

Smoke Alarm Tests May Not Adequately Indicate Smoke Alarm Function

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Smoke alarms are one of the most promoted prevention strategies to reduce residential fire deaths, and they can reduce residential fire deaths by half. Smoke alarm function can be measured by two tests: the smoke alarm button test and the chemical smoke test. Using results from a randomized trial of smoke alarms, we compared smoke alarm response to the button test and the smoke test. The smoke alarms found in the study homes at baseline were tested, as well as study alarms placed into homes as part of the randomized trial. Study alarms were tested at 12 and 42 months postinstallation. The proportion of alarms that passed the button test but not the smoke test ranged from 0.5 to 5.8% of alarms; this result was found most frequently among ionization alarms with zinc or alkaline batteries. These alarms would indicate to the owner (through the button test) that the smoke alarm was working, but the alarm would not actually respond in the case of a fire (as demonstrated by failing the smoke test). The proportion of alarms that passed the smoke test but not the button test ranged from 1.0 to 3.0%. These alarms would appear nonfunctional to the owner (because the button test failed), even though the alarm would operate in response to a fire (as demonstrated by passing the smoke test). The general public is not aware of the potential for inaccuracy in smoke alarm tests, and burn professionals can advocate for enhanced testing methods. The optimal test to determine smoke alarm function is the chemical smoke test. (*J Burn Care Res* 2011;32:e135–e139)

Smoke alarms reduce residential fire-related death and injury by providing an early warning to the presence of fire, allowing occupants to escape.^{1–3} Smoke alarms are one of the most promoted prevention strategies to reduce deaths from residential fires, and they can reduce residential fire deaths by half.^{4–6} National smoke alarm giveaway and installation programs have shown promise in increasing the number of homes with functional smoke alarms and in reducing residential fire death and injury.^{7–10} Many safety and health promotion messages

recommend that owners test their alarms every 6 months and change batteries as needed.

Two steps are necessary for a smoke alarm to function. First, the alarm must identify the presence of smoke through a sensor device. Second, the alarm must be triggered, usually as a loud, high-pitched sound, through the alert device. The alarm depends on a power source, usually a battery or household electric current with a battery backup, to operate. Smoke alarms are required to have a test button that triggers the alert device when pushed. The smoke alarm button, however, tests only the alert device and does not provide information on the sensor device (ie, whether or not the smoke alarm can detect smoke). Furthermore, if the button mechanism itself breaks, the alerting device within the alarm may still be functional even though the button does not sound the alarm. Consumers rely almost exclusively on the smoke alarm button test to determine whether smoke alarms in their home are functional. However, the smoke alarm button test does not indicate whether or not the alarm can successfully identify smoke through the sensor device.

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Chemical smoke can be used to test both steps. In a chemical smoke test, a nontoxic chemical similar to smoke is sprayed into the alarm. If the alarm sounds, then both the alert device and the sensor device worked, and the alarm is fully functional. No studies have compared the performance of smoke alarms on these two different tests.

Using a randomized controlled trial (RCT) of 691 homes, we tested more than 3000 smoke alarms to see whether different types of alarms varied in their performance on these functionality tests. We specifically examined the two major types of smoke alarms with regard to their testing status. The two major types of smoke alarms are ionization and photoelectric. Ionization alarms detect smoke-sized particulates through an electric current that when interrupted triggers circuitry to sound the alarm. Photoelectric alarms detect smoke through a beam of light that when interrupted scatters the light into a sensor that sounds the alarm. We also examined the battery types of carbon-zinc, alkaline, and lithium.

MATERIALS AND METHODS

Study Design and Source Population

This analysis uses data from a previously published RCT to compare smoke alarm and battery function. The original RCT was designed to examine long-term function of smoke alarm and battery combinations. Details about the study design, study protocol, the CONSORT diagram, and the RCT results can be found elsewhere.^{11–13} In summary, participants in the smoke alarm trial were recruited between July 2003 and June 2004 from an ongoing cohort study in a rural Iowa county.¹⁴ From the original 1187 cohort households, 1005 were located. Of these, 691 (68.8%) agreed to participate, 100 (10%) could not be contacted after four attempts on different days and times, 214 (21.3%) refused, and 3 were excluded because their alarms were hardwired and not subject to replacement by study alarms. The smoke alarm trial examined photoelectric and ionization smoke alarms as well as carbon-zinc and lithium batteries. Participating homes were randomized into one of the four smoke alarm/battery combinations: ionization/zinc, ionization/lithium, photoelectric/zinc, and photoelectric/lithium. The randomization scheme led to a similar distribution of households by smoke alarm/battery type. Randomization groups had similar distributions of households by number of occupants, occupants' age and gender, smokers, and age of household.

