Letters

RESEARCH LETTER

Diffusion of Carbon Monoxide Through Gypsum Wallboard

Carbon monoxide (CO) poisoning is a significant US health problem, responsible for approximately 500 accidental deaths annually,[1] and a risk of 18% to 35% for cognitive brain injury 1 year after poisoning.[2] Most morbidity and mortality from CO poisoning is believed to be preventable through public education and CO alarm use.

States have been enacting legislation mandating residential CO alarm installation.[3] However, as of December 2012, 10 of the 25 states with statutes mandating CO alarms exempted homes without fuel-burning appliances or attached garages, believing that without an internal CO source, risk is eliminated. This may not be true if CO diffuses directly through wallboard material.

Methods | A Plexiglas chamber divided by various configurations of gypsum wallboard was used to determine whether CO diffuses across drywall. Single-layer 0.25- and 0.5-inch thick wallboard, double-layer 0.5-inch thick wallboard, and double-layer 0.5-inch thick wallboard painted on 1 side were tested.

Carbon monoxide test gas (3000 ppm) was infused into 1 chamber at 15 L per minute to a concentration of 500 to 600 ppm and then CO concentrations were measured once per minute in each chamber for 24 hours with monitors having a resolution of 1 ppm and range of 0 to 999 ppm (Biosystems Toxipro Single-Sensor Gas Monitor, Honeywell Inc). Six trials for each of the plain wallboard configurations were performed (3 in each direction) and 3 trials with the painted double-layer wallboard, infusing CO on the unpainted side. Experiments were performed from March 22, 2012, through November 28, 2012.

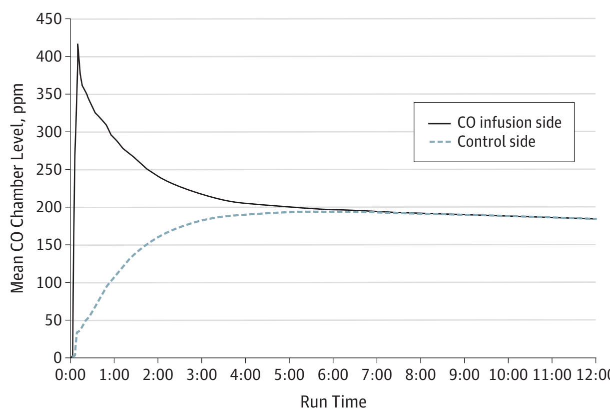
We sought to determine how rapidly a concentration of CO toxic to humans (100 ppm) would be reached in the noninfused chamber and whether diffusion would then continue, measuring the time until the chambers reached less than 5% of their initial concentration difference. Mean and standard deviation results were calculated using GraphPad statistical software (GraphPad Software Inc).

Results | Carbon monoxide diffused across single-layer gypsum wallboard of 2 thicknesses, double-layer wallboard, and painted double-layer wallboard (**Table**). When CO was infused into 1 chamber, the concentration reached 500 ppm within 7 minutes. The increase in CO concentration in the noninfused chamber followed rapidly, reaching 100 ppm 17 to 96 minutes after the infusion stopped, depending on the configuration. Concentrations of CO were less than 5% different between the 2 chambers by 12 hours in all configurations.

Table. Time to Diffusion of Carbon Monoxide (CO) Through Drywall of 2 Thicknesses and 3 Configurations to Reach a Toxic Level (100 ppm) and Also Equilibrate to Less Than 5% of Their Initial Difference

	Mean (SD)			
	CO-Infused Chamber		Noninfused Chamber	
	Peak CO, ppm	Mean CO Infusion Time, min	Mean Time to Reach 100 ppm of CO, min	Mean Time to CO <5% of Initial Difference, min
Drywall barrier				
Single-layer 0.25-inch thick (n = 6)	584 (51)	7 (2)	24 (20)	209 (67)
Single-layer 0.5-inch thick (n = 6)	530 (6)	7 (2)	52 (14)	205 (17)
Double-layer 0.5-inch thick (n = 6)	528 (11)	7 (1)	67 (6)	366 (44)
Painted double-layer 0.5-inch thick (n = 3)	533 (9)	7 (2)	103 (6)	654 (29)

Figure. Mean Carbon Monoxide (CO) Levels Across 0.5-in Wallboard (n=6 Trials)



Levels of CO were measured once per minute during and after CO infusion into 1 of 2 chambers separated by 0.5-inch thick gypsum wallboard.

