Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

American Journal of Infection Control 41 (2013) 1218-23

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major article

Physiologic and other effects and compliance with long-term respirator use among medical intensive care unit nurses

Terri Rebmann PhD, RN, CIC [a,*], Ruth Carrico PhD, RN, CIC [b], Jing Wang PhD [c]

[a] Institute of Biosecurity, Saint Louis University, School of Public Health, St Louis, MO
[b] School of Medicine, University of Louisville, Louisville, KY
[c] Department of Biostatistics, Saint Louis University School of Public Health, St Louis, MO

Key Words:
Filtering face piece respirator
Pandemic
Influenza
Preparedness
Disaster
N95 respirator

Background: Long-term use of respiratory protection may be necessary, but compliance may be low, and physiologic effects have not been well evaluated.

Methods: Ten nurses participated; physiologic effects, subjective symptoms, and compliance with wearing an N95 alone or with a surgical mask overlay were assessed. Longitudinal analysis based on multivariate linear regression models assessed changes in outcome variables (CO_2, O_2, heart rate, perceived comfort items, compliance measures, and others). Analyses compared changes over time, and compared wearing only an N95 to wearing an N95 with a surgical mask overlay.

Results: Most nurses (90%, n = 9) tolerated wearing respiratory protection for two 12-hour shifts. CO_2 levels increased significantly compared with baseline measures, especially when comparing an N95 with a surgical mask to only an N95, but changes were not clinically relevant. Perceived exertion; perceived shortness of air; and complaints of headache, lightheadedness, and difficulty communicating also increased over time. Almost one-quarter (22%) of respirator removals were due to reported discomfort. N95 adjustments increased over time, but other compliance measures did not vary by time. Compliance increased on day 2, except for adjustments, touching under the N95, and eye touches.

Conclusion: Long-term use of respiratory protection did not result in any clinically relevant physiologic burden for health care personnel, although many subjective symptoms were reported. N95 compliance was fairly high.

Pandemics, outbreaks of emerging infectious diseases, and bioterrorism attacks may necessitate long-term filtering face piece respirator (N95) use for health care personnel.[1] However, researchers and experiences during the 2009 influenza A pandemic indicate that N95 supplies may be insufficient during a future event.[1,2,3] In response to this potential problem, the Centers for Disease Control and Prevention (CDC)[4] and the Occupational Safety and Health Administration[5] issued guidance regarding extending the use or reuse of N95s during a future influenza pandemic. In addition, the Institute of Medicine issued a report that proposed a strategy for prolonging the useful life of N95s through the use of a surgical mask overlay that is intended to provide barrier protection for the N95.[6]

Research examining potential physiologic impacts of long-term N95 use has been limited. Most has been laboratory based,[7,8] meaning that work conditions were approximated by walking on a treadmill and/or involved young, healthy subjects.[9,10] Only 1 study has examined long-term N95 use among health care personnel in an actual work setting,[11] and that study only assessed perceived intolerance. In addition to physiologic factors, researchers indicate that subjective symptoms/conditions, such as perceived comfort, headaches, or difficulty communicating with patients, may affect health care personnel's tolerance of long-term N95 use. In retrospective studies, researchers reported that long-term use of N95s during the severe acute respiratory syndrome outbreak was associated with an increased frequency of headaches[12] and physical discomfort.[13]

In addition to examining tolerance, it is important to assess staff compliance. Noncompliance with N95 use can put staff at risk from

* Address correspondence to Terri Rebmann, PhD, RN, CIC, Associate Professor, Institute for Biosecurity, Saint Louis University School of Public Health, 3545 Lafayette Avenue, Room 463, Saint Louis, MO 63104.
E-mail address: rebmannt@slu.edu (T. Rebmann).

Support for this study was provided in support of community and business resilience by the Kentucky Critical Infrastructure Protection program, managed by the National Institute for Hometown Security for the US Department of Homeland Security.

Conflicts of interest: None to report.

http://dx.doi.org/10.1016/j.ajic.2013.02.017

infection, a factor believed to be associated with the high rate of severe acute respiratory syndrome among health care personnel.[14] A study using self-reported compliance found that less than half of all health care personnel reported being compliant when using an N95, and that study only examined the practice of touching the N95 when measuring compliance.[15] Other noncompliant behaviors, such as adjusting the N95 during use or touching under the N95, were not assessed. In addition, researchers indicate that N95 compliance may decrease over time; the longer N95s are worn, the less compliant staff become.[16] A prospective study examining tolerance and observed compliance with long-term N95 use among health care personnel providing routine patient care in an actual work environment has never been conducted.

