Evaluation of the Filtration Efficiency of the N95 Filtering Facepiece Respirator for Airborne Methicillin-Resistant *Staphylococcus aureus*

D. D. Ferguson, T. C. Smith, K. J. Donham, P. T. O'Shaughnessy

ABSTRACT. *Airborne methicillin-resistant* Staphylococcus aureus *(MRSA) was detected inside a swine facility that presented a risk of respiratory colonization and infection to swine and swine workers. Viable airborne MRSA was sampled using an Andersen cascade impactor, and total airborne particulates were sampled using an optical particle counter. The filter efficiency of the N95 filtering facepiece respirator (FFR) was evaluated to determine its effectiveness for airborne MRSA. Our study showed that the filter for the N95 FFR had efficiency greater than 95% for airborne MRSA.*

Keywords. *Airborne MRSA, Air sampling, Bioaerosol, Confined animal feeding operation, N95 filtering facepiece respirator, Swine, Zoonosis.*

Numerous research publications have documented a variety of aerosol exposures that resulted in respiratory symptoms in producers and workers in swine buildings. Aerosolized particulate matter is one of those hazardous exposures. Animal feeding operations have been found to have high concentrations of dust particles. Dust particles in swine feeding facilities consist of predominantly organic material such as pig dander, animal feed, feces, fungi, bacteria, and gases (Chien et al., 2011; Clark et al., 1983; Crook et al., 1991; Donham et al., 1986). High levels of bioaerosols in swine feeding facilities have been linked to animal and human activities. The activity of feeding pigs has been identified to increase exposure to airborne dust to swine workers (Kim et al., 2008; O'Shaughnessy et al., 2010). Bioaerosols inside swine feeding facilities can lead to potential respiratory health hazards (Chang et al., 2001; Clark et al., 1983). Respiratory symptoms or conditions such as non-allergic asthma, organic toxic dust syndrome, and bronchitis have been identified in swine workers (Andersen et al., 2004; Crook et al., 1991; Donham et al., 1989).

An additional potentially hazardous exposure is antibiotics that are added to the feed or water. They are often added to the feed of growing animals at sub-therapeutic levels for the economic advantage of increased rate of weight gain and feed efficiency. However, using antibiotics in feed can present a risk of development of antibiotic-resistant organisms (Chapin et al., 2005; Murphy et al., 2007), possibly leading to resistant infections in swine and swine workers (Hong et al., 2012). Antibiotic-resistant bacteria have

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been detected in the nasal passages of swine workers (Létourneau et al., 2010; Smith et al., 2009). Methicillin-resistant *Staphylococcus aureus* (MRSA) is one of those organisms, being identified as a zoonotic pathogen in swine workers, veterinarians, and swine (Leedom Larson et al., 2010; Price et al., 2012). Although the clinical picture of livestock-associated MRSA is unclear in the U.S., hospital- and community-acquired MRSA has resulted in a major pubic health problem, resulting in upper respiratory infections, pneumonia, skin lesions, and nosocomial surgical site infections (Lozano et al., 2011; Ramirez et al., 2012; Smith et al., 2011). In the livestock environment, MRSA can spread by direct contact between swine workers and swine, contact with fomites, and through airborne transmission (Smith et al., 2010). The spread of MRSA via airborne transmission in swine facilities presents a potential respiratory hazard to swine workers and veterinarians (Leedom Larson et al., 2010; Smith et al., 2009; Smith et al., 2010).

The National Institute of Occupational Safety and Health (NIOSH) approved a standard to regulate the testing, certification, and use of respiratory devices to protect workers in environments where the source of inhalation hazards cannot be engineered out of the air (NIOSH, 1995). NIOSH designated three types of face filtering facepiece respirators (FFR): not resistant to oil (N), resistant to oil (R), and oil proof (P). The three types are certified at classifications of 95, 99, and 100, which represent 95%, 99%, and 99.97% filtering efficiency, respectively. The FFRs are pretreated at and tested under various conditions to simulate working conditions (Moyer and Stevens, 1989). Some of the conditions include testing at 38°C and 85% relative humidity for 42 days (NIOSH, 1995). To improve the efficiency of the FFRs and reduce face seal leakage, fit testing is also required by the NIOSH standard (NIOSH, 1995). N95 FFRs and surgical masks have been used for infection control in hospital settings. Surgical masks are used to protect patients from inhalation hazards from healthcare workers, and N95 respirators are used to protect the wearer from inhalation hazards from the environment (Chen et al., 1994; McCullough et al., 1997; Qian et al., 1998; Weiss et al., 2007).