The **Figure** illustrates the kinetics of gas movement across 0.5-inch wallboard. In all experiments, the CO concentration in the infused side increased rapidly to 500 ppm, then decreased precipitously when the infusion was discontinued. Concentrations of CO in the noninfused side simultaneously began to increase as CO rapidly diffused across the wallboard.

Discussion | A recent report[4] described 3 instances of CO poisoning attributed to CO diffusion through floorboards among residents living above restaurants that cooked with charcoal.

To our knowledge, our study is the first examining CO diffusion across wallboard.

There are numerous media reports describing simultaneous CO poisonings in different units of multifamily dwellings. Even though CO might have traveled through ventilation ducts, hallways, or stairways, the building configurations in many such cases are inconsistent with this explanation, raising the possibility that CO passes through walls.

This study showed that CO can pass through gypsum wallboard. Gypsum's permeability to CO is due to its porosity. Pores in 0.5-inch thick wallboard averaged 466 μm in diameter in 1 report.[5] Because a CO molecule is about 0.387 nm in diameter, it is not surprising that it could easily travel through a pore 1 million times its size. Diffusion across painted drywall was slower, likely due to pore obstruction by paint. Even though this was a laboratory-based experiment that should be replicated in a real-world setting, a recent study[6] found similar results using generators in a model house garage.

The ability of CO to diffuse across gypsum wallboard may explain at least some instances of CO poisoning in contiguous residences. Exempting residences without internal CO sources from the legislation mandating CO alarms may put people in multifamily dwellings at risk for unintentional CO poisoning.

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Author Contributions: Dr Hampson had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
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Acquisition of data: Courtney, Holm.
Analysis and interpretation of data: Hampson, Courtney, Holm.
Drafting of the manuscript: Hampson, Courtney, Holm.
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COMMENT & RESPONSE

Complications From Surgery and Hospital Finances

To the Editor In their article examining the relationship between surgical complications and hospital finances, Dr Eappen and colleagues[1] focused on contribution margin, calculated as revenue minus variable costs. The authors categorized nursing labor costs as variable costs; however, in the short run, labor costs in health care are fixed and do not change with volume at the margin.[2,3]

Consider the effect of avoiding a single complication. Less nursing time would be required for an individual patient, and administrators could rapidly take financial advantage of the need for less labor time if they employed a nursing workforce that was paid by the hour and could be released and retained on the same day. But that is not how health care labor works. Nurses tend to be hired as annual salaried employees who are paid regardless of whether a patient had a complication.

There is an argument that reducing surgical complications might unleash nursing labor (and bed) capacity, which could be used to generate additional revenues, assuming a queue for services exists.[3,4] However, that unleashed capacity is not fungible because both staff and bed capacity are perishable and must be consumed when and where they occur to generate revenues. For example, freeing up staff and space in a neurology unit does not allow an additional cardiology patient to be admitted.

These financial realities do not mean that hospitals should abandon efforts to reduce surgical complications; however, they do mean that hospital administrators should not expect to see short-term reductions in labor costs from those efforts. With fewer complications, insurers might experience reduced expenditures.[5] However, the very high contribution margins that Eappen et al[1] reported—ones that are higher still if health care labor is considered a fixed cost—and the perishability of unleashed capacity conspire to incentivize unnecessary admissions.

In the short run, should hospitals use captured excess capacity to treat patients who did not need to be treated, insurance costs might paradoxically increase, offsetting any cost savings associated with complication avoidance. Only in the longer run, if hospital administrators are able to eliminate, limit to a particular ward, or accurately predict and allocate staff for anticipated surgical complications, nursing labor might be considered briefly variable until it is adjusted to better match a more predictable demand.

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