The purpose of this study was to determine physiologic and subjective effects of long-term respiratory protection (ie, N95 and N95 with a surgical mask overlay) use among health care workers during routine patient care duties. Aims included the following: (1) determine changes to transcutaneous carbon dioxide (CO_2) and oxygen saturation (O_2) levels related to long-term N95 use; (2) determine whether the addition of a surgical mask as an outer barrier over an N95 results in increased physiologic and subjective effects compared with the use of an N95 alone; (3) determine whether subjective symptoms, such as comfort and perceived exertion, increase during long-term N95 use; and (4) evaluate health care personnel N95 compliance during long-term use.

METHODS

This study used a repeated-measures crossover design. All subjects were followed for two 12-hour shifts/days (intersession interval $\geq$1 day). After being evaluated for eligibility, participants were randomly assigned to wear only an N95 or an N95 with mask overlay for a single 12-hour shift. During the second shift, participants were crossed over to the other intervention.

Subjects

Inclusion criteria included nurses working in the University of Louisville Hospital medical intensive care unit (MICU) who are nonsmokers (defined as having never smoked or not smoked in the last year), 20 to 50 years old, not pregnant, and able to pass quantitative fit testing. Exclusion criteria included any medical or physical symptom/condition that could potentially put subjects at risk from prolonged N95 use, including pregnancy, arrhythmias, hypertension, poorly controlled asthma, history of panic attacks or claustrophobia, and/or seizure disorder. Quantitative fit testing was conducted on all potential subjects prior to study enrollment; only those who passed fit testing were enrolled. Ten subjects were enrolled.

Variable measurement

Physiologic and subjective symptoms were measured at baseline (ie, start of shift before putting on N95 or N95/mask), every 30 minutes throughout the shift, before N95 or N95 mask removal during shift, and at end of shift. Physiologic variables included blood pressure, heart rate, CO_2, and O_2. CO_2 and O_2 were measured using a SenTec CO_2 and O_2 saturation sensor (SenTec AG, Therwil, Switzerland). Subjective symptoms measured include perceived exertion, perceived thermal comfort, perceived respirator comfort, and subjective symptoms related to wearing an N95. Perceived exertion was measured using the Borg Rating of Perceived Exertion Scale,[8] consisting of a Likert scale ranging from 6 to 20 points, with 6 = *no exertion at all* to 20 = *maximal exertion*. Perceived comfort was measured using a modified Frank Scale of Perceived Thermal Comfort Scale,[8] consisting of a Likert scale ranging from 0 to 10 points, with 0 = *coldest you've ever been* to 10 = *hottest you've ever been*. Perceived N95 comfort was measured using a modified Roberge Respirator Comfort Scale,[8] consisting of a Likert scale ranging from 1 to 5 points, with 1 = *most comfortable you've ever felt wearing an N95 respirator* to 5 = *most uncomfortable you've ever felt wearing an N95*. Subjective symptoms related to wearing an N95 included nausea, headache, light headedness, visual difficulties, shortness of breath, palpitations, confusion, and difficulty communicating; these variables were assessed using the Roberge Subjective Symptoms During Work Scale,[8] a Likert scale ranging from 1 to 5 points, with 1 = *not noticeable* to 5 = *very noticeable*. Study researchers collected the physiologic and subjective symptom data.

Respirator compliance was measured by direct observation of subjects throughout their work shift. Observations were conducted by student workers; inter-rater reliability was assessed prior to data collection. Compliance observations were obtained for a 10-minute interval during each hour of each shift (12 observations per subject per shift) by watching the nurse as he/she performed work duties. The following components of N95 compliance were collected: (1) number of N95 adjustments, (2) number of N95 touches, (3) number of face touches (ie, touching anywhere on the face, not counting the eye[s]), (4) number of under-the-N95 touches (ie, using a hand or finger[s] to reach under the N95), and (5) number of eye touches. Because of patient care priorities that required the nurses to be in a room with the blinds drawn for privacy, some compliance data collection points were late or missed altogether.

