Review Article

Glutaraldehyde Exposure and its Occupational Impact in the Health Care Environment

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Abstract

　　Despite the search for effective and less toxic substitutes, glutaraldehyde (GA) remains one of the few substances capable of high-level instrument disinfection in modern health care. Workers commonly affected include operating room nurses, radiographers, x-ray technicians and cleaners. Widespread hospital usage combined with its well-known irritant properties, has ensured an increase in occupationally-related illnesses during recent years. Operating room nurses, laboratory workers and x-ray technicians frequently contact GA in both the liquid and vapor form. Workplace exposure is usually dependent on job tasks, ventilation levels and the use of protective equipment. GA is a relatively potent irritant and sensitizer, with a well-documented history of symptoms following occupational exposure. Although mechanisms for GA toxicity have been postulated, research on the toxicological, teratogenic and carcinogenic potential of this chemical has shown inconsistent results. Reducing workplace exposure to its lowest possible level represents the most important hazard reduction strategy. This may be achieved by keeping GA containers tightly sealed when not in use, maintaining adequate ventilation levels and the rigid adherence to appropriate personal protective equipment. Substitution with automated cold sterilization machines may be another appropriate measure, while banning unnecessary practices such as GA fogging and its use as a surface disinfectant may also be helpful in reducing occupational exposure in the health care environment.

　　Key words: glutaraldehyde, occupational exposure, health care environment, toxicology, disinfection

Introduction

　　Despite the search for effective and less toxic substitutes, glutaraldehyde (GA) remains one of the few substances capable of high-level instrument disinfection in modern health care environments. Workers commonly affected include operating room nurses, radiographers, x-ray technicians and cleaners. Widespread hospital usage combined with its well-known irritant properties, has ensured an increase in occupationally-related illnesses during recent years. Operating room nurses, laboratory workers and x-ray technicians frequently come into contact with GA in both the liquid and vapor forms. As with most toxic chemicals used in the workplace, substitution with less toxic alternatives is always preferable. Nevertheless, its relatively low cost and current ubiquity in both occupational

and domestic environments suggests that GA will continue to be a concern among health care workers for some time. GA usage persists in many workplaces around the world, particularly those in developing countries where occupational health knowledge among staff members and the regulation of dangerous chemicals are both suboptimal. The 21st century also heralded a new era of super-infections such as SARS and avian influenza, where rapid disinfection was urgently required. Some of these needs were met by GA-related products, and will continue to be. As such, it is reasonable to assume that GA will remain a ubiquitous disinfectant in various health care environments, particularly those in developing countries. For these reasons we considered it necessary to conduct a detailed review of GA, from both the theoretical and practical perspectives. Unlike previous reports, we have provided a comprehensive analysis of the chemical, toxicological, occupational and hazard reduction aspects of this elusive chemical.

Background

　　Glutaraldehyde ($C_5H_8O_2$) was first synthesized in 1908, by boiling ozonide of cyclopentene with water to release several

Table 1   Ranked sporicidal activity of various aldehydes

Aldehyde	Sporicidal Activity	Aldehyde	Sporicidal Activity
Adipaldehyde	Slightly active	Glyoxal	Good
Succinaldehyde	Slightly active	Formaldehyde	Good
Malonaldehyde	Slightly active	Glutaraldehyde	Excellent

Adapted from Russell & Hopwood, 1976 (1) and Gorman et al., 1980 (2).

Table 2   Chemical and physical properties of glutaraldehyde

Properties	Value	Properties	Value
Chemical formula	$C_5H_8O_2$	Vapour pressure	0.116 Torr (50% aq.)
Molecular weight	100.13	Vapour density (air=1)	3.4
Boiling point	187–188°C	Refractive index	1.43300 at 25°C, 589 nm
Freezing point	−14°C	Absorption maximum	280 nm
Density (H_2O=1)	0.72	Odor threshold	0.04 ppm

Adapted from Russell & Hopwood, 1976 (1), Gorman et al., 1980 (2), Beauchamp et al., 1992 (6) and Ballantyne et al., 2001 (9).