A study researcher who was a volunteer firefighter and trained in smoke alarm installation according to

guidelines of the National Fire Protection Association visited the home of each participant to conduct a baseline survey, identify the type of any smoke alarms found in the home, and test the function of these existing alarms (these alarms were designated "original alarms"). Original smoke alarms were replaced with study alarms by randomization category. Follow-up visits to test the study smoke alarms were conducted at 12 and 42 months postinstallation, through February 2008. At the 42-month follow-up, 81.9% of the smoke alarms installed through the study were functional. Ionization alarms with zinc batteries were the least likely to function (72.7%); photoelectric alarms with lithium batteries were the most likely to function (88.8%).¹³ A total of 633 (91.6%) households were followed through 42 months, and these 633 households were included in this analysis. The study was approved by the University of Iowa Institutional Review Board in September 2002.

Smoke Alarm Tests

Smoke alarm tests were conducted at three points: 1) the original smoke alarms; 2) at the 12-month follow-up for the study smoke alarms; and 3) at the 42-month follow-up for the study smoke alarms. The original smoke alarms found in the homes at study baseline were tested before replacement with study alarms. After testing the original alarms, they were removed and replaced with study alarms according to the household randomization scheme. At installation, all study smoke alarms passed both the button test and the smoke test. Study smoke alarms were tested at the 12- and 42-month follow-up visits.

Two tests were used to identify smoke alarm function. Alarms were first tested by pressing the smoke alarm test button to test the alert function of the smoke alarm. The alarm button was pushed for 3 seconds, and the alarm was considered to be functional on this test if it sounded within 3 seconds. Alarms were also tested by a chemical smoke test to test both alert and sensor functions. Chemical smoke was sprayed at a distance of 3 inches into the smoke alarm for 3 seconds. The alarm was considered to be functional on this test if it sounded within 3 seconds.

Statistical Analysis

The proportion of alarms passing both tests, one of the two tests, or neither test was compared for the original smoke alarms and for the study smoke alarms at 12- and 42-month postinstallation. Functionality was examined by smoke alarm and battery types using χ^2 tests.

Table 1. Smoke alarm function comparing chemical smoke test and alarm button test, 1105 original smoke alarms in 633 households*

	Ionization			Photoelectric			Total (n = 1105)
	Carbon-Zinc (n = 57)†	Alkaline (n = 1013)	Lithium (n = 12)	Carbon-Zinc (n = 4)	Alkaline (n = 16)	Lithium (n = 3)	
Passed both tests	37 (64.9)	819 (80.8)	11 (91.7)	4 (100.0)	12 (75.0)	2 (66.7)	885 (80.1)
Passed smoke test only‡	1 (1.8)	12 (1.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	13 (1.2)
Passed button test only§	8 (14.0)	56 (5.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	64 (5.8)
Failed both tests	35 (7.2)	126 (12.4)	1 (8.3)	0 (0.0)	4 (25.0)	1 (33.3)	167 (15.1)

* 132 alarms with missing smoke alarm or battery types were excluded; 40 hardwired smoke alarms were excluded.
† Carbon-zinc had significantly more alarm failures than alkaline ($P < .01$). Cell sizes were too small to test other comparisons.
‡ Alarms that pass the smoke test only are functional but appear to the consumer not to work.
§ Alarms that pass the button test only appear to the consumer to work, but will not respond in a fire.

RESULTS

Table 1 represents the distribution of smoke alarm types purchased by home owners and found in their homes before the randomized trial. Among the 1105 smoke alarms found in the study homes at baseline, 13 (1.2%) passed the smoke test but not the button test, indicating that the alarm was functioning but the button mechanism had broken (Table 1). Of the same 1105 alarms, 64 (5.8%) passed the button test but not the smoke test, indicating that the sensor function failed (ie, alarm could not detect smoke and would not function in a fire), although the button test indicated that the alarm was functioning. Ionization

alarms with zinc batteries had the highest proportion of alarms that passed the button test but failed the smoke test (14.0%). Only 23 (2.1%) of the original alarms were photoelectric, and none of these were discordant on the test results.

After 12 months of follow-up, 19 (1.0%) of alarms passed the smoke test only and 17 (0.9%) passed the button test only (Table 2). By 42 months of follow-up, 3.0% of alarms passed the smoke test only and 0.5% passed the button test only. In both follow-up periods, alarms with zinc batteries (with battery life lasting approximately 18–24 months) were significantly more likely to pass the smoke test but fail the

Table 2. Smoke alarm function comparing chemical smoke test and alarm button test, 12 months and 42 months after installation in 633 rural Iowa homes