To help protect workers in swine feeding facilities from airborne transmission of MRSA, a mitigation program protecting workers from aerosolized substances needs to be implemented. Although source control is the best approach, a respirator or personal respiratory protective device (RPD) may need to be used as an adjunct to source control, and may be the only protection perceived as possible and affordable by swine producers. When recommending and selecting a respirator for this purpose, one needs to choose an efficient RPD. Harnish et al. (2013) demonstrated that the N95 FFR was effective at filtering H1N1. The two-strap N95 FFR has been identified as an effective RPD to help prevent exposure to airborne contaminants, including infectious agents (Cho et al., 2010; Qian et al., 1998; Rengasamy et al., 2008). Although respirators for use in swine production have been evaluated for their effectiveness in protection from dusts (Popendorf et al., 1995), there has not been an evaluation of respirator efficiency for protection against infectious agents in swine buildings (Popendorf et al., 1995).

The purpose of this study was to evaluate the filter efficiency of the N95 FFR to protect against airborne MRSA exposure in a swine feeding facility. It was hypothesized that the filter associated with the N95 FFR would have an efficiency of at least 95% against airborne MRSA.

Materials and Methods

The efficiency of the N95 FFR was determined first by developing a test exposure chamber in the laboratory. After the test chamber was refined in the laboratory, it was taken to a swine facility, where air within the building was sampled gravimetrically and by a photometer particle counter (OPC) before and after flowing through the N95 FFR.

Sampling Site

A swine confined animal feeding operation (CAFO) study site in the Midwest was selected, as it was representative of modern swine production facilities, and we had previously documented that the workers and swine at the facility were culture positive for MRSA (Smith et al., 2009). The producers were willing to cooperate for this study, informed consent was obtained, and all requirements of the institutional review board (IRB) were followed. The veterinarian for the facility helped facilitate the study, providing consultation in the conduct of sampling at the facility. The study site consisted of two buildings and produced approximately 48,000 feeder hogs per year. Pigs entered the site at 14 days of age and left at the age of 60 days and weighing 23 kg (50 lbs). The stocking density of the two buildings was one pig per 0.37 m^2 (4 ft^2).

Ventilation for the facility was provided by sixteen 61 cm (24 in.) and eight 35 cm (14 in.) wall fans (both thermostat controlled) and eight 23 cm (9 in.) continuous pit fans. The facility had double-sided curtains that could be raised for increased ventilation during warm seasons. The volume of the study room was 364 m^3 (12,847 ft^3). The sampled facility was power washed with detergent and biocide between each group of pigs that cycled through the building. The topography of the area surrounding the facility was flat without any wind buffers.

Exposure Test Chamber

We refined the N95 FFR exposure test chamber at the Environmental Modeling and Exposure Assessment Facility at the Institute for Rural and Environmental Health of the University of Iowa. The respirator exposure test chamber was a modified version of a test chamber that had been used in a previous pilot study (Newnum, 2010). The laboratory setup is shown in figure 1. The N95 FFR (model 7130N95, North by Honeywell, Cranston, R.I.) was placed between two polymethyl methacrylate covers and placed inside a dust chamber with a metal tube of 6.4 mm (1/4 in.) outer diameter inserted at the back of the chamber. The N95 FFR was attached to this metal tube. An inlet tube was placed inside this metal tube to sample the airborne particles that passed through the N95 FFR (filtered air). A second inlet tube was inserted through the back of the test chamber and was positioned next to and in front of the N95 FFR to sample unfiltered air in the test chamber.