reactive products (1). Its ability to reduce the sweating of hides was later observed by chemists, and by the 1960s, GA had become a commercial leather-tanning product (2). Between 1963 and 1964, GA was adopted by the health care industry as a cold disinfectant for surgical instruments and anesthesia equipment (3–5). GA is commercially manufactured by acid hydrolysis of 2-alkoxy-3,4-dihydro-2H-pyran molecules (6). Prior to commercial GA production, formaldehyde had been a common medical disinfectant, despite its irritant properties, the significant time required for cold disinfection and its relative inability to kill bacterial spores (2). Searches for effective formaldehyde substitutes lead researchers to investigate the other aldehydes, before concluding that buffered alkaline solutions of GA (pH 7.5–8.5) had far superior antimicrobial and sporicidal properties (7). In this regard, a ranked comparison of the sporcidal activity of various aldehyde solutions is demonstrated in Table 1.

Chemical Properties of Glutaraldehyde

The basic physical and chemical properties of GA are listed in Table 2. Pure GA is a colorless, oily liquid with a characteristically pungent odor in the vapor phase. It is completely soluble in water and ethanol, and partially soluble in benzene or ether (6). GA has a mildly acidic pH in aqueous solutions, where it can be buffered to alkaline pH by adding sodium bicarbonate to form a highly stable antimicrobial

solution (8–10). GA is most commonly referred to as *glutaraldehyde* or its International Union of Pure and Applied Chemistry (IUPAC) name *1,5-pentanedial* and its Chemical Abstracts Service (CAS) number 111-30-8 (1, 2, 6, 9). At the molecular level, GA is a five carbon saturated dialdehyde that readily polymerizes in aqueous solution (6). Its broad biocidal activity arises from the propensity to cross-link with NH_2 groups on protein chains, such as lysine residues in microbial cell walls (2, 6). The twin aldehyde groups also undergo typical aldehyde reactions, forming hydrazones, cyanohydrins, oximes and bisulphite complexes in solution (1).

GA is stable in light, but easily oxidizes in the presence of air. The stability of aqueous solutions decreases with increasing temperature and pH, reaching peak stability in 2% solution at pH 7.7 (6). Above pH 9 however, there appears to be an extensive loss of aldehyde groups (1). The polymerization characteristics into many different equilibrium structures have been studied extensively, with C-NMR spectroscopy revealing at least five general forms, ranging from free aldehydes, hemihydrate and dihydrates, to cis and trans isomers of the cyclic hemiacetal form. Figure 1 shows a graphical indication of some important GA structures present during aqueous equilibrium states at room temperature (1, 2, 6). Changes in pH, temperature or both will displace equilibrium, resulting in different concentrations of the various forms. The widespread
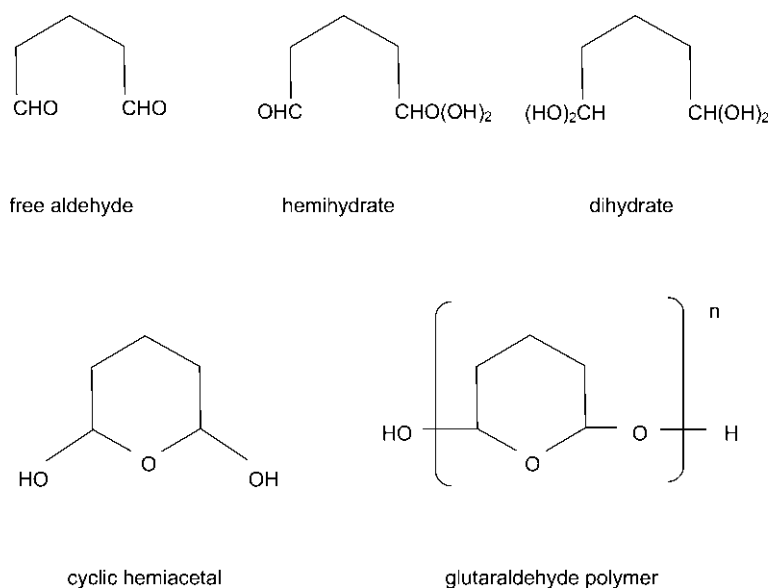

Fig. 1   Some glutaraldehyde equilibrium structures. Adapted from Russell & Hopwood, 1976 (1), Gorman et al., 1980 (2) and Beauchamp et al., 1992 (6).