	Ionization		Photoelectric		Total (n = 1928)
	Carbon-Zinc (n = 483)	Lithium (n = 458)	Carbon-Zinc (n = 438)	Lithium (n = 549)	
12-mo follow-up*					
Total	483	458	438	549	1928
Passed both tests	440 (91.1)	437 (95.4)	412 (94.1)	527 (96.0)	1816 (94.2)
Passed smoke test only†	5 (1.0)	3 (0.7)	8 (1.8)	3 (0.6)	19 (1.0)
Passed button test only‡	3 (0.6)	1 (0.2)	3 (0.7)	10 (1.8)	17 (0.9)
Failed both tests	35 (7.2)	17 (3.7)	15 (3.4)	9 (1.6)	76 (3.9)
42-mo follow-up§					
Total	451	431	447	521	1850
Passed both tests	330 (73.2)	370 (85.8)	347 (77.6)	451 (86.6)	1498 (81.0)
Passed smoke test only†	11 (2.4)	8 (1.9)	20 (4.5)	17 (3.3)	56 (3.0)
Passed button test only‡	3 (0.7)	1 (0.2)	4 (0.9)	2 (0.4)	10 (0.5)
Failed both tests	107 (23.7)	52 (12.1)	76 (17.0)	51 (9.8)	286 (15.5)

* Alarms with lithium batteries were more likely to function on both tests than alarms with carbon-zinc batteries ($P < .01$).
† Alarms that pass the smoke test only are functional but appear to the consumer not to work.
‡ Alarms that pass the button test only appear to the consumer to work but will not respond in a fire.
§ Photoelectric alarms were more likely to function on both tests ($P < .01$) than ionization; carbon-zinc batteries were more likely to pass the smoke test only than lithium batteries ($P < .01$); and lithium batteries were more likely to function than carbon-zinc batteries ($P < .01$).

button test. Photoelectric alarms with lithium batteries (with a battery life lasting approximately 10 years) were the most likely to pass the button test but fail the smoke test in the 12-month follow-up, and alarms with zinc batteries were the most likely to pass the button test but fail the smoke test at the 42-month follow-up.

CONCLUSIONS

Alarms that passed the button test and failed the smoke test may be particularly dangerous because these alarms appear to the consumer to function (through the button test) even though the alarm will not respond to smoke in a fire. The percentage of these alarms was highest among the smoke alarms found in homes at baseline, which best represents the population of smoke alarms that would be expected without intervention (as these were not study alarms). These may also be older smoke alarms than the study alarms.

Although the proportion of these alarms was small (5.8% of original alarms), they could pose a significant threat to home occupants in the case of a fire. The United States had an estimated 112,362,848 households in 2008 (<http://www.census.gov/population/projections/nation/hh-fam/table1n.txt>). The average household, including single and multiple family homes, requires three smoke alarms to be fully covered. Thus, if every household had sufficient smoke alarms, there would be approximately 337,088,544 installed in U.S. households, of which 19,551,136 would not operate during a fire even though the alarm test button worked. Research on smoke alarm function in low- and middle-income countries is nearly nonexistent, but lack of smoke alarm test regulations in many countries suggests that a higher proportion of smoke alarms internationally could be nonfunctional.

Alarms that pass the smoke test but not the button test would function in a fire, although the consumer relying on the test button would not know that the alarm was working. In this type of test discordance, the smoke alarm button mechanism is the nonfunctional part. This discordance could lead the consumer to replace batteries that remain operational or to replace the alarm (even though it would work), which is a cost consideration. This result was most common after 42 months of follow-up, which suggests that with age, alarm button mechanisms become more likely to fail.

Although we could not measure the age of the original smoke alarms in households at baseline, it is

likely that the original smoke alarms were older than the study alarms. If so, this suggests that as smoke alarms age, the ability to detect smoke may fail. In addition to changing smoke alarm batteries, consumers also need to periodically replace their smoke alarms.

Discordance on smoke alarm test results were found in all combinations of smoke alarm and battery types to varying degrees at different study periods. Generally, discordance was higher for carbon-zinc than lithium batteries. This result is consistent with the findings from the original smoke alarm trial, which found that lithium batteries, and in particular in combination with a photoelectric alarm, were most likely to function after 42 months of follow-up.¹³ These findings suggest that lithium batteries are more likely to function and also have a longer battery life than carbon-zinc batteries (10 years vs 18 months).

This study has several limitations. We did not examine the location of smoke alarms with regard to test results. We did not collect information about the original smoke alarms beyond the type of alarm and battery.

These data represent a challenge to residential fire safety advocacy efforts. Although smoke alarms can reduce the risk of residential fire death by half,^{2,3} approximately one-third of residential fire deaths in the United States occur in a home without a functioning smoke alarm.^{15,16} Although surveys in the United States indicate that more than 90% of households have at least one functional smoke alarm, fewer than 20% of residents report regularly checking their function.^{17,18} Proper maintenance is essential; the National Fire Protection Agency reports that 23% of fire deaths occurred in homes with smoke alarms that did not function.¹⁹

The number of consumers who use the chemical smoke test to test their smoke alarms is unknown but is likely to be very small because such a small proportion of homes report any type of routine smoke alarm maintenance. Small cans of smoke detector test spray can be purchased for approximately \$3.00 online or at most safety supply stores. Using chemical smoke may represent one additional step and thus a potential barrier to proper smoke alarm maintenance. Burn professionals can help educate consumers about the most effective methods for testing their smoke alarms and encourage replacement of alarms as instructed by the manufacturers.

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