MICU temperature and relative humidity were measured and documented at the start and end of each shift during the study; readings were obtained at the nurses' station in the center of the unit. Subjects were provided Kimberly Clark N95s and Kimberly Clark Tecnol surgical masks for the study. These were chosen because they are one of the brands stockpiled by the CDC's Strategic National Stockpile and are likely to be the brands provided to hospitals during a pandemic. Subjects were instructed to follow their employer's extended use/reuse policy related to N95 use; this policy is based on published guidance outlining safe extended/reuse of N95s.[1] Subjects could replace their N95 and/or N95/mask combination as needed because of discomfort, perceived loss of integrity, and others. The University of Louisville and Saint Louis University institutional review boards approved this study.

Data analysis

Longitudinal analysis based on multivariate linear regression models were used to assess changes in outcome variables (blood pressure, CO_2, O_2, heart rate, perceived comfort items, compliance measures, and others) over time. The advantage of using longitudinal study is that it provides information about individual change over time, separate from differences among subjects at baseline. Analyses were run comparing changes over time because of wearing only an N95 and comparing changes when wearing only an N95 to wearing an N95/mask combination. *T* tests were used to compare the average time nurses wore their assigned respiratory protection before first removal and the average time they wore the 2 types of respiratory protection. All analyses were conducted using SAS (SAS Institute Inc, Cary, NC).

RESULTS

Ten MICU nurses participated in the study on day 1; 9 completed both days. All participating nurses were white, and most (90%, n = 9) were female, with an average age of 35 (range: 24-48) years. Most (60%, n = 6) had a bachelor's degree and were not

Table 1
Tolerance for and compliance with wearing respiratory protection

	Day 1			Day 2		
	N95 alone	N95 plus mask	*P* value*	N95 alone	N95 plus mask	*P* value*
Average time worn before first removal (min)	214.4	199	NS	171	219.3	NS
Average time worn per episode (min)	223.7	159.1	NS	145.3	207.6	NS
	Mean			Mean		
	N95 alone	N95 plus mask	*P* value*	N95 alone	N95 plus mask	*P* value*
Number of face touches	5.8	5.8	NS	3.6	2.3	NS
Number of eye touches	0	.80	NS	.80	.75	NS
Number of N95 touches	14.6	8.0	NS	6.6	10.7	NS
Number of touches under the N95	0	1.0	NS	.80	.50	NS
Number of N95 adjustments	6.6	8.8	NS	3.2	6.5	NS

N95, N95 respirator; *NS*, nonsignificant.
*As determined by a *t* test.

Table 2
Impact of long-term respirator usage, alone and with mask overlay, on respirator compliance

	Noncompliant behavior when examining only those wearing an N95 alone									
	Face touches		Eye touches		N95 touches		Touches under the N95		N95 adjustments	
Factor	β	*P* value	β	*P* value	β	*P* value	β	*P* value	β	*P* value
BMI	.002	NS	.007	NS	.10	<.01	.008	NS	−.01	NS
Time	.002	NS	.003	NS	.02	NS	−.002	NS	−.03	<.05
Years wearing N95	.05	=.05	−.007	NS	.10	<.05	−.02	<.01	−.01	NS
Day shift	−.30	NS	.07	NS	−.30	NS	.20	=.01	.50	NS
	Noncompliant behavior when comparing wearing an N95 alone to an N95 plus mask									
	Face touches		Eye touches		N95 touches		Touches under the N95		N95 adjustments	
Factor	β	*P* value	β	*P* value	β	*P* value	β	*P* value	β	*P* value
Day 2	−.20	=.05	.04	NS	−.40	<.05	.01	NS	−.30	NS
Day shift	−.20	NS	.10	=.05	.60	=.05	.10	NS	.80	<.001

N95, N95 respirator; *BMI*, body mass index; *NS*, not significant.

a charge nurse (80%, n = 8). Participants had an average of 11 years of experience wearing an N95 and 9.5 years of nursing experience; 60% (n = 6) worked day shift. All but 1 (90%) were overweight as determined by having a body mass index (BMI) equal to or greater than 25, and half (n = 5) were obese (ie, BMI ≥ 30).

