 μm. Higher numbers indicate greater filtering efficiency. The N99 respirator, previously called a high-efficiency particulate air-filter respirator, is capable of filtering 99.97 percent of these airborne particulates. A powered air-purifying respirator with a high-efficiency particulate air filter is recommended for use by health care workers during

cough induction and other aerosol-generating procedures in patients with tuberculosis.[15,16]

SELECTION AND USE OF RESPIRATORS

Respirators should be chosen for the protection they provide, not for comfort, although compliance suffers when respirators are uncomfortable. Respirators of all types are unpleasant to wear, especially for an extended period. Noncompliance is one of the major limitations of respirators.[17] Unfortunately, few data are available on the reasons for noncompliance with respirator use. Several studies evaluating the factors associated with a worker's decision whether to use a respirator found that comfort and the ability to talk and see were important.[17-19]

To ensure that the best respirator is chosen, that it is maintained properly, that the workers are trained in how to use it, and that the workers are medically fit to use it, a written respiratory-protection policy should be implemented by the employer.[4-6,8,10,11] This type of program is mandated by the Occupational Safety and Health Administration (OSHA) and should be established even if a workplace is not covered by OSHA regulations.[10] The worker should be fitted with a respirator approved by the National Institute for Occupational Safety and Health that will provide the best protection while allowing the worker to perform necessary tasks.

The choice of respirator and filter can be made with the use of various algorithms available in the literature[4,11] or selection guides provided by the manufacturers. Much, if not all, of the required information can be found on manufacturers' Web sites. These algorithms consider factors such as the type of exposure, job tasks, and oxygen level. The clinician's roles are to identify the need for respiratory protection, assess whether the worker is medically able to use the respirator, and then to refer the worker to qualified sources (see Supplementary Appendix 1 with the text of this article at http://www.nejm.org). Most physicians should not try to select the specific respirator that a patient should use at home or at work unless they have special expertise in occupational health.

After the type of respirator is selected, the user should undergo either qualitative fit-testing (which measures the wearer's ability to detect an irritant or flavorant in an aerosol) or quantitative fit-testing (which measures the number of particles inside, as compared with outside, the respirator) by specially trained technicians to determine which size and brand of respirator fits best. Because most respirators were initially designed for average-sized men, women and persons with unusual facial features may require different respirators.[12] In addition, men with beards or large moustaches will not obtain an adequate fit with any respirator designed to seal against the face.[10] Someone who buys a respirator off the shelf cannot be sure it will provide protection unless it has been properly fit-tested.

Every year people die after donning air-purifying respirators and then entering confined, oxygen-deficient spaces. During the 1991 Gulf War, respirators were distributed to thousands of Israeli civilians. Suffocation from improper mask use was cited as the most direct cause of death in 13 of them.[14] Users must be informed of the limitations of the respirators that they have been assigned as well as when to use them, how to put them on, how to clean and maintain them, how to inspect them for damage, and how to change filters if necessary.[4,6,10,11,20] Simply storing the respirator in the wrong place may negate its usefulness. If a charcoal filter cartridge is left in an area containing solvents, the adsorption capability of the filter will be consumed, even if it is not being worn. For example, home hobbyists may expose filter cartridges to solvents in basements and garages and then wonder why they taste and smell fumes through the mask.

PHYSIOLOGICAL EFFECTS OF RESPIRATORS

Respirators can affect the respiratory, cardiovascular, and musculoskeletal systems. In addition, respirators may compromise vision, communication, and certain motor skills. The tight-fitting, air-purifying type of respirator can substantially increase the work of breathing by increasing the resistance to both inspiratory and expiratory airflow and by increasing dead-space ventilation. The increase in inspiratory resistance is the dominant physiological effect.[21-23] It increases inspiratory time, decreases peak inspiratory flow at moderate workloads, and decreases minute ventilation at high workloads.[24,25] A recent study demonstrated that maximal tolerable workloads decreased in a linear fashion with increasing inspiratory resistance.[24] Increasing the dead space also decreases maximal tolerable workloads in a linear fashion and decreases wearer comfort. However, increasing the dead space does not substantially alter breathing patterns or induce hypoventilation.[26] Tight-fitting, air-purifying respirators do not have substantial cardiovascular effects.[27,28]

A self-contained breathing apparatus significantly increases the heart rate and cardiac work because of its weight.[29] In addition, those using these types of respirators are usually required to wear additional layers of protective clothing that may be heavy and impermeable and may affect temperature regulation. Most respirators can cause small elevations in blood pressure at high work rates.[30]

DETERMINING WHETHER A PERSON CAN USE A RESPIRATOR SAFELY

After performing a basic medical assessment, the clinician is responsible for deciding whether a worker can

safely use a respirator. Ideally, the clinician should know the type and weight of the respirator, the duration and frequency of respirator use, the physical effort required by the job, whether protective clothing or other equipment will be worn, and whether extremes of temperature and humidity may be encountered[10] (Table 3).

Some workers with cardiovascular disease may be unable to perform jobs involving, for example, strenuous work, heat-induced stress, oxygen-deficient or toxic environments, or the use of a self-contained breathing apparatus.[31] If there is uncertainty about a worker's cardiovascular fitness, it may be helpful to administer an exercise test while the worker is wearing the respirator or to allow the person to use the respirator at work on a trial basis, with follow-up assessment.[27,32-34]

The increased work of breathing imposed by a respirator may influence the ability to tolerate its use, especially by a person with asthma or emphysema. Nonetheless, most people with lung disease can use a respirator during activity at moderate workloads.[25,28,35,36] Underlying lung disease is not necessarily a contraindication to respirator use. As Johnson and colleagues showed, anxiety can decrease the maximal tolerable workload to an even greater extent than does the increased work of breathing created by a respirator.[37] A history of inability to tolerate the closed-in sensation of a tight-fitting respirator is a common indicator that a person will have difficulty using the respirator.[38]

Other medical issues must be considered when the environment is immediately dangerous to life or health, so that even brief removal of the respirator could be hazardous. People with chronic productive cough, emesis, or illnesses that may result in loss of consciousness, such as poorly controlled diabetes mellitus or epilepsy, are at potentially greater risk than are people without such conditions in such environments. Other conditions may also prevent workers from tolerating certain types of respirators. For example, the components of the mask touching the face may cause contact dermatitis in some people. Musculoskeletal conditions that produce back pain could prevent the use of a self-contained breathing apparatus.