use of GA in diluted form (1–2%) as a cold disinfectant solution exploits both the aqueous stability and ready polymerization characteristics of these equilibrium states (1, 2, 6). As the free aldehyde form of this chemical is the most efficient polymerizer, the presence of adequate free-aldehyde groups in solution ensures effective biocidal properties. At the molecular level, this is due to the cross-linking of aldehyde groups with primary amines, such as the lysine residues within microbial cell walls (2, 6). Its limited shelf-life arises due to its tendency to spontaneously polymerize over time, leaving limited aldehyde radicals and a solution with markedly diminished antibacterial properties. Conversely, freshly prepared solutions kept at higher temperatures (usually higher than 25°C) contain most of the GA in a free aldehyde form, which is highly bactericidal.

Metabolic Pathways of Glutaraldehyde

As with many other volatile aqueous compounds, inhalation is the major route for GA absorption in humans. Skin absorption is another possible pathway, although only a small proportion of cutaneously-applied GA has been shown to be available for systemic absorption (9). Although GA is metabolized extensively to CO_2, the fate of non-carbon atoms and the exact kinetic processes during in vivo GA metabolism have not been clearly elucidated (1, 2, 6). Whereas the toxicological processes of GA *in vivo* share similarities with those of other aldehydes, the actual metabolic process behind GA transformation are also only partially understood. Nevertheless, many pharmacokinetic studies have been conducted using [^{14}C] GA, mainly in the rabbit and rat (9). Beauchamp et al. (6) proposed a possible metabolic pathway, similar to that shown in Figure 2.

They suggested that upon reaching the liver, GA is probably oxidized to glutaric semialdehyde and then to glutaric acid. Further metabolism is then achieved by synthesis of a coenzyme A thioester. The resulting glutaryl CoA is reduced by glutaryl CoA dehydrogenase to produce glutaconyl CoA, which is then decarboxylated to crotonyl CoA. A hydration reaction subsequently produces β-hydroxybutyryl CoA. The final stage of GA metabolism is probably similar to that of other aldehydes and involves conversion into acetyl CoA, followed by a final oxidative process by which CO_2 is produced (6). This lack of distinct metabolite represents one of the difficulties in tracking the metabolic processes of GA and/or determining the systemic loading of GA following absorption. The metabolism pathway is not definitive either, as animal models have shown that increasing the dose probably results in a shift in the elimination pathways. The potential for *cumulative* toxicity arising from GA exposure seems limited due to its rapid biotransformation and elimination (9).

Toxicity to Animals

Although it has long been studied in both humans and animals (14–26), the *acute* toxicity of GA remains a contentious issue. Nevertheless, GA presents a certain degree of hazard to various organisms. At the broadest level, GA may affect marine life when released into the environment via hospital wastewater (14, 15). In the natural environment GA has been shown to be equally toxic to warm water and cold water fish, although slightly less toxic to saltwater fish than freshwater fish (16). Its toxicity does not appear to be appreciably increased with repeated long-term exposure in this manner. Environmental toxicity also depends on the type of marine organism exposed, with LC_{50} (in mg GA/L of water) values ranging from 0.11 mg/L in calanoid copepods, to 465 mg/L in green crabs (16). As early as 1963, Stonehill et al. (3) reported that the LD_{50} of