Respirator tolerance and compliance

Most nurses (90%, n = 9) tolerated the use of respiratory protection for 2 full 12-hour shifts. Only 1 (10%) withdrew because of unwillingness to continue wearing respiratory protection; this subject wore it for approximately 30 minutes before withdrawing from the study. Of the nurses who participated in the entire study, each used an average of 3 N95s for each 12-hour shift. Nurses wore the N95 alone or with a mask for 214 and 199 minutes on average, respectively, before the first removal for any reason (Table 1); this time difference was not significant. Daily average times wearing the N95 alone or with a surgical mask during each episode were 223.7 and 159.1, respectively (Table 1); this time difference was not significant. Each time a nurse removed his/her N95, the reason for removal was documented. In total, nurses removed their respirator 68 times during the study, either to eat or drink, because it was the end of his/her shift, or because the N95 was uncomfortable in some way. About half of the removals (55.9%, n = 38) were reported to be because the nurse wanted to eat or get a drink. About one-quarter of the removals (22.1%, n = 15) were because the shift ended, and the remaining one-quarter (22.1%, n = 15) were due to reported discomfort. Qualitative statements made by nurses as reasons for removal included comments such as, "It is getting hard to breathe," "[the N95] is uncomfortable," and "I can't breathe."

Five types of N95 noncompliance were assessed: (1) N95 adjustments, (2) N95 touches, (3) face touches, (4) under-the-N95 touches, and (5) eye touches. On average, each nurse was noncompliant with their respirator 25.7 times per shift. The most frequent types of noncompliance included touching the N95 and adjusting the N95 or N95/mask combination. There was no relationship between the amount of time an N95 or N95/mask combination was worn and compliance with wearing the N95 on 4 of the 5 compliance measures: face, eye, or N95 touches or touches under the N95 (Table 2). Nurses wearing an N95 alone were less likely to adjust it toward the end of their shift compared with earlier in the shift; in contrast, when nurses were wearing the N95/mask combination, the number of N95 adjustments did not vary by time (Table 2). Compliance increased on day 2 in relation to the number of times a nurse touched the N95, regardless if he/she was wearing only an N95 or a N95/mask combination (Table 2).

Effects of long-term respirator and respirator/mask combination use

Wearing an N95 for an entire 12-hour shift had statistically significant negative effects on some physiologic measures and subjective symptoms. Over time, nurses' CO_2 levels became significantly elevated, from a statistical standpoint, compared with beginning-of-shift baseline measures; perceived exertion; perceived shortness of air; and complaints of headache, lightheadedness, and difficulty communicating also increased over time (Tables 3 and 4). CO_2 levels increased from a baseline average of 32.4 at the beginning of the shift to 41.0 at the end of each shift. There were no changes in nurses' blood pressure, O_2 levels, perceived comfort,

Table 3
Impact of long-term respirator usage on physiologic measures and subjective symptoms

	Blood pressure		CO_2		O_2		Heart rate	
Factor	β	*P* value	β	*P* value	β	*P* value	β	*P* value
BMI	−.003	NS	−.10	NS	−.07	<.05	2.0	<.001
Age	−.02	<.001	−.20	<.05	−.001	NS	.01	NS
Time	.003	NS	.20	<.01	.005	NS	−.30	NS
Years wearing N95	.02	<.001	.30	<.01	−.05	NS	−.20	NS
Day shift	−.20	<.05	−3.5	<.01	.80	<.05	−2.7	NS

	Headache		Lightheadedness		Visual challenge	
Factor	β	*P* value	β	*P* value	β	*P* value
BMI	.10	<.001	.02	<.05	.03	<.001
Age	.06	<.01	−.01	=.01	.06	<.001
Day 2	1.2	<.001	.008	NS	.06	NS
Time	.07	<.001	.01	<.01	.005	NS
Years wearing N95	−.10	<.001	−.01	NS	−.08	<.001
Day shift	1.3	<.001	.40	<.001	.01	NS

BMI, body mass index; *NS*, not significant.

perceived thermal comfort, or complaints of visual difficulties compared with baseline levels.

Wearing an N95 with surgical mask overlay had statistically significant negative effects over and above those associated with wearing only an N95. CO_2 levels, nausea, and complaints of visual challenges increased significantly more when nurses were wearing the N95 and mask than when only wearing an N95 (see Table 5). Wearing an N95 with mask did not have a significant negative impact over and above wearing only an N95 in relation to blood pressure, O_2 levels, heart rate, headache, lightheadedness, perceived exertion, perceives shortness of breath, perceived comfort, perceived thermal comfort, or impeded communication.