Two optical particle counters (OPCs, Grimm Technologies, Inc., Douglasville, Ga.) were used to sample the filtered and unfiltered air (Peters et al., 2006). Air was pulled through the sample inlets in the test chamber at 85 L min^{-1} flow rate, representing the NIOSH N95 FFR certification flow rate, by a stationary air mover (workshop vacuum cleaner) that was monitored with an inclined-vertical manometer and a Venturi flowmeter (Dwyer Instruments, Inc., Michigan City, Ind.). The OPCs operated at a flow rate of 1.2 L min^{-1}, and the chamber pressure was monitored with a digital manometer (Dwyer Instruments, Inc.). At the end of the preliminary test, the test chamber was taken into the

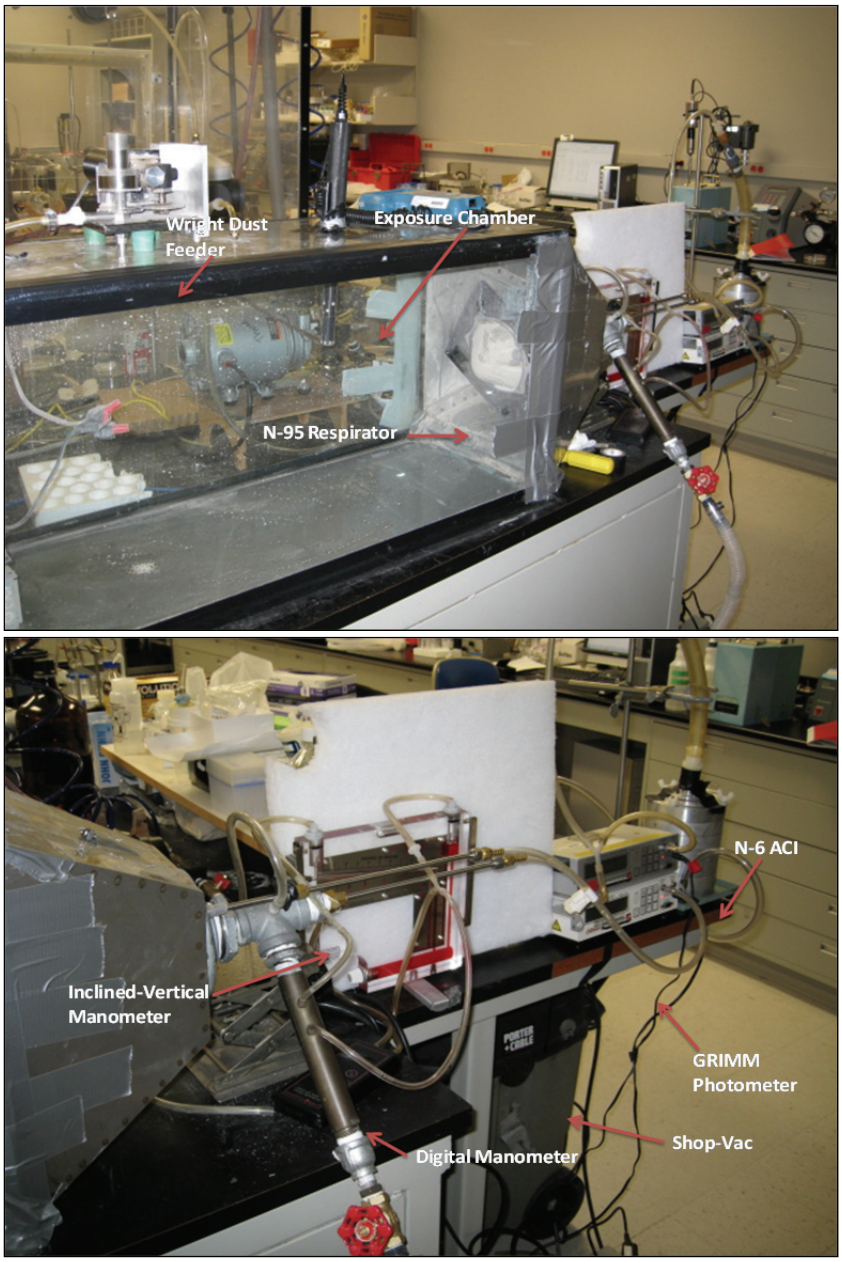

Figure 1. N95 FFR laboratory test chamber sampling.