$$OCHCH_2CH_2CH_2CHO$$

NAD$^+$

NADH

$$OCHCH_2CH_2CH_2COOH$$

NAD$^+$

NADH

$$HOOCCH_2CH_2CH_2COOH$$ $$CO_2$$

$$HOOCCH_2CH_2CH_2COSCoA$$ $$CH_3COSCoA$$

FAD

FADH$_2$ $$CH_3CHOHCH_2COSCoA$$

$$HOOCCH_2CH=CHCOSCoA \longrightarrow CH_3CH=CHCOSCoA$$
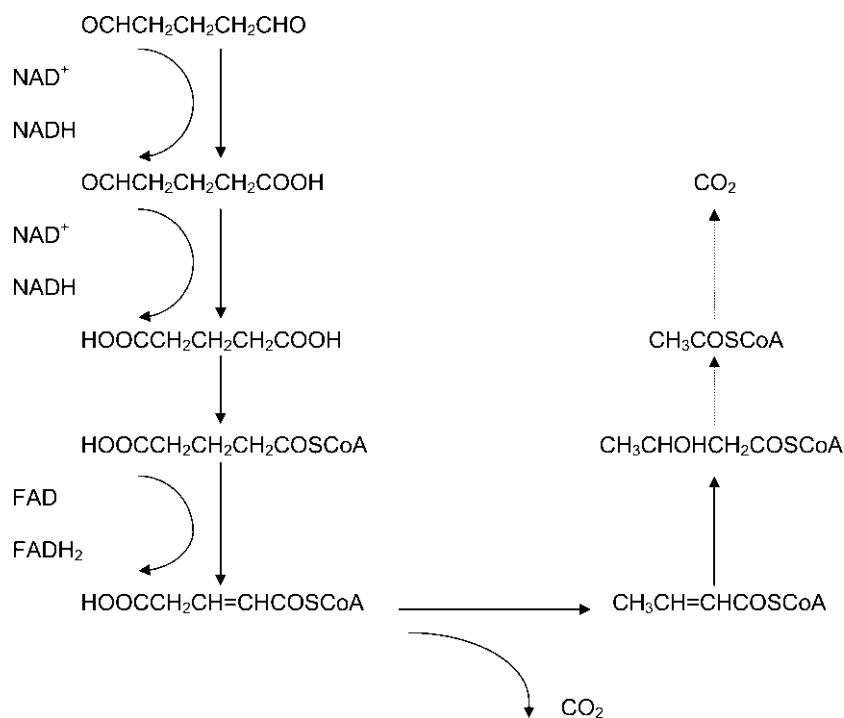
$$CO_2$$

Fig. 2   Theoretical metabolism of glutaraldehyde. Adapted from Beauchamp et al., 1992 (6).

GA (by acute intravenous administration) was 15.0 mg/kg body weight in mice and 9.8 mg/kg body weight in rats. Later experiments with different exposure categories revealed an array of responses. LC_{50} values between 40 and 5000 ppm have been demonstrated in rats when exposed via inhalation (6). The oral toxicity of GA in rats may range from 1.3 mg/kg body weight (in a 50% aqueous solution) to 12.3 mg/kg body weight (in a 1% aqueous solution) (6). Mice appear to be more susceptible to acute peroral toxicity than rats, whereas for rabbits, 15% concentration solutions and lower are not usually lethal at 16.0 ml/kg body weight LD_{50} when administered perorally (18). Other experiments however, have failed to conclusively link dosage-related mortality when GA was administered via the drinking water of rats (9).

Although GA is known to be a dermal irritant, repeated skin contact does not usually cause systemic toxicity, and there is little evidence for target organ toxicity when exposed via this route. Nevertheless, a dermal LD_{50} of 2560 μg/kg has been experimentally achieved in rabbits (6). As a sensitizer, Gad (17) demonstrated interspecies differences in GA potency calculations in guinea pig and human sensitization tests, before developing a relative potency classification. Using this classification system, the potency of a particular substance relative to other materials can be rated. In a ranked test of dermal sensitizer potency, GA was rated as a high, Class-2 potency index compound with patch testing scores lower than formalin but higher than that of cinnamic aldehyde solutions (17). The mutagenic and teratogenic properties of GA have also shown inconclusive results using animal models. Experimental studies have been unable to conclusively link GA with DNA damage, developmental toxicity and reproductive toxicity (6, 9, 18). Genetic toxicology studies have suggested that GA produces inconsistent positive responses in mammalian cells, and negative results in studies conducted in rats and mice (18–20). Two-generation developmental studies have not shown GA to be a teratogen, nor demonstrated any adverse reproductive effects (9). GA was also shown to have no teratogenic effects on rat offspring, even at doses sufficiently high to induce severe maternal toxicity (24).