Relationship between weight and respirator tolerance and compliance

Nurses having a higher BMI had statistically significant negative effects on some physiologic measures and subjective symptoms than nurses with lower BMIs, independent of time the N95 was worn or whether they wore an N95 alone or with a mask. Nurses with a higher BMI had lower O_2 levels and higher heart rates while wearing either type of respiratory protection (an N95 alone or with a mask) (Tables 3 and 5). Heavier nurses also reported significantly more negative effects on subjective symptoms than nurses who weighed less. Nurses with higher BMIs reported higher perceived exertion, perceived shortness of breath, perceived discomfort, complaints of feeling warm while wearing the N95, headaches, lightheadedness, visual challenges, and impeded communication than nurses with lower BMIs, independent of time the N95 was worn or whether they wore an N95 alone or with a mask (Tables 3-5). Complaints of nausea also increased significantly more among nurses with a higher BMI when wearing an N95 plus a surgical mask than among nurses with a lower BMI (Table 5). Nurses with higher BMIs also performed one of the most potentially high-risk noncompliant behaviors in terms of cross contamination than nurses with lower BMIs: touching the N95. Nurses with a higher BMI were significantly more likely than those with a lower BMI to touch their respirator when wearing an N95 (Table 2).

DISCUSSION

From a physiologic standpoint, the nurses participating in this study tolerated long-term use of respiratory protection well, regardless of whether they wore an N95 alone or with a surgical mask overlay. The only negative physiologic change resulting from long-term respiratory protection use was elevated CO_2 levels, with CO_2 increasing over time when wearing an N95 alone, and increasing even more significantly, from a statistical standpoint, when wearing an N95 and mask compared with when they only wore an N95. However, although there were statistically significant negative physiologic changes over time associated with wearing respiratory protection (especially among those wearing an N95 with a mask overlay), these changes were not clinically relevant. For instance, the statistically significant rise in CO_2 levels over time from baseline to the end of the shift did not result in CO_2 levels that reached the clinical definition of hypercapnia (defined as an arterial CO_2 level $\geq$ 45). Therefore, from a physiologic perspective, long-term use of respiratory protection proved to not cause negative effects for the nurses in this study.

An interesting finding from this study is that, although the nurses did not experience any clinically significant negative physiologic effects from wearing respiratory protection, they reported many subjective symptoms. For example, perceived shortness of breath increased over time when nurses wore any type of respiratory protection. Although physiologic measures of heart rate, O_2, and CO_2 did not reflect a difficulty with gas exchange, nurses reported feeling more short of breath the longer they wore respiratory protection. Other subjective symptoms also increased over time, including complaints of headache, lightheadedness, perceived exertion, and impeded communication. When wearing an N95 with mask overlay, nurses reported feeling more nausea and had more visual challenges than when they wore only an N95. Although these symptoms do not represent life-threatening conditions, they are unpleasant and may affect health care personnel's willingness or ability to tolerate long-term N95 usage that would be necessary during a disaster.

Contrary to prior research on health care personnel tolerance of long-term use of respirators that found that the average time health care personnel would tolerate N95 usage was less than 8 hours,[11] this study found that almost all nurses were willing to wear the assigned respiratory protection for the duration of two 12-hour shifts (ie, the entire length of the study). In this study, only 1 nurse had high intolerance to wearing an N95 (as evidence by withdrawing from the study because of discomfort after only half an hour). The reasons for the longer tolerance despite increasing complaints of discomfort seen in this study are not known. It is possible that the timing of the 2 studies played a role in the subjects' tolerance for wearing N95s. This study occurred after the 2009 H1N1 pandemic, an event that necessitated prolonged use of N95s for many health care personnel until the H1N1 vaccine was released, and one that involved a shortage of N95s among many health care agencies.[3] Study participants' recent experiences during the 2009 pandemic may have provided increased motivation to tolerate long-term use of N95s.

Although the majority of nurses in this study had a high tolerance for long-term respirator use, 1 of the 10 subjects withdrew very early on because of discomfort. In addition, some MICU nurses who worked at the hospital from which subjects were recruited refused to participate because of an unwillingness to wear an N95 for 2 entire shifts. It is likely that volunteer subjects tolerate wearing N95s better than those who refused to even be screened for the study. This has implications for future disasters during which health care personnel may be required to wear N95s for long periods of time. More frequent work breaks may need to be incorporated into work shifts when long-term N95 use is required. Future studies should also examine other factors that may help increase health care personnel tolerance of long-term N95 usage.