OSHA requires that "a physician or licensed health-care professional . . . medically evaluate employees to determine under what conditions they can safely wear respirators."[10] Those who perform these evaluations should be sensitive to the implications that certification decisions have for employment and job reassignment. Some workers will lose their jobs if they cannot be medically cleared to use a respirator. OSHA requires the administration of a medical questionnaire or an initial medical evaluation that obtains the same information. Some of the key information required is outlined in Table 3. Other testing is left to the discretion of the health care professional. No specific guidelines regarding clearance are provided. The American Thoracic Society endorses the use of questionnaires,[32] and one recent study confirmed the sensitivity of this approach.[39]

Table 3. Information Needed to Determine Fitness of a Person to Use a Respirator.*

Type and anticipated use of respirator
Frequency and duration of use
Level of physical activity during use
Use of protective clothing or other equipment
Physical stresses in the work environment (e.g., temperature and humidity)
Type and level of exposure to toxic substances during respirator use
Previous experience in using a respirator
Previous difficulty in using a respirator (e.g., eye irritation, rash, anxiety, weakness, and fatigue)
Health factors that may affect fitness to use a respirator†
Smoking status
Conditions that could affect safety in dangerous environments (e.g., seizures, diabetes, claustrophobia, and anosmia)
Pulmonary disorders (e.g., chronic obstructive pulmonary disease, severe asthma, and interstitial lung disease)
Cardiovascular disorders (e.g., atherosclerosis and arrhythmias)
Dermatologic disorders (e.g., facial scarring, latex hypersensitivity, and pseudofolliculitis barbae requiring beard growth that impairs fit)
Visual acuity and need for eyeglasses‡
Musculoskeletal conditions (especially back injury and back pain) and fitness (e.g., range of motion, ability to climb, and ability to lift more than 25 lb [11 kg])‡

*Adapted from Occupational Safety and Health Administration standard 29 CFR Part 1910.134.[10]

†Medical conditions do not necessarily disqualify workers from respirator use.

‡This information must be obtained from a person who expects to use a full-face respirator or self-contained breathing apparatus.

The physical examination and further medical testing are performed at the discretion of the physician. Examinations are recommended if specific symptoms are elicited on the questionnaire. Spirometry or exercise testing may be helpful for anyone with symptoms consistent with the presence of cardiopulmonary disease.[32] Regular follow-up after certification, with repeated medical clearance and repeated assessment of the fit of the respirator, is recommended[32] and in some circumstances required[10] by federal regulations. Recommended criteria for certification have been proposed.[27,32,34] Most experts agree that a person who is medically qualified to perform a job without a respirator will usually be able to perform the same job safely with a respirator.[27,32-34,40] Therefore, it is not surprising that more than 95 percent of workers referred for medical clearance to wear a respirator do not have substantial contraindications.[38,39]

When evaluating a worker for the use of a respirator, the clinician should be cognizant of the need for

TABLE 4. RECOMMENDATIONS FOR THE RESPIRATOR USER.

Consider your environment

Know the hazards that you will encounter and when to use a respirator.
If workers around you are required to wear respirators, you should probably also wear one.
Never wear an air-purifying respirator in conditions of low oxygen levels or during exposure to highly toxic substances.
If you are choosing your own respirator for home use, read the directions and understand its limitations.
If you can taste, smell, or feel the toxin, the respirator is not protective.

Wear respirators correctly

If an employer requires the use of a respirator, make certain that a written respiratory-protection program complying with the requirements of the Occupational Safety and Health Administration is in place.
Test the fit of your respirator to determine whether it is the appropriate size and model.*
When you put your respirator on, test both the inhalation and the exhalation valves.
Do not alter the respirator in any way (e.g., do not mix brands of cartridges and do not use petroleum jelly or cotton along the edge of the mask).
Remember that eyeglasses, eyebrow piercings, beards, or other objects that break the seal of the respirator will substantially lower its protection factor.
Do not remove or loosen your respirator when you are working in a contaminated atmosphere.

Maintain the equipment

Store respirators and cartridges in clean, protected environments.
Change respirator cartridges regularly.

*Supplementary Appendix 1 (available with the full text of this article at http://www.nejm.org) lists organizations that can conduct or arrange for fit-testing.

confidentiality. The health care provider is required to inform both the employer and employee in writing whether the employee is able to use a respirator, whether there are any limitations on its use, and whether further medical evaluation is recommended. Because of patient confidentiality, the employer should not be provided with the specific medical reasons for the decision.

When there are no other practical and immediate means of protection against airborne hazards, respirators can save lives, but only if there has been appropriate attention to respirator selection, training on respirator use (Table 4), and medical evaluation. Even in the best of circumstances, the respirator only adds a margin of safety and cannot guarantee complete protection. It is, at best, a secondary preventive measure. Efforts by workers, industry, labor, and government to control environmental and occupational hazards must continue to be the primary preventive strategy.

We are indebted to Shawn Arbuckle for helpful discussions and advice on the practicalities of respirator-fit testing, and to Joy Davis for assistance in the preparation of the manuscript.

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