Toxicity to Humans

Assessing the acute toxicity of GA in humans has been difficult following animal experimentation, because of innate physiological differences between species and the confounding effects of long-term chronic exposure. Furthermore, oral LD_{50} values derived from toxicity studies of animals are not generally appropriate for humans, as swallowing is regarded as an unlikely route of exposure (18). Skin contact at a sufficient level to cause death is also improbable in an occupational setting. Only one direct GA-related fatality has been reported in humans (21). In this particular case, mislabeling of specimen bottles led to a patient accidentally receiving a subdural injection of GA, from which they subsequently died (21). Hemminki and others (22, 23) conducted two retrospective studies of the relationship between spontaneous abortions and GA exposure among health care workers, and found no correlations. The irritant properties of GA are well known in humans however (26–28), and probably share many similarities with animal models. A reasonably linear relationship between exposure dose and irritation has been experimentally demonstrated in animals (18), and this assumption is probably appropriate for humans. Similarly, the development of GA hypersensitivity, which is mediated by GA exposure concentration in mice (25), may also be extrapolated to humans.

Occupational Exposure to Glutaraldehyde

The major routes of occupational GA exposure are direct vapor inhalation and direct skin contact. These are summarized in Table 3. Total exposure is related to numerous physical workplace factors, such as contact frequency, contact duration, environmental GA concentration and the presence of personal protective equipment (PPE). Operating room personnel performing cold sterilization with GA are regularly exposed throughout their working day, because of continuous requirements for sterile instruments (26–28). Among nurses using endoscopic equipment, occupational GA exposure appears to be a combination of the frequency of sterilization, GA concentration in the sterilizing solution, the endoscope rinsing method, the size of the room, general room ventilation or airflow and whether any exhaust extraction vents are used. Furthermore, the removal of instruments from GA solutions often involves a lengthy rinsing procedure, during which skin contact and vapor inhalation may occur simultaneously (28, 30). Sterilization rooms are often small with poor ventilation, and instruments are usually hand-held over the sink. As such, health care workers performing cold disinfection are regularly exposed to GA, both from vapor inhalation and accidental splashes (29, 30).

X-ray technicians are often exposed to GA at work, because it is widely used as a hardening agent during the processing of x-ray film (31). Automated film processing

Table 3   Occupational exposure to glutaraldehyde

Major Route	Activity Resulting in Exposure	Workers Exposed
Skin Contact	• Cold disinfection of equipment (4, 5)	• Operating theater nurses (22, 23)
	• Fixing specimens for microscopy (33, 38)	• Laboratory technicians (33, 38)
	• Processing x-ray films (43, 46)	• X-ray technicians (31, 32)
	• Cleaning and disinfecting (34, 40)	• Cleaners, veterinarians (39, 40)
Inhalation	• Cold disinfection of equipment (28, 37)	• Operating theater nurses (30, 36)
	• Fixing specimens for microscopy (33, 38)	• Laboratory technicians (33, 38)
	• Processing x-ray films (43, 46)	• X-ray technicians (43, 46)
	• Cleaning and disinfecting (34, 40)	• Cleaners, veterinarians (39, 40)

Table 4   Occupational disorders caused by glutaraldehyde

Category	Symptom	Workers Affected
Acute	• Skin irritation (41, 49) • Eye irritation (49, 57) • Contact dermatitis (39–41) • Headache (28, 30, 43)	• Operating theater nurses (22, 23, 30, 36) • Laboratory technicians (33, 38) • X-ray technicians (31, 32, 43, 46) • Cleaners, veterinarians (39, 40, 43)
Chronic	• Irritant contact dermatitis (41) • Chronic dermatitis (39) • Systemic sensitization (45, 50) • Occupational asthma (45–48, 50)	• Operating theater nurses (22, 23, 30, 36) • Laboratory technicians (33, 38) • X-ray technicians (31, 32, 43, 46) • Cleaners, veterinarians (39, 40, 43)

equipment, for example, generally uses a 2% GA solution diluted from a 50% concentrate (32). Exposure usually occurs when pouring chemicals into the machine, as well as via mists, vapors, leaks and evaporation from the film itself. Pathology technicians and researchers who fix tissues or specimens with GA in histology or pathology laboratories may also be exposed to the substance (33). GA is often used for fixing specimens prior to electron microscopy. Similar to nurses, their exposure is generally related to chemical vapors and direct skin contact during their handling of GA in the laboratory. In certain countries such as Japan, another potential workplace exposure occurs among hospital staff members performing routine disinfection, possibly because GA manufacturers advertise their product as an all-purpose disinfectant (34). Similar to nurses and cleaners, laboratory technicians may directly come into contact with GA while sterilizing bench tops and laboratories with GA solutions (33).