A unique finding from this study is the relationship between weight and N95 tolerance and compliance. Nurses with higher

Table 4
Impact of long-term respirator usage, alone and with mask overlay, on perceived exertion and comfort

	Perceived exertion and comfort of those only wearing an N95 alone									
	Perceived exertion		Perceived shortness of breath		Perceived discomfort		Thermal discomfort		Impeded communication	
Factor	β	*P* value	β	*P* value	β	*P* value	β	*P* value	β	*P* value
BMI	.40	<.001	.05	<.01	.05	<.01	.20	<.001	.07	<.001
Age	.10	<.001	−.001	NS	.03	<.05	−.03	NS	−.01	NS
Day 2	.50	NS	1.0	<.001	.30	NS	−.50	NS	.60	<.05
Time	.07	<.001	.02	=.01	.01	NS	.003	NS	.02	=.01
Years wearing N95	−.30	<.001	.03	<.05	−.06	<.001	−.06	<.05	−.07	<.001
Day shift	1.3	<.01	.50	=.01	.50	=.01	−.30	NS	1.2	<.001
	Perceived exertion and comfort when comparing wearing an N95 alone to an N95 plus mask									
	Perceived exertion		Perceived shortness of breath		Perceived discomfort		Thermal discomfort		Impeded communication	
Factor	β	*P* value	β	*P* value	β	*P* value	B	*P* value	β	*P* value
BMI	.40	<.001	.10	<.001	.03	<.01	.10	<.001	.20	<.001
Age	.05	<.01	−.05	<.001	.008	NS	−.04	<.001	−.05	<.001
Day 2	.20	NS	−.08	NS	.20	<.01	−.02	NS	.008	NS
Time	.05	<.001	.02	<.01	.01	NS	.01	NS	.02	<.01
Years wearing N95	−.20	<.001	.06	<.001	−.05	=.001	−.03	NS	−.01	NS
Day shift	1.2	<.001	−.09	NS	.70	<.001	−.10	NS	.80	<.001

N95, N95 respirator; *BMI*, body mass index; *NS*, not significant.

Table 5
Impact of long-term respirator usage on physiologic measures and subjective symptoms when comparing an N95 alone versus an N95 with mask overlay

	Blood pressure		CO_2		O_2		Heart rate	
Factor	β	*P* value	β	*P* value	β	*P* value	β	*P* value
BMI	−.007	<.05	−.20	<.001	−.06	<.001	1.6	<.001
N95 & mask	−.002	NS	1.0	<.01	−.20	NS	2.0	NS
Age	−.02	<.001	−.06	NS	.02	NS	.10	NS
Day 2	−.02	NS	.90	=.01	.20	=.05	.80	NS
Time	−.0005	NS	.10	<.001	−.009	NS	.003	NS
Years wearing N95	.02	<.001	.20	<.01	−.04	NS	−.30	NS
Day shift	−.07	NS	−1.7	<.05	.50	<.05	−.60	NS
	Headache		Nausea		Lightheadedness		Visual challenge	
Factor	β	*P* value	β	*P* value	β	*P* value	β	*P* value
BMI	.20	<.001	.01	<.001	.02	<.001	.10	<.001
N95 & mask	−.01	NS	.04	=.01	.04	NS	.40	<.001
Age	.03	<.05	−.004	<.05	−.02	<.01	.02	<.01
Day 2	.30	<.01	−.04	<.05	−.05	NS	−.20	=.01
Time	.08	<.001	.003	NS	.01	<.001	.004	NS
Years wearing N95	−.09	<.001	.007	<.05	−.02	<.01	.004	NS
Day shift	.80	<.001	−.02	NS	.40	<.001	−.50	<.001

N95, N95 respirator; *BMI*, body mass index; *NS*, not significant.

BMIs were less compliant when wearing an N95, in terms of being more likely to touch their respirator, than those with lower BMIs. This more frequent touching of the respirator may have been related to perceived discomfort because nurses with higher BMIs reported many more subjective symptoms (such as more perceived shortness of breath, discomfort, thermal discomfort, and headaches) related to wearing respiratory protection than nurses with lower BMIs. These findings have not been identified in previous research on N95 tolerance[8,11] and have potential significant implications for future disaster response. In the US general population, 33% of people are overweight (but not obese), and another 36% are obese[17]; data specific to nurses could not be found, but there is no reason to believe that a lower rate of obesity among health care personnel would exist compared with the United States as a whole. With such a high rate of overweight and/or obese health care personnel, and an associated lower tolerance for long-term N95 usage among these individuals, it may be difficult to safely implement extended use or reuse policies for N95s without building in additional break times for staff. Additional studies are needed to further examine the relationship between weight and N95 tolerance and compliance.