field for sampling. Both the laboratory test and the field replicate were done only once. All instruments were calibrated according to manufacturer instructions. To perform this preliminary test, a standard test dust was used (Arizona Road Dust, Powder Technology, Inc., Burnsville, Minn.). A Wright dust feeder was used to aerosolize the powder.

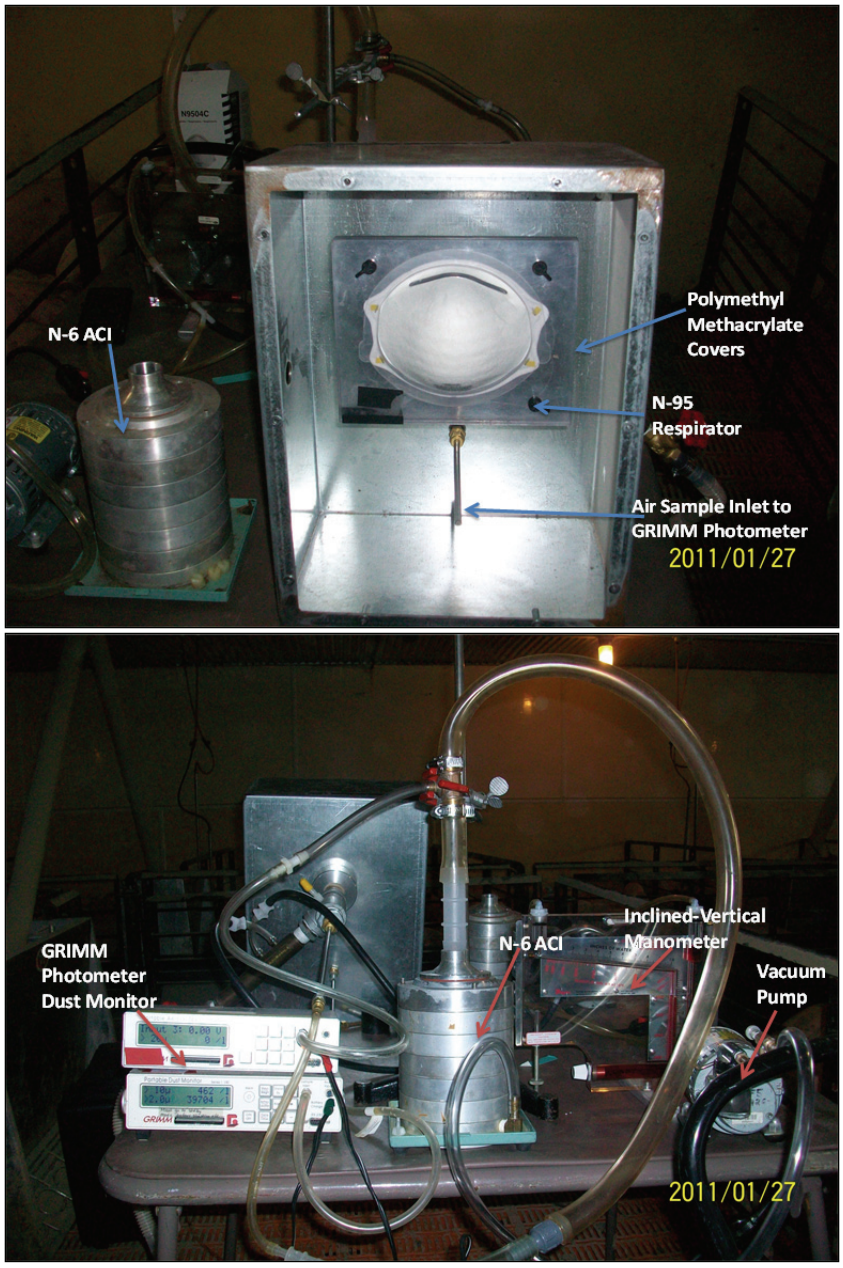

Figure 2. N95 FFR field chamber sampling inside a barn with pigs.