Occupational Disorders from Glutaraldehyde

Adverse symptoms following occupational exposure to GA have been well documented and can usually be divided into acute and chronic effects. The main adverse symptoms are listed in Table 4. As GA is a reasonably strong irritant, the most common acute symptoms arising from occupational exposure usually involve irritation of the eyes, rhinitis and conjunctivitis (33). GA vapor may also irritate the respiratory tract, resulting in coughing or wheezing, and usually elicit an irritation response at around 0.3 parts per million (ppm) (35). Corneal injury and inflammation have been experimentally induced at a 1% concentration, with severe corneal injury occurring at 45% GA concentration in rabbits (18). For humans, however, the possibility of encountering such high airborne concentrations is fairly remote. Accidental splashes of GA solution towards the face are the most likely situation leading to eye damage. Similarly, GA-induced skin irritation more likely occurs due to repeated accidental contact with GA solutions, rather than through vapor exposure (36). Aqueous GA solution is well-known for its contact irritancy, with an irritation threshold believed to be around 1%, and with skin corrosion occurring at concentrations of approximately 45%. In this regard, contact dermatitis caused by direct and repeated contacts with GA solution remains a common symptom following occupational GA exposure.

GA was first used for medical disinfection in 1963 (3) and reports of GA-induced contact dermatitis began appearing as early as 1968 (37). The substance is a well-known sensitizer, with chronic exposure leading to sensitization in certain people who regularly come into contact with GA at work. In one study, health care workers were more than eight times as likely to be allergic to GA, than people who were not employed in health care (38). Patch-testing has shown that GA is also capable of inducing allergic contact dermatitis (39–41). Allergic contact dermatitis caused by workplace substances has important occupational repercussions, as it may lead to persistent dermatitis, which then requires a change of career (38). Nethercott et al. for example, found that five of their patients with GA-related contact dermatitis were forced to change their occupation because of the disease (39). Whether repeated GA exposures actually cause occupational asthma, however, is currently under debate. Although numerous reports of work-related asthma have appeared in the medical literature (42–49), not all studies have shown a positive correlation with GA exposure (9). Furthermore, although laboratory tests do exist for GA-related IgE, some studies have shown that only a small percentage of subjects with symptoms actually have these specific antibodies (50, 51). As such, it remains to be proven whether GA exposure actually causes workplace asthma.

Reducing Occupational Exposure

Given the undoubted irritant properties of GA, it is important to reduce exposures in the workplace to their lowest possible level. This may be achieved by a combination of the strategies outlined in Table 5. Firstly, GA should be used only where other substances are inappropriate (52). Certain GA alternatives such as hydrogen peroxide, peracetic acid-hydrogen peroxide (PAHP) and orthophthaldehyde, have been suggested for the cold disinfection of endoscopic equipment (53, 54). These substances may be safer than GA, particularly PAHP, as it is not believed to cause allergic reactions (55). On the other hand, the relative safety and carcinogenic potential of new disinfectants used to replace GA may not yet be known. In situations where GA usage cannot be avoided, one of the most important issues for controlling occupational exposure is its environmental concentration. Airborne concentration is generally related to molecular availability and ambient temperature within the workplace, which is in turn, related to vapor pressure and solution concentration. Increasing temperature and solution concentration subsequently increases the vapor pressure of GA mixtures and thus, its environmental concentration. As such, good occupational hygiene principles need to be adopted and

Table 5   Reducing occupational exposures

Category	Methodology
Substitution	• GA should only be used where other methods of sterilization or disinfection are inappropriate (35, 52)
	• Replace GA with alternative disinfectant such as hydrogen peroxide, peracetic acid-hydrogen peroxide (PAHP) or orthophthaldehyde (53, 54)
Minimization	• Skin contact and vapor inhalation should be minimized by using personal protective devices such as masks and gloves (33, 36, 52)
	• Reduce the number of people working in areas where GA is being used (35)
	• Spills of GA-containing liquids should be immediately cleaned up as soon as they occur (35, 52)
	• Extraction fans should be installed, and preferably, push/pull ventilation systems (27, 33, 35, 36, 53)
	• All devices that contain GA solutions should be covered and sealed when not in use and only opened for the duration of use (33, 35, 36, 52)
	• Training and education for staff with emphasis on appropriate occupational hygiene techniques as mentioned above (33, 35, 52)

rigidly followed in workplaces that use GA (33, 52).