The nurses in this study were fairly compliant with wearing respiratory protection, meaning that they wore it correctly and did not frequently engage in behaviors that might lead to potential auto-inoculation, even over long periods of time. Contrary to the authors' hypothesis, nurses did not become less compliant over the course of a shift and actually became more compliant the second day of wear than the first in terms of the number of times they adjusted their N95 or touched their face or the respirator. The reasons for this are unknown but may be because the nurses became accustomed to wearing the N95 over the course of the study. This finding is different from a previously published study that found that N95 compliance decreases over time.[16] This may be because the Seale et al study[16] occurred over 4 weeks versus only 2 shifts observed in this study or because this sample consisted of only intensive care nurses. Researchers have indicated that intensive care unit staff are often more compliant with N95s than health care personnel in other areas/units.[15] One somewhat troubling finding from this study is that the most frequently performed noncompliant behaviors involved 2 practices that may put health care personnel at risk of exposure to infectious particles when wearing N95s: touching the N95 and/or adjusting it during use. Better or more frequent education of health care personnel may be needed to reduce these potentially harmful behaviors and protect workers from exposure because knowledge has been found to be associated with better adherence to proper respirator practice.[15]

Nurses in this study were asked to follow their hospital's extended use/reuse of N95 policy, which included instructions to replace their N95 whenever they believed the integrity was compromised, the N95 became soiled, or when they believed the N95 to be difficult through which to breathe. Sometimes the nurse participants reused an N95 (ie, redonned it after removal), and other times they chose to don a new N95. Each nurse used an average of 3 N95s per shift during the study, regardless of how often he/she chose to don and doff respiratory protection. This finding provides a general guideline for hospitals to use when estimating the number of N95s needed per staff member during a disaster if an extended-use/reuse policy is implemented by the agency and is different from previously published recommendations regarding

how to estimate the number of N95s that may be needed during a disaster.[2]

This is the first study to examine long-term use of respiratory protection in a health care setting in terms of compliance, tolerance, and physiologic effects of use. It is also the first study in a health care setting to compare the physiologic impact of wearing an N95 alone to the N95 with mask overlay combination recommended by the Institute of Medicine to be used during times of limited resources. This study also has a robust methodology because of the nature of the randomization of subjects and the repeated measures design. One potential limitation of this study is that volunteer subjects may tolerate N95s better than those who refused to be screened for the study, reducing the generalizability of the findings to all health care personnel. Another potential limitation is the use of transcutaneous measurement of CO_2 versus the more accurate method of arterial measurement; however, transcutaneous CO_2 measurement has been shown to have adequate accuracy,[18,19] and it has been used in all previous studies examining the physiologic impact of N95 use because of the avoidance of potential complications related to arterial punctures.[1,7] Last, because only intensive care unit nurses were recruited, the findings may not be generalizable to workers in other areas of the hospital or to non-nurse health care personnel.

CONCLUSION

Long-term use of N95s, when worn alone or with a mask overlay as an outer barrier, did not result in a significant physiologic burden for health care personnel over the course of 2 work shifts. Despite the fact that health care personnel reported subjective symptoms related to wearing N95s and that these complaints increased over time, worker tolerance for long-term N95 usage was high. Nurses' compliance with wearing N95s was also high, even after long-term use. Findings from this study indicate that many health care personnel can tolerate long-term use of N95s, alone or with an outer barrier. Additional studies are needed to further examine factors that influence intolerance of long-term use of N95s among some health care personnel and the relationship between weight and N95 tolerance and compliance to identify ways to maximize worker tolerance of N95s before another biologic disaster occurs.

Acknowledgment

The authors thank the MICU nurses who participated in this study and who not only agreed to wear respiratory protection for long periods of time while performing their job duties but were willing to interrupt their work to be assessed every 30 minutes.