The field test setup is shown in figure 2. The test chamber used in the laboratory trial was placed in the center of the swine facility and sampled (in an empty pen to prevent damage from the hogs) at a height of 1.3 m from the ground to simulate the breathing

zone of workers. The laboratory setup was modified to also collect viable airborne particles using an N-6 Andersen cascade impactor (ACI) and deposit them on CHROMagar plates in triplicate runs. Samples downstream (filtered) of the respirator were taken at 15 and 20 min, whereas samples upstream (unfiltered) of the respirator were taken at 30 and 60 s to account for the expected high concentration (cfu m^{-3}) of particles. A commercial air mover (workshop vacuum cleaner) provided a constant flow rate of 85 L min^{-1} of air through the N95 FFR and was monitored with a manometer. The flow rate for the viable N-6 ACI was set to 28.3 L min^{-1}, and the OPC was set at 1.2 L min^{-1}. Each sampling time of 30 min was conducted in triplicate for data reliability. The count per liter of particles determined by the OPC was stored on the instrument and was analyzed at the laboratory for percentage efficiency. The CHROMagar culture plates were sealed with tape, labeled, placed in Ziploc bags, and finally placed (upside down) in a cooler with ice packs for transport to the laboratory.

Bacterial Diagnostics

At the Center for Emerging Infectious Diseases Laboratory, the CHROMagar MRSA plates were incubated at 35°C for 48 h. Representative colonies from the CHROMagar plates were subcultured on Columbia CNA (Remel, Lenexa, Kans.) for diagnostic testing. Identification tests for *S. aureus* isolates included the catalase test, the coagulase test, and the *S. aureus* latex agglutination assay (Pastorex Staph-plus, Bio-Rad). Methicillin resistance was confirmed by testing for the presence of penicillin-binding protein (PBP2′) (MRSA latex agglutination test, Oxoid, Ltd.). Isolates were stored at -80°C. Positive and negative controls were used for all tests.

We determined the filter efficiency as the ratio of the difference of particulates in unfiltered air outside the respirator and particulates in filtered air divided by the unfiltered particles. Efficiency is reported as a percentage: Efficiency = (particulates in unfiltered air – particulates in filtered air) / (particulates in unfiltered air) × 100.

Results

Figure 3 shows the laboratory test results for the N95 FFR using the OPCs. In the laboratory test, the N95 FFR had efficiencies greater than 98.61% for Arizona dust particles. Results of the field test are shown in table 1. Analysis of CFUs of MRSA using the N-6 ACI revealed an efficiency of 99.25% with a mean particulate size of ≤5.85 µm.

The field test results for the efficiency of the N95 FFR for particulates using the OPC are shown in figure 4. These measurements were done in an empty pen while the barn was populated with pigs. Particulates above the mean particle size of 0.58 µm had N95 FFR efficiency greater than 96.07%. The mean particulate size of ≤0.45 µm had efficiency less 95%.

The efficiency curve shown in figure 4 is not identical to that shown in figure 3, which represents the efficiency of the FFR with a standard test dust. The efficiency for the FFR in the field was slightly lower than 95%. The results from the field test were obtained with the dust in the swine barn. Furthermore, we recognize the possibility of leaks in the device holding the FFR, which may lower efficiency. A leak test was conducted in which the FFR was mounted and remounted to the device multiple times to determine whether a leak could occur, as measured by differences in pressure drop across the FFR. As shown