The enclosure of GA in using containers which are long and deep, and that have close-fitting lids is important. These container lids must be kept firmly closed when not in use. GA should be disposed of using a pump, rather than pouring out the solution (38), and accidental spills should be cleaned up immediately. Local exhaust ventilation can be used in disinfection areas wherever practical, with approximately 7 to 15 air changes per hour (53). This method may also be appropriate for reducing GA exposure among radiographers (56). Increasing the general ventilation rate of rooms is advisable, as well as simply reducing the number of people in the immediate area. Although cold sterilizing machines are gradually replacing manual GA disinfection in many countries, they may still be problematic if operated in areas with poor general ventilation (57). Furthermore, natural ventilation is not always reliable for reducing GA exposure, and may actually increase the dispersion of GA vapor to other workplaces (58).

Preventing accidental contact with GA is also very important, and often occurs due to inappropriate work practices and unsuitable or insufficient personal protective equipment (PPE). In fact, it has been suggested that many GA-induced symptoms are more related to procedural factors rather than airborne exposures (36). This is particularly important with respect to skin problems, many of which may arise from placing instruments into GA solution with ungloved hands. Therefore, appropriate PPE should consist of gowns and aprons, protective gloves made of an appropriate material (not latex), forearm protectors, eye protection with close fitting goggles, and personal respirators (33). Damaged gloves should be replaced immediately (52). Although the use of appropriate PPE would appear to be the obvious method for reducing exposure, it is not always practical. A previous study of Italian operating room staff for example, revealed that only 38% regularly wore appropriate PPE while handling GA solutions (59). It is incumbent on health professionals to enforce appropriate PPE usage both for themselves and their colleagues. Some additional GA exposure minimization techniques may be appropriate and are not necessarily expensive. In Japan, it was found that replacing the collection bucket of an automated endoscope washing machine helped reduce GA vapor levels (60). In another example, Oie and Kamiya (34) reported that simply advising hospitals of GA risks, helped them to reduce unnecessary GA exposure during common disinfection procedures. All of these techniques may be useful in reducing the occupational GA burden among health care workers. In 2005 an airborne GA concentration limit of 0.05 ppm was also introduced in Japan, and workplaces exceeding this concentration must now provide respiratory protection for employees (61).

Conclusions

Despite the search for effective and less toxic substitutes, GA remains one of the few substances capable of high-level instrument disinfection in modern health care. GA is a relatively potent irritant and sensitizer, with a well-documented history of adverse symptoms following occupational exposure. Although certain mechanisms underlying GA toxicity have been postulated, research on the toxicological, teratogenic and carcinogenic potential of this chemical has shown inconsistent results. From an occupational perspective, reducing workplace exposure to its lowest possible level represents the most important hazard reduction strategy. This may be achieved by keeping GA containers tightly sealed when not in use, maintaining adequate ventilation levels and a rigid adherence to personal protective equipment. Substitution with automated cold sterilization machines may be another appropriate measure, while banning unnecessary practices such as GA fogging and the use of GA as a surface disinfectant may also be helpful in reducing the occupational burden among staff. As with most toxic chemicals used in work environments, the substitution with less toxic alternatives is always preferable. Nevertheless, the relatively low cost of GA and its ubiquity in both occupational and domestic environments, have contributed to the widespread use of this product. In 1968 when Sanderson and Cronin (37) reported some of the first cases of GA-induced contact dermatitis, they suggested that the chemical should be replaced as soon as alternatives are available. Nearly 40 years later however it remains in use, particularly in developing countries where the supply of disposable equipment and autoclaves are inadequate (62). The 21st century also heralded a new era of super infections such as SARS and avian influenza, where rapid disinfection is urgently required. Some of these needs were met by GA-related products, and will continue to be. As such, it is reasonable to assume that GA will remain a ubiquitous disinfectant in various health care environments, particularly those in developing countries. For these reasons, continued vigilance is needed for the control and monitoring of workplace environments where GA is used and also for the ongoing assessment of health effects among exposed workers.

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