References

1. Rebmann T, Alexander S, Cain T, Citarella B, Cloughessy M, Coll B, et al. APIC position paper: extending the use and/or reusing respiratory protection in health care settings during disasters. 2009. Available from: http://www.apic.org/Resource_/TinyMceFileManager/Advocacy-PDFs/APIC_Position_Ext_the_Use_and_or_Reus_Resp_Prot_in_Hlthcare_Settings1209l.pdf. Accessed October 11, 2009.
2. Radonovich LJ, Magalian PD, Hollingsworth MK, Baracco G. Stockpiling supplies for the next influenza pandemic. Emerg Infect Dis 2009;15:e1.
3. Rebmann T, Wagner W. Infection preventionists' experience during the first months of the 2009 novel H1N1 influenza A pandemic. Am J Infect Control 2009;37:e5-16.
4. Centers for Disease Control and Prevention. Interim guidance on planning for the use of surgical masks and respirators in health care settings during an influenza pandemic. 2006. Available from: http://www.cdc.gov/flu/professionals/infectioncontrol/maskguidance.htm. Accessed August 10, 2009.
5. Occupational Safety and Health Administration. Pandemic influenza preparedness and response guidance for healthcare workers and healthcare employers. 2007. Available from: http://www.osha.gov/Publications/3328-05-2007-English.html. Accessed October 15, 2010.
6. Goldfrank LR, Liverman CT. Preparing for an influenza pandemic: personal protective equipment for healthcare workers. Washington [DC]: Institute of Medicine; 2007.
7. Roberge RJ, Coca A, Williams WJ, Palmiero AJ, Powell JB. Surgical mask placement over N95 filtering facepiece respirators: physiological effects on healthcare workers. Resp 2010;15:516-21.
8. Roberge RJ, Coca A, Williams WJ, Powell JB, Palmiero AJ. Physiological impact of the N95 filtering facepiece respirator on healthcare workers. Respir Care 2010;55:569-77.
9. Mardimae A, Slessarev M, Han J, Sasano H, Sasano N, Azami T, et al. Modified N95 mask delivers high inspired oxygen concentrations while effectively filtering aerosolized microparticles. Ann Emerg Med 2006;48:391-9. e1-2.
10. Johnson AT, Scott WH, Lausted CG, Coyne KM, Sahota MS, Johnson MM. Effect of external dead volume on performance while wearing a respirator. AIHAJ 2000;61:678-84.
11. Radonovich LJ Jr, Cheng J, Shenal BV, Hodgson M, Bender BS. Respirator tolerance in health care workers. J Am Med Assoc 2009;301:36-8.
12. Lim EC, Seet RC, Lee KH, Wilder-Smith EP, Chuah BY, Ong BK. Headaches and the N95 face-mask amongst healthcare providers. Acta Neurologica Scandinavica 2006;113:199-202.
13. Nickell LA, Crighton EJ, Tracy CS, Al-Enazy H, Bolaji Y, Hanjrah S, et al. Psychosocial effects of SARS on hospital staff: survey of a large tertiary care institution. Can Med Assoc J 2004;170:793-8.
14. Ofner M, Lem M, Sarwal S, Vearncombe M, Simor A. Cluster of severe acute respiratory syndrome cases among protected health-care workers, Toronto, Canada, April 2003. Morb Mort Wkly Rep 2003;52:433-6.
15. Nichol K, McGeer A, Bigelow P, O'Brian-Pallas L, Scott J, Holness L. Behind the mask: determinants of nurse's adherence to facial protective equipment. Am J Infect Control 2013;41:8-13.
16. Seale H, Corbett S, Dwyer DE, MacIntyre CR. Feasibility exercise to evaluate the use of particulate respirators by emergency department staff during the 2007 influenza season. Infect Control Hosp Epidemiol 2009;30:710-2.
17. Centers for Disease Control and Prevention. Selected health conditions and risk factors: United States, selected years 1988-1994 through 2009-2010. 2011. Available from:http://www.cdc.gov/nchs/hus/healthrisk.htm. Accessed October 4, 2012.
18. Carter R, Banham SW. Use of transcutaneous oxygen and carbon dioxide tensions for assessing indices of gas exchange during exercise testing. Respir Med 2000;94:350-5.
19. Sridhar MK, Carter R, Moran F, Banham SW. Use of a combined oxygen and carbon dioxide transcutaneous electrode in the estimation of gas exchange during exercise. Thorax 1993;48:643-7.