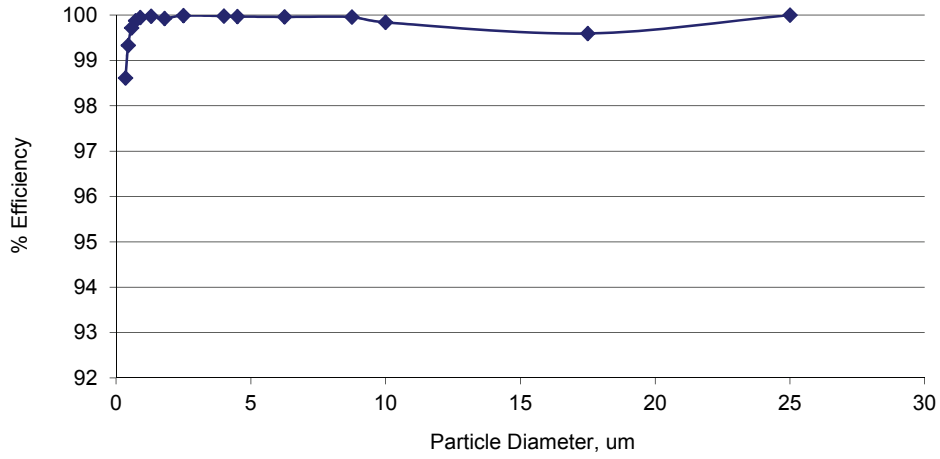

Figure 3. N95 FFR efficiency laboratory trial using the OPC.

Table 1. N95 FFR filter efficiency field trial using the N-6 Andersen sampler (CFU of MRSA).

Particle Diameter (µm)			Unfiltered	Filtered	Efficiency
Lower Limit	Upper Limit	Average	(CFU m^{-3})	(CFU m^{-3})	(%)
1.1	2.1	1.60	9187.28	36.12	99.61
4.7	7	5.85	2826.86	21.20	99.25
7	-	20.00	18374.56	37.69	99.80

in figure 5, the maximum and minimum pressure obtained varied by about 0.02 in. H_2O, which may account for the differences shown in figures 3 and 4. This finding may be due to differences in FFR performance, such as filter characteristics (Qian et al., 1998).

Discussion

The study results showed that the N95 FFR had efficiency greater than 99% for viable MRSA particles, as assessed by the Andersen cascade impactor. It was also determined that a slight reduction in pressure during the testing of the N95 FFR suggests that the N95 FFR may have not been fully sealed, which might have led to a slight downward shift in efficiency. With an effective seal, the N95 FFR is capable of providing a high degree of protection. This finding is important for providing assurance that a respiratory protection program in swine facilities may be effective in reducing the risk of transmission of air-borne MRSA to workers.

In addition to the results from the Andersen cascade impactor (detecting CFUs), the OPC was used to determine the efficiency of the N95 FFR for all particulates. The filter efficiency of the N95 FFR decreased as the size of the particles decreased. For particles

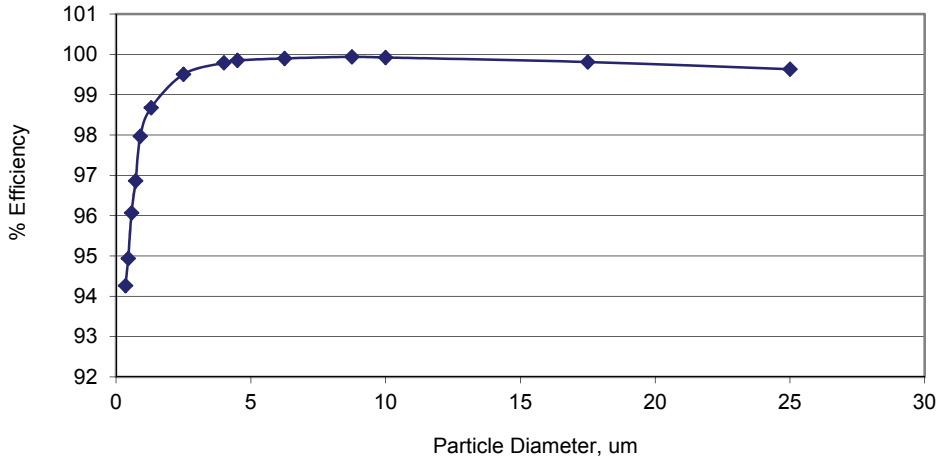

Figure 4. N95 FFR efficiency field trial inside a barn with pigs using the OPC.

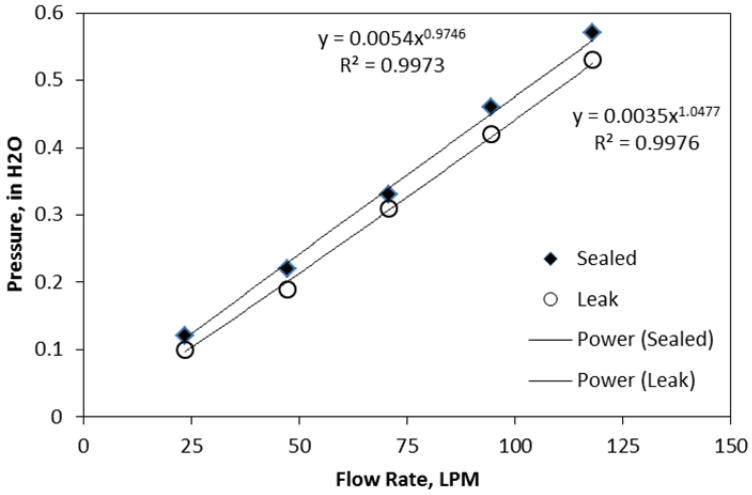

Figure 5. Leak pressure and flow relationship for N95 FFR.

smaller than 0.45 µm (respirable size range), the filter efficiency was less than 9%. Lee et al. (2005) found that the assigned protection factor of 10 for the N95 FFR is insufficient for particles smaller than <5 µm. The assigned protection factor represents the factor by which the N95 FFR can reduce exposure to contaminants. These findings indicate that the

particle size affected the efficiency of the N95 FFR (Harnish et al., 2013).

Overall, the results from this study suggest that the N95 FFR, when well sealed and fit tested, can be an effective RPD for control of MRSA infection in swine CAFO settings.

This study had several strengths. The respirators were evaluated both in the laboratory and in an actual swine barn. Furthermore, the swine barn had been previously identified as positive for MRSA in the air and in the nasopharynx of swine workers and pigs in the building (Smith et al., 2009). In addition to using a direct-reading instrument to sample particle concentration (i.e., the OPC), we simultaneously used the Andersen cascade impactor, which is a standard technique for viable air sampling.

There were also limitations with this study. The sample size of the study was small. We only performed three time trials. This study did not address the effect of relative humidity on the effectiveness of the N95 FFR, and the N95 FFR was not tested on human subjects. Leakage of total dust particles may have led to the filter efficiencies of less than 95% for respirable dust particles. However, the leak test showed the potential for only a slight leak. Given the inadequate filtration efficiency provided by the N95 FFR for total dust particles of the respirable size range (i.e., less than 0.45 μm using an OPC), further studies are needed.

Conclusion

Our findings can be used by swine producers to help justify an N95 FFR program in their facilities to help reduce the possibility of transmission of airborne viable MRSA particles to workers inside swine CAFOs. A compliant N95 FFR program can be used to help protect workers in swine facilities from potential respiratory illnesses. As found in our study, aerosolized MRSA was identified in a swine feeding facility. We showed that the N95 FFR is an efficient filter against aerosolized MRSA. We tested the N95 FFR with a seal and with a leak, which means that each person in an N95 FFR program needs to be fit tested to improve the effectiveness of the filtration provided by the N95 FFR. With MRSA particles in swine buildings likely being associated with swine epithelial cells, dried fecal matter, and feed (larger particles), the N95 FFR will provide the required protection against MRSA particles inside swine facilities. Our pilot study results are surprising and suggest that further studies are warranted to evaluate the filter efficiency of the N95 FFR against MRSA